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

IERS
Annual Report
2008–2009

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IERS Annual Report 2008–2009

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1 Foreword

In the 2008–2009 period the IERS took significant steps to fulfill its mandate to provide fundamental reference frames for scientific and other users. The relevant IERS/IVS Working Group completed its work on the Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry. The ICRF2 catalogue was documented in IERS Technical Note 35 and adopted as the fundamental celestial reference frame by a resolution of the IAU General Assembly in August 2009. The ITRS Center worked closely with the four Technique Centers to generate validated time series input for the incremental approach first used for ITRF2005. The data reprocessing was long and arduous. Although the nominal end date was not achieved, it is clear that the result was worthwhile.

Two components of the IERS took steps to refresh their work. The Conventions Center systematically revised and updated the IERS Conventions in preparation for a new edition. To revitalize the present GGFC Special Bureaus a new call was issued, and the GGFC was restructured. The structural changes were instituted to allow for the establishment of operational products and for inclusion of new operational products. In addition, the Earth Orientation Center revised Bulletin B in May 2009 based on input from the user community.

The Working Group on Combination and the Working Group on Prediction finished their work in 2008 and 2009, respectively. A new Working Group on Combination at the Observation Level was established in 2009.

A number of workshops were held, partially co-organized with GGOS: GGOS Unified Analysis Workshop, Follow-Up Meeting, Vienna, Austria, April 15, 2008; IERS Workshop on EOP Combination and Prediction, Warsaw, Poland, October 19–21, 2009; Second GGOS Unified Analysis Workshop, San Francisco, USA, December 11–12, 2009.

While considerable progress was made in specific areas, achieving greater integration, consistency and accuracy for all the IERS products still will require considerable thought and work. As the requirements from the science and other user communities become more stringent it may be that fundamental conceptual advances are needed. It must be kept in mind that the IERS is a Service, and useful, reliable and credible products are the keys to relevance.

Chopo Ma
Chair, IERS Directing Board

2 The IERS
2.1 Structure

From 2008 to 2011, 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 2008 and 2011.

Analysis Coordinator

Markus Rothacher (until 9 October 2010)
Thomas Herring (since 10 October 2010)

Central Bureau

Director: Bernd Richter

Technique Centres

International GNSS Service (IGS)
IGS Representatives to the IERS Directing Board:
Jim Ray (from 1 January to 31 December 2008),
Steven Fisher (from 1 January 2009 to May 2010),
Urs Hugentobler (since May 2010)
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, Bruno Garayt (since Dec. 2009)
IERS Representative to the IDS Governing Board:
Ron Noomen (until 2009), Chopo Ma (since 2009)

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 (until 31 December 2009)
Gérard Petit (since 1 January 2010)

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 Oceans
Chair: Richard S. Gross

Special Bureau for Hydrology
Chair: Jianli Chen

Special Bureau for the Atmosphere
Chair: David A. Salstein

Special Bureau for Combination (since 1 January 2010)
Chair: Tonie van Dam

Special Bureau for the Core (until 31 December 2009)
Chair: Tim van Hoolst

Special Bureau for the Mantle (until 31 December 2009)
Erik R. Ivins

Special Bureau for Tides (until 31 December 2009)
Chair: Richard D. Ray

Special Bureau for Gravity/Geocenter
(until 31 December 2009)
Chair: Michael M. Watkins

Special Bureau for Loading (until 31 December 2009)
Chair: Hans-Peter Plag
Vice-chair: Tonie van Dam

ITRS Combination Centres

Deutsches Geodätisches Forschungsinstitut (DGFI)
Primary scientist: Hermann Drewes (until April 2010)
Manuela Seitz (since May 2010)

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
(until October 2009)
Chair: William H. Wooden (until August 2009),
Brian J. Luzum (from September to October 2009)

IERS/IVS Working Group on the Second Realization of the ICRF
Chair: Chopo Ma

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

Working Group on SINEX Format
(established in April 2011)
Chair: Daniela Thaller

(*Status as of December 2011*)

2.2 Directing Board

In 2008 to 2011, the IERS Directing Board had the following members (for addresses see Appendix 2):

Chair	Chopo Ma
Analysis Coordinator	Markus Rothacher (until 9 October 2010) Thomas Herring (since 10 October 2010)
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 (until 31 December 2009), Gérard Petit (since 1 January 2010)
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	Jim Ray (from 1 January to 31 December 2008), Steven Fisher (from 1 January 2009 to May 2010), Urs Hugentobler (since May 2010)
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 G. 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
Appleby, Graham
Arias, Elisa Felicitas
Behrend, Dirk
Biancale, Richard
Boucher, Claude
Bruyninx, Carine
Capitaine, Nicole
Carter, William E.
Chao, Benjamin F.
Chen, Jianli
Dow, John M.
Fagard, Hervé
Feissel-Vernier, Martine
Ferland, Remi
Fischer, Steven
Gaume, Ralph A.
Gendt, Gerd
Gross, Richard S.
Kolaczek, Barbara
McCarthy, Dennis D.
Melbourne, William G.
Moore, Angelyn W.
Neilan, Ruth E.
Noomen, Ron
Nothnagel, Axel
Pearlman, Michael R.
Pugh, David
Ray, Jim
Reigber, Christoph
Rothacher, Markus
Salstein, David
Sarti, Pierguido
Schuh, Harald
Schutz, Bob E.
Shelus, Peter J.
Seitz, Manuela
Thaller, Daniela
Veillet, Christian
Vondrák, Jan
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: Alik Ismail-Zadeh
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 December 2011*)

3 Reports of IERS components

3.1 Directing Board

The IERS Directing Board (DB) met twice in the course of each of the years 2008 and 2009. Summaries of these meetings are given below.

Meeting No. 46

April 13, 2008, Technical University of Vienna, Vienna, Austria

Introduction and approval of agenda

The Chair, Chopo Ma, welcomed the guests and the members of the IERS Directing Board. The agenda was adopted with a slightly changed order of items.

Formalities

The Directing Board accepted the minutes of IERS Directing Board Meeting No. 45.

Angie Moore left the Directing Board as IGS representative; Robert Weber was her substitute for this meeting.

Chopo Ma explained the new process for Action Items. These will be no longer postponed to the next IERS Directing Board meeting. They will get a date and the IERS Central Bureau will monitor the process and keep the Directing Board informed.

Action Items of Directing Board Meeting No. 44

C. Ma recalled the open Action Items from the IERS Directing Board Meeting No. 44.

Decision: In the future the Action Items will be better defined for responsibility and date.

Open Action Items:
44.01 Letter to stations asking for geodetic local tie measurement
44.04 Specifications for the next ITRF 200X
44.07 Prepare TN on new C04; outline will be provided by W. Wooden.
44.09 Application of UT1–UTC or TAI

Discussion on Leap Second

The review of Action Item # 44.09 lead to a controversial discussion within the Directing Board. B. Luzum proposed to collect the pros and cons. J. Ray points out that for all tidal computations UT1 is necessary.

Decision: The IERS should have again a position whether the Leap Second is still necessary for the UT1 definition.

New Action Items:
46.01 Collection of pros and cons to keep the leap second and preparation of a draft report
46.02 IERS Central Bureau prepares a letter; consult Dennis McCarthy.

Discussion on Action Items of IERS Directing Board Meeting No. 45

Most of the Action Items will be discussed and/or answered during the IERS Directing Board meeting.

45.02 ITRS/ITRF Web page should have links to other survey reports. Zuheir Altamimi asks for help. Item will be included in the "station letter".

45.03 see Action Item # 44.01

45.04 Submit modified proposal for ICRS Centre.

ITRS/ITRF

Z. Altamimi reported about the status of a new ITRF2008. From IGS no reprocessed combined solution is available yet. Only the Potsdam Dresden Reprocessing (PDR) covering 6 years (2000 – 2005) is usable. More individual solutions from analysis centres like MIT, ESOC might be accessible at the end of 2008. IVS is ready with a reprocessed solution including the mean pole tide correction since last fall. The reprocessing within the ILRS is still under way; some experimental solutions from ASI, GRGS and GFZ exist.

When comparing the PDR with the ITRF2005 a scale change by 5 ppb is visible. The new DORIS solution is more stable. Presently the IGS solution is better than the single PDR. F. Lemoine informed that the new satellites Jason 2 and Gyrosat will have DORIS on board.

H. Drewes discussed the strategy of a new TRF developed within the GGOS-D project part of the R&D programme Geotechnologien, which is financed by the German Ministry of Education and Research. The improvements compared to the ITRF2005 are homogeneously processed date sets with identical standards, conventions, models and parameters. The absolute instead of the relative phase centre corrections are used which result in a smaller number of inconsistencies (jumps) for the station coordinate series weighed against the ITRF2005.

J. Ray referred to the special website <http://www.ngs.noaa.gov/igsacc/reprocess/reprocess.html> where more details are given concerning the reprocessing of GPS time series. The reprocessing will start in 2007 going backwards hopefully to 1994. He expects that the whole process will take several years and combined results might be available earliest in 2010.

E. Pavlis as ILRS Analysis Coordinator promised a trial version of a new combined series for end of June. F. Lemoine, IDS, expects a combined series for the end of this year. IVS will have a new combination for the ITRF200X.

New Action Items:
46.03 A combined DORIS series should be made available.
46.04 IGS Analysis Coordinator should report on progress of IGS reanalysis regularly.

ICRS/ICRF

A. Fey gave details concerning the progress of Working Group on ICRF-2. The overall goal is to have the ICRF-2 ready for adoption at the IAU General Assembly 2009. There were 4 meetings but the work has fallen far behind. Several dedicated Working Group meetings are needed within the next 12 months.

N. Capitaine informed the IERS Directing Board what is necessary to implement the IAU resolutions 2006 in the IERS Conventions and SOFA. Mainly the IERS Conventions Chapter 5 has to be updated.

The 2007 SOFA (Standards of Fundamental Astronomy) software release (a library of Fortran sub-programs implementing official IAU algorithms for fundamental astronomy computations) incorporates the 2006 precession. A “cookbook” that introduces the SOFA routines associated with precession-nutation and Earth rotation is available at <http://iau-sofa.hmnao.com/2007_0810/sofa/sofa_pn.pdf>.

Because the IERS has benefited significantly from informal collaborations with SOFA in the past, there have been some reflections about the future coordination between SOFA and IERS. The SOFA Board (chaired by P. Wallace and including B. Luzum) supports the idea of closer ties with IERS, while retaining the current IAU Division 1 link. Several options for such a rapprochement have been considered, on which IERS should be consulted; i.e. SOFA:

- becoming a new IERS product centre, with assuming responsibility for IERS software, or
- becoming one component of the IERS Conventions Centre, with assuming responsibility for the whole of the Conventions software, or
- keeping its own Division 1 role, but with more formal links with IERS, within e.g. Commission 19.

A formal letter will be sent to hear SOFA’s opinion on these suggestions.

N. Capitaine presented reduced models for the IAU 2006 X, Y series, out of which one can achieve the full accuracy that is available without EOP corrections. At present, users are obliged to first compute the full model and then add IERS corrections to the results. If the IERS would provide additional tabulations for corrections dX, dY values with respect to a shorter model, this would produce an identical final CIP X, Y at a fraction of the computing costs. N. Capitaine was asked to provide a report on this matter at the next IERS Directing Board meeting.

New Action Items:

46.05 Development of a plan of actions and milestones to realise the new ICRF II

46.06 Rewriting IERS Conventions 2003, Chapter 5

46.07 Formal approach on how SOFA could be included in the IERS Conventions and how they will respond / report to the IERS Conventions
46.08 Provision of a report on reduced models for the celestial pole offsets dX, dY and their applications

Earth orientation products

C. Bizouard presented the extended EOP Web Service that offers the Earth orientation parameters and the Earth orientation matrix at a given date. He demonstrated the tool, which allows the computation of the excitation function of the Earth rotation and the comparison with the geophysical excitation functions. The Directing Board did not accept the proposed changes of Bulletin B.

J. Ray contributed two presentations. The first dealt with the analysis effect in IGS polar motion estimates. The second was a presentation prepared for the EGU on the combination of VLBI UT1 with GPS LOD estimates by Kalman filter.

W. Wooden talked about the discrepancies between the 05C04 UT1 values and the Rapid Service/Prediction Centre UT1 values. His conclusion was that the problem occurs when VLBI data are missing and that 05C04 UT1 and 05C04 LOD do not agree well with the Rapid Service/Prediction Centre values, the SPACE2006 solutions as well as with the IGS finals LOD.

Decision: If there was no substantial reason for a change, the format for Bulletin B should remain the same.

New Action Items:
46.09 Jim Ray will cooperate with
- Daniel Gambis and Christian Bizouard on filtering.
- Brian Luzum and William Wooden to improve prediction considering the outcome of the prediction campaign.

A draft report will be prepared.
46.10 JPL will report on their experience to improve UT1 products.
45.06 The Earth Orientation Centre and the Rapid Service/Prediction Centre will investigate and resolve discrepancies in UT1 between both centres.

Role of Combination Research Centres

Starting with the Terms of Reference M. Rothacher explained the role of the Combination Research Centres (CRCs). Running for almost 8 years the present activities are very diverse and inhomogeneous. There is no flexibility and mechanism to redirect the work of the CRCs. As a result M. Rothacher proposed that the IERS Terms of Reference should be changed in such a way that the Research Centres (RCs) will contribute to the requested activity only for a limited period of 4 – 5 years. The present CRC activities should be closed at the end of 2008, while a new call for proposals should be launched to start with new, well-defined activities in 2009.

The following discussion was very controversial: suggesting working groups instead of RCs, bring the RCs closer to the product centres, present CRCs do basic research and need a longer time span. Finally, it was decided that the Directing Board will follow M. Rothacher's proposal.

Decisions:
Terminate the present CRCs at the end of 2008.
Launch a call for RC with well define tasks in 2009.

New Action Items:
46.11 Notification of the CRCs about termination, IERS Message for the public
46.12 Change Terms of Reference to a limited time period, and generalise the name to Research Centres
46.13 Prepare a call for the new RCs

Progress on setting up a Working Group on Combination at Observation Level

R. Biancale presented his ideas to create a "Working Group on Combination at Observation Level". From his experience combination at observation level implies e.g. the processing of two or more space techniques, harmonizing the input models, evaluating appropriate weights between techniques, connecting techniques on ground or in space, searching for high frequency products, … The major goals and objectives of the WG are the coordination of the Combination Pilot Project, to set standards for a rigorous combination, to study systematic biases, local ties and co-location, to validate combined products, to produce long-term series and to define future IERS products.

New Action Item:
46.14 Write a charter for the WG according to the IERS rules, compile a list of members, define a time schedule.
Review by Directing Board

Future of the GGFC structure, implementation

R. Gross summarized the present structure and the new one proposed by Tonie van Dam at the Directing Board Meeting No. 45. He felt that the structure in the proposal is too complicated whereas the existing structure is clear and simple. M. Rothacher started his presentation by a list of the products and repeated his idea how new components can be initiated. Most of the members of the Directing Board agreed that the Special Bureaus should be revitalised by new calls.

Decisions:
Revitalise the present Special Bureaus by new calls.
Add a new Special Bureau for Propagation Delays.

New Action Items:
45.09 List user requirements and available and/or necessary products, send to IERS Directing Board.

46.15 Specify the products and operation scheme for the Special Bureaus and send out a draft for the calls to the IERS Directing Board members.
46.16 Review and comment on the calls, propose an evaluation process / group.

Consequences of the Unified Analysis Workshop

M. Rothacher reported on the progress of the Unified Analysis Workshop decided action items. He explained the extension of the SINEX format, the reference pressure field, the tests on atmospheric loading, the generation of daily SINEX files, the definition of meta data standards, and the documentation of Analysis Centres' modelling standards and parameterisation. Z. Altamimi was against the new SINEX format and proposed an extension without destroying the general format.

Results of the EOP Prediction Comparison Campaign, consequences

H. Schuh demonstrated the results of the EOP prediction comparison campaign. The objectives were the comparison of the various methods, models, techniques and strategies, which can be applied for EOP prediction with equal rules. In total 12 scientists participated with 20 prediction techniques in four categories: ultra short-term (10 days), short-term (30 days), medium term (500 days) and long term (20 years). The findings will result in a joint paper and cooperation with the IERS Working Group on Predictions. A direct comparison with the results of the IERS Rapid Service/Prediction Centre is still missing.

Report on GGOS and GEO

M. Rothacher informed about the recent developments in GGOS and GEO. In Bertinoro the GGOS Steering Committee arranged a GGOS retreat. Besides the discussion about the GGOS2020 document the major outcomes were the discussion and preparation of the Call for Proposals for the GGOS Coordination Office and GGOS Portal, the Bureau for Networks and Communication, the Bureau for Standards and Conventions and the Bureau for Satellite and Space Missions. In addition the Terms of Reference were revised, especially the vision and mission statements.

Reports of the Unions (IAU/FAGS)

N. Capitaine as the IAU representative in IERS and Federation of Astronomical and Geophysical Data Analysis Services (FAGS) gave details about the planned scientific meetings relevant to IERS. The focus of her presentation was on the development of FAGS. ICSU decided to reform the World Data Centres (WDC) and FAGS. In doing so ICSU established an ad hoc Strategic Committee on Information and Data (SCID). The Committee recommended the following: to create a new ICSU World Data System incorporating the WDC and FAGS as well as other state-of-the-art data centres and services. More details with a timeline were given.

IERS Conventions updates

The presentation by B. Luzum started with a summary about the latest updates and the work in progress of the introduction, terrestrial reference frame, transformation, site displacement, tidal variation in the Earth's rotation, tropospheric model and general relativistic models. B. Luzum continued to present a new template as an initial step in the process of software standardization. The last part was devoted to the comparisons of the Unified Analysis Workshop recommendations and the ones given at the IERS Workshop on Conventions. The next edition of the Conventions will be published in late 2008 or early 2009.

New Action Item:
46.17 Comments on Software template

IERS Rapid Service/Prediction Centre Status Report and Activities of the IERS Working Group on Prediction

W. Wooden reported that the Rapid Service/Prediction Centre modified the weighting for the polar motion contributors, added IGS ultras to combination, modified code to handle e-VLBI, increased AAM forecast from 5 to 7.5 days, and will migrate to a new operational machine. Near-term actions are investigations on the quality of UTGPS data and AAM studies to improve the AAM combination.

The Working Group builds on the foundation laid by the Prediction Comparison Campaign and the Combination Pilot Project and creates the potential for new EOP products. Presently the survey is being analysed and tasks are being set up to understand the fundamental properties of input data sets and prediction algorithms.

Report of the Central Bureau

B. Richter reported that the IERS Annual Report 2006 was completely ready since 4 weeks, was available in electronic form, and that the paper print was on the way. The deadline for Annual Report 2007 is May 31, so far no contributions have been received, reminders will be sent after the EGU assembly. Contributions not available at the due date will be marked in the Annual Report as "not available".

According to the Terms of Reference 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).

New Action Items:
46.18 Reminder for Annual Report 2007
46.19 Final Reports of chairs of Working Group on Site Survey and Co-location, Working Group on Combination for Annual Report 2008

Miscellaneous

Z. Altamimi is one of the members of the "US national requirement for geodetic infrastructure" committee. The 12 committee persons will prepare a report at the end of the year.

Next IERS Directing Board meeting / workshops

To avoid the meeting conflicts before and during major assembles it is proposed to hold the fall IERS Directing Board meeting separately. As a compromise for the American and European colleagues Washington D.C. was suggested as the meeting place, and the date should be October 27, 2008.

Presently there is no proposal for an IERS Workshop.

Decision: Next IERS Directing Board meeting in Washington DC on October 27, 2008

New Action Items:
46.20 Check meeting places
46.21 Proposal for an IERS Workshop

Meeting No. 47

October 27–28, 2008, US Naval Observatory, Washington D.C., USA

Introduction and approval of agenda

The Chair, Chopo Ma, welcomed the guests and the members of the IERS Directing Board. The agenda was adopted.

Formalities

The Directing Board accepted the minutes of IERS Directing Board Meeting No. 46.

ITRS/ITRF

Report from the ITRS Centre and ITRS Combination Centres

To prepare the ITRF2008 Z. Altamimi performed a lot of detailed investigations to analyse the discrepancies between the techniques. New local ties in Tahiti and Herstmonceux are available. In both cases differences at the centimetre level are present. As a local effect the change of the event timer in Herstmonceux was demonstrated, where the main effect in the analysis is in the z-component. He also compared the SLR combination of ASI and GRGS as well as the effect of the mean pole tide correction on the IVS scale, which results in an overall scale shift by –0.5 ppb. So the scale difference between SLR and VLBI still exists. From 1995 on DORIS shows similar scale behaviour like VLBI and the reprocessed GPS series from MIT follow the same line. The single new and closed stations in the SLR network do not show a direct effect on the SLR scale but in general the scale is affected by the network degradation.

Because the scale is one to one affected by the vertical velocities a detailed study was presented to monitor the vertical velocities of the core stations with respect to geophysical processes. In conclusion Z. Altamimi stated that the scale drift between SLR and VLBI is most probably due to the two different networks, the scale stability is critical to avoid internal distortions and biased vertical velocities, and the IGS reprocessing makes significant improvements.

Specifications for the ITRF2008

M. Rothacher explained that for the ITRF 2008 the same strategy will be used as for ITRF2005. The Technique Centres will submit combined time series, for SLR and VLBI since the 1980ies, DORIS from 1993 on, and the IGS will provide reprocessed time series from 2000 till 2008. No correction for any geophysical fluid loading effects will be applied.

The following schedule to realize the ITRF2008 is foreseen:

November 10, 2008	Dissemination of the Call
February 10, 2009	Deadline for submissions by Technique/Analysis Centres
April 19–24, 2009	EGU: Preliminary results
until May 10, 2009	Analysis by the ITRS Combination Centres and agreement on one solution
June 15, 2009	Final ITRF2008 solution

Report on the recent co-location survey at Herstmonceux

H. Fagard demonstrated the results of the re-observation of the local ties at Hermonceux between the SLR 7840 marker, the GPS HERS and the GPS HERT. Differences of up to 11 mm compared to the old measurements were found.

Report from IDS

F. Lemoine gave a status report about the JASON-2 mission launched on June 20, 2008 with DORIS on board for tracking. Four more missions are planed with DORIS as tracking system, Jason-3 and more possible missions are under discussion.

Presently 6 analysis centres handle the data and the combination is performed in Toulouse. Gilles Tavernier left the Governing Board, the new Chairperson is Pascal Willis. Pascale Ferrage became a member of the Governing Board. Due to the Terms of Reference positions have to be renewed, the process should be finished by the end of the year.

IDS plans to contribute to the ITRF2008 by a combined and validated product. 2–4 Analysis Centres will process the full series from 1993 to 2008 and partial solutions from the others.

Because DORIS is an active tracking system the station network is continuously renewed and well distributed. Most of the stations are co-located by other geodetic space techniques.

ILRS Analysis Working Group Report

E. Pavlis presented the current activities of the ILRS AWG. The results of the re-analysis 1993 – 2007 are very homogenous for the Analysis Centres GFZ, ASI, GRGS, and GA, the historical data (1983 – 1992) are reprocessed by ASI and GFZ.

Decisions:
The schedule of ITRF2008 was accepted, but more time should be given for evaluation. The final ITRF2008 should be ready for the IAG meeting in Buenos Aires.

Pierguido Sarti was appointed as head of the Working Group on Site Survey and Co-location.

New Action Items:
47.01 Add a sentence in the call ITRF 2008 to include the validation by Technique Centres, modify the date with the target to be ready for IAG.
47.02 All Technique Centres should contribute to ITRF2008.
47.03 P. Sarti should set up a new charter for Working Group on Site Survey and Co-location.
47.04 Send a letter to authorities performing the local tie surveys and thank for the activities.
47.05 IVS is asked to sort out the effect of atmospheric loading for their distribution to the ITRF2008.
47.10 Technical Note for ITRF2005

ICRS/ICRF

C. Ma reviewed the activities of the IERS/IVS Working Group on the Second Realization of the ICRF and presented the schedule to continue. The aim is still to present a new ICRF at the IAU General Assembly in Rio de Janeiro, August 2009.

Earth orientation products

Report of the Earth Orientation Centre

Based on a survey among Bulletin B users D. Gambis proposed a revised Bulletin B. The proposed new format is not accepted by the Directing Board, especially the two line information which would cause new programming in the application software. A new proposal should be developed.

In the continuance of the presentation D. Gambis described the eight steps of the EOP combination algorithm and gave an outline for the publication.

In three viewgraphs he compared various solutions of the X-, Y-pole residuals and LOD residuals with igs00 to demonstrate the smoothness of the IERS solution.

As a result of the comparison of 05C04 with Bulletin A the Directing Board decided that the 05C04 should not contain predictions and should be handled as a “frozen” series.

C04 constancy

W. Wooden and B. Luzum investigated the C04 constancy. They compared a half year data set, taking the current C04 and compared it to the fixed value at the beginning of the series. As a result they found changes with every solution (twice/week) and sometimes significant changes of more than 1 mas.

Rapid Service/Prediction Centre status report

W. Wooden informed about recent improvements by extending the AAM forecast data from NOAA NCEP and Navy NOGAPS from 5 to 7.5 days. The prediction accuracy improved by 15% beyond 5 days. After testing new intensive baselines will be added. Depending on the results of the investigations the new UTGPS data (more satellites, better orbit modelling ...) will be incorporated into the operational products. New algorithms for combining AAMs with new data sources are studied. Rapid turn-around e-VLBI (RT e-VLBI) are processed and provided faster than the IGS Ultra rapid. First investigations on the effect of RT e-VLBI on Rapid Service/Prediction Centre combination and prediction products show a noticeable improvement in the combination solution.

Report of the Working Group on Prediction

This report was presented by W. Wooden. By reviewing the different input data sets and algorithms the Working Group will create the potential of new improved EOP products. W. Wooden described the goals and objectives, the requirements, input data, algorithm considerations, and prediction methods. The findings of the Working Group – definitive user requirements, a comprehensive look at prediction methods and data sets – will be described in an IERS Technical Note.

Status of UT1 discrepancy investigation

J. Ray noted that there are larger than expected discrepancies between the 05C04 UT1 values and the Rapid Service/Prediction Centre UT1 values. Several investigations show that problems occur when VLBI data are missing. Furthermore, 05C04 UT1 and LOD do not agree as well with Rapid Service/Prediction Centre and SPACE2007 UT1 respectively Rapid Service/Prediction Centre and SPACE2007 LOD. 05C04 LOD derived from UT1 does not agree as well with IGS Finals LOD.

Ways to improve EOP products

R. Gross recommended to include more data like e-VBLI for UT1, LLR for UT0, real-time GPS for polar motion but basis for a proper combination should be the consistent use of reference frame. OAM might improve the predictions but are not yet available from ocean modelling groups. R. Gross used AAM provided by NCEP and ECMWF, OAM provided by JPL, and UT1 predictions using JPL's Kalman Earth orientation filter to create several test cases.

New Action Items:
47.06 Prepare a proposal for a new bulletin format
47.08 Remove the prediction part from C04

First actions of the Working Group on Combination at the Observation Level

D. Gambis presented a first report of the Working Group on Combination at the Observation Level. The aim is to process several space techniques by using the same input models for each technique, the same constants and standards. The various techniques will be connected by local ties on ground or in space using multi-technique satellites. Presently active in the Working Group are GRGS, DGFI, TUM, OPA; ASI plans to join in spring 2009. The combination will be made in two steps: 1. Processing of the observations by uniform software, 2. Accumulation of normal equations. In spring 2009 first results will be available for comparison.

New Action Item:
47.09 Draft of charter for Working Group on Combination at the Observation Level. Distribute to Directing Board after refinement.

IERS Conventions updates

B. Luzum gave an overview of IERS conventions updates since December 2007 and an outline of work in progress for various chapters. It is planned to publish the next registered edition of the Conventions in 2009.

Reports of the Unions (IAU/WDS)

Information on recent meetings, works and publications related to the IAU, 2009 IAU meetings

N. Capitaine informed in detail about the IAU symposium "Relativity in Fundamental Astronomy" to be held in Virginia Beach, VA, USA, on April 27 – May 1, 2009, the International Year of Astronomy and the IAU General Assembly in Rio de Janeiro on August 03–14, 2009.

Information on the ICSU 2008 General Assembly and the implementation of the ICSU World Data System (WDS)

After detailed discussions FAGS and the World Data Centres will be replaced by the new World Data System. The final report of the ad hoc Strategic Committee on Information and Data (SCID) informed in detail about the transition. The new WDS will function under the oversight of a new WDS Scientific Committee (WDSSC) to replace the current Panel on World Data Centers and FAGS Council. The transition period before the implementation of the WDS is approximately 12 months.

New Action Item:
47.12 IERS should work for membership in WDS.

Report of the Central Bureau

IERS Data and Information Centre

B. Richter showed the general functionalities of the IERS Data and Information Centre. For most IERS products meta data according to ISO 19115 were produced as well as a proposal for SINEX file meta data. All IERS products are standardized in format and interactive tools will allow plotting the data and performing data analysis.

Annual Report of IERS

The status of the Annual Report 2007 was given. There are still some contributions missing.

Scheduling of the elections of the IERS Chair

Chopo Ma is willing to act as IERS Chair for a second term. The necessary formalities for election will be arranged by the Central Bureau.

Change of Terms of Reference concerning Research Centres

Some changes in the Terms of Reference are necessary due to decisions of the IERS Directing Board to dissolve the Combination Research Centres and establish Research Centre(s):

Current Terms of Reference:

COMBINATION CENTER(S)

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

Changes:

1. Replace “COMBINATION CENTER(S)” by “ITRS COMBINATION CENTER(S)”.

2. Delete first paragraph on Combination Research Center(s).

3. Add:

RESEARCH CENTER(S)

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

Current Terms of Reference:

DIRECTING BOARD (DB)

The Directing Board consists of the following members:

…

- One representative from the Combination Research Center(s).

Changes:

Delete “One representative from the Combination Research Center(s).”

Decision: The proposed changes in the Terms of Reference were accepted.

New Action Item:
47.11 The Central Bureau should send out a notification that the present Chair is willing to serve for a second period.

Calls for GGFC Special Bureaus

Via telephone T. van Dam joined the IERS Directing Board meeting and presented a proposal for a new GGFC structure. The main points are: there are three major fluids: Atmosphere, Ocean, Hydrology. Within one fluid centre e.g. atmosphere all products will be provided, here: AAM, loading, geocentre, TWV, atmospheric tides … In addition to the product centres GGFC science and support products will be offered. Each of the mayor centres will have a chair, who organise the work within the centre. The products are generated by individuals or institutions on a self binding commitment. The calls will be launched in two steps, first the chairs will be searched and then the institutions providing the operational products.

Decision: The Directing Board accepted the proposed new structure in general.

New Action Items:
47.13 Update the graphic of the structure of the proposed GGFC
47.14 Contact the chairs and possible product providers
47.15 Prepare two calls for chairs and for product providers

Report on GGOS and GEO

M. Rothacher informed about the call for the new GGOS components, new GGOS mission statement and further updates of the GGOS Terms of Reference. The GGOS 2020 reference document is available and will be published by Springer. A list of upcoming meetings und next major steps was presented.

B. Richter summarized the major steps in GEO since the last IERS Directing Board meeting.

Does the present structure of IERS fulfil the requirements?

ITRS: Towards an international standard?

Z. Altamimi presented an idea by Claude Boucher to place the ITRS/ITRF under the BIPM umbrella. This could give more recognition of the ITRF as international standard. Claude Boucher will work on a position paper.

ISO geodetic registry

B. Richter reported about another possibility to get more formal international acceptance. Presently the ISO TC 211 searches for a candidate for a registration authority of ISO/TS 19127 Geographic information – Geodetic codes and parameters. When the ISO register is set up the ITRF can be registered and will become an ISO-accepted standard.

Product review

M. Rothacher as Analysis Coordinator gave a short review of IERS products and draws steps towards a rigorous combination for the ITRF2008, weekly routine combined products up to daily routine combined EOP products. For this he presented two strategies.

Discussion of an IERS Executive Committee

For more intensive discussion within the IERS especially in between the Directing Board meetings it is proposed to form an IERS Executive Committee. After a short discussion the IERS Directing Board decided not to follow this suggestion.

New Action Item:
47.16 Which information is necessary to get the ISO stamp?

Miscellaneous

New Action Item:
47.18 Telecom each month, participants: IERS Chair, IERS Analysis Coordinator, IERS Central Bureau and experts if necessary

Next IERS Directing Board meeting / workshops

The next IERS Directing Board meeting was proposed to be held in Vienna prior the EGU at the Technical University on April 19, 2009.

W. Wooden proposed a workshop on EOP prediction in Warsaw in the fall of 2009. A decision will be made at the next Directing Board meeting.

The next GGOS/IERS Unified Analysis Workshop should be held in December prior to the AGU Meeting.

New Action Items:
47.17 Check date for Directing Board meeting at EGU meeting on Sunday before, contact H. Drewes to check for IAG Executive Committee meeting

Meeting No. 48

April 19, 2009, Technical University of Vienna, Vienna, Austria

Introduction and approval of agenda

The Chair, Chopo Ma, welcomed the guests and the members of the IERS Directing Board. He reported that he wrote a letter of support w.r.t. the Italian VLBI activities in Matera and Noto; unfortunately it wasn't helpful as was reported at the Bordeaux VLBI Meeting in March 2009.

Formalities

The Directing Board (DB) accepted the minutes of IERS Directing Board Meeting No. 47.

ITRS/ITRF

Z. Altamimi gave a preliminary analysis in view of ITRF2008. Combined solutions to the ITRF2008 were submitted from all TCs:

- IGS: final solution
- IDS: preliminary combined solution based on 7 AC solutions.
- ILRS: preliminary solution including historical SLR data starting 1984
- IVS: final solution but only 4 ACs contributed and used models may not be consistent.

Feedback of all preliminary results was sent to the techniques. 5 new local ties w.r.t. ITRF2005 are available: Tahiti, Tsukuba, Herstmonceux, Medicina and Greenbelt.

The ILRS intrinsic origin and scale show a much more internal stability as within ITRF2005. No problems are showing up when comparing with ITRF2005, except a slight drift in TY and a drift in the scale. When including historical data the results are getting much noisier but the behaviour of the origin and the scale does not change, i.e. these parameter are completely driven by the data after 1992.

3 ILRS stations with discontinuities in the vertical component were discovered: Herstmonceux, Zimmerwald and Haleakala. Recently for Herstmonceux the range and time bias corrections were set up and should be applied for this station. But the biases were not applied by all ACs contributing to the ILRS combined solution. Therefore a new combined solution will be prepared by the ILRS. The IVS combined solution shows a scale with respect to ITRF2005, and an offset of 0.5 – 0.6 ppb appears because of the application of the correct pole tide model (according to IERS conventions).

The IDS solution shows discontinuities in scale due to changing the number of satellites. The combined solution is dominated by the ESA solution and the discontinuities within. Therefore ESA should reanalyze the solution.

For local tie residuals, a VLBI-GPS test combination was performed. Compared to ITRF 2005 it seems that the local tie residuals are better in quality. For some stations an improvement by a factor of 2 for the up component was achieved.

In summary, there is a significant improvement of the reprocessed solutions of all techniques.

However, the following problems remain:

- ILRS has some bias issues to be fixed.
- IDS shows a scale and translation in Z?
- For IGS including early data from 1995 to 2000 would be good.
- IVS is probably ok.
- A multi-technique combination should be done.

Updated schedule for the creation of ITRF2008:

November 10, 2008	Dissemination of the Call
February 10, 2009	Deadline for submissions by Technique/Analysis Centres
April 19-24, 2009	EGU: Preliminary results
Until May 20, 2009	Final submission by TCs
Until June 20, 2009	Analysis by ITRF CCs Preliminary ITRF2008 solution
June 20 – July 20, 2009	Preliminary ITRF2008 solution for evaluation by TCs / ACs
July 31, 2009	Final ITRF2008 solution

H. Drewes pretended the status of the ITRF2008 computation at DGFI. IGS, IVS, and ILRS combined solutions were analyzed; the IDS combined solution was not analyzed because it is not the official solution.

For IGS, about 130 discontinuities more than in the IGS station discontinuities list were identified. The list of discontinuities is different from the IGN list.

For ILRS (1993 – 2008), only a few discontinuities were identified in addition to the ILRS list. The list will be discussed at ILRS AWG meeting in Vienna. The results are similar to that of the IGN solution.

Form the IVS solution, 324 single-baseline sessions were excluded. Discontinuities were taken from IVS; only the approximation of the movement of station PIETOWN is still unclear (to be resolved by IVS).

Next work will comprise finalizing the IGS and IVS analysis and the TRF computation, the analysis of the ILRS data, the analysis of the IDS time series, and an inter-technique combination.

IERS Working Group on Site Survey and Co-location

P. Sarti argued for a continuation of the IERS Working Group on Site Survey and Co-location.

Identified areas of work of the group are

- Standards and documentation
  (Guidelines, survey reports, possibly store reports and data)
- Coordination
  (Share know-how and join efforts between survey teams)
- Research
  (investigate discrepancies btw. space geodesy and tie vectors, alignment of tie vectors into a global frame)
- Cooperation
  (between TCs and CCs as well as GGOS BNC, IAG Commission 4?).

Work items are:

Item 1: site survey standards:
- revise former local tie activities
- produce new documentation

Item 2: site survey activities:
- promote accurate surveying
- remotely assist on field operations
- provide computational support

Item 3: tie vector estimation:
- set guidelines on computational procedures
- provide tie vectors with full variance covariance matrix in SINEX
- improve local ties

Item 4: coordination and research:
- Can local ties be accurate enough?
- Local ties aim at locating the conventional reference point.

- Space geodesy observables are acquired at the electric reference point.
- Reference points are stochastically determined (e.g. single path variations of the Medicina telescope due to receiver displacement, vertex displacement and focal length variation together show variations of about 2 cm).

The work to be done includes compiling a list of members and a schedule.

Working Group on Combination at the Observation Level

D. Gambis explained the plans of the new Working Group on Combination at the Observation Level. The charter of the WG was proposed at IERS DB Meeting No. 46. It's main goal is to bring together groups capable to do combinations at observation level and to improve the homogeneity, precision and resolution of the products. The planned activities of the WG are described in 9 tasks in the charter of the WG.

Currently GRGS and DGFI are jointly responsible for the working group. Different software packages are being used at the institutions and activities started to exchange SINEX files. First GRGS SINEX files from GINS software turned out not to be readable at DGFI. The export to SINEX in GINS will be improved.

Activities should be extended to other groups like ASI, GSFC, and Chinese colleagues, who already expressed their interest in that work. However, they have not yet been participating actively.

Decision: The DB accepted the charter of the Working Group on Site Survey and Co-location.

New Action Items:
48.01 Z. Altamimi will sent out a new schedule for ITRF 2008.
48.02 P. Sarti will finalize a list of WG members and a schedule of the Working Group on Site Survey and Co-location and send it to IERS DB.
48.03 The Working Group on Combination at the Observation Level was asked to send a revised charter to the DB.

ICRS/ICRF

IERS/IVS Working Group on the Second Realization of the ICRF

C. Ma presented an account of the IERS/IVS Working Group on the Second Realization of the ICRF. The sixth meeting of the WG took place in March 27–28 at Bordeaux Observatory. Short reports as well as action items were distributed during the meeting. The official documentation of the ICRF2 is in preparation and will be published as IERS TN No. 35. The draft is due mid June and will be posted on the IERS web site by mid July. A “Resolution on the Second Realization of the International Celestial Reference Frame” was prepared for the IAU General Assembly in August. The draft will be sent to the IAU after distributing to the IERS DB.

IAU related issues

C. Ma gave also a note on IAU related issues. The IAU Symposium 261 “Relativity in Fundamental Astronomy – Dynamics, Reference Frames and Data Analysis” will take place in Virginia Beach (USA) from April 27 to May 1, 2009. The 27th IAU General Assembly will take place in Rio de Janeiro (Brazil) from August 3 to 14, 2009. The Joint Discussion 6 “Time and Astronomy” will take place on August 6–7. Submission of resolutions of type B (relevant for the resolution regarding ICRF2) are due May 15.

Re-organization of the ICRS Centre

J. Souchay reported about the re-organization of the ICRS Centre. A new director was elected at Paris Observatory and new tasks for the ICRS Centre were identified. Therefore, a revised proposal for the ICRS Centre was set-up to be signed by the directors of Paris Observatory and U.S. Naval Observatory.

Decision: The DB accepted the revised proposal for the ICRS Centre.

New Action Items:
48.04 The Central Bureau will send the draft resolution on the “Second Realization of the ICRS” to the IERS DB.
48.05 Responses from the IERS DB members to the draft resolution are asked.

Earth orientation products

D. Gambis summarized the status and function of current and new or changed EO products.

Status of C04:

- The series is available from ftp/web.
- The values are fixed until today – 30 days.
- Preliminary values are available for the last 30 days.
- The series is updated every year or when necessary (e.g. after issue of a new ITRF).
- An IERS Technical Note is in preparation, the draft was reviewed by W. Wooden.
- Corrections and comments are going to be taken into account.

Proposal of revised monthly Bulletin B:

- A survey asking users for their needs was done in Spring 2008.
- A new presentation was proposed based on the survey results.
- It is already available from ftp.

Differences in UT1 (100 µs) occur between Bulletin A and 05C04. The differences can be attributed to:

- gaps in the UT1 intensive data (up to 4-5 days)
- different weighting of UT1 intensives
- too weak smoothing in the 05C04 solution

Including an integration of LOD from GPS as a correction when VLBI intensives are erroneous or filling gaps when UT1 intensives are missing yield better results.

Quality of EOPs from IVS EOP combination

A. Nothnagel discussed the quality of EOPs from the IVS EOP combination. Two combined EOP products are provided by the IVS Analysis Coordination in Bonn. There are quarterly solutions where the whole series of 24 VLBI sessions is being re-processed and intensive solutions re-processed every Tuesday and Thursday when results of VLBI Intensives appear. During the last year significant improvements were achieved w.r.t. the quality of the products. Problems within single solutions of the ACs were identified and solved. For instance systematic differences were found between the solutions of the ACs using the software packages CALC/SOLVE and OCCAM. These were due to different high-frequency EOP models used in the software packages. Much better results were achieved as soon as both software packages used the models recommended in the IERS Conventions. Since late 2008 VLBI uses an own TRF for combination because some Russian stations participated which do not have reliable coordinates in ITRF2005. As a result it can be said that the combination is always better than the input of the individual solution.

Working Group on Prediction

W. Wooden reported about the activities of the IERS WG on Prediction. The tasks are to determine which prediction products are useful to the user community, and to make a detailed examination of the fundamental properties of the different input datasets and algorithms.

Current activities are:

- Organizing an IERS Workshop on EOP Combination and Prediction (WGP): It will be hosted by Space Research Centre in Warsaw. The Science Organizing Committee was established. The preliminary program is under review.
- Completing analysis of data and algorithms for presentation at the workshop.

WGP expectations are:

- Definitive user requirements.
- Comprehensive look at prediction methods.
- Comprehensive look at new data sets.
- IERS Technical Note describing current state-of-the-art EOP prediction including requirements, methods, and data set information content.

Decision: The format change of Bulletin B was accepted.

Future of the GGFC structure, implementation

The draft Call for Proposals (CfP) was sent out last week by the Central Bureau. The call was prepared by M. Rothacher and T. van Dam.

A presentation of the CfP was given by M. Rothacher. The structure of the GGFC should be updated in order to allow for the establishment of regular, reliable, and precise products as operational products and to allow for the inclusion of new operational products. The new GGFC structure will be divided into an Operational Component (GGFC-OC) and a Science Support Component (GGFC-SSC). The first component will host products that can be provided regularly, with acceptable latency, and sufficient precision. The latter component will host products that do not change with any regularity, but are nonetheless required by the IERS community. For the GGFC-OC, there will be 4 Special Bureaus: Atmosphere, Hydrology, Oceans, and Combination Products (from mixed fluids data sets). For the GGFC-SSC only 3 Special Bureaus are foreseen in the beginning: Core, Mantle, and Tides. Each SB will be chaired.

The call asks for three types of proposals:

- Individuals interested to chair one of the CBs.
  (Existing Chairs are very much encouraged to submit a proposal.)
- Accreditation of one or more operational products produced by a specific institution.
- Accreditation of already existing operational products produced by a specific institution

The call describes in detail:

- Responsibilities of the SB Chairs and how to submit a proposal.
- Process of accreditation for new official IERS products.
- Process of accreditation for already existing operational products.

Proposals will be reviewed by the IERS DB with input from the GGFC Chair. Funds required by the institutions in the framework of the GGFC have to be provided by the proposing institution.

The IERS DB members raised the following question when discussing this proposal: How to take care that existing SB chairs will send a proposal to stay as a chair in the new structure? Answer: T. van Dam will get into contact with the chairs before sending out the call and encourage them in order to answer the CfP and remain active in the future in the framework of the GGF. Does a joint call together with IAS, IGFS might make sense? Answer: The CfP will be sent out and is open to all IAG services.

The members of the evaluation committee to decide upon the proposals will be selected after the proposal deadline.

Schedule:

May 22, 2009:	Dissemination of the Call for Proposals
August 15, 2009:	Due date for Proposals
October 09, 2009:	Report by the evaluation committee to the IERS DB
Mid October, 2009:	Decisions by IERS Directing Board
End of October, 2009:	Notification of proposers on proposal acceptance
January 1, 2010:	Start of the product generation activities.

Decision:
The Call for Proposals is approved by the IERS DB and actions given below should be followed up.

New Action Items:
48.06 T. van Dam will contact current SB chairs to inform them about the GGFC Call for Proposals and push them to contribute to the new GGFC structure.
48.07 The Central Bureau will send out the GGFC Call for Proposals.

Renewal of the Analysis Coordinator

According to the IERS Terms of Reference (ToR) the AC serves for a four-year term, renewable once by the DB. Accordingly the term of M. Rothacher as AC ends on August 31, 2009. He is willing to continue till December 31, 2009 to provide more time to find a successor.

Since the ToR does not specify how to find a new AC the following procedure is proposed:

- Find appropriate candidates (DB).
- Ask candidates about their willingness (CB).
- Set up final list of candidates.
- Election by DB (by email in the second half of 2009).
- Installation of the new AC on January 1, 2010.

New Action Items:
48.08 Comments of DB members on how to proceed should be sent to the CB until end of April.

Reports of the Unions (IAU/WDS)

B. Richter described the planned implementation of the new ICSU World Data System.

A meeting of the World Data System Transition Team (5 members from FAGS and 5 members from WDC) took place on March 9–11 at ICSU in Paris with participation of the Unions, GEO, CODATA, etc. The summary of the discussions during the meeting will be circulated shortly as well as the WDS-TT White paper (about 10 pages). The paper includes the proposed criteria for the accreditation of a WDS. As soon as these documents are ready, a survey will be sent out to identify the community interested in being part of the new WDS.

ICSU created two new committees, the WDS Scientific Committee and the Strategic Coordinating Committee for Information and Data (SCCID). The ICSU nomination process for these committees is under way.

For a report of IAU, see above under ICRS/ICRF.

Decision:
IERS should work for membership in WDS.

New Action Item:
47.12 IERS should work for membership in WDS.

Conventions

This report was presented by Brian Luzum. The updates to the IERS Conventions are listed at <http://tai.bipm.org/iers/convupdt/convupdt.html>.

Updates since the last IERS DB Meeting in October 2008 were:

Chapter 4: Terrestrial Reference Systems and Frames

- 10 April 2009: Chapter has been significantly rewritten with Z. Altamimi and C. Boucher as the primary authors. A presentation of the ITRF2005 is now included.

Chapter 7: Displacement of Reference Points

- 10 April 2009: The subroutine dehanttideinel.f was updated to correct for a bug in software (the effect of this bug was < 0.05 mm).
- 19 February 2009: Section on models for displacement of reference points of instruments has been rewritten.
- Subroutines dehanttideinel.f and hardisp.f updated for leap second and hardisp.f has been improved by increasing the number of terms and correcting a sign error in the long-period tides.

Chapter 9: Models for Propagation Delay

- 12 February 2009: New section on ionospheric models for radio techniques.
- Chapter title changed accordingly.

Chapter 10: General Relativistic Models

- 12 December 2008: Added note 6 to state a sign error in a reference.

Work in progress:

Introduction:

- Define classification of models and criteria for choosing models

Chapter 3: Dynamical Realization of ICRF

- Revisions underway to include newer ephemeris

Chapter 5: Transformation

- Further revisions for consistency with IAU Resolutions

Chapter 6: Geopotential

- General rewrite including new geopotential model
- Rewrite of “Effect of Ocean Tides” (under review)

Chapter 7: Site displacement

- General rewrite
- Atmospheric tidal loading
- Routines revisited

Chapter 8: Tidal Variations in Earth Rotation

- Rewrite of the model for ocean tides; work on new model begun by R. Gross
- Review of the model for diurnal and semidiurnal EOP variations

Software Standardization

- Revised software template to be consistent with SOFA template

Additional Material

- New web page at <http://tai.bipm.org/iers/convupdt/convupdt_aux.html>

IERS Conventions changes – not yet started:

Chapter 1: General Definitions and Numerical Standards

- Incorporate recommendations of IAU NSFA WG

Chapter 2: Conventional Celestial Reference System and Frame

- Incorporate ICRF-2

Incorporate recommendations of IAU Commission 52 (RIFA)

- Not yet completed

A late 2009 publication date is estimated for the next registered edition of the Conventions.

Next IERS Directing Board meeting / workshops

IERS Workshop on EOP Combination and Prediction (presentation by W. Wooden)

Goal: Provide specific recommendations that when implemented will mitigate existing shortfalls / deficiencies in current techniques / IERS products

Time: 19–21 October 2009

Location: Space Research Centre, Warsaw, Poland

Proposed topics:
- Space geodetic EOP observations
- Sub-daily EOP tide models
- Long-term EOP tide models
- EOP combinations
- Non-geodetic AAM + OAM predictions
- EOP predictions

Deadline: Abstracts 1 August 2009

SOC: Orhan Akyilmaz, Aleksander Brzezinski, Daniel Gambis, Richard Gross, Wieslaw Kosek (co-chair), Brian Luzum, Zinovy Malkin, Jim Ray, Harald Schuh, Tonie van Dam, William Wooden (co-chair)

Next steps:
- SOC to finalize the preliminary program
- IERS Message to advertise workshop
- Session chairs to provide white papers / draft recommendations
- LOC to continue preparations

GGOS / IERS Unified Analysis Workshop 2009 (presentation by M. Rothacher)

Date and Location:
- Dates: December 8-9, 2009
- Place: Embassay Suites, Napa Valley

Participants:
- GGOS , IERS, IGS, IVS, ILRS, IDS, IGFS experts
- By invitation only
- Each service selects / nominates ~5 participants / experts

Sessions:
- Preparation by a team of chairs / co-chairs composed of one member of each Service
- Position papers

Topics:
- Topic 1: Details of Product Generation and Future (including portal and meta data)
- Topic 2: Technique-specific biases and co-location
- Topic 3: Modeling aspects, modeling based on external data (atmosphere, ocean, …)
- Topic 4: Combination, common parameters, and combined products
- Topic 5: Network simulations and analyses

Next Steps:
- Send UAW 2009 session proposal to IAG Services for comments and modification

- Ask IAG Services to select / nominate the participants
- Start preparations of sessions and position papers
- Setup web pages (Bernd Richter, … ?)

The next IERS DB meeting is proposed to be held right after the workshop in Warsaw for 1 and ½ day.

New Action Items:
48.09 Sent out an IERS Message w.r.t. the Workshop on EOP Combination and Prediction.
48.10 Ask for comments from the IERS DB to the proposed Agenda for the Unified Analysis Workshop.

Meeting No. 49

October 22–23, 2009, Space Research Centre, Polish Academy of Sciences, Warsaw, Poland

Introduction and approval of agenda

The Chair, Chopo Ma, welcomed the guests and the members of the IERS Directing Board. New in the Directing Board are Aleksander Brzezinski and Rüdiger Haas. The agenda was adopted.

Formalities

The Directing Board (DB) accepted the minutes of IERS Directing Board Meeting No. 48. The Annual Report 2007 is ready and will be online on October 26, 2009.

Proposals for new GGFC components, implementation

T. van Dam introduced the people who sent in the 8 proposals: 4 proposals for the chairs of the GGFC Sub Bureaus Atmosphere (SBA), Combined Products (SBCP), Hydrology (SBH), Ocean (SBO), 4 proposals for new GGFC products:

- Frank Flechtner: GRACE AOD products, contribution to SBCP
- Maik Thomas: combined atmosphere + ocean + hydrology AM, contribution to SBA
- Johannes Boehm: Vienna mapping functions 1 and zenith delays, contribution to SBA
- Tonie van Dam: loading from atmosphere, hydrological, non-tidal ocean and combined products, contribution to SBA, SBH, SBO, SBCP

The proposals were reviewed by 5 reviewers.

Summary of reviews:

- No comments on the proposed chairs.
- Missing components, especially research products.
- New products should be reviewed by the chairs and case by case by external reviewers but accepted by the DB.

The chair of GGFC should be active as chair of the combination centre.

Products should be operational. After the structure will be in place, more proposals should be solicited.

Missing components are: Cryosphere observations or models, solid Earth models: post glacial rebound, core, and mantle. T. van Dam will contact the corresponding chairs of old SBs.

Accreditation of new products is important. D. Salstein's (SBA) and R. Gross' (SBO) products should be used right away; the hydrology products should be checked because they are not very user friendly.

M. Rothacher asked for product statistics w.r.t. timeline, availability, latency … within one year. Documentation for each product should to be ready by the next DB meeting. Chairs to confirm membership lists. GGFC to take care of lists.

Decision: The DB accepted the proposals for the chairs and products.

New Action Items:
49.01 T. van Dam will inform the chairs about products their SB will receive and about their role in the accreditation process.
#49.02 The Central Bureau should send e-mails about proposal acceptance and reviewers' feedback to all proposers.
#49.03 T. van Dam should contact the chairs of old SBs.
#49.04 The Central Bureau should send an e-mail to the community announcing structure and chairs as well as products in accreditation, and requesting proposals for missing products.

Earth orientation products

D. Gambis summarized the status and function of current and new or changed EO products. The Technical Note is under discussion; the manuscript circulates between Observatoire de Paris and USNO. The new format of Bulletin B is available in parallel to the old. At the end of 2009 only the new format will be available, the old one only on request. C04 is supposed to be the basis. The schedule for aligning the C04 to ITRF2008 is:

- Check consistency of data between 2005 and 2008.
- When ITRF 2008 is official then C04 should be checked immediately and be ready in a month.
- Announcement of new series C04(08) should simultaneously be made in Paris and Washington.

Workshop on EOP Combination and Prediction

B. Luzum reported about the IERS Workshop on EOP Combination and Prediction (9 – 21 October 2009). The workshop made recommendations to IERS, IERS Conventions, IERS Rapid Service/Prediction Centre, IERS GGFC, and IAG Services. Maik Thomas will prepare a letter to ECMWF requesting data access. Short-term prediction series should be handled differently than the long-term ones. There are only a few users of 1-year predictions.

IVS UT1 intensives should be available in SINEX. Recommendation 12 demands to provide EOP prediction accuracy goals, having in mind concrete goals, not just “better” predictions. The DB members discussed, who work can follow on – as working group on combination of predictions or as a pilot project? A first test suggests that a pilot project would be better. B. Luzum will be the lead and prepare a call. [See also Section 4.2 of this Annual Report 2008–09.]

Decisions: The DB will write a letter to ECMWF. The DB encourages going ahead with a working group or a pilot project.

New Action Items:
49.05 B. Luzum will talk to R. Ray to update the subdaily tide model.
49.06 Combining of geophysical fluids data sets (intra or multi fluids), coordinated by T. van Dam, should ask B. Luzum for details.
#49.07 M. Thomas will prepare a letter to ECMWF requesting data access.
#49.08 B. Luzum will prepare a pilot project on combination of predictions.

Report on status of ITRF 2008

H. Drewes announced that DGFI has not yet finished combining different techniques, but intra-technique combinations are ready. A first presentation will be made at the AGU meeting.

Z. Altamimi stated that IGN ITRF2008 is characterized by a combination of 4 techniques; concerning the EOP the techniques contribute differently: IVS 1980–2009, full EOP set; IGS 1997–2009.5, PM, PM rate, LOD; ILRS 1984–2009, PM, LOD; IDS 1993–2009, PM, LOD. There are new ties, including new data from Russia, for a total of 600 sites and 800 stations.

Preliminary analysis of ITRF2008P yielded the following: there is a negligible origin shift and drift of SLR/ILRS wrt ITRF2005; there is no drift in scale. ILRS has included range biases, differences in VLBI–SLR scale drift is 0.04ppb. The offset between VLBI–SLR scale is 1 ppb. The agreement for the frame is 0.5 ppb. The combined adjustment of coordinates, velocities (600 – 800) and EOP requires ~40000 unknowns (5 days computing time). Inconsistencies in the EOPs affect the solution of the frame. There is an unexplained drift in the VLBI/IVS Y component of PM.

The schedule is the following: The final IGN solution needs fine tuning for another 2 weeks, DGFI needs one month, then both solutions are ready for evaluation. Only one solution will be presented but with information on agreement in velocities, differences in application of local ties, agreement in positions, and understanding of how EOPs affect the frame.

P. Sarti submitted a written report for the IERS WG on Site Survey and Co-location [see the web pages of the WG].

Working Group on Combination at the Observation Level

R. Biancale reported about the IERS Working Group on Combination at the Observation Level (COL). During the kick-off meeting, 25 participants reviewed the state of the art of combination. There are four institutions with different software packages for combination: GEODYN, DOGS-CS, GINS, BERNESE, EPOS (GFZ). Observatoire de Paris (OP) twill set up a forum to activate the discussion between the four groups. DGFI and OP agreed to compare solutions on the basis of SINEX files. The test period benchmark is: 3 weeks around the CONT08 campaign. The standards and models to be used are open. Laurent Soudarin prepared a form to give more details about the software used. Forum participants have to register. Combined SINEX files have to be submitted by Feb. 2010 for comparison. Before the EGU meeting decisions will be made to focus work.

Report on GGOS and GEO

M. Rothacher gave a report on GGOS activities since IERS DB meeting No. 48 including the new components in GGOS, the GGOS documents (especially the GGOS2020 book), meetings and workshops (past and planned), and the next major steps. A GGOS retreat will take place in Miami in the first week of February.

The 2nd IERS / GGOS Unified Analysis Workshop will be held in San Francisco on December 11–12, 2009 (see below).

IERS relationship to GGOS/GGOS products

To find the right points for the planned GGOS retreat there was a general discussion on the IERS relationship to GGOS and GGOS products. M. Rothacher as chair of GGOS stated that GGOS is not a service. GGOS as an umbrella will not produce products. Products of the IAG Services are GGOS products and the benefit for the services is greater international visibility.

Z. Altamimi discussed the structure of GGOS and that there should be a better interaction with the IAG Services. He proposes a change of the structure with a board of directors to give a better visibility to the Services. Services are supported by agencies, depending on the funds of the agencies.

D. Gambis pointed out that GGOS is relying on the IAG Services, so the services should be more involved in GGOS with a stronger relationship between GGOS and the services. M. Rothacher noted that the services should support GGOS.

C. Ma remarked that GGOS does not create the services, which have higher level sponsors.

Z. Altamimi demanded that if GGOS likes a push then the structure has to be improved, diminishing the influence of other players in the SC, e.g. IAG Commissions.

C. Ma draw attention to the fact that IERS is different from the Technique Services. GGOS can be seen as the unified voice of geodesy. GGOS is the corresponding Observing System (OS) to other OS. Z. Altamimi GGOS should be an advocate for the infrastructure that supports the services.

B. Richter reported about the planned initiative to create an Intergovernmental Committee for GGOS. The tasks of such an intergovernmental body will be

- Advocate and secure resources for the GGOS infrastructure.
- Coordination among the involved agencies.
- Promote and represent GGOS where necessary.
- Find an organizational umbrella to establish an intergovernmental arrangement.

Priorities will be developed in cooperation with GGOS. A first meeting of corresponding agencies, the IAG President, the GGOS Chair, and representations from the IAG Services will be held in Frankfurt am Main on Nov. 1–2, 2009.

New Action Item:
49.09 B. Richter should report from the Frankfurt meeting to the DB.

ICRS/ICRF

C. Ma presented a report of the IERS/IVS Working Group on the Second Realization of the ICRF. Compared to the original ICRF the new ICRF is characterized by the following qualities:

- 14 years additional observations
- Utilizes numerous advances in observing, analysis and modeling
- 5 times as many sources (3414)
- Noise floor 5–6 times lower (40 micro arc sec)
- Axis stability 2 times better (10 micro arc sec)

ICRF2 work was done by the IERS/IVS Working Group on the Second Realization of the ICRF, endorsed by the IERS DB and the IVS DB, proposed by IAU Division I Working Group on the Second Realization of the ICRF, supported by IAU Division I and accepted by IAU in resolution B3. Details can be read in IERS Technical Note No. 35.

A. Brzezinski summarized the IAU XXVII General Assembly (GA) held in Rio de Janeiro, Aug. 3 –14, 2009. Sessions of interest were: business meeting of Division I, business meetings of Commissions of Division I, e.g., IAU Commission 19, Joint Discussion 6 “Time and Astronomy”. Two IAU resolutions were supported by Division I: resolution B2 on IAU 2009 astronomical constants, B3 on the second realization of the ICRF. New officers were elected for Comm. 19 for the period 2009–2012: President Harald Schuh, Vice President Chengli Huang, members at large: Christian Bizouard, Ben Chao, Richard Gross, Wieslaw Kosek, David Salstein, representative for the IERS Bernd Richter. The new officers for Division I for the period 2009–2012 are: President Dennis McCarthy, Vice-president Sergei Klioner. A. Brzezinski went through the new ToR and gave an outlook to possible activities for the next term. Presentations from the IAU GA were posted on the Commission 19 webpage <http://iau-comm19.cbk.waw.pl/>.

New Action Item:
#49.10 The Central Bureau should send an official letter to IAU that B. Richter represents the IERS.

Renewal of the Analysis Coordinator

The proposal and election of an Analysis Coordinator is still pending. Background: the term of M. Rothacher ended in 2008. He is willing to continue until a solution is found. Several potential candidates were asked but none agreed to serve as IERS Analysis Coordinator. During the discussion on how to proceed, Z. Altamimi proposed a group formed from the Services, preferably the TC Analysis Coordinators. The tasks of the analysis coordinator should be redefined. An alternative could be to collect new names from the DB or to prepare a call.

Proposals to continue:

- ask the DB to suggest names,
- alternatively to prepare a call,
- to establish a group of TC AC to work together, to improve the consistency of products (mainly EOP, ITRF).

New Action Item:
#49.11 The Central Bureau should collect comments from the DB on the two proposals.

Reports on ICSU activities

B. Richter presented the ICSU World Data System (WDS) as a new body combining the old World Data Centres and the Federation of Astronomical and Geophysical Data Analysis Services (FAGS). After a first call IERS asked to become a member. Ruth Neilan is a member of WDS steering committee.

The ICSU Strategic Coordination Committee on Information and Data (SCCID) will establish and assert a visible and effective strategic leadership role, on behalf of the global scientific community, in relation to the policies, management and stewardship of scientific data and information. Furthermore it will provide strategic advice, where appropriate, to guide the implementation of the new ICSU WDS structure and the continued development of CODATA. B. Richter is a member of the SCCID.

Next IERS Directing Board meeting / workshops

M. Rothacher elucidated the planes for the GGOS Unified Analysis Workshop 2009:

Date and Location:

- Dates: December 10–11, 2009
- Location: Grand Hyatt, San Francisco

Participants:
- GGOS, IERS, IGS, IVS, ILRS, IDS, IGFS experts
- By invitation only
- Each service selects / nominates ~5 participants / experts

Sessions:
- Preparation by a team of chairs / co-chairs composed of one member of each Service
- Position papers

Topics:
- Topic 1: Details of Product Generation and Future (including portal and meta data)
- Topic 2: Technique-specific biases and co-location
- Topic 3: Modelling aspects, modelling based on external data (atmosphere, ocean, …)
- Topic 4: Combination, common parameters, and combined products
- Topic 5: Network simulations and analyses

Next Steps:
- Send UAW 2009 session proposal to IAG Services for comments and modification
- Ask IAG Services to select / nominate the participants
- Start preparations of sessions and position papers
- Setup web pages (Bernd Richter)

The next IERS DB meeting was proposed to be held before the EGU in Vienna (1 day) on May 2 (Sunday). [Due to an overlap with the IAG EC meeting it was later shifted to May 1, 2010.]

The second 2010 meeting of the IERS DB could be held in the USA or in Europe, e.g. in conjunction with the GRACE science meeting in Portugal, the Journées at the beginning of September in Paris, or the IAG Commission 1 meeting in October in Paris. A proposal was made that the Paris meetings should follow each other.

New Action Items:
#49.12 The CB should ask Harald Schuh for a meeting room.
#49.13 Feedback is asked from Z. Altamimi if the fall DB meeting can be held in conjunction with the Paris meetings.

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. 46, April 13, 2008, at Technical University Vienna, Austria, No. 47, October 28, 2008, at the US Naval Observatory in Washington, D.C., USA, No. 48, April 19, 2009, at Technical University Vienna, Austria, and No. 49, October 22–23, 2009, at the Space Research Centre of the Polish Academy of Sciences in Warsaw, Poland. Between the meetings the CB coordinated the work of the DB.

Together with the Global Geodetic Observing System (GGOS), the CB prepared a Follow-Up Meeting of the GGOS Unified Analysis Workshop, held April 15, 2008, at the Technical University Vienna, Austria, and the Second GGOS Unified Analysis Workshop, held December 11–12, 2009, in San Francisco, CA, USA. The programme and the presentations of these meetings were published at the IERS web site. For summaries see Section 4. The CB represented the IERS at several other meetings.

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 2008 and 2009 the web site was regularly enlarged and updated.

The IERS Annual Report 2006 appeared in online and in printed form. The IERS Annual Report 2007 was published in online form and was prepared for print. The CB started also to prepare the IERS Annual Report 2008 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 Commission 19 (Rotation of the Earth) of the International Astronomical Union (for the period 2005 – 2008) and for the International Association of Geodesy (for the period 2007 – 2009).

During the years 2008 and 2009, 33 IERS Messages (Nos. 123 – 155) 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 2008 and 2009 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), which was developed by the Central Bureau between 2002 and 2005, is in the operational mode since 2006. The system is continuously being adapted and extended by new components in order to fulfill 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.

Besides routine work like maintenance of the data bases of users, products and web pages, in 2008 and 2009 further developments of the IERS DIS concentrated on the following aspects:

- migration of the IERS web site to a new Content Management System (“Government Site Builder”, the CMS used within the division of the German Federal Ministry of the Interior),
- improvement of the IERS Plot Tool,
- development of an interactive data analysis tool,
- 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 be a fully compliant with ISO 19115, and adaption of the existing metadata to this profile,
- development of tools for the management of metadata,
- creating metadata for the so-called Global Geophysical Fluids

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 central part of the electronic infrastructure of the research unit is the common Web portal <http://www.erdrotation.de>.

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.

Initial points of the data pool for ERIS are the data series provided by the IERS. As an international service dedicated to Earth rotation and reference systems the IERS maintains the official data series concerning the Earth rotation parameters, the related reference frames, and a collection of relevant data concerning the geophysical fluids influencing the Earth rotation. In ERIS these data series are amended by data from other sources accessible via links to the original locations of publication. Because of the close cooperation between ERIS and the IERS Central Bureau ERIS has direct access to the data archive of the IERS and to applications developed for the IERS. In return, techniques and software developed in ERIS will be used after a phase of testing also by the IERS.

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.

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. The EOP Reader has access to data series stored in the IERS data archive. Currently, the series Bulletin A and B, the Finals Daily, the Finals Data, the Finals All, and the C04 series[1] are available.

Furthermore, a concept for an interactive tool for time series analysis has been developed and an industrial partner was engaged for the implementation. A graphical user interface allows 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 analysis results will be presented as data and visualizations; the import of own data series is managed via an import wizard. The application flow runs via three main steps: Data – load data files, Procedure – run analysis operations, and Output – give results as data and visualizations. All intermediate results are stored. The following analysis procedures are 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.

The conceptual framework for the visualization component was finished. This module will illustrate the interactions within the "system Earth" and their effects on Earth rotation. It contains parameterized model descriptions and a modular visualization engine that will allow an interactive use via the ERIS web portal.

Staff

Dr. Bernd Richter, *Director*

Dr. Wolfgang R. Dick, *scientist*

Carola Helbig, *secretarian*

Dr. Alfred Kranstedt, *scientist (until May 2008)*

Anja Niederhöfer (formerly Kreutzmann), *scientist (since May 2008)*

Alexander Lothhammer, *technician (until January 2011, on leave from November 2007 to October 2008)*

Peter von Rappard, *technician (from May 2009 to December 2010)*

Sandra Schneider, *technician (on leave from May 2009 to December 2010)*

Dr. Wolfgang Schwegmann, *scientist (until March 2010)*

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[1] http://www.iers.org/EOP

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Wolfgang R. Dick, Anja Niederhöfer, Bernd Richter

3.3 Analysis Coordinator

Unified Analysis Workshops in 2007 and 2009

The organization of the two UAWs was certainly one of the major tasks of the IERS Analysis Coordinator in the years 2007 and 2009. The Unified Analysis Workshop of 2007 has already been described in the IERS Annual Report 2007, and for the Unified Analysis Workshop 2009 a description may be found in this volume, Section 4.3. Some of the major action items are summarized here:

- **IERS Working Group on SINEX:** The proposal was made to create an IERS WG for the maintenance and updating of the SINEX format. Some of the tasks that were already clear were the inclusion of satellite antenna PCV parameters, the documentation of models and procedures used by the Analysis Centers and a new layout of SINEX format description. The IERS WG on SINEX was finally established in April 2011 with Daniela Thaller as the chair.
- **Combination of SLR Range Biases:** SLR range biases should be combined at the ILRS Combination Centers. This would improve the consistency of the combined solutions of the ILRS. This recommendation has not yet been implemented by the ILRS Combination Centers.
- **Apply atmospheric loading on the observation level:** Is atmospheric loading to be applied on the observation level for next reprocessing? A lot of tests have been done in the meantime by Tonie van Dam, Rolf Dach, Johannes Böhm and others. The final decision has not yet been taken. The topic is very controversial.
- **Reference pressure field for atmospheric loading:** In order to select a reference pressure field for atmospheric loading (and other corrections depending on pressure; e.g. a priori troposphere gradients), it was agreed that it makes sense to collect the information on reference pressure fields used by the different loading centers. In addition, tests should be done to see the differences between different approaches. The outcome of the selection of the reference pressure field should be reported to the IERS Conventions Center for inclusion into the IERS Conventions. The status today is that different groups still use different reference pressure fields.
- **Subdaily ERP tidal model:** The model for subdaily ERP tidal terms was not of sufficient accuracy anymore. Libration was not correctly handled at present. The release of an improved subdaily model is being planned by the IERS Conventions Center.

- Solar radiation pressure models for GNSS satellites: Solar radiation pressure modeling and parameterization is a crucial issue not only for GNSS but also for other satellites. A common effort to solve this problem should be initiated. In the meantime quite some progress was achieved in this issue (e.g. by Urs Hugentobler and others).
- Documentation of AC modeling and parameterization standards: A detailed documentation of AC modeling and parameterization standards would be very beneficial for all combination centers and also for the ITRF computations. However, so far this has not been realized.

Whereas some action items have been fulfilled in a short time frame others are still pending. But step by step the combination of the IERS products can be improved. The lists of all the action items of the UAW 2007 and the UAW 2009 are available at the web pages <http://www.iers.org/UAW2007> and <http://www.iers.org/UAW2009>.

Special Meetings and Conference Sessions on Combination Issues

2007

- EGU Meeting 2007, Vienna: Session G4 “What Constraints do Earth Rotation, Shape and Gravity Measurements Place on the Dynamical Processes of the Solid Earth?”, chaired by R. Gross, H.P. Plag
- XXIV IUGG General Assembly, 2–13 July 2007, Perugia, Italy: Session GS005 The Global Geodetic Observation System (GGOS), convened by M. Rothacher, R. Neilan, H.P. Plag
- IERS Conventions Workshop, 20–21 September 2007, Sèvres, France
- Journées “Systemes de reference spatio-temporels”, “The Celestial Reference Frame for the Future”, 17–19 September 2007, Paris Observatory
- Unified Analysis Workshop, 5–7 December 2007, Monterey, USA, organized by GGOS and IERS
- AGU Fall Meeting, 10–14 December 2007, San Francisco: Session on “The Global Geodetic Observing System: Observing and Interpreting Mass Transport in the Earth System”

2008

- EGU Meeting 2008, 13–18 April 2008, Vienna: Session G12 “GGOS: Observing and Interpreting Earth’s Mass Transports”, chaired by R. Gross, H.P. Plag, M. Rothacher
- UAW 2007 Follow-up Meeting, 15 April 2008, Technical University of Vienna, Vienna: “UAW Action Items”, chaired by M. Rothacher
- AOGS 5th Annual Meeting, 16–20 June 2008, Busan, Korea: GGOS session

- AGU Fall Meeting, 15–19 December 2008, San Francisco: Session on "Global Geodetic Observing System: Science and Instrumentation", convened by R. Gross, H.P. Plag, M. Rothacher

2009

- EGU Meeting 2009, 19–24 April 2009, Vienna: Session G8 "The Global Geodetic Observing System: Ground and Space-based Infrastructure for Earth Science", Convener: R. Gross, Co-Conveners: M. Rothacher, H.-P. Plag
- IAG Scientific Assembly 2009, 31 August – 4 September 2009, Buenos Aires, Argentina: GGOS session
- Second Unified Analysis Workshop 2009, 11–12 December 2009, San Francisco, CA, USA, organized by GGOS and IERS
- AGU Fall Meeting, 14–18 December 2009, San Francisco: Session on "GGOS and the Global Water Cycle", convened by H.P. Plag, R. Gross, C.K. Shum

Reference

Rothacher M., Boonkamp H., Angermann D., Böhm J.: Sub-Commission 1.1. Coordination of Space Techniques, IAG Commission 1 – Reference Frames, Final Report, IAG Commission 1 Bulletin No. 20, p. 13–24, DGFI, München, 2007.

Markus Rothacher

3.4 Technique Centres
3.4.1 International GNSS Service (IGS)

The International Global Navigation Satellite System Service (IGS) is a federation of more than 200 organizations from around the world that pool resources and expertise to provide the highest quality Global Navigation Satellite Systems (GNSS) data 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. These products contribute to IERS objectives of realizing the International Terrestrial Reference Frame (ITRF) and monitoring Earth orientation parameters. The IGS is a service of the International Association of Geodesy (IAG), one of the associations of the International Union of Geodesy and Geophysics (IUGG). This report highlights IGS activities of interest to the IERS during 2008–09.

IGS Tracking Network

At the end of 2009, the IGS network consists of 420 GNSS tracking stations that meet strict quality standards required to be included in generating IGS products. 132 of these were used in realizing the IGS05 reference frame, typically the oldest stations with long-term stable position time series. Of concern to the IGS reference frame product is that only 73 of the 132 used in IGS05 are still suitable for using in the reference frame solutions. A gradual decrease in the IGS05 stations is the result of equipment changes, seismic events, decommissioning, or in some instances, unknown reasons casing discontinuities in the position time series. New procedures for upgrading reference frame stations will be included in the next revision of IGS site guidelines to improve traceability as station equipment is upgraded. 93 stations have the capability to track the GLONASS satellites and contribute to generation of the GLONASS orbit product, though the GLONASS satellites have so far not been used in the IGS reference frame product. More GLONASS capable stations are urgently needed for this activity. Most stations return observation data on an hourly or more frequent basis to support the generation of the IGS rapid and ultra rapid products, which allow low latency access to the IGS reference frame. 120 IGS stations stream data in near real time to support of the real-time pilot service. The number of IGS stations that are co-located with other geodetic techniques to promote combination and inter-comparisons of products and systems has remained unchanged, and concerns over accuracy of the tie surveys remains, though is being addressed through the GGOS Bureau for Network and Communications where IGS participates.

134 stations are co-located with external high-precision frequency standards and are used in generating the IGS clock products and 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 and Figures 1–4. A complete listing of IGS network stations and related information can be found online at <http://igs.org/network/netindex.html>.

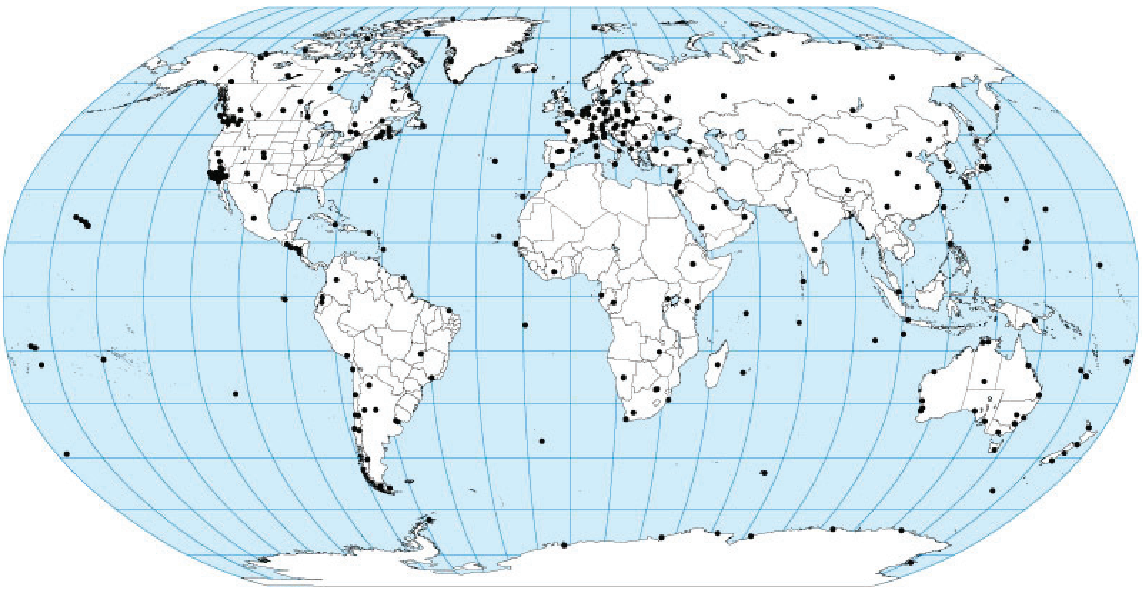

Fig. 1: IGS Global Tracking Network provides high quality tracking data used in support of diverse applications, including contributing to the realization of the ITRF.

Table 1: Summary of IGS station capabilities.

Total Stations	420
Reference Frame Stations	73
VLBI Co-located	25
SLR Co-located	37
Doris Co-located	55
Timing Lab Stations	80
Tide Gauge Project Stations	103
Multi GNSS (GPS/GLONASS)	93
Real-time Project Stations	120

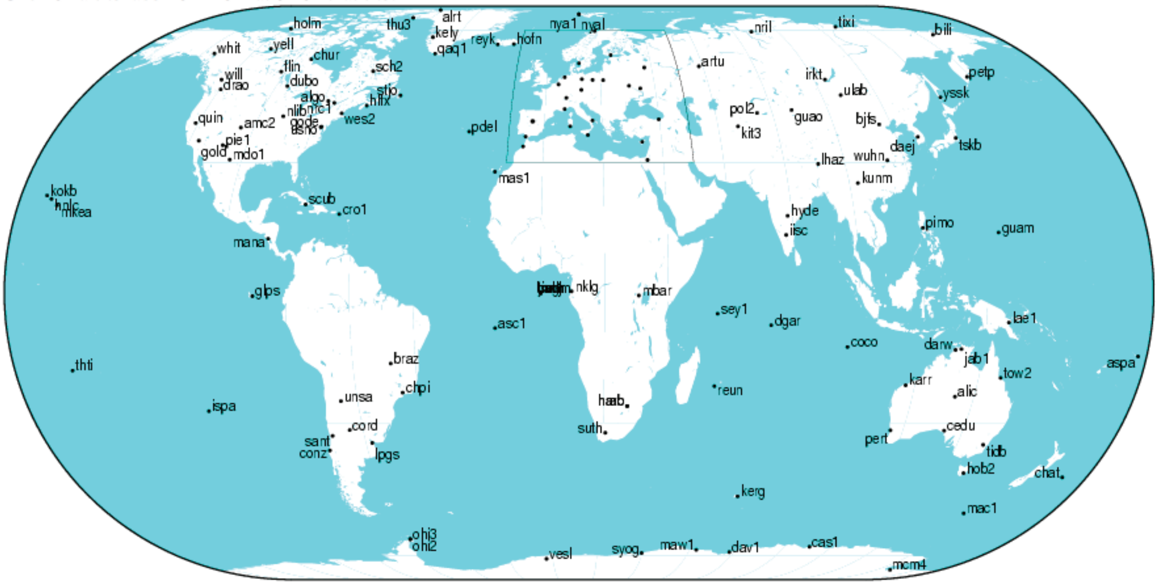

Fig. 2: IGS stations used in the realization of the IGS05 reference frame.

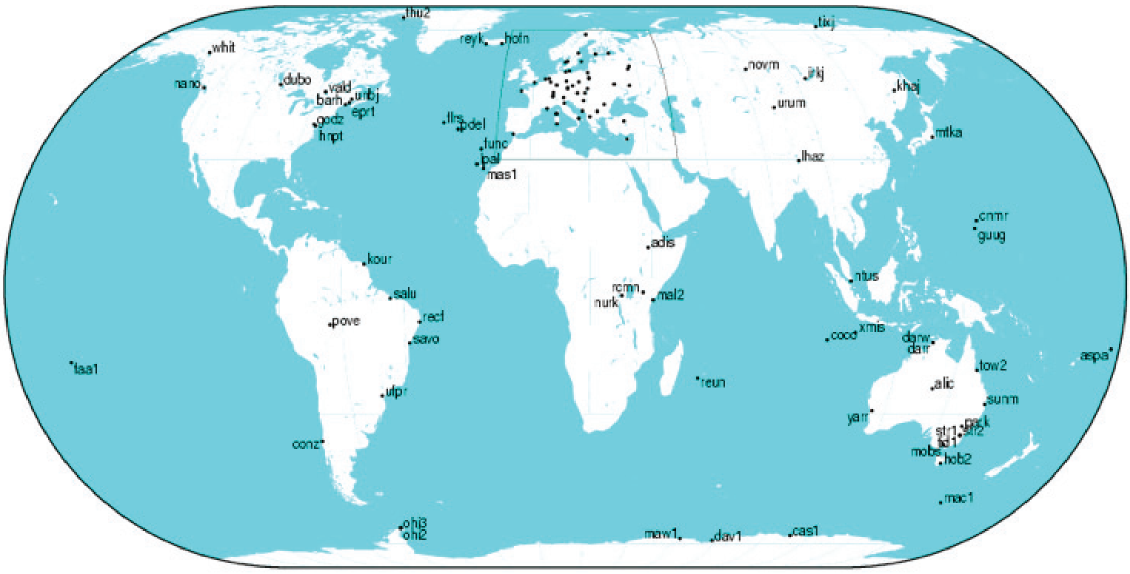

Fig. 3: IGS stations capable of tracking GLONASS satellites.

Quality of IGS Products

The IGS Analysis Centers (see <http://igs.org/organization/centers.html#ac>) have continued to improve product precision and consistency. Table 2 gives an overview of the estimated quality of the IGS core products at the end of 2009.

The combined and rapid orbit quality is depicted in Figures 4 and 5, which agreed at a level of approximately 3 mm at end of year 2009. Details related to the IGS products can be found on the

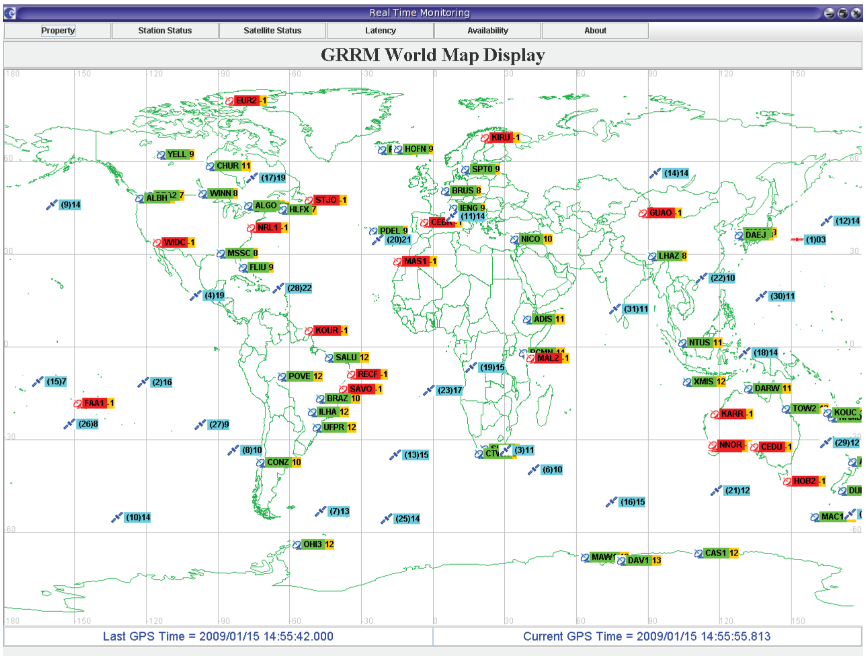

Fig. 4: Real time pilot network.

IGS web site (see <http://igs.org/components/compindex.html>). Various evaluations of the IGS product quality can be found in the Analysis Coordinator section of the IGS website (see <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
GPS Orbits	2.5 cm	2.5 cm	3 cm	5 cm
GPS 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			
GLONASS Orbits	5 cm			

Delivery of IGS SINEX Products

Weekly IGS SINEX products and related routine activities continued to be delivered on time with the support of M. Pirazewski (emr). Eight Analysis Centers (ACs) (cod, emr, esa, gfz, jpl, mit, ngs, and sio) have contributed weekly SINEX products (for acronyms see <http://igs.org/organization/centers.html#ac>). Two Global Network Associates Analysis Centers (GNAACs) (mit, ncl) have also continued to contribute independent combinations. Station coordinates are estimated for all of the IGS stations by the different ACs, with approximately 350 stations used in the weekly

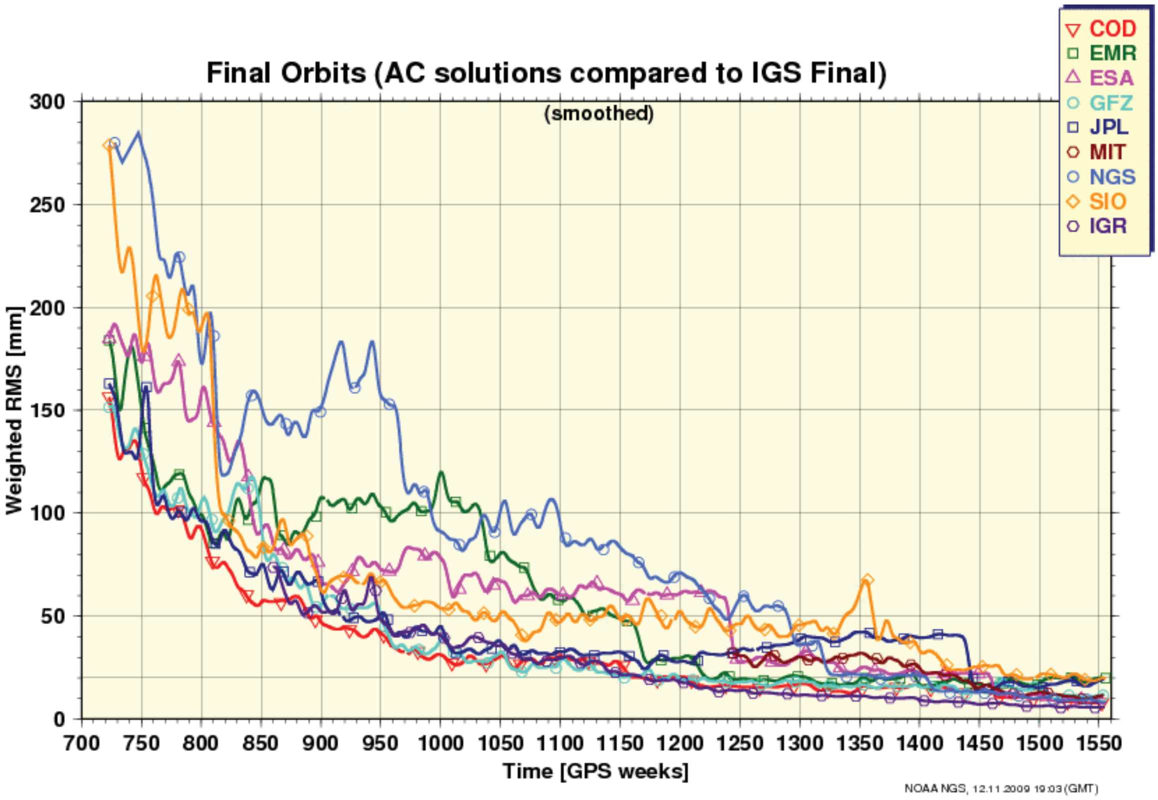

Fig. 5: Weighted RMS differences of all ACs and IGS final orbits to the IGS final combined orbit.

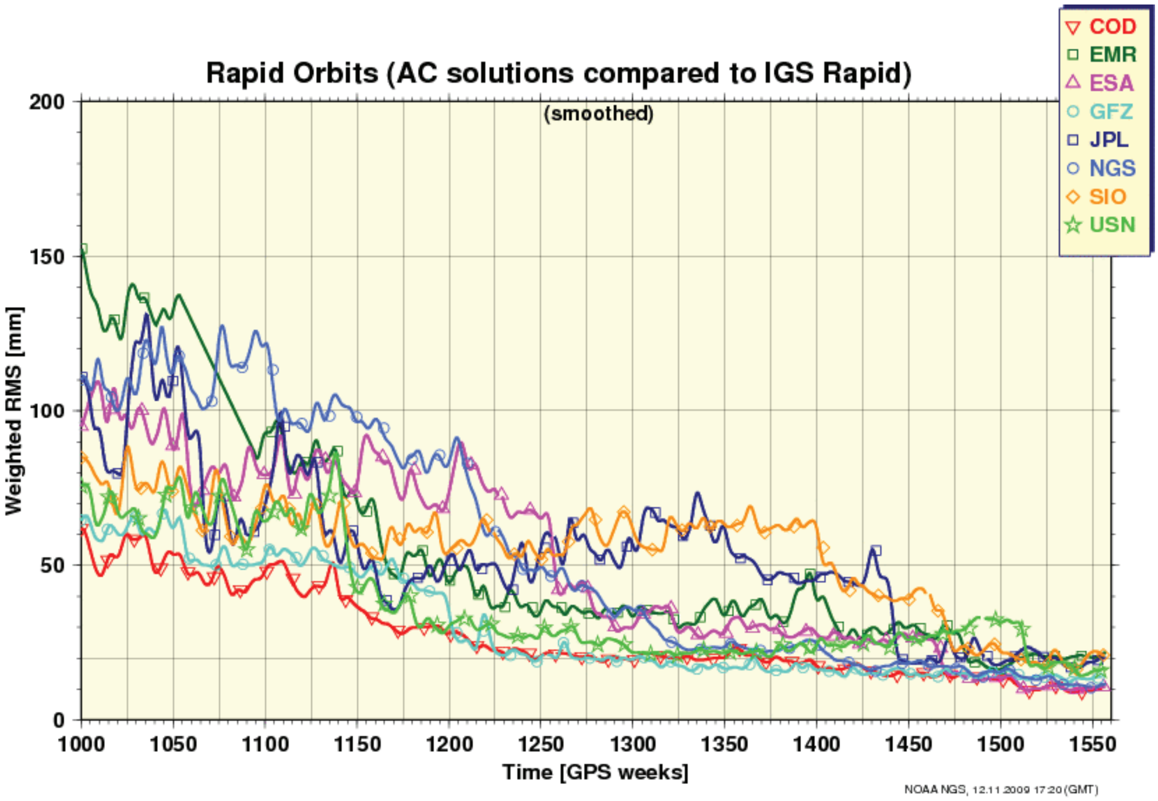

Fig. 6: Weighted RMS differences of all ACs' rapid orbits to the IGS rapid combined orbit.

combined products. Since 2008, the number of stations provided by the ACs increased at a rate of about 2 per month, though as previously mentioned, discontinuities or outages at core stations used in IGS05 is of concern that should be addressed in order to preserve the time series of these stations for as long as possible. The weekly IGS SINEX products include station coordinates, earth rotation parameters and apparent geocenter. The internal consistency of the SINEX products has been stable. The AC coordinates residuals with respect to the weekly combined product have standard deviations of 1–2mm and 3mm in horizontal and vertical components respectively. The AC pole position and rates are consistent at approximately 0.03 mas and 0.05–0.10mas/d with respect to the IGS weekly combined. The ACs weekly apparent geocenter estimates is consistent in X&Y at 3–4 mm and in Z at 7mm. The combined weekly IGS apparent geocenter is generally within 1cm of the ITRF05 origin. Several stations experience seasonal fluctuations mainly in the height component of up to several mm.

Reprocessing

Reprocessing has been a principal task of the ACs for the past several years. The main objective is to provide fully consistent IGS products, going back to 1995. Most of the IGS components have been involved in this activity, from the addition of several station data sets, to ensuring that the ACs use consistent models. A test campaign using data from GPS weeks 1042 to 1060 (1999/12/26 to 2000/05/06) was selected and all the ACs were invited to participate. 5 ACs (esa, mit, ngs, pdr, sio) contributed weekly solutions. The original combination included the station coordinates, the Earth Rotation Parameters (ERPs) and the implicit apparent geocenter. Feedback was provided to the ACs and a number of issues were resolved. For the few issues that weren’t resolved, affected parameters were removed from the combination. The ACs software models and processing strategy was to be identical for the reprocessing (1995 – 2007) and production (since 2008) to ensure fully consistent IGS products. As several ACs did not contribute solutions to the original test period, additional checks were made as new ACs started contributing to the reprocessing effort. As of the beginning of 2009, 11 ACs (cod, emr, esa, gfz, gtz, jpl, mit, ngs, pdr, sio, ulr) were contributing independent solutions to the reprocessing. Some ACs have also resubmitted improved reprocessed solutions. Gfz and ulr were specifically contributing GPS stations in the vicinity of tide gauges as part of their global contribution and the TIGA working group. Ncl also provided independent combination of the ACs station coordinates. Station coordinates time series were reviewed; several discontinuities were added while others removed. The reprocessed solutions for years between years 1997 and 2007, and the productions solutions for year 2008-2009.5 have been preliminarily prepared for ITRF2008.

Succession of Reference Frame Coordinator

The responsibility for generating the IGS reference frame product will transition from Natural Resources Canada to Institut Geographique National (IGN), France in the beginning of 2010.

Summary

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 (see <http://www.igs.org/> and <http://acc.igs.org/>).

Steve Fisher, Remi Ferland and Paul Rebischung

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. Here we summarize the status and developments in 2008–2009.

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 (for the best stations this number is a few millimeters). The absolute quality of the individual observations is at the 10 mm level, with a significant number of stations doing significantly better. The geometry of the SLR network has been a point of concern over the years. However, the network has improved (cf. Figure 1), in part due to the reinstatement of some key-sites that were shut down in 2004 and in 2008 due to the return to action of sites at Maidanak, Komsomolsk and the new Russian site in Altay. 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. 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 the end of 2010. Several other stations

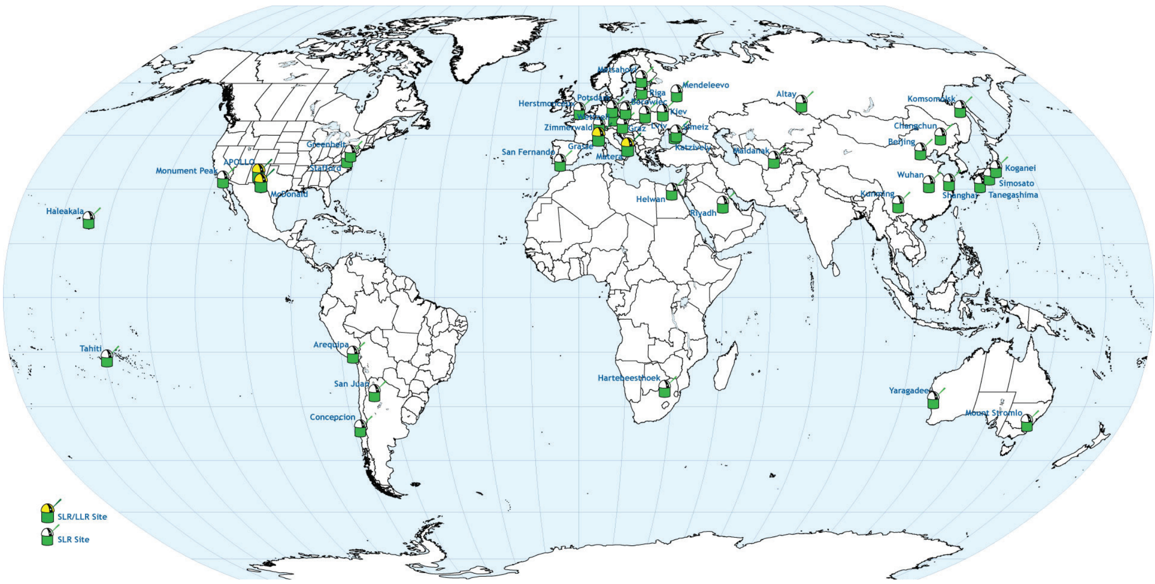

Fig. 1: The global network of SLR stations (status early 2010).

switched to high repetition rate systems, e.g. Herstmonceux, UK; Zimmerwald, Switzerland; Changchun, Shanghai and Beijing in China, and more sites with similar systems will soon be added to the network. This evolution will slowly lead us to the GGOS-era network as described in their GGOS2020 document. Statistics of the data collected as pass segments during the calendar years 2008 and 2009 are summarized in Tables 1 & 2. 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) which include the GPS,

Table 1: ILRS Network Tracking Statistics for 2008.

Site Name	Station	Number of Passes			
		Low	LAGEOS	High	Total
Ajaccio (FTLRS)	7848	772	4	0	776
Arequipa	7403	1,426	131	0	1,557
Beijing	7249	1,632	314	113	2,059
Borowiec	7811	143	65	0	208
Burnie (FTLRS)	7370	495	4	0	499
Changchun	7237	4,019	608	441	5,068
Concepcion	7405	1,792	821	355	2,968
Grasse	7845	36	32	9	77
Graz	7839	4,753	654	539	5,946
Greenbelt	7105	3,377	511	250	4,138
Haleakala	7119	1,820	405	0	2,225
Hartebeesthoek	7501	1,200	254	17	1,471
Helwan	7831	23	0	0	23
Herstmonceux	7840	3,956	872	427	5,255
Katzively	1893	1,187	310	227	1,724
Kiev	1824	725	90	0	815
Koganei	7308	472	125	60	657
Komsomolsk-Na-Amure	1868	0	27	5	32
Kunming	7820	601	61	0	662
Lviv	1831	182	22	0	204
Maidanak	1864	0	3	0	3
Matera	7941	2,880	800	77	3,757
McDonald	7080	1,075	335	243	1,653
Monument Peak	7110	1,548	366	115	2,029
Mount Stromlo	7825	5,979	1,250	448	7,677
Potsdam	7841	1,827	313	7	2,147
Riga	1884	319	58	4	381
Riyadh	7832	3,173	823	383	4,379
San Fernando	7824	3,019	440	72	3,531
San Juan	7406	5,975	1,132	1,475	8,582
Shanghai	7821	1,265	164	29	1,458
Simeiz	1873	820	282	86	1,188
Simosato	7838	123	40	0	163
Tahiti	7124	347	98	10	455
Tanegashima	7358	378	64	85	527
Wettzell	8834	4,455	1,011	366	5,832
Yaragadee	7090	10,481	2,085	1,525	14,091
Zimmerwald	7810	4,276	832	811	5,919
Totals:	38 stations	76,551	15,406	8,179	100,136

Table 2: ILRS Network Tracking Statistics for 2009.

Site Name	Station	Number of Passes			
		Low	LAGEOS	High	Total
Altay	1879	45	69	95	209
Arequipa	7403	605	12		617
Beijing	7249	766	114	25	905
Borowiec	7811	673	47		720
Changchun	7237	5,211	539	408	6,158
Concepcion	7405	377	108	3	488
Concepcion@847	7405	3,380	1,183	673	5,236
Grasse	7829	101			101
Grasse_MEO	7845	648	474	326	1,448
Graz	7839	4,119	618	464	5,201
Greenbelt	7105	5,175	812	467	6,454
Haleakala	7119	1,832	457		2,289
Hartebeesthoek	7501	1,660	424	92	2,176
Helwan	7831	6			6
Herstmonceux	7840	3,759	821	434	5,014
Katzively	1893	1,798	172	290	2,260
Kiev	1824	1,198	98		1,296
Koganei	7308	1,311	288	273	1,872
Komsomolsk	1868	14	38	25	77
Kunming	7820	225	14		239
Lviv	1831	458	28		486
Matera_MLRO	7941	1,876	578	253	2,707
McDonald	7080	1,133	387	262	1,782
Monument_Peak	7110	1,496	322	342	2,160
Mount_Stromlo_2	7825	5,760	1,047	337	7,144
NRL	7865	1			1
Papeete	7124	236	73	18	327
Potsdam_3	7841	2,603	449	88	3,140
Riga	1884	702	91	3	796
Riyadh	7832	1,275	278	144	1,697
San_Fernando	7824	2,915	277	106	3,298
San_Juan	7406	4,512	1,087	1,219	6,818
Shanghai_2	7821	1,306	133	87	1,526
Simeiz	1873	894	167	93	1,154
Simosato	7838	763	224	3	990
Tanegashima	7358	584	128	206	918
Wettzell	8834	4,833	894	348	6,075
Yarragadee	7090	10,434	2,035	1,488	13,957
Zimmerwald@532	7810	6,025	1,209	1,352	8,586
Totals:	39 stations	80,709	15,695	9,924	106,328

GLONASS, ETALON and GIOVE-A/B satellites (GALILEO test s/c), as well as a number of recently launched Beidou satellites, part of the Chinese Navigation Constellation COMPASS. There are some additional experimental satellites at HEO orbits (e.g. JAXA's ETS-8) that are only tracked by part of the network due to their geographical coverage limitations.

From all of the ILRS observatories (nearly 40), there are only a few sites that are technically equipped to carry out Lunar Laser

Ranging (LLR) to retro-reflector arrays on the surface of the Moon (Figure 2) or spacecraft orbiting around the Moon. The McDonald Observatory in Texas, USA and Observatoire de la Côte d' Azur, France were the only operational LLR sites over the past years, achieving a typical range precision of 18–25 mm. The latter underwent renovation since late 2004, and returned to action in September 2009. 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 set of data from APOLLO was released in 2009, with about 640 normal points available in total. The APOLLO data shall soon be provided in the newly adopted ILRS data format (CRD). The data distribution of all LLR observatories is shown in Figure 3.

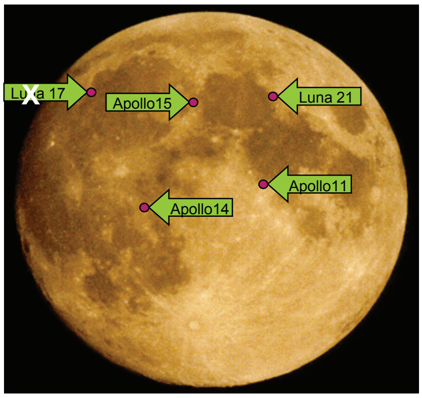

Fig. 2: Retro-reflector sites on the Moon, Luna 17 has not been successfully tracked until 2009.

Table 3: Values from LLR for some relativistic parameters and their realistic errors.

Nordtvedt parameter η (test of the strong equivalence principle)		$(6 \pm 7)\ 10^{-4}$
time variable gravitational constant	$\dot{G}/G$ [yr^{-1}] $\ddot{G}/G$ [yr^{-2}]	$(2 \pm 7)\ 10^{-13}$ $(4 \pm 5)\ 10^{-15}$
preferred frame parameters (coupled with velocity of the solar system)	α_1 α_2	$(-4 \pm 9)\ 10^{-5}$ $(2 \pm 2)\ 10^{-5}$
preferred frame parameter (coupled with dynamics within the solar system)	α_1	$(1.6 \pm 4)\ 10^{-3}$

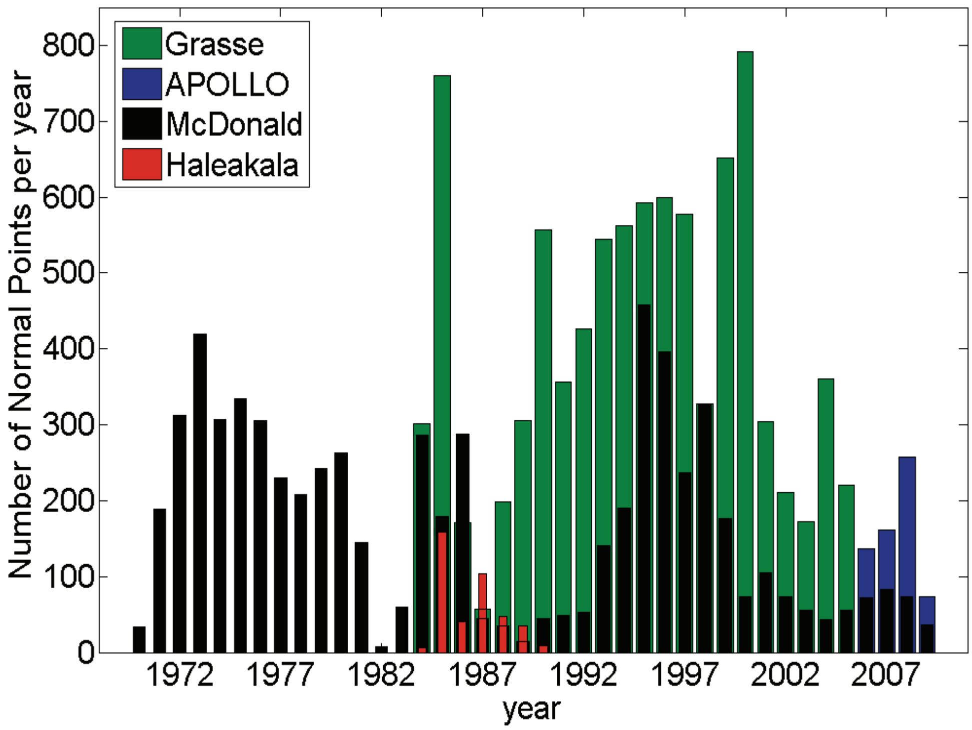

Fig. 3: The LLR NP data collected at all LLR observatories from 1970 until 2009.

There are now plans for the Matera, Italy and the new Wettzell, Germany stations to join the LLR tracking network in the near future, in addition to the already announced intentions of the Mt. Stromlo, Australia station, as well as the plans for establishing a lunar capability at the South African site of Hartebeesthoek, once a new telescope is installed. Today, the results from LLR are considered among the most important science return of the Apollo era. Lunar laser ranging has continuously provided range data for about 40 years, generating about 16800 normal points. Based on appropriate modeling and sophisticated data analysis, LLR determines many parameters of the Earth-Moon dynamics like lunar ephemeris, lunar physics, the Moon's interior, reference frames and Earth orientation parameters.

LLR has also become the strongest tool for testing Einstein's theory of general relativity in the solar system. By extending the standard solution, it is possible to solve for parameters related to gravitational physics, like the temporal variation of the gravitational constant, metric parameters as well as the strong equivalence principle and preferred-frame effects (Soffel et al., 2008). The latter can be related to gravito-magnetic effects in the solar system constraining possible deviations from Einstein's theory. Recent results for some selected relativity parameters including realistic errors are given in Table 3.

Even further predictions of general relativity (secondary effects), which were not fit for in the past, can be investigated, e.g., those parameterizing effects of modifications of Einstein's theory. In addition, quantum physical predictions, assuming Lorentz violation, which will manifest itself as oscillatory perturbation of the lunar orbit, can be determined.

The moon is also investigated with dedicated lunar orbiters. One of them is the Japanese mission Kaguya (Selene) launched in 2007. Its data were used to produce a lunar map with unprecedented accuracy and spatial resolution, especially of the far side of the Moon.

Missions

In 2008–2009, a total of ~30 satellites (including the Moon) were being tracked by laser (Figure 4). During 2008 the ILRS completed its effort to develop a standardized design for retro-reflector arrays on future missions. The basic principles adopted will provide guidelines for future designs that will yield guaranteed results in the quality and quantity of tracking data. Year 2008 was a year of several new missions launched with retro-reflector arrays. On April 26 GIOVE-B was successfully placed in orbit. On June 20, Jason-2/OSTM was launched as follow-on to the successful oceanographic radar-altimeter-carrying satellites TOPEX/POSEIDON

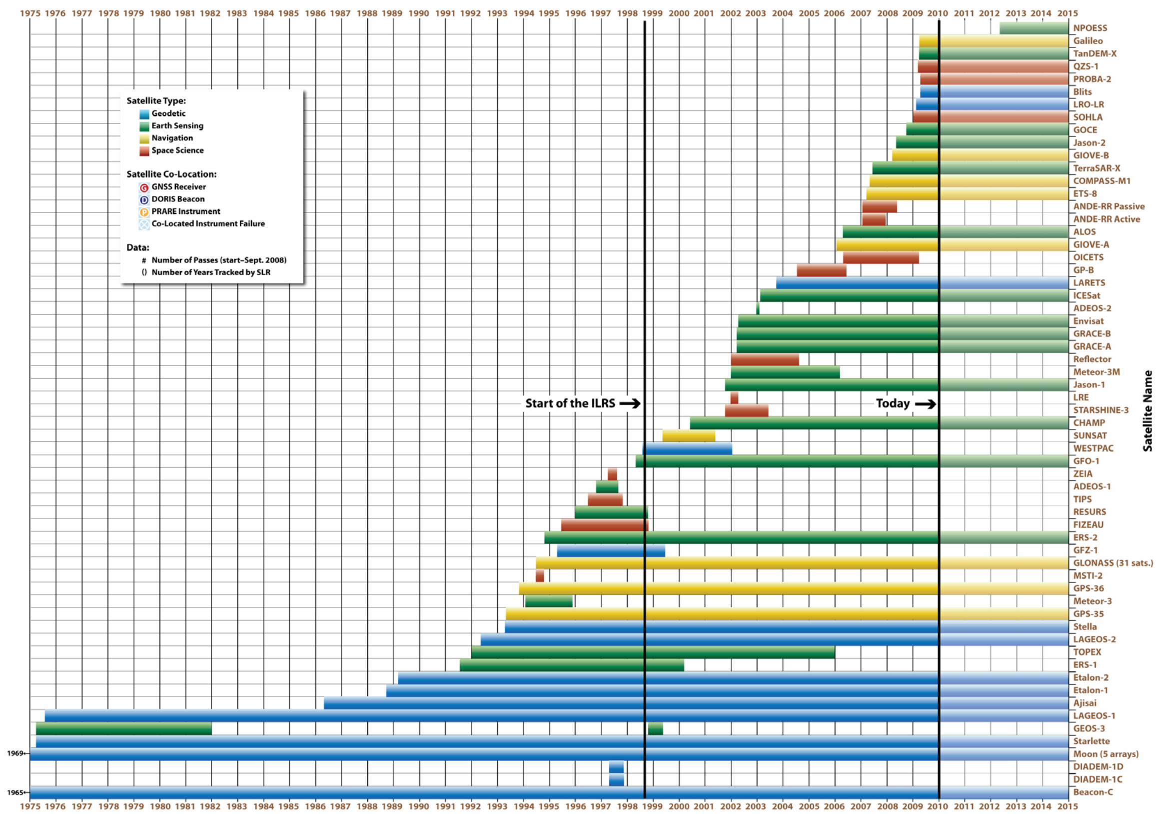

Fig. 4: The currently tracked SLR missions (status early 2010).

and Jason-1. One of the exciting facets of this mission is the T2L2 time synchronization experiment carried onboard, something that will generate new interest in tracking this target. The year concluded with the launch of two triplets of GLONASS spacecraft, one on September 25 and one on December 25, placing in orbit the six M-type spacecraft that occupy the slots 110 through 115. The new satellites improved significantly the service provided by GLONASS and ILRS selected three of the M-type s/c to be tracked routinely for orbit calibration purposes (102, 109, 115). During 2008 we also lost some targets due to decay or loss of scientific interest after failure of the main instrumentation. After a successful tracking campaign, Naval Research Lab's (NRL) ANDE-RRP (Atmospheric Neutral Density Experiment Risk Reduction – Passive component) mission re-entered on May 25, 2008. The other half of the mission, the active spacecraft ANDE-RRA, had already re-entered on Dec. 25, 2007. Sometime in late September GFO-1 went into safe mode and after unsuccessful attempts to right the spacecraft, operations terminated on September 25, 2008 and along with that tracking by the ILRS network. In late 2008 the ILRS network started tracking of the COMPASS M1 satellite, a component of the new Chinese Navigation Constellation Beidou (COMPASS).

Over 2009, ILRS continued preparations 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). One goal is to take photographs of the old landing sites. After careful planning and coordination with stations that showed interest in participation, the project has arrangements with a significant number of the ILRS sites to participate in tracking LRO-LR that eventually launched successfully on June 17, 2009.

On March 17, 2009 (exactly seven years after the date of the GRACE mission launch!), the new gravitational mapping mission GOCE of ESA was successfully launched and soon after it was tracked by the ILRS network. The GOCE mission, due to its very low orbiting altitude—295 km!, put to test the predicting and tracking facilities of ILRS. It was a pleasant surprise to see that the systems worked perfectly in all areas and provide continued support to the mission through all of its phases.

The last launch of 2009 with ILRS interest was that of BLITS (Ball Lens In The Space), an experimental satellite launched by the Federal Space Agency of Russia (Figure 5). As the name of the mission implies, this is a very novel design of two concentric glass balls (one contained in the other) with slightly different refractive indices that result in turning these balls into a spherical retro-reflector with a very precisely known signature. The results

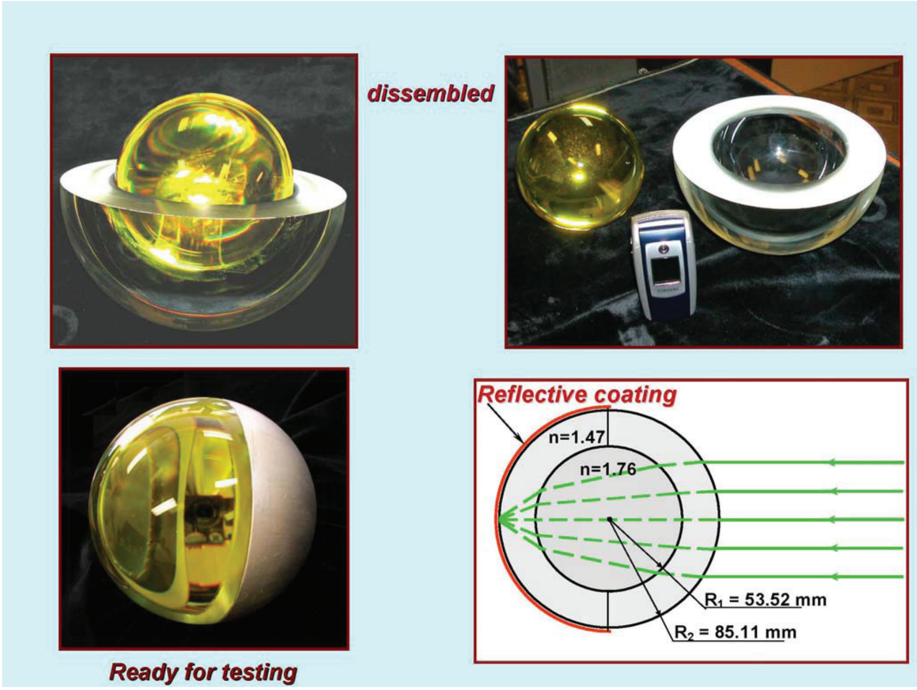

Fig. 5: The BLITS (Ball Lens In The Space) spacecraft design (courtesy FSUE IPIE).

of the initial tracking data indicate that this type of design has the potential to cover the needs of GGOS for very low and stable target signature satellites for extremely accurate reference frame applications.

Several dedicated tracking campaigns were successfully executed during 2008 and 2009. Three of them involved one or both of the GIOVE spacecraft and a fourth one targeted the two aging GPS spacecraft that carry retro-reflectors (GPS-35 & 36), as they were nearing their operational lifetime. In mid-2008, GPS-35 was set “unhealthy” in the US Navigation bulletins and ILRS ceased tracking operations. This left us with only one GPS satellite with laser retro-reflectors onboard. Other dedicated campaigns tracked the IceSAT/NASA and OICETS/JAXA missions.

Analysis and science

The main topic on which most of the Analysis Centers focused their work during 2008 was the preparation of the ILRS submission to ITRS for the development of ITRF2008. As it was already planned since the development of ITRF2005, ILRS’ Analysis Working Group (AWG) was to extend their analysis period to cover the interval 1983 to present. This would provide a much longer record for some sites with long histories and it would generate new, improved coordinates and velocities for several sites that were active in the early years of SLR but no longer exist. The primary concern of all AC analysts was the meticulous treatment of measurement biases, known from engineering tests or detected during the analysis. With the accuracy of the results reaching a few millimeters at worst, even small biases of comparable magnitude cause discontinuities in the TRF and force the introduction of ad hoc “breaks” in the series which must be avoided at all costs since they cause instability in the end-product.

An initial analysis was submitted to ITRS near the end of 2008, which upon their preliminary analysis served as the basis for the final submission (in mid-2009), taking into account the feedback from ITRS. The final version of the ITRF2008 was not released in 2009 as planned, but an extensive evaluation and validation period of the preliminary version proved very useful for the improvement of future realizations. Figure 6 shows the offsets of the origin and scale components for the data period included in the ILRS contribution to ITRF2008 (1984 – 2009). The newly added period of historical data (1984 to 1992) is based on LAGEOS data alone and ground systems with much less accurate data than the present network, which are the reason behind the large and often systematic behavior during the early years.

The corresponding components for the period 1993 to 2009 are based on data from LAGEOS 1 & 2, as well as data from the ETALON 1 & 2 after 2002. It is evident that the contribution of additional targets helps considerably to stabilize the series and the improved data quality results in demonstrating mainly seasonal signals of geophysical origin. One of the significant improvements of this re-analysis was the compilation and validation of a complete set of measurement biases at all sites, which was put in a SINEX-like standardized format and will be from now on the basis

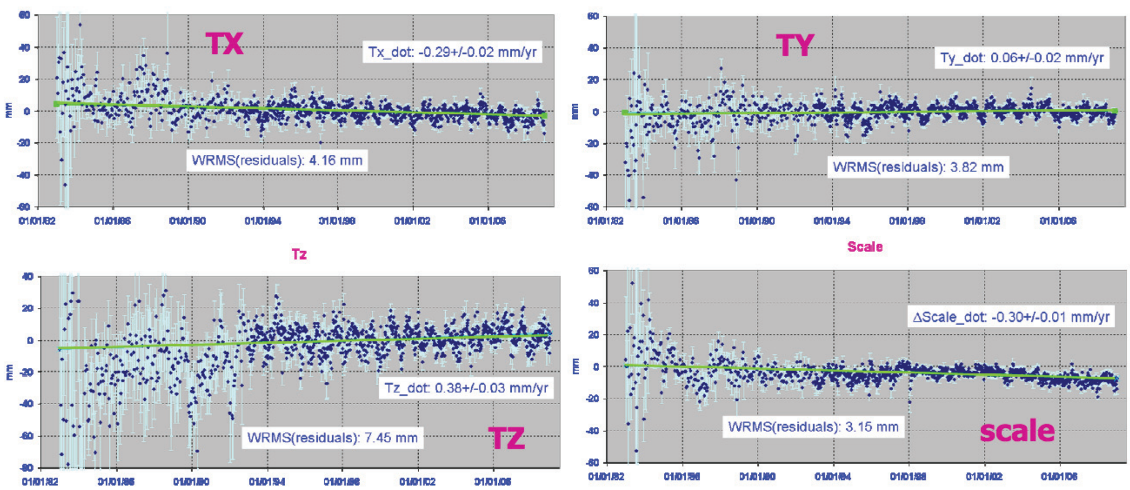

Fig. 6: Time-series of X, Y, and Z offsets and scale factor averages of the ILRS-A official combination origin with respect to the reference TRF (SLRF2005) origin (proxy for “geocenter” variations) and scale as observed by SLR (1984.0 – 2009.0).

of any SLR data analysis effort. This is also available through the ILRS web pages to any other SLR data analysts, to ensure that the data are correctly treated by anyone user and for any reason, whether it is for ILRS official products or independent research.

During 2008–2009, ILRS continued improving the models and procedures used in the analysis of the range data collected from the ILRS network, and in particular, the accurate determination of the target signature ("center of gravity to effective reflection surface" – CoG). The ILRS-established task forces dedicated to improving the target signature characterization and the communication between tracking stations and the analysts were very active during this period. On several occasions biases detected at sites were reported within hours and corrective action was taken immediately, to limit the repercussions on the analysis products. Additionally, following the characterization of the LAGEOS targets, the target signature task force adopted a comparable table for the two ETALON satellites. This improved consistency and accuracy of the CoG magnitude will lower significantly the limits of error on the scale definition of the ITRF from SLR.

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 and along with VLBI, its absolute scale. The root-mean-square (RMS) of the weekly X-Y-Z offsets and Δ-scale is 4 mm, 4 mm, 7 mm and 3 mm, respectively, for the 1984–2009 period. Statistics for the more recent period are by far better.

Since 2003, the ILRS AWG submits on a weekly basis their products 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 with efforts underway to further decrease this latency period. During 2008-2009, six ACs (ASI, BKG, GFZ, GRGS, JCET and NSGF) contributed to the Pilot Project for this daily product, with more ACs expected to join the group in 2010. A NEOS evaluation of the new product indicates that the quality is now nearing that of the weekly product, which is based on the contributions from eight ACs. The ILRS will decide in 2010 whether to evolve this PP into an official product (replacing the weekly one), or to discontinue it.

During 2009 the European Space Agency Space Operations Center (ESOC) underwent benchmark activities to become an official ILRS Analysis Center under the codename "ESA". Most of the testing formalities were successfully completed at the end of 2009, so it is expected that in early 2010, ESA will be accepted as the ninth member of the official ILRS Analysis Working Group.

Meetings

The ILRS held a number of meetings over the 2008-2009 period. In 2008 we convened the 16th International Laser Workshop at Poznań, Poland, with the theme "SLR – the next generation". The very successful workshop was attended by most of the ILRS members and associates and the proceedings were published in two volumes.

<http://www.astro.amu.edu.pl/ILRS_Workshop_2008/index.php>

Recognizing the increasing number of navigation constellations that rely heavily on SLR to calibrate and support their operations, in the fall of 2009 we organized the ILRS Technical Workshop on "SLR Tracking of GNSS Constellations". The workshop, which took place in Metsovo, Greece, September 14–19, 2009, brought together the GNSS and SLR communities in order to understand, plan and propose synergistic collaborations that will help GGOS meet its goals in the coming years.

<http://www.ntua.gr/MIRC/ILRS_W2009/>

In addition to these two main events, the ILRS participated in several international meetings and held several internal meetings of its Central Bureau, Governing Board and the various Working Groups.

<http://ilrs.gsfc.nasa.gov/about_ilrs/meetings.html>

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3.4.3 International VLBI Service (IVS)

Report for 2008

IVS Organization and Activities

During 2008, 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. In March 2008 the fifth IVS General Meeting (GM2008) took place at the Institute of Applied Astronomy (IAA), St. Petersburg, Russia. Two IVS Directing Board meetings were held, one in March at IAA, St. Petersburg, Russia, and the other in September at the Dominion Radio Astrophysical Observatory, Penticton, BC, Canada. The nineth IVS Analysis Workshop was held on March 7, 2008 in connection with the GM2008. The seventh International e-VLBI Workshop was held at Shanghai Astronomical Observatory (SHAO), Shanghai, China in June 2008.

In June 2008 the IVS issued a call soliciting proposals for the installation and operation of IVS Combination Centers and additional Operational Analysis Centers and Associate Analysis Centers. Combination Centers are a new type of Analysis Centers that are tasked with preparing IVS combination products in cooperation with the Analysis Coordinator in a timely fashion. At its September meeting the IVS Directing Board approved the proposals from BKG/DGFI, Germany and from the Korea Astronomy & Space Science Institute (KASI) to become Combination Centers. DGFI changed from an Associate to an Operational Analysis Center and Sternberg Astronomical Institute (SAI) of Moscow State University became a new Operational Analysis Center. At the beginning of the year the Max Planck Institute for Radioastronomy, Bonn, Germany already applied for becoming an IVS member organization for the operation of the Bonn Correlator. The proposal was unanimously approved at the March Directing Board meeting.

IVS published its 2007 Annual Report in May 2008 and three newsletter issues (April, August, December) which keep the community informed about IVS activities. The Proceedings of the Fifth IVS General Meeting were published in August 2008 in the Russian „Nauka“ (Science) series.

Network Stations

A total of 1267 station days were used in 187 geodetic/astrometric sessions during the year. Observing sessions coordinated by IVS remained at an average of ~3.5 days per week, similar to previous years. The total number of sessions and of station days increased with respect to the previous year due to the observation of the two-week long continuous VLBI campaign 2008 (CONT08). The major observing programs during 2008 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), on weekend days (Saturday and Sunday, Int2) on the baseline Wettzell (Germany) to Tsukuba (Japan), and on Monday mornings (Int3) in the middle of the 36-hour gap between the Int1 and Int2 Intensive series on the network Wettzell (Germany), Ny-Alesund (Norway), and Tsukuba (Japan).

CONT08 A fifteen day campaign of continuous VLBI sessions, observed in the second half of August 2008 and coordinated by the IVS Coordinating Center at NASA Goddard Space Flight Center. The goal of the campaign was to acquire state-of-the-art VLBI data over a two-week period to demonstrate the highest accuracy of which VLBI is capable.

IVS-T2 Bi-monthly sessions coordinated by the 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 in extending the CRF by observing “new” sources. Eighteen sessions were observed for the maintenance of the ICRF in 2008 primarily in the southern hemisphere. Eight of them were scheduled with emphasis on the far southern hemisphere (CRD) and three with emphasis on the median south.

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 2008.

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

JADE

The JApanese Dynamic Earth observation by VLBI (JADE) had nine 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

Nine research and development sessions were observed in 2008. Three of them were scheduled to observe high redshift radio sources, three to test 512 Mbps recording modes for possible usage in the continuous VLBI campaign 2008 (CONT08), and three to vet geodetic sources for the second realization of the ICRF.

The Network Coordinator's data base of station performance showed a data loss of 15.1%, slightly worse (3.7%) compared to 2007. For the CONT08 campaign the data loss was 9.3%. The most significant causes of data loss were antenna reliability (19.2%), RFI (14.8%), and receiver problems (13.8%). Unidentified problems accounted for about 17.7% of the loss.

Correlators

The correlators at Haystack Observatory (USA), the U.S. Naval Observatory (USA), and at Max Planck Institute for Radioastronomy (Germany) continued their efficient processing of the data recorded on Mark 5 disk media. Several 24-hour sessions are now correlated in less than a day. The correlator at MPIfR Bonn routinely used its 1 Gbps connection for electronic data transfer (e-transfer) with several network stations that are already connected. A high-speed connection of the USNO correlator further progressed and is expected to be available in the first half of 2009.

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.

IVS Operational Data Analysis and Combination

The combination process for the two IVS EOP series (rapid and quarterly solutions) has been continued exclusively on the basis of datum-free normal equations in SINEX format. In 2008, six IVS Analysis Centers (BKG, DGFI, GSFC, IAA, OPA, 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 six 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.

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 that are observed with networks of limited extension or which are scheduled for a different purpose like radio source monitoring.

The results are reported in two EOP time series, the rapid solution file (ivs08r1e.eops) and the quarterly solution file (ivs-08q4e.eops), in the IVS EOP Exchange format. Companion files containing the nutation offsets in the X, Y paradigm are routinely generated through a standard transformation process (ivs08r1X.eops, ivs08q4X.eops).

VTRF2008

In 2008, it became obvious that a new TRF for the IVS EOP determinations had to be computed for several reasons. ITRF2005, used in 2007 and 2008, has a noticeable deficit due to the pole tide error which had been made in the IVS contribution to ITRF2005. The post-quake movements of GILCREEK in ITRF2005 lacked the continuity of the piece-wise linear elements, thus introducing discontinuities. In addition, for the sites of SVETLOE, ZELENCHK, and BADARY either only limited observations had been available for ITRF2005 or no observations had been available yet. Of course, all other stations took their benefit from more data in the new computations as well. VTRF2008 is being used for all combinations of IVS since December 2008.

Thermal Expansion of Radio Telescopes

Thermal expansion effects have been considered already for a long time but concerted activities to include it in IVS data analysis have only started in 2008. At the Nineth IVS Analysis Workshop in St. Petersburg, it was decided to make thermal expansion modeling the first chapter of the IVS Analysis Conventions. This should serve as a proper reference for all analysis descriptions. In addition, a decision was made to use the GPT model (Boehm et al. 2007) to compute the reference temperature for each telescope. Any expansion effect can and should now be computed relative to these mean temperatures. In the meantime, the current status of thermal expansion modelling has been documented in a refereed paper (Nothnagel, 2008) which is the written documentation of Chapter 1 of the IVS Analysis Conventions.

One of the necessary parts of a model for expansion effects is a list of all telescopes‘ construction dimensions. In such a list, all dimensions like effective height of the elevation axis above the ground for azimuth-elevation telescopes or height of primary axis above secondary axis for polar or XY antennas, just to name a few, have to be tabulated for all telescopes. Quite some effort has been invested to collect the information for this list and further efforts are still necessary to gather the missing information for a few more telescopes. The list is available under <http://vlbi.geod.uni-bonn.de/IVS-AC/Conventions> together with the reference paper.

Since the reference temperatures of all telescopes are long-term means from a model, no effective change in the realizations of terrestrial reference frames are expected. However, annual variations in station coordinates, especially in the height component, are expected to reduce. Consequently, Earth orientation parameters from VLBI observations may also be affected, mainly with an annual signature.

Technology Development

The VLBI2010 Committee of the IVS submitted a Progress Report on the status of the development of the next generation geodetic VLBI system (VLBI2010 system), which summarizes the progress made in the development of the new system up to the end of 2008. The report covers Monte Carlo simulations showing the impact of the new operating modes on the final products. A section on system considerations describes the implications for the VLBI2010 system parameters by considering the new modes and system-related issues such as sensitivity, antenna slew rate, delay measurement error, RFI, frequency requirements, antenna deformation, and source structure corrections. This is followed by a description of all major subsystems and recommendations for the network, station, and antenna. Then aspects of the feed, polarization processing, calibration, digital back end, and correlator subsystems are covered. A section is dedicated to the NASA proof-of-concept demonstration. Finally, sections on operational considerations, on risks and fallback options, and on the next steps complete the report.

One important outcome of the 7th International e-VLBI Workshop was the creation of a task force to study and recommend a universal VLBI data format that is suitable for both on-the-wire e-VLBI data transfer, as well as direct disk storage. This task force, called the VLBI Data Interchange Format (VDIF) Task Force, is envisioned as the first of a two-part effort, the second of which will address standardization of e-VLBI data-transmission protocols. The formation of the VDIF Task Force was prompted particularly by the increased e-VLBI activity and the difficulties encountered when data arrive in different formats from various instruments and various parts of the world. A final report to the VLBI community is expected in early 2009.

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Report for 2009

IVS Organization and Activities

During 2009, the 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. On March 25, 2009 the IVS celebrated its 10th anniversary in a special whole day event with invited speakers in Bordeaux, France. The celebration took place after the 19th Working Meeting of the European VLBI Group for Geodesy and Astrometry (EVGA), March 23–24, 2009 in Bordeaux. The 10th IVS Analysis Workshop was held on March 26, 2009 in Bordeaux, directly after the 19th Working Meeting of the EVGA.

The IVS Directing Board had its first meeting after the elections 2008/2009 also in Bordeaux, prior to the 19th Working Meeting of the EVGA. The second IVS DB meeting was held at the end of August in Buenos Aires, Argentina, prior to the IAG Scientific Assembly 2009.

The IVS organized the VLBI2010 Workshop on Future Radio Frequencies and Feeds, held March 18–20, 2009 in Wettzell and Höllenstein, Germany. The VLBI2010 Project Executive Group (V2PEG) was established in March 2009 to support the implementation of VLBI2010. The 8th International e-VLBI Workshop was held in Madrid, Spain, in June 2009. The 5th IVS Technical Operations Workshop (TOW2009) was held April 27–29, 2009 at Haystack Observatory, USA.

In 2009, Karadeniz Technical University, Trabzon, Turkey, was accepted as a new IVS Associated Analysis Center. The station Warkworth, New Zealand, operated by the Auckland University of Technology, was welcomed as an IVS Network Station. The BKG/DGFI Combination Center commenced operation in October 2009.

In the summer of 2009 the IVS published the 2008 Annual Report. Furthermore, three IVS newsletters were published in April, August and December to keep the community informed about IVS activities. The progress report of the VLBI2010 Committee (V2C) with the title “Design aspects of the VLBI2010 system” was published in June 2009.

Network Stations

A total of 1309 station days were used in 158 geodetic/astrometric sessions during the year. Observing sessions coordinated by IVS remained at an average of ~3.1 days per week, similar to previous years. The major observing programs during 2009 were:

IVS-R1, IVS-R4

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

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), on weekend days (Saturday and Sunday, Int2) on the baseline Wettzell (Germany) to Tsukuba (Japan), and on Monday mornings (Int3) in the middle of the 36-hour gap between the Int1 and Int2 Intensive series on the network Wettzell (Germany), Ny-Ålesund (Norway), and Tsukuba (Japan). Svetloe (Russia) participated as third station in 21 Int1 sessions.

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

IVS-CRF The Celestial Reference Frame (CRF) sessions, coordinated by the U.S. Naval Observatory, provide astrometric observations that are required for improving the current CRF and in extending the CRF by observing ‘new’ sources. Four sessions were observed for the maintenance of the ICRF in 2009.

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 2009.

IVS-OHIG The purpose of the IVS-OHIG (Southern Terrestrial Reference Frame) sessions is to tie together optimally the sites in the southern hemisphere. The participating sites include all the sites available in the south.

APSG The Asia-Pacific Space Geodynamics (APSG) program operated two sessions in 2009.

JADE The JApanese Dynamic Earth observation by VLBI (JADE) had seven sessions during 2009. 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 2009. The main objective in 2009 was to improve scheduling strategy for the Intensive sessions.

IYA09

The IVS contributed on November 18/19, 2009 to IAU's and UNESCO's International Year of Astronomy 2009 by a "VLBI super session" that involved 33 network stations and observed more than 240 of the ICRF2 defining sources within 24 hours. This session is the largest geodetic VLBI session that ever was observed.

The database of station performance, maintained by the IVS Network Coordinator, showed a data loss of 21.5%, which was unfortunately worse (+6.4%) than 2008. However, this increase can to a large extent be explained by a different way of handling accounting station failures. The most significant causes for data loss were related to antenna problems (29.4 %) and receiver problems (18.6 %). Unidentified problems accounted to 14.2 % of the data losses. The total number of experiments in 2009 was 15% less than 2008, but the number of stations per session increased to 7.9 on average.

Correlators

The correlator at Haystack Observatory (USA), the correlator at the U.S. Naval Observatory in Washington (USA), the BKG/MPIfR correlator at the Max Planck Institute for Radioastronomy in Bonn (Germany) and the correlator at the Geographical Survey Institute (GSI) in Tsukuba, Japan continued their efficient processing of the data recorded for the IVS. The Haystack correlator increased its correlation hours by ~20 % and processed e.g. all R&D sessions and the IYA09 experiment. The Washington correlator processed all R4 and Int1 sessions, and the still remaining CONT08 session. Since mid of 2009 the Int1 data from Wettzell are e-transferred directly to the Washington correlator, speeding-up the turnaround time for these sessions. The Bonn correlator routinely used its 1 Gbps network connection for e-transfer from several network stations in Europe and Japan and processed e.g. all R1, Europe OHIG , and Int3 sessions. The Int2 sessions were processed at the GSI correlator in Tsukuba, Japan, in a completely automated mode with turnaround times of less than 1 hour after the end of an observing session. Additionally, the Tsukuba correlator processed four ultra-rapid 24-hour dUT1 sessions on the baseline Onsala–Tsukuba.

Data Centers

The IVS Data Centers continued to receive databases 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 at BKG (Germany), Paris Observatory (France), and Goddard Space Flight Center (USA).

IVS Operational Data Analysis and Combination

The combination process for the two IVS EOP series (rapid and quarterly solutions) has been continued exclusively on the basis of datum-free normal equations in SINEX format. In 2009, six IVS Analysis Centers (BKG, DGFI, GSFC, IAA, OPA, 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 at least 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 (see <http://vlbi.geod.uni-bonn.de/IVS-AC/data/timeliness_2.html>).

Every three months the quarterly solution is updated. For this solution 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 that are observed with networks of limited extension or which are scheduled for a different purpose like radio source monitoring.

The results are reported in two EOP time series, the rapid solution file and the quarterly solution file, both in the IVS EOP Exchange format. Solutions files are available in two forms, expressed with nutation offsets dX, dY referred to the IAU2006 precession-nutation model excluding free core nutation, and with nutation offsets dPsi, dEps referred to the IAU2000A precession-nutation model excluding free core nutation.

Contribution to ITRF2008

The IVS contribution to the ITRF2008 was generated at the IVS Analysis Coordinator's office. It consists of session-wise datum-free normal equations which are the result of a combination of individual series of session-wise datum-free normal equations provided by seven IVS Analysis Centers (BKG, DGFI, GSFC, IGGB, OPA, SHA, and USNO). All these individual series are completely reprocessed following homogeneous analysis options according to the IERS Conventions 2003 and the IVS Analysis Conventions.

Based on the experience gathered since the combination efforts for ITRF2005, the consistency of the individual VLBI solutions has improved considerably. The agreement in terms of the WRMS of the terrestrial reference frame (TRF) horizontal components is 1 mm and of the height component is 2 mm. Comparisons between ITRF2005 and the combined TRF solution for ITRF2008 yielded systematic height differences of up to 5 mm with a zonal signature. These differences can be related to a pole tide correction referenced to a zero mean pole used by four of five IVS ACs in the ITRF2005 contribution instead of a linear mean pole path as recommended in the IERS Conventions. Periodic annual variations in scale are reduced considerably from 2.7 mm to 1.7 mm due to the correction for thermal expansion of the radio telescopes.

Realization and adoption of ICRF2

The Second Realization of the International Celestial Reference Frame (ICRF2) was adopted in August 2009 at the XXVII General Assembly of the International Astronomical Union (IAU) in Rio de Janeiro, Brazil, as Resolution B3. The ICRF2 replaced the previously used first realization (ICRF) effective 1 January 2010. The International Earth Rotation and Reference Systems Service (IERS) published as IERS Technical Note No. 35 (<http://www.iers.org/TN35>) about the computation of the ICRF2. The ICRF2 was an effort of a joint IERS/IVS working group and was overseen by an IAU working group. ICRF2 contains precise positions of 3414 compact extragalactic radio sources, more than five times the number in the ICRF. Further, the ICRF2 is found to have a noise floor of ~40 microarcseconds, some 5–6 times better than ICRF, and an axis stability of 10 microarcseconds, nearly twice as stable as ICRF. Alignment of ICRF2 with the International Celestial Reference System (ICRS) was made using 138 stable sources common to both ICRF2 and ICRF-Ext2.

Technology Development

During 2009 progress continued towards the goal of a next-generation VLBI2010 system, e-VLBI, and other technical aspects. Some important highlights were:

In March the IVS organized the VLBI2010 Workshop on Future Radio Frequencies and Feeds in Wettzell and Höllenstein, Germany. At this workshop several crucial decisions for VLBI2010 were taken. It was decided e.g. that the broadband frequency range should be 2.2-14 GHz, that VLBI2010 should be backwards compatible with the previous S/X-systems, that the future telescopes should allow a future inclusion of frequencies up to Ka-band, that an end-to-end VLBI2010 demonstration should be performed in early 2012, and that a transition plan from S/X to VLBI2010 should be developed. Subsequently, a VLBI2010 Project Executive Group (V2PEG) was established in March 2009 to support the implementation of VLBI2010.

At the Technical Operations Workshop in May 2009 three different types of digital backends (DBEs) were intercompared by zero-baseline correlation tests. The DBEs included the European DBBC, the Chinese CDAS, and the DBE1 developed by Haystack Observatory, USA. In general, good agreement was found.

The VLBI Data Interchange Format (VDIF) Task Force presented the VDIF specification at the June 2009 eVLBI meeting in Madrid. The proposal was accepted and ratified.

The VLBI2010 Committee (V2C) authored a progress report with the title “Design aspects of the VLBI2010 system” that was published in June 2009.

In November 2009 a VEX2 Task Force was created to further develop the current VEX (VLBI Experiment Documentation) file format.

During 2009 a phase-calibration system for VLBI2010 was developed and tested, work continued to complete a broadband feed-horn for VLBI2010, to develop the next generation digital backend and an improved data recording system that allows higher data rates.

Work continued to set up a VLBI2010 test bed involving the Westford telescope and the MV3 antenna at NASA/GSFC.

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3.4.4 International DORIS Service (IDS)

Overview

The current report presents the different activities held by all components of the International DORIS Service (IDS). In a first step, we will present the current status of the DORIS system (available satellites and tracking network). In a second step, we will present the activities of the IDS Central Bureau (IDS Web site management and DORIS-related email distributions). We will then focus on the most recent activities conducted by the Analysis Centers (ACs) and the Analysis Coordination in preparation of ITRF2008. Finally, we will present other activities related to meetings and publications.

1 DORIS system

1.1 DORIS satellites

During this report period (2008–2009), the number of DORIS satellites has remained between five and six (see Table 1).

In mid 2008, a new DORIS satellite (Jason-2) was launched including a new generation receiver on-board: digital, 7-channel, allowing direct phase measurement like GPS (instead of Doppler data).

In the near future, several new DORIS satellites are already planned (and approved): CryoSat-2, SARAL, HY-2A, Jason-3, … This should increase or at least stabilize the number of DORIS satellites in the 2010–2016 time period. In July 2009, the SPOT-2 satellite was prepared for decommissioning. A series of maneuvers changed the orbit so the spacecraft will re-enter the Earth's atmosphere in less than 25 years. SPOT-2 was launched in 1990 with a planned six-month test mission. After 19 years of successful operations, it has greatly exceeded the most optimistic expectations.

Table 1: DORIS data available at IGN. As of August 2009

Satellite	Start	End	Type
SPOT-2	31-MAR-90 04-NOV-92	04-JUL-90 15-JUL-09	Remote sensing
TOPEX/Poseidon	25-SEP-92	01-NOV-04	Altimetry
SPOT-3	01-FEB-94	09-NOV-96	Remote sensing
SPOT-4	01-MAY-98	–	Remote sensing
SPOT-5	11-JUN-02	–	Remote sensing
Jason-1	15-JAN-02	–	Altimetry
ENVISAT	13-JUN-02	–	Altimetry, Environment
Jason-2	12-JUL-08	–	Altimetry

1.2 DORIS tracking network

The DORIS permanent tracking network remains very stable (Figure 1). About 50% of the DORIS stations are in co-location with other geodetic space techniques: GPS (38), SLR (9) and VLBI (6).

Fig. 1: DORIS permanent tracking network. July 2009.

The renovation of the DORIS network is now complete. Most of the DORIS beacons (55) are third generation beacons (except two) and use a stable geodetic mount (cf. Fagard, 2006).

2 IDS Governing Board

Following the IDS status, a new Governing Board was elected at the end of 2008 (see Table 2).

Table 2: IDS Governing Board following elections in December 2008

Name	Institution	Country	Mandate
Pascale Ferrage	CNES	France	Member at large
Bruno Garayt	IGN	France	Network representative
Frank Lemoine	GSFC	USA	Analysis Coordinator
Chopo Ma	GSFC	USA	IERS representative
Carey Noll	GSFC	USA	Network representative
Michiel Otten	ESOC	Germany	IAG representative
John Ries	U. Texas/CSR	USA	Member at large
Laurent Soudarin	CLS	France	Director IDS Central Bureau
Pascal Willis (chair)	IGN/IPGP	France	Analysis Center representative

3 IDS Central Bureau

3.1 IDS Web site

The IDS Central Bureau maintains the IDS website. In 2009, the URL was changed to <http://ids-doris.org>. Users were asked to use the new address (DORISmail 624). The IDS website archives information of direct interest to the IDS Analysis Centers and to the DORIS community in general:

- DORIS results such as plots and data of DORIS station coordinate time series at <http://ids-doris.org/network/ids-station-series.html >
- DORIS station site logs at <http://ids-doris.org/network/sitelogs.html>
- daily statistics of Precise Orbit Determination (POD) residuals per station
- specific events affecting DORIS satellites (maneuvers, change of on-board software, ...) or stations (discontinuity, data gap or temporary failures, …)

In particular, a kml file was created to allow a virtual tour of DORIS tracking stations on GoogleEarth.

Access to the IDS website is still steadily increasing from month to month since spring 2000. In early 2009, this website was accessed about 2000 times each month on a regular basis.

3.2 IDS Mail system

Several types of emails are distributed by the IDS Central Bureau:

- DORISMail: general DORIS interest
- DORISReports: reports related to DORIS data and products
- AWG and IDS Analysis Forum: technical discussion between analysis centers, combination and coordination

Everyone is welcome to subscribe to any of these emails. See more details on <http://ids-doris.org/report/mails.html>.

4 IDS Data Centers

The IDS data flow organization remains the same, but is now more robust. It is based on two data centers: one on the East Coast of the U.S. (CDDIS at NASA GSFC) and one in Europe (IGN in France). Recently, the two data centers were gradually upgraded in order to be exact mirrors of each other and to be able to continue on an operational basis, even if one of them is inaccessible due to a temporary failure.

These two data centers archive the DORIS data as well as the IDS products (station coordinates and velocity, geocenter motion, earth orientation parameters, ionosphere data, etc.).

5 IDS Analysis Centers

Like the other technique services in IAG, IDS has now a large number of independent Analysis Centers.

In preparation for ITRF2008, seven ACs submitted long time series of DORIS results in SINEX format from 1993.0 to 2009.0 (Table 3). Besides these operational groups, several other groups are also considering to join in the future, such as NCL in Newcastle, UK. Even for those using the same software packages (IGN-INASAN for GIPSY/OASIS and GSFC-Geoscience Australia for GEODYN), great care was taken to define the processing strategies to be

Table 3: List of IDS Analysis Centers submitting time series of weekly station coordinates in preparation of ITRF2008. July 2009.

Acronym	Analysis Center	Country	Software package
ESA	ESOC	Germany	NAPEOS
GAU	Geoscience Australia	Australia	GEODYN
GOP	Geodetic Observatory Pecny	Czech Rep.	Bernese
GSC	GSFC	USA	GEODYN
IGN	IGN	France	GIPSY/OASIS
INA	INASAN	Russia	GIPSY/OASIS
LCA	CNES/CLS	France	GINS/DYNAMO

at the same level of quality but using different approaches (e.g., Gravity field model, tropospheric mapping functions, etc.).

This approach is a complete change for IDS, as in the past only two independent solutions were regularly submitted to the previous ITRF combinations. Several meetings were held by the Analysis Coordinator (Frank Lemoine), inviting all ACs to make them benefit from the experience of the other groups, to compare results, and to prepare for the AC submissions for ITRF2008.

6 IDS Combination

For the first time, IDS made a combined time series of all available weekly solutions (from 1993.0 to 2009.0).

For the first time, DORIS satellites orbits derived from the seven ACs were systematically inter-compared. This allowed us to isolate processing anomalies and assured that the processing of the DORIS data was at a comparable level for all the ACs. The results were excellent, showing agreement at the 1–2 cm level in the radial component, even without trying to select compatible data processing strategies for models or parameter estimation.

Following the availability of ITRF2005, a new DPOD2005 coordinate data set was derived, expanding to new DORIS stations or to stations not considered in the original ITRF2005, due to non-linear displacements. DORIS stations' discontinuities were also analyzed. A dedicated Web page was created:

<http://www.ipgp.fr/~willis/DPOD2005.htm>

7 Meetings

In 2008 and 2009 years the IDS organized the following meetings:

- DORIS Analysis Working Group Meeting, Paris, France, 13–14 March, 2008
- DORIS Analysis Working Group Meeting, Paris, France, 5–6 June, 2008
- IDS Workshop, Nice, France, 12–14 November, 2008
- DORIS Analysis Working Group Meeting, Paris, France, 23–24 March, 2009

All presentations from these meetings are made available by the Central Bureau on the IDs website at <http://ids-doris.org/meetings/ids-meetings.html>.

8 Publications

In 2006, a DORIS Special Issues was published in the Journal of Geodesy 80(8-11), including 17 peer-reviewed articles.

A second DORIS Special Issue is currently in preparation in Advances in Space Research.

IDS published a 2006–2008 activity report and a 2009 activity report that were broadly distributed to all DORIS participants and relevant services (see: <http://ids-doris.org/report/governing-board.html#activity>).

All DORIS related articles published in international peer-reviewed journals are available on the IDS Web site at <http://ids-doris.org/report/publications/peer-reviewed-journals.html>.

Conclusions

In conclusion, even if the DORIS context is rather stable in terms of network and satellite constellation, a major change happened to the IDS as seven Analysis Centers now actively participate in operational DORIS data processing and as a combined IDS solution is now available in preparation of ITRF2008. The launch of the new Jason-2 satellite should also open some new opportunities in the IDS, as it brings more data (7-channel receiver), better quality (equivalent to 0.3 mm/s) and the possibility to process these data using a GPS-type technique (access to raw DORIS phase measurement instead of Doppler data). In the near future several new satellites of this type should be launched, insuring a minimum of four DORIS satellites for the 2010–2016 time period.

Laurent Soudarin

3.5 Product Centres
3.5.1 Earth Orientation Centre

This section presents the activities and main results of the Earth Orientation Centre located at Paris Observatory. According to the IERS Terms of Reference, the Earth Orientation Centre is responsible for monitoring Earth orientation parameters including long term consistency, publications for time dissemination (DUT1) and leap second announcements. Earth Orientation Parameters (EOP: Polar motion, Universal Time (UT1), Length of Day (LOD) and Celestial pole offsets) are available to a broad community of users in various domains such as astronomy, geodesy, geophysics, space sciences and time.

EOPs are given in the form of combined solutions derived by the Technique Centers (IGS, IVS, ILRS and IDS). Various solutions are computed: a long-term solution (IERS C01) since 1846 and the Bulletin B given at one-day intervals published monthly with a 30 day delay. Bulletin B is updated in the operational C04.

Another issue is the maintenance of the consistency between the EOP system and the terrestrial reference frame. So far, Earth Orientation Parameters and the terrestrial frame are separately computed. This leads to increasing inconsistencies between both of them. At the end of 2009, these inconsistencies were small but significant for polar motion. All IERS reference solutions (C01, Bulletin B , C04 as well as Bulletin A derived by the Rapid Service/ Predictions Center, US Naval Observatory) were recomputed and aligned to the EOP solution associated to the current ITRF2008.

Combined daily series: Bulletin B and 05 C04, statistics over 2008–2009

This section gives statistics (Tables 1 to 3) in term of formal errors and WRMS of the combined technique centres and individual solutions with respect to the combined solution Bulletin B and 05C04 over the years 2008 and 2009. Only combined solutions derived by the various technique centres are used in the IERS combinations. Statistics concerning individual series are given as a feedback to the analysis centres.

New format of Bulletin B since January 2010

Bulletin B issued by the IERS EOP Centre was more than 20 years old. Following a survey which was made in 2007 among the community, a new presentation is available since January 2010. The new Bulletin B and its content description are available at
<ftp://hpiers.obspm.fr/iers/bul/bulb_new/bulletinb.dat>
and
<ftp://hpiers.obspm.fr/iers/bul/bulb_new/bulletinb.pdf>.

Table 1: Estimated accuracies of individual solutions compared to the combined solutions Bulletin B and 05 C04 over 2008–2009. 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

Individual solutions		Estimated uncertainties				
		Time	Terrestrial Pole	UT1	LOD	Celestial Pole
			µas	µs		µas
VLBI – 24 h						
EOP (AUS)	01 R 01	3–4d	150	10.0		85
EOP (BKG)	03 R 02	1–4d	130	9.1		79
EOP (GSFC)	07 R 01	1–4d	111	9.7		70
EOP (IAA)	05 R 02	1–4d	130	8.6		73
EOP (MAO)	03 R 01	1–4d	110	8.7		87
EOP (OPA)	07 R 01	1–4d	130	9.7		74
EOP (USNO)	06 R 02	1–4d	101	8.8		58
EOP(IVS)	02 R 01	1–4d	115	4.4		40
VLBI – Intensive						
EOP (BKG)	03 R 02	1–3 d		18.0		
EOP (GSFC)	06 R 01	1–3 d		17.3		
EOP (SPBU)	05 R 01	1–3 d		14.3		
EOP (USNO)	05 R 01	1–3 d		19.1		
SLR						
EOP (ASI)	03 L 02	1d	230		54.1	
EOP (IAA)	02 L 01	1d	190		31.4	
EOP (MCC)	97 L 01	1d	185		–	
EOP (ILRS)	05 L 01	1d	160		17.2	
GPS						
EOP (CODE)	98 P 01	1d	33		15.0	
EOP (EMR)	96 P 03	1d	54		22.0	
EOP (ESOC)	96 P 01	1d	60		19.3	
EOP (GFZ)	96 P 02	1d	35		14.3	
EOP (IAA)	01 P 01	1d	160		30.1	
EOP (JPL)	96 P 03	1d	45		17.3	
EOP (NOAA)	96 P 01	1d	77		15.9	
EOP (SIO)	96 P 01	1d	45		22.0	
EOP (USNO)	03 P 01	1d	–		23.0	
EOP (IGR)	07 P 01	1d	35		8.0	
EOP (IGS)	96 P 02	1d	25		8.0	

Table 2: Mean and standard deviation in microarcsecond of the differences between various combined techniques solutions and IERS 05C04 over 2008–2009

EOP	IGS Comb – IERS 05C04		ILRS Comb – IERS 05C04		IVS Comb – IERS 05C04	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
X (μas)	–27	23	32	156	–325	121
Y (μas)	–32	24	–23	166	73	110
UT1 (μs)					1	4.4
LOD (μs)	4	8	47	40		
Dψsinε (μas)					8	40
Dψ(μas)					–12	35

Table 3: Mean and standard deviation for Pole components and UT1 of the differences between various solutions and Bulletin B over 2008–2009

EOP	Unit	Bull A – Bull B		Comb JPL – Bull B	
		Mean	Standard deviation	Mean	Standard deviation
X	μas	–66	32	–145	31
Y	μas	–5	33	–39	21
UT1	μs	–20	9	–25	10

The content of Bulletin B is:

1 - DAILY FINAL VALUES AND PRELIMINARY VALUES OF x, y, UT1–UTC, dX, dY
and their respective uncertainties. Angular unit is milliarcsecond (mas), time unit is millisecond (ms).

2 - DAILY SMOOTHED VALUES OF CELESTIAL POLE OFFSETS (dPsi1980, dEps1980)
with respect to IAU 1980 precession-nutation model and their uncertainties.

3 - EARTH ANGULAR VELOCITY: DAILY VALUES OF LOD, OMEGA AT 0hUTC
LOD: Excess of the Length of day – 86400 s TAI
OMEGA: Earth angular velocity

4 - INFORMATION ON TIME SCALES: TAI–UTC, leap second announcements

5 - SUMMARY OF CONTRIBUTED EARTH ORIENTATION PARAMETERS SERIES

Reset of Bulletin B and C04 to the new system consistent to ITRF2008, new reference solution since 1 February 2011

Maintaining the consistency between the current EOP solution 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., 2008). The ITRF2008 has the same characteristics than ITRF2005. Its release was the opportunity to re-align the C04 to the ITRF2008 system. Relative to 05C04, changes in the EOP series consist of:

1) A negligible bias in x-pole and a bias of about -50 ± 25 microarcseconds in y-pole in the sense of y (08C04) – y (05C04);

2) Changes in UT1–TAI and celestial pole offsets are respectively on the order of 2 microseconds, 1, and 17 microarcseconds which are at the level of the WRMS between IVS individual solutions.

Other IERS EOP series (Bulletin B, C01) have been expressed in this new system consistent with ITRF2008. The Rapid Service/Prediction Center solutions (Bulletin A and daily) are as well expressed in the new reference system.

Long-term series: C 01 (1846–2008)

EOP(IERS) C 01 is a series of the Earth Orientation Parameters given at 0.1 year interval from 1846 to 1889 (polar motion only) and 0.05 year interval from 1890 until now (polar motion, celestial pole offsets, UT1–UTC since 1962). For many decades, the observations were made using mostly visual and photographic zenith telescopes. Since the advent of the space era in the 1960’s, new geodetic techniques were used for geodynamics. Now, the global 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 2011 to be consistent with the reference system associated with ITRF2008. 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).

1962–2008: 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 coefficients. These terms describe the position of the Earth's figure axis with respect to the Terrestrial Reference Frame. This axis should coincide with the observed position of the rotation pole averaged over the same time period.

The mean polar motion is affected by a long-term drift westward (direction 70.7 deg West, rate: 4.2 mas/yr). The mean rotation axis with respect to the IERS Terrestrial Reference Frame can be considered as the long-term trend obtained after filtering out the Chandler and seasonal terms, every year from 1900 to 2009 (Shiskin et al., 1965). Figure 1 represents the polar motion over 2001–2009 and the path of the mean pole since 1900. The coefficients of the IERS (2010) mean pole model are available in Conventions 2010 (Petit and Luzum, 2010). The table is available at the following address: <http://hpiers.obspm.fr/eop-pc/>.

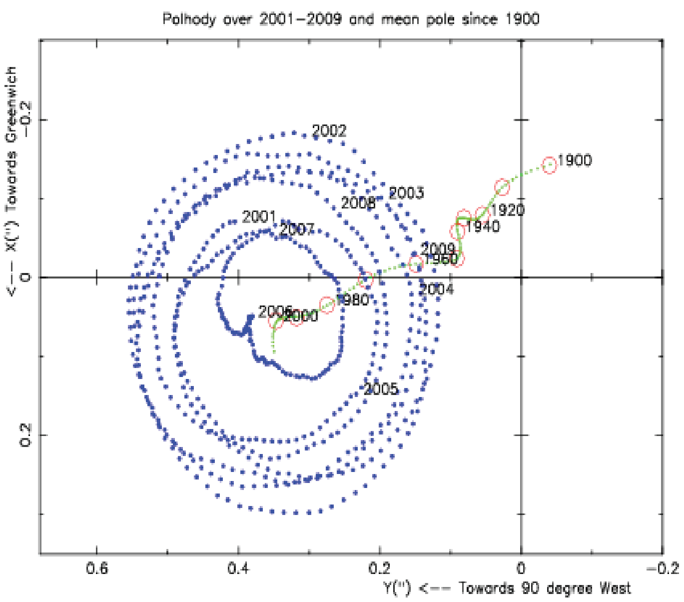

Fig. 1: Mean polar motion (1900–2010) and IERS C04 polhody over 2001 – 2009

Staff

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Christian Bizouard	Astronomer
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Jean Yves Richard	Engineer
Olivier Becker	Engineer
Morad Saïl	Engineer (until December 2008)
Pascale Baudoin	Secretary

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

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3.5.2 Rapid Service/Prediction Centre

Report for 2008

Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Centre (RS/PC) 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 05 C04 system of the IERS Earth Orientation Centre (EOC) at the Paris Observatory by way of a robust linear estimator. Statistical weighting used in the spline is proportional to the inverse square of the estimated accuracy of the individual techniques. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Weights in the algorithm may be either *a priori* values estimated by the standard deviation of the residual of the techniques or values based on the internal precision reported by contributors. Estimated accuracies of data contributed to the IERS Rapid Service/Prediction Centre are given in Table 1. These estimates are based on the residuals between the series and the combined RS/PC EOP solution for 2008.

Table 1: Estimated accuracies of the techniques in 2008. 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	0.17	0.23			
IAA SLR	0.19	0.23			
MCC SLR	0.18	0.20			
GSFC VLBI Intensives			0.015		
USNO VLBI Intensives			0.016		
GSFC VLBI	0.07	0.08	0.004	0.4	0.1
IAA[1] VLBI	0.09	0.12	0.004	(0.1)	(0.1)
IVS[1] VLBI	0.13	0.14	0.004	(0.1)	(0.1)
USNO VLBI	0.08	0.10	0.004	0.4	0.1
IGS Final	0.01	0.02			
IGS Rapid	0.04	0.05			
IGS Ultra	0.05	0.06			
USNO GPS UT*			0.015*		
EMR GPS UT*			0.030*		
USNO AAM UT			0.015		

*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.

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Centre solutions and 05 C04 EOP solutions for 2008. 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	–0.03	0.04
y	–0.01	0.04
UT1–UTC	–0.003	0.014
Bulletin A Weekly Solution (finals.data)[1]		
x	–0.00	0.04
y	–0.06	0.04
UT1-UTC	0.004	0.030
Bulletin A Daily Solution (finals.daily)		
x	0.01	0.05
y	-0.07	0.07
UT1–UTC	0.011	0.056

[1] Statistics computed over the 7-day combination solution period prior to solution epoch.

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. While the celestial pole offset combination software can combine either $\delta\psi$ and $\delta\varepsilon$ or dX and dY, for historical reasons, it uses $\delta\psi$ and $\delta\varepsilon$. Therefore, IAA and IVS VLBI dX and dY values are converted to $\delta\psi$ and $\delta\varepsilon$ in the combination process. The LOD are derived directly from the UT1–UTC data. The analytical expression for the first derivative of the cubic spline passing through the UT1–UTC data is used to estimate the LOD at the epoch of the UT1–UTC data.

The only data points that are excluded from the combination process are the points whose errors, as reported by the contributors, are greater than three times their average reported precision, or those points that have a residual that is more than four times the associated *a priori* error estimate. Since all of the observations are reported with the effects of sub-daily variations removed, the input data are not corrected for these effects (see IERS Gazette No. 13, 30 January 1997).

The uncertainties in the daily values listed in Bulletin A are derived from the quality of the spline fit in the neighborhood of the day in question. Table 2 shows the accuracies of Rapid Service/

Prediction Center's combination solution for the running, weekly, and daily products compared to the 05 C04 series maintained by the IERS EOC. 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 05 C04 series for the entire year. The comparison of the 52 weekly solutions to the 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 determined from a series of differences spanning one year where each element of the series is the difference 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 rapid solution and the 05 C04 and presents the data used in Table 2 for the determination of the daily solution statistics. This year, the mean residuals between the daily solution and the 05 C04 were essentially the same. 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 most significant change for the standard deviation came in the daily solution residuals. This is due to the incorporation of the IGS Ultra data into the daily solution in 2007. It is anticipated that the inclusion of the new USNO UTGPS data set into the combination in March 2009 will have a positive impact on the UT1–UTC results (Stamatakos *et al.*, 2009). This will be a topic for further 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

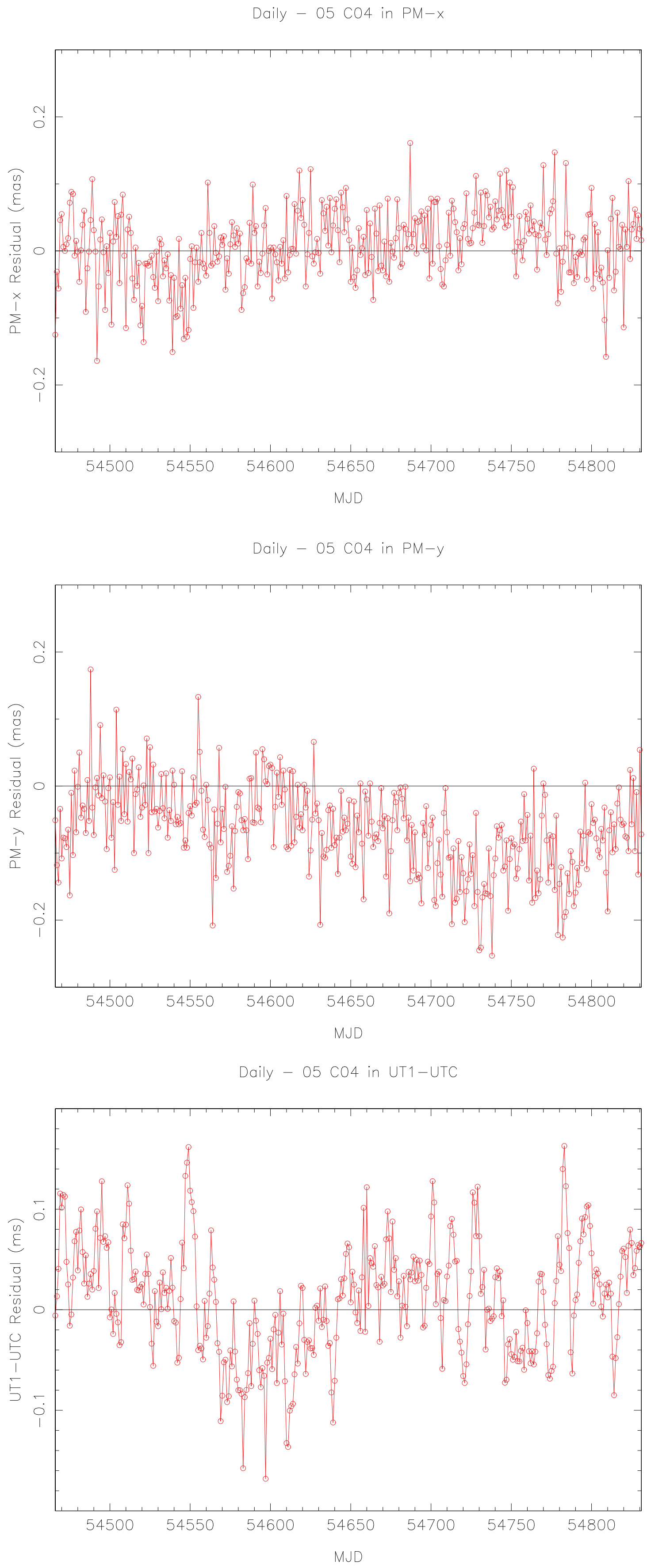

Fig. 1: Residuals between daily rapid solutions at each daily solution epoch for 2008 and the Earth orientation parameters available in 05 C04 series produced in March 2009.

components (T. Johnson, personal 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, $(\mathrm{UT2R–TAI})_n$, the smoothed time value from n days in the past, $<(\mathrm{UT2R–TAI})_{-n}>$ is subtracted from the most recent value, $(\mathrm{UT2R–TAI})_0$

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

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 (Kammeyer, 2000). 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 National Centers for Environmental Prediction (NCEP) and U.S. Navy's Operational Global Atmospheric Prediction System (NOGAPS) model's AAM analysis and forecast data (UTAAM). AAM-based predictions are used to determine the UT1 predictions out to a prediction length of 7 days. For longer predictions, the LOD excitations are combined smoothly with the longer-term UT1 predictions described above. 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 daily solution predictions and the 05 C04 solution for 2008. Initial estimates indicated that the UT1–UTC prediction performance would be improved by 42% at 10 days into the future by the addition of UTAAM to the combination and prediction process (Johnson *et al.*, 2005). However, comparisons of the UT1–UTC prediction performance from 2003 to those estimated in 2001 (before UTAAM was

Table 3: Root mean square of the differences between the EOP time series predictions produced by the daily rapid solutions and the 05 C04 combination solutions for 2008. Note that the prediction length starts counting from the day after the last available observation is made for polar motion or UT1–UTC/LOD.

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
1	.38	.31	.126
5	1.86	1.38	.375
10	3.38	2.42	.718
20	5.70	4.27	2.08
40	10.6	6.94	5.63
90	23.4	7.81	16.2

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

For 2008, the prediction errors were, in general, better than those of 2007. The polar motion prediction errors improved slightly over 2007 due to the incorporation of the IGS Ultra data into the daily combination. The UT1–UTC prediction shows a slight improvement due to the switch from AAM forecast lengths being extended from 5 to 7.5 days as well as the occasional availability of rapid turnaround e-VLBI intensives. The use of the new USNO UTGPS series should also positively impact the near-term UT1–UTC predictions.

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 extended, the bias becomes progressively smaller. 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

Table 4: Root mean square of the differences between the nutation prediction series produced by the daily rapid solutions and the 05 C04 solution for 2008.

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.16	.17	.42	.17
5	.17	.17	.43	.17
10	.17	.18	.45	.18
20	.19	.19	.49	.20
40	.23	.23	.57	.23

of celestial pole offsets 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 predictions and the 05 C04 for 2008 are given in Table 4.

Predictions of TT–UT1 up to 2018 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; Stamatakos *et al.*, 2009).

Center Activities in 2008

During 2008, much of the RS/PC activities have concentrated on improving the operational software, updating and monitoring currently used datasets, and investigating potential new data sets. Specific accomplishments include modifying the nutation combination code to more readily use either $\delta\psi/\delta\varepsilon$ or dX/dY representations and making modifications for the announced leap second. In addition, diagnostics for the AAM data are now available. A new web site was created as part of an organization-wide effort. This new web presence is located at <http://www.usno.navy.mil/USNO/earth-orientation>. Additional work to increase the robustness of an alternate site now allows us to run EOP solutions off site.

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

Availability of Rapid Service

The data available from the IERS Rapid Service/ Prediction Centre consist mainly of the data used in the IERS Bulletin A. These data include: x, y, UT1–UTC, dX and dY from IAA VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from GSFC VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from USNO VLBI; x, y, UT1–UTC, 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 Centre 1-day SLR; x, y, LOD from the International GNSS Service; UT from USNO GPS; UT from NRCanada (EMR) GPS; UT from NCEP AAM; UT from NAVY NOGAPS AAM; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Rapid Service/Prediction Centre; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Earth Orientation Centre; and predictions of x, y, UT1–UTC from the IERS Rapid Service/Prediction Centre.

Table 5: Predicted values of TT–UT1, 2009–2018. 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)
2009 Jan 1	65.777	0.000
2009 Apr 1	65.86	0.01
2009 Jul 1	65.95	0.02
2009 Oct 1	65.98	0.03
2010 Jan 1	66.07	0.04
2010 Apr 1	66.3	0.2
2010 Jul 1	66.4	0.3
2010 Oct 1	66.6	0.4
2011 Jan 1	66.8	0.4
2011 Apr 1	66.9	0.5
2011 Jul 1	67.1	0.6
2011 Oct 1	67.2	0.8
2012 Jan 1	67.3	0.9
2012 Apr 1	67.	1.
2012 Jul 1	68.	1.
2012 Oct 1	68.	1.
2013 Jan 1	68.	1.
2013 Apr 1	68.	2.
2013 Jul 1	68.	2.
2013 Oct 1	68.	2.
2014 Jan 1	68.	2.
2014 Apr 1	69.	2.
2014 Jul 1	69.	2.
2014 Oct 1	69.	2.
2015 Jan 1	69.	3.
2015 Apr 1	69.	3.
2015 Jul 1	69.	3.
2015 Oct 1	69.	3.
2016 Jan 1	70.	3.
2016 Apr 1	70.	3.
2016 Jul 1	70.	3.
2016 Oct 1	70.	4.
2017 Jan 1	70.	4.
2017 Apr 1	70.	4.
2017 Jul 1	70.	4.
2017 Oct 1	71.	4.
2018 Jan 1	71.	5.

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 Centre in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current 365 days' worth of predictions via electronic mail from

ser7@maia.usno.navy.mil or through

<http://www.usno.navy.mil/USNO/earth-orientation> or

<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 Centre 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 June 2008, Gillian Brockett resigned from the IERS Rapid Service and Prediction Center to attend graduate school.

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Brian Luzum, Nicholas Stamatakos, Gillian Brockett,
Merri Sue Carter, Beth Stetzler, William Wooden

Report for 2009

Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Center (RS/PC) 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 with respect to the 05 C04 system of the IERS Earth Orientation Centre (EOC) at the Paris Observatory are determined using a robust linear estimator. Statistical weighting used in the spline is proportional to the inverse square of the estimated accuracy of the individual techniques. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Weights in the algorithm may be either *a priori* values estimated by the standard deviation of the residual of the techniques or values based on the internal precision reported by contributors. Estimated accuracies of data contributed to the IERS Rapid Service/Prediction Centre are given in Table 1. These estimates are based on the residuals between the series and the combined RS/PC EOP solution for 2009.

Table 1: Estimated accuracies of the techniques in 2009. Units are milliseconds of arc for x, y, $\delta\psi$, $\delta\varepsilon$, dX, and dY and milliseconds of time for UT1–UTC. Note that AAM results are no longer provided since the AAM data are now only used for predictions and the previous statistics were misleading.

Contributor Information	Estimated Accuracy				
Name, Type	x	y	UT1	$\delta\psi$ (dX)	$\delta\varepsilon$ (dY)
ILRS SLR	0.16	0.26			
IAA SLR	0.20	0.22			
MCC SLR	0.17	0.26			
GSFC VLBI Intensives			0.016		
USNO VLBI Intensives			0.019		
GSFC VLBI	0.11	0.10	0.005	0.29	0.12
IAA[1] VLBI	0.13	0.19	0.008	(0.07)	(0.07)
IVS[1] VLBI	0.10	0.11	0.006	(0.12)	(0.05)
USNO VLBI	0.14	0.09	0.006	0.29	0.09
IGS Final	0.01	0.02			
IGS Rapid	0.05	0.08			
IGS Ultra	0.06	0.08			
USNO GPS UT*			0.013*		
EMR GPS UT*			0.022*		

*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.

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Centre combination solutions and the 05 C04 EOP solutions for 2009. 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	-0.02	0.05
y	-0.01	0.04
UT1-UTC	-0.000	0.008
Bulletin A Weekly Solution (finals.data)[1]		
x	0.00	0.04
y	-0.07	0.05
UT1-UTC	0.002	0.020
Bulletin A Daily Solution (finals.daily)		
x	-0.01	0.04
y	-0.04	0.05
UT1-UTC	-0.004	0.043

[1] Statistics computed over the 7-day combination solution period prior to solution epoch.

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. While the celestial pole offset combination software can combine either $\delta\psi$ and $\delta\varepsilon$ or dX and dY, for historical reasons, it uses $\delta\psi$ and $\delta\varepsilon$. Therefore, IAA and IVS VLBI dX and dY values are converted to $\delta\psi$ and $\delta\varepsilon$ in the combination process. The LOD are derived directly from the UT1–UTC data. The analytical expression for the first derivative of a cubic spline passing through the UT1–UTC data is used to estimate the LOD at the epoch of the UT1–UTC data.

The only data points that are excluded from the combination process are the points whose errors, as reported by the contributors, are greater than three times their average reported precision, or those points that have a residual that is more than four times the associated *a priori* error estimate. Since all of the observations are reported with the effects of sub-daily variations removed, the input data are not corrected for these effects (see IERS Gazette No. 13, 30 January 1997).

The uncertainties in the daily values listed in Bulletin A are derived from the quality of the spline fit in the neighborhood of the day in question. Table 2 shows the accuracies of Rapid Service/

Prediction Center's combination solution for the running, weekly, and daily products compared to the 05 C04 series maintained by the IERS EOC. 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 05 C04 series for the entire year ("Bulletin A Rapid Solution" statistics). The comparison of the 52 weekly solutions to the 05 C04 series gives the statistics of the residuals computed over the new combination results for the 7-days prior to the solution epoch ("Bulletin A Weekly Solution" statistics). The statistics for the daily solution are determined from a series of differences spanning one year where each element of the series is the difference for the day of the solution epoch ("Bulletin A Daily Solution" statistics). 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 rapid solution and the 05 C04 and presents the data used in Table 2 for the determination of the daily solution statistics. This year, the mean residuals between the daily solution and the 05 C04 were essentially the same. The small bias differences in the polar motion components are of unknown origin and are currently under investigation. The periodic differences in the UT1–UTC residuals appears to be related to inclusion of AAM analysis data in the combination solution. Discussion of mitigation strategies for this problem is provided in the section Center Activities in 2009. There has been a slight improvement in the UT1–UTC results due to the inclusion of the new USNO UTGPS data set into the combination in March 2009 (Stamatakos *et al.*, 2009).

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

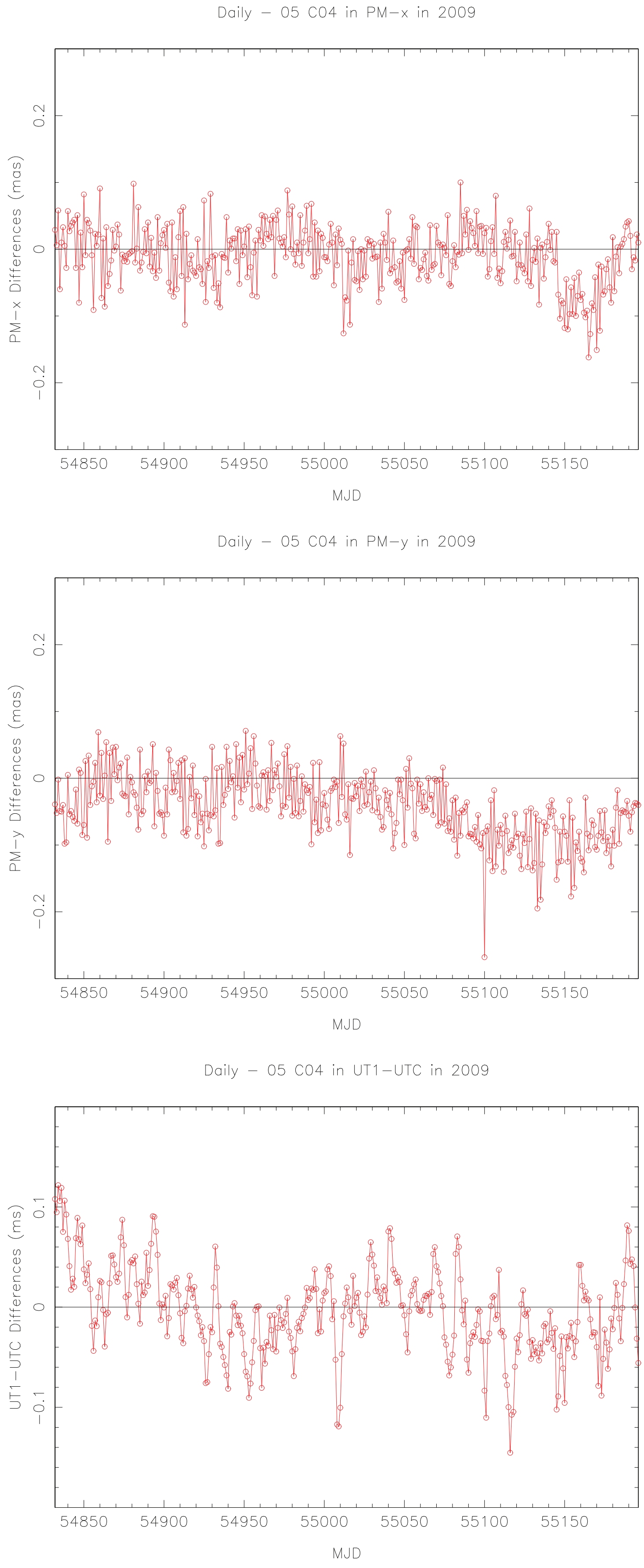

Fig. 1: Differences between the daily rapid solutions at each daily solution epoch for 2009 and the Earth orientation parameters available in the 05 C04 series produced in April 2010.

components (T. Johnson, personal 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, $\langle(UT2R–TAI)_{-n}\rangle$ is subtracted from the most recent value, $(UT2R–TAI)_0$

$$(UT2R–TAI)_n = 2(UT2R–TAI)_0 - \langle(UT2R–TAI)_{-n}\rangle.$$

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

The 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 (Kammeyer, 2000). 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 National Centers for Environmental Prediction (NCEP) and U.S. Navy's Operational Global Atmospheric Prediction System (NOGAPS) model's AAM analysis and forecast data (UTAAM). AAM-based predictions are used to determine the UT1 predictions out to a prediction length of 7 days. For longer predictions, the LOD excitations are combined smoothly with the longer-term UT1 predictions described above. 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 daily solution predictions and the 05 C04 solution for 2009. Initial estimates indicated that the UT1–UTC prediction performance would be improved by 42% at 10 days into the future by the addition of UTAAM to the combination and prediction process (Johnson *et al.*, 2005). However, comparisons of the UT1–UTC prediction performance from 2003 to those estimated in 2001 (before UTAAM was

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Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
1	.43	.29	.112
5	2.04	1.26	.366
10	3.49	2.34	.757
20	5.85	4.16	1.72
40	10.2	7.00	5.61
90	17.6	13.9	17.4

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

For 2009, the polar motion prediction errors were worse in x but better in y in comparison to 2008. The UT1–UTC prediction shows a slight improvement. The improvement in UT1–UTC is likely due to the occasional availability of rapid turnaround e-VLBI intensives and the use of the new USNO UTGPS series.

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 extended, the bias becomes progressively smaller. 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 offsets start before the solution epoch and the length of the prediction into the future can and does vary in the

Table 4: Root mean square of the differences between the nutation prediction series produced by the daily solutions and the 05 C04 combination solutions for 2009.

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.19	.14	.50	.13
5	.19	.15	.51	.14
10	.20	.15	.53	.15
20	.22	.16	.57	.16
40	.24	.18	.63	.19

daily solution files. The differences between the daily predictions and the 05 C04 for 2009 are given in Table 4.

Predictions of TT–UT1, up to 1 January 2019, 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.*, 2005; Stamatakos *et al.*, 2008; Stamatakos *et al.*, 2009).

Center Activities in 2009

During 2009, much of the RS/PC activities have concentrated on improving the operational software, updating and monitoring currently used datasets, and investigating potential new data sets. Specific accomplishments include providing additional diagnostic information for the nutation combination solution.

In early 2010, a revised method of processing AAM data was implemented. Early results indicate that there is an improvement in the combination and short-term prediction of UT1–UTC. The AAM analysis data were removed from the UT1–UTC combination except for the one data point corresponding to the last combination point. It should be noted that the AAM forecasts are still a valuable part of the UT1–UTC prediction process.

A new web site was made operational in early 2009. This new web presence is located at <http://www.usno.navy.mil/USNO/earth-orientation>. This new site provides all of the old functionality plus new features. By the middle of 2010, it is anticipated that this new web site will feature a transformation calculator that will provide both the transformation matrices as well as quaternion representations of the rotations between terrestrial and celestial reference frames.

Additional work to increase the robustness of an alternate site now allows us to run EOP solutions off site. This capability was tested on 4 November 2009 when the main combination and prediction computer suffered a hardware failure. Operations were seamlessly transferred to the off site backup computer with no significant problems.

A new global solution was received from the GSFC VLBI analysis center. This new solution was examined and new slopes and biases were computed.

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,

Table 5: Predicted values of TT–UT1, 2010–2019. 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)
2010 Apr 1	66.168	0.000
2010 Jul 1	66.238	0.007
2010 Oct 1	66.26	0.01
2011 Jan 1	66.34	0.02
2011 Apr 1	66.45	0.02
2011 Jul 1	66.8	0.2
2011 Oct 1	66.9	0.3
2012 Jan 1	67.0	0.4
2012 Apr 1	67.1	0.4
2012 Jul 1	67.3	0.5
2012 Oct 1	67.4	0.7
2013 Jan 1	67.5	0.8
2013 Apr 1	67.7	0.9.
2013 Jul 1	68.	1.
2013 Oct 1	68.	1.
2014 Jan 1	68.	1.
2014 Apr 1	68.	1.
2014 Jul 1	68.	2.
2014 Oct 1	68.	2.
2015 Jan 1	69.	2.
2015 Apr 1	69.	2.
2015 Jul 1	69.	2.
2015 Oct 1	69.	2.
2016 Jan 1	69.	2.
2016 Apr 1	69.	3.
2016 Jul 1	69.	3.
2016 Oct 1	69.	3.
2017 Jan 1	70.	3.
2017 Apr 1	70.	3.
2017 Jul 1	70.	3.
2017 Oct 1	70.	3.
2018 Jan 1	70.	4.
2018 Apr 1	70.	4.
2018 Jul 1	70.	4.
2018 Oct 1	70.	4.
2019 Jan 1	71.	4.

$\delta\psi$ and $\delta\varepsilon$ from GSFC VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from USNO VLBI; x, y, UT1–UTC, dX and dY from IVS combination VLBI; UT1–UTC from GSFC 1-day Intensives; UT1–UTC from USNO 1-day Intensives; x, y from International Laser Ranging Service 1-day SLR; x, y from Institute of Applied Astronomy 1-day SLR; x, y from the Russian Mission Control Centre 1-day SLR; x, y, LOD from the International GNSS Service; UT from USNO GPS; UT from NRCanada (EMR) GPS; UT from NCEP AAM; UT from NAVY NOGAPS AAM; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$, and dX and dY from the IERS Rapid Service/Prediction Center; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Earth Orientation Centre; and predictions of x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$, and dX and dY 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 Centre in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current 365 days' worth of predictions via electronic mail from

ser7@maia.usno.navy.mil or through

<http://www.usno.navy.mil/USNO/earth-orientation> or
<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 Centre staff consisted of the following members:

Brian Luzum	Director
Nick Stamatakos	Operational program manager, 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
Nathan Shumate	Assists in daily operations and support, research, and software maintenance

In April 2009, Nathan Shumate started work at the IERS Rapid Service and Prediction Center. William Wooden retired in August 2009.

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Brian Luzum, Nicholas Stamatakos, Merri Sue Carter,
Beth Stetzler, Nathan Shumate

3.5.3 Conventions Centre

The Conventions Center is operated 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 by electronic means. In addition to the electronic releases, printed versions of the Conventions will be provided at less frequent intervals or when major changes are introduced.

Over 2008 and 2009, the work accomplished or in progress is the following:

1. Technical content of the IERS Conventions

The background work of keeping track of corrections, typos and small changes that improve the readability of the documents continued in 2008 and 2009. More technical or complex issues are first discussed, *e.g*. through the Advisory Board, where topics are identified as needing investigation and possible developments for future versions of the Conventions.

The 2007 IERS Workshop had decided on a new registered edition of the Conventions, tentatively planned for the end of 2009. Therefore, over the period covered by this report, focus has been put on all contributions required for the new edition.[1] In early 2008, it was determined that this work should include:

- A major rewrite of all chapters dealing with both celestial and terrestrial reference systems and the transformation between them;
- A new conventional geopotential model and a rewrite of the section on Earth tides;
- Updated models for the displacement of reference points, as needed;
- A review of the document to ensure consistency with the recommendations of the IAU and IUGG and with the conclusions of the Unions' working groups.

Work on the following major topics was started, ongoing or completed in 2008–2009 (see Section 3 for a detailed list of the updates to the electronic version of the Conventions):

1.1 Terrestrial reference frame

A general revision of the chapter was completed with the primary goal of incorporating the ITRF 2005 into the new chapter. After circulation to the IERS Conventions Advisory Board it was released

1 At the time of this report, the registered edition of the IERS Conventions (2010) is available on line at <http://tai.bipm.org/iers/conv2010/conv2010.html>. It will be described in the IERS report for 2010.

in April 2009. The principal contributors to this effort are Z. Altamimi, C. Boucher, U. Hugentobler and J. Ries.

1.2 Terminology and models for transformations between reference systems

Significant modifications were made to Chapter 5 to incorporate the IAU 2006 Precession model into the Conventions, to ensure that the terminology is consistent with current IAU Resolutions, and to reorganize the chapter for better readability. After circulation to the Advisory Board, the new version was released in June 2009. The principal contributors to this effort are N. Capitaine and P. Wallace.

1.3 Geopotential

Work has been initiated to determine a new conventional geopotential model and to rewrite the section on Earth tides. The principal contributors to this effort are S. Bettadpur, R. Biancale, F. Flechtner, F. Lemoine, N. Pavlis, J. Ray and J. Ries.

1.4 Models for the displacement of reference points

Work has continued to provide a conventional model for the loading due to surface pressure oscillations at mostly diurnal and semidiurnal periods caused by heating of the atmosphere. The principal contributors to this effort are T. van Dam and R. Ray.

Models for technique dependent effects that affect the link between reference points of instruments and a reference marker are being introduced. It is intended to provide only a short description of such models along with a link to a more detailed description, generally provided by the technique services. So far, this section contains models for a reference temperature (provided by J. Boehm), the thermal expansion of VLBI antennas (provided by A. Nothnagel) and GNSS antenna phase center offsets and variations (provided by R. Schmid).

1.5 Tidal variations in Earth rotation

Deficiencies in the zonal tidal model for Earth rotation of the IERS Conventions (2003) have been documented. An improved model is being developed by R. Gross.

1.6 Ionospheric models for radio techniques

A new section regarding ionospheric models for radio techniques, including higher order terms, has been completed and released in February 2009. The principal contributors to this effort were M. Pajares, A. Krankowski, O. Colombo, J.J. Valette, F. Mercier, J. Ray, and G. Petit.

1.7 General relativistic models for space-time coordinates and equations of motion

The new definition of Barycentric Dynamical Time (TDB) has been incorporated along with a correspondingly new description of the relations between time scales. A new section “Transformation between proper time and coordinate time in the vicinity of the Earth” has been introduced. The principal contributors to this effort have been U. Hugentobler, J. Kouba, S. Klioner, G. Petit, J. Ries, and J. Ray.

1.8 Adjustments for the 2008 leap second

The subroutines dehanttideinel.f and hardisp.f have been updated for the leap second that occurred at the end of 2008.

2. 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 started, on-going or completed in 2008–2009:

2.1 Conventions Update web page updated

The Conventions Update page (<http://tai.bipm.org/iers/convupdt/convupdt.html>) 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 the 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.

2.2 Conventions auxiliary web page created

A new web page (<http://tai.bipm.org/iers/convupdt/convupdt_aux.html>) of additional, supporting material has been created. This page presents materials that complement the IERS Conventions but are not formally a part of them. They are provided as additional information, such as test cases, technical notes written by contributors to the Conventions, etc. They are not subject to the same review process as the Conventions chapters and associated programs. This information was added in December 2008.

2.3 Software standardization

A topic discussed at the Conventions Workshop was the benefits of providing standardized software. To accomplish this, a software template has been developed, analogous to the IAU Standards of Fundamental Astronomy (SOFA) software template, to provide information to users, documentation, test cases and a distribution license. Implementation of this template on existing draft software and additional standardization of code was carried out in 2008 and 2009 and should be ready to release with the next registered edition of the Conventions.

3. Dissemination of information

The Conventions web site (<http://tai.bipm.org/iers/>) 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 file including an archive of the discussion forum (<http://tai.bipm.org/iers/forum>) which has been discontinued.

The list of all updates brought over the years to the IERS Conventions (2003) is available online at <http://tai.bipm.org/iers/conv2010/convupdt/convupdt.html>. (Please note that the previous link <http://tai.bipm.org/iers/convupdt/listupdt.html> now provides the updates to the current edition (2010) of the IERS Conventions.)

5. Conventions Center staff

Felicitas Arias (BIPM)
Brian Luzum (USNO), co-director
Dennis McCarthy (USNO)
Gérard Petit (BIPM), co-director
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 Centre (Observatoire de Paris and US Naval Observatory) of the IERS and the International VLBI Service for Geodesy and Astrometry (IVS), in coordination with the IAU. The present report was jointly prepared by the Paris Observatory and US Naval Observatory components of the ICRS Centre. The ICRS Centre web site (<http://hpiers.obspm.fr/icrs-pc>) provides information on the characterization and construction of the ICRF (radio source nomenclature, physical characteristics of radio sources, astrometric behaviour of a set of sources, radio source structure). This information is also available by anonymous ftp (<hpiers.obspm.fr/icrs-pc>), and on request to the ICRS Centre (icrspc@hpopa.obspm.fr).

Maintenance and extension of the ICRF

In the framework of the validation of individual VLBI references frames, individual celestial reference frames obtained in 2008 by three laboratories have been compared to ICRF-Ext.2 (Fey et al., 2004).

The reference frames analyzed

The individual frame RSC (BKGI) 08 R 03 elaborated at the Federal Agency for Cartography and Geodesy and the Geodetic and Geoinformation Institute of the University of Bonn (Germany) has been evaluated using CALC 10.0 / SOLVE release 2007.10.04. 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 – November 2008. VMF1 mapping function has been applied for the troposphere modeling.

RSC (IAA) 08 R 01 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 – October 2008. 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) 08 R 01 frame was obtained at the Paris Observatory analysis centre with the CALC 10.0 / Solve 2008.07.31 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 2008 and the NMF mapping function has been applied for the troposphere modeling. Troposphere gradients have been adjusted in the solution.

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 (BKGI) 08 R 03	1868	209	0.04	225	0.04	101	0.02	84	0.09	1249	0.41	-81;+89
RSC (IAA) 08 R 01	1037	212	0.05	285	0.09	102	0.03	109	0.20	389	0.54	-85;+84
RSC (OPA) 08 R 01	603	209	0.06	102	0.07	98	0.03	50	0.11	44	0.18	-81;+84

Positions and velocities of stations have been estimated as global parameters for the three 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.

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 are of similar quality.

Comparison of individual celestial frames to ICRF-Ext.2

The catalogues listed in Table 1 have been compared to ICRF-Ext.2. The algorithm of comparison revised last year 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 (BKGI) 08 R 03	209	0 ± 16	–26 ± 16	–14 ± 17	–33 ± 14
RSC (IAA) 08 R 01	212	–11 ± 19	–41 ± 19	–7 ± 20	–18 ± 17
RSC (OPA) 08 R 01	209	–44 ± 19	7 ± 18	–11 ± 19	–16 ±16

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 45 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 25 μas. The dz parameter quantifies the bias between the principal plane of each individual frames and that of the ICRS. For the solution computed by BKGI, the biase is significant. In contrast, the principal planes of the OPA and IAA frames are aligned to that of ICRS at the level of 18 μas.

Investigation of future realizations of the ICRS

The International Celestial Reference System (ICRS), adopted by the International Astronomical Union (IAU) in 1997, forms the underlying basis for all astrometry by defining the reference directions of a quasi-inertial celestial coordinate system that are fixed with respect to the most distant objects in the universe. Since 1 January 1998, the ICRS has been realized by the International Celestial Reference Frame (ICRF) which is based on the radio wavelength astrometric positions of compact extragalactic objects determined by the technique of very long baseline interferometry (VLBI).

In coordination with the IAU, the task of maintaining the ICRS was given to the International Earth Rotation and Reference System Service (IERS), with the International VLBI Service for Geodesy and Astrometry (IVS) having operational responsibility for the VLBI realization. Significant developments and improvements in geodetic/astrometric VLBI observing and analysis have been made since the initial generation of the ICRF, hereafter ICRF1. Sensitivity of VLBI observing systems to weaker sources and overall data quality have improved significantly due to advances in VLBI receiver and recording systems and due to better observing strategies coordinated by the IVS. The use of newer and more modern radio telescopes, such as the 10 station Very Long Baseline Array (VLBA) of the National Radio Astronomy Observatory, has also greatly improved the sensitivity and quality of recent data. Further, enhanced geophysical modeling and computers with faster processors have allowed significant improvements in data analysis techniques and astrometric position estimation.

With the addition of over fourteen years of new geodetic/astrometric VLBI data taken since ICRF1, we are now better able to select a set of more positionally stable sources, which are more uniformly distributed on the sky and are better able to define the ICRS axes. The additional data also allows us to filter out the most positionally unstable sources, avoiding possible distortion of the frame that might otherwise occur. Further, the large amount of imaging data now available allows us to identify and remove sources with extensive intrinsic structure that could cause potential problems due to temporal structure changes.

At the XXVI meeting of the IAU General Assembly held in Prague, Czech Republic in 2006, an IAU Working Group was established specifically to oversee the generation of a second realization of the International Celestial Reference Frame, hereafter ICRF2. An IERS/IVS Working Group was then established specifically for the purpose of generating ICRF2. This was a truly international effort with Working Group members from numerous countries including the USA, France, Germany, Italy, Russia, Ukraine, Australia, and China.

The end result of the 3-year effort of the IERS/IVS Working Group was ICRF2 (Fey, Gordon and Jacobs, 2009), which contains precise positions of 3414 compact extragalactic sources, more than five times the number as in ICRF1. The ICRF2 has a noise floor of approximately 40 micro-arcseconds, some 5–6 times better than ICRF1, and an axis stability of approximately 10 micro-arcseconds, nearly twice as stable as ICRF1. Alignment of ICRF2 with the ICRS was made using 138 stable sources common to both ICRF2 and ICRF1. Future maintenance of ICRF2 will be made using a set of 295 new “defining” sources selected on the basis of positional

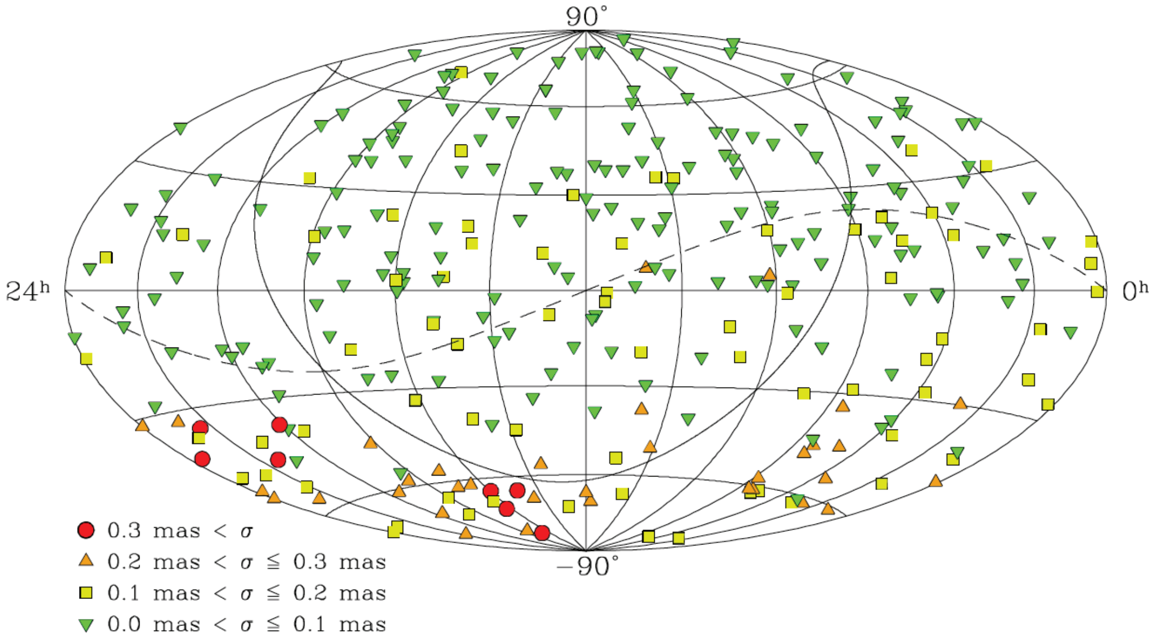


Fig. 1: The distribution of the 295 new ICRF2 "defining" sources on an Aitoff equal-area projection of the celestial sphere. ICRF2 defining sources were selected on the basis of positional stability and the lack of extensive intrinsic source structure. The dotted line in this figure represents the Galactic equator.

stability and the lack of extensive intrinsic source structure. The stability of these 295 defining sources, and their more uniform sky distribution eliminates the two largest weaknesses of ICRF1.

On Thursday, August 13, 2009 at the second session of the XXVII General Assembly of the IAU held in Rio de Janeiro, Brazil, members approved, without dissent, Resolution B3 adopting the ICRF2 as the fundamental celestial reference frame as of 1 January 2010.

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-Lite) 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 2008 and 2009, ICRS Centre personnel continued their participation in the NASA SIM mission, through direct involvement in one of the SIM key science projects: Astrophysics of Reference Frame Tie Objects. In addition, ICRS Centre personnel worked on development of 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) (see Gaume et al., 2009).

Monitor source structure to assess astrometric quality

VLBA RDV observations and analysis

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 2008 and 2009. 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 2008 and 2009, a total of twelve VLBA RDV experiments were observed.

VLBA high frequency reference frame

VLBA observations to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) continued in 2008 and 2009. 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 2009 work resulted in two published manuscripts presenting the results of the high frequency reference frame observations (Charlot et al., 2010; Lanyi et al., 2010).

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 7279 Very Long Baseline Array (VLBA) images of 782 sources at radio frequencies of 2.3 GHz and 8.4 GHz. Additionally, the RRFID contains 1706 images of 282 sources at frequencies of 24~GHz and 43~GHz. The RRFID can be accessed from the Analysis Center web page or directly at <http://rorf.usno.navy.mil/rrfid.shtml>.

The Bordeaux VLBI Image Database

The Bordeaux VLBI Image Database (BVID) is a web accessible database of radio frequency images of ICRF sources. The BVID currently contains 1898 Very Long Baseline Array (VLBA) images of 824 sources at radio frequencies of 2.3 GHz and 8.4 GHz. The BVID can be accessed from the Analysis Center web page or directly at <http://www.obs.u-bordeaux1.fr/BVID/>.

Maintenance of the link to the Hipparcos catalog

During the reporting period (2008/2009) USNO continued to make progress in the areas of UCAC project (release of UCAC3), the extragalactic link to radio frame sources, URAT, and JMAPS.

UCAC3, the first all-sky catalog of the USNO CCD Astrograph Catalog (UCAC) project was release in August 2009 at the IAU GA and the data are available from CDS. Unfortunately the reductions of the NPM data were not completed in time which lead to preliminary proper motions of stars fainter than about R = 13 for declinations north of –30 deg with significant systematic errors up to about 10 mas/yr (Zacharias et al. ,2010a). The final release, UCAC4, expected in 2011 will fix this and other issues, and also make positions at CCD observing epochs public.

Re-reductions of the Southern Proper Motion (SPM) data could be completed in collaboration with Yale University, leading to very accurate proper motions in UCAC3 for south of –30 deg declination utilizing the SPM first epoch data on the Hipparcos system. Based on the first and second epoch SPM data the SPM4 catalog was created containing about 100 million stars with highly accurate proper motions based on an extragalactic system utilizing galaxies (<www.astro.yale.edu/astrom/spm4cat/spm4.html>).

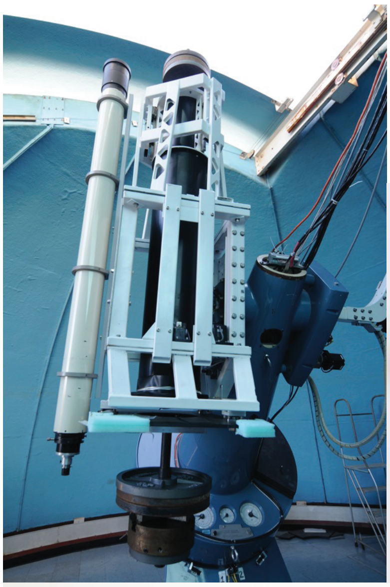
While comparing the original and the 2007 versions of the Hipparcos Catalogue with UCAC and other data, large position differences up to several 100 mas were found for some stars in a random sample of about 1500 stars. These are problem cases related to the short epoch span of Hipparcos observations. All combinations of which catalog is off are seen. Results were presented at a DDA meeting (Zacharias et al., 2009).

Reductions of the deep CCD images taken of extragalactic, compact radio sources during the UCAC project continued, with 1 more observing run reduced. Reviewing the results of several such observing runs, systematic offsets between the optical and radio positions are found far in excess of expected, internal errors for some sources. This could be an issue of the Tycho-2 reference frame itself, or a physical offset of the centers of emission (optical-radio) for some quasars. The effect is on the 30 mas level and preliminary results were presented at the 2009 IAU GA (Zacharias & Zacharias, 2009).

Monitoring a sample of 12 ICRF optical counterparts continued at the 1.55m telescope at NOFS, as well as photometric monitoring for reference frame source selection (Ojha et al., 2009). USNO also participated in the construction of the Large Quasar Reference Frame (LQRF), (Andrei et al., 2009), and the Space Interferometry Mission, SIMLite project (Unwin et al., 2009). In a collaboration with Copenhagen Univ. the Brorfelde Schmidt CCD catalog was published (Zacharias et al., 2010b). It contains accurate positions of 13.7 million stars north of +49 deg declination on the Tycho-2 system and goes deeper than UCAC.

Hardware construction of the USNO Robotic Astrometric Telescope (URAT) continued (Zacharias, Wieder, & Bredthauer, 2009). The mechanical work for the new tube assembly of the 20 cm USNO astrograph "redlens" was completed by the USNO Instrument Shop. Wiring of the mount and work on the electronic interface began. Manufacturing of STA1600B CCD chips (10560 x 10560 pixels) was successful. Delivery of the "4-shooter" camera (4 of these large CCDs plus 3 guide chips) is expected in 2010. For latest progress about the URAT project see:

<http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/urat/usno-robotic-astrometric-telescope-urat/>



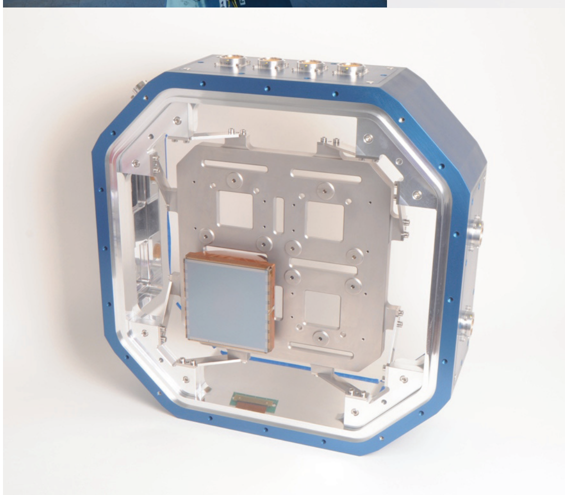


Fig. 2: Top Left: Nearly Completed URAT Telescope
Top Right: Size of STA1600B CCD compared to a modern digital camera.
Bottom: One STA1600B CDD in the URAT cryostat

Linking the ICRF to frames at various wavelengths

Optical representation of the ICRS

In recent years there was a significant increase of the number of optically bright quasars for which an ICRF related astrometric position can be derived, along with an improvement of the evenness of their sky distribution (Véron-Cetty & Véron, 2006; Souchay et al., 2008). This enabled to build an optical representation of the ICRS, the LQRF (Andrei et al., 2009) formed by 100,165 QSOs all-sky distributed (see next paragraph).

This answers to the requirements such as from micro and macro lensing, binaries, and space density counts, as well as the requirements of space astronomy missions. In particular, for the forthcoming Gaia mission an Initial Quasar Catalogue is being compiled. The workpackage is formed by A.H. Andrei (ON/MCT, OATo/INAF, OV/UFRJ), C. Barache (SYRTE/OP), D.N. da Silva Neto (UEZO/RJ), F. Taris (SYRTE/OP), G. Bourda (Obs. Bordeaux), J.-F. LeCampion (Obs. Bordeaux), J. Souchay (SYRTE/OP), J.I.B. Camargo1 (ON/MCT), J.J. Pereira Osório (CICGE/FCUP), M. Assafin (OV/UFRJ), P. Charlot (Obs. Bordeaux), R. Vieira Martins (ON/MCT), S. Bouquillon (SYRTE/OP) & S. Anton (CICGE/FCUP). Also A.-M. Gontier (SYRTE/OP) belonged to this workpackage and her absence will be sorrowly felt.

The latest version of the Gaia Initial Quasar Catalogue (GIQC_III) contains 174,744 sources, divided in 3 categories: defining (full reliability, 123,880 sources), candidate (lacking full confirmation of redshift or magnitude or pointlikeness, 24,229 sources), and other (pending confirmation of two or more characteristics, 26,235 sources). The GIQC_III includes morphological indexes, as derived from the study of the target's PSF from DSS R, B, and I plates, in comparison with at least 6 well imaged neighbor stars. It also includes the most reliable positions, magnitudes, and redshifts. Figure 3 presents an extract of the GIQC_III. The catalogue may be consulted on demand to oat1@on.br (A. Andrei).

The morphological indexes were determined from 5x5 arcmin cuts of B, R, I DSS images. At least 6 well imaged are retained as comparison to the quasar's PSF. The IRAF measures SHARP (probing skewness), SROUND (probing roundness), and GROUND (probing normalness) define the indexes. The robustness of the morphological indexes was verified by a trial bench on 1,343 R images for which also the SDSS DR7 images (0.396 arcsec/px) were retrieved. The results show that the PSF analysis reproduces well the SDSS star/galaxy separator and that the DSS plates per-

RA (deg)	DEC (deg)	MAG	z	Rshr	Rsrn	Rgrn	Bshr	Bsrn	Bgrn	Ishr	Isrn	Igrn	Class
0.000000	-0.032778	19.40	1.560										C P
0.002083	-0.450833	20.09	0.250										O F
0.005291	-2.033269	19.29	1.356	0.75	0.10	0.13							D
0.005735	-30.607458	19.18	1.143	0.20	0.01	0.91							D
0.007326	-31.373790	19.74	1.331	0.73	0.44	0.00				1.82	1.14	1.37	D
0.011279	-25.193609	21.56	1.314										O F
0.012178	-35.059062	17.09	0.508	0.59	0.20	0.27				0.39	0.80	0.07	D
0.022792	-27.419533	19.11	1.930	0.12	1.01	0.41							D
0.027500	0.515278	20.37	1.823										D S
0.033333	-63.593333	17.00	0.136										C A
0.034167	0.276389	20.03	1.837										D S
0.038604	15.298477	19.40	1.199	0.92	0.02	0.30	0.36	0.92	0.08	1.11	1.51	1.46	D S
0.039089	13.938450	18.29	2.240	0.59	0.23	0.14	0.63	0.91	0.09	2.07	0.16	1.43	D S

Fig. 3: The first lines of the Gaia Initial Quasar Catalogue – GIQC_III RA and DEC are self-explanatory. And so is the redshift (z) on the 4th column. MAG is V whenever available, when it is not g, r, or the weighted average of the available colors. It follows 3 groups (from the DSS R, B, and I plates) of 3 PSF estimators (SHARP, SROUND, and GROUND) for which the closer to 0, the more stellar-like is the QSO PSF (in the local photometric standard). The first Class column is Defining, Candidate, or Other. The second Class column is SDSS source (for Ds); ICRF source, optically point-like AGN, or Poor observational history (for Cs); Empty field, low precision Radio position, Unreliable detection, or optically Faint (for Os).

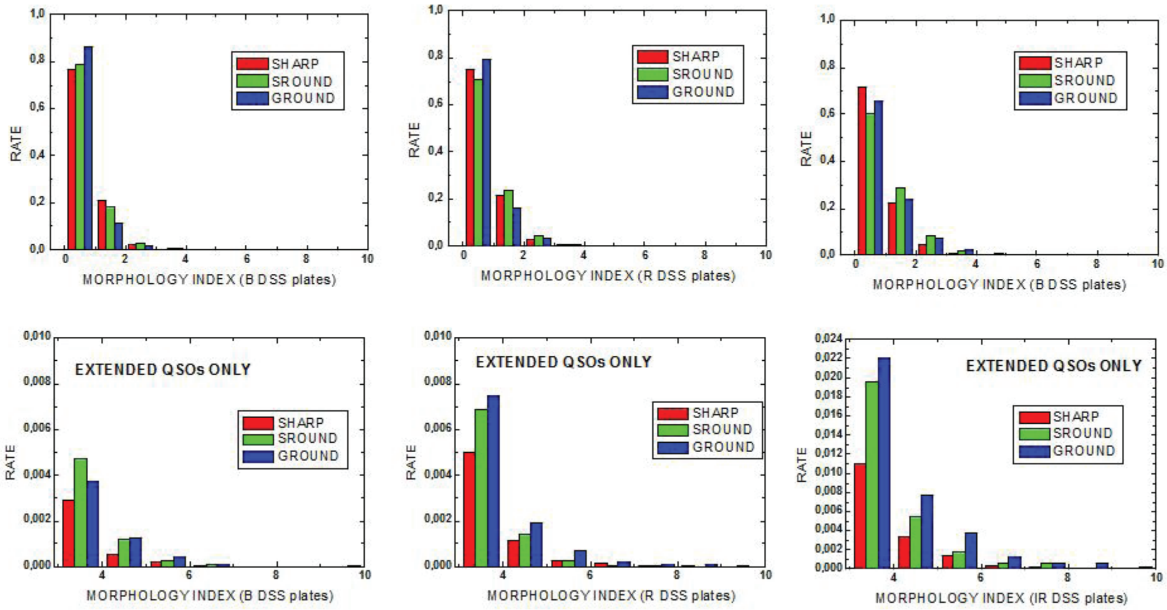


Fig. 4: Histograms of the morphological indexes are shown on the upper row. The second row zooms the histograms into the region of non-pointlikeness. It is evident that the degree of non-pointlikeness varies along the spectrum. The bluer the QSO is looked to, the deeper into the power force it is perused, and the more pointlike it looks. Notice that the atmosphere transparency works right against this.

form much alike to the SDSS frames. The excess (rate of objects beyond 2 σ) of non-stellar quasars is significant as given by all the indicators, on both the DSS2 and DR7 images, measured either against the field stars or the SDSS classified stars.

Construction of the LQRF

The large number, and all sky repartition of quasars from different surveys combined with their presence in large, deep astrometric catalogs, enabled to build an optical materialization of the ICRS (International Celestial Reference System) following its defining principles, namely, kinematically non-rotating with respect to the ensemble of distant extragalactic objects, aligned to the mean equator and dynamical equinox of J2000, and realized by a list of adopted coordinates of extragalatic sources.

The LQRF (Large Quasar Reference Frame) (Andrei et al., 2009) was built with the care of avoiding wrong matches of its constituents quasars, of homogenizing the astrometry from the different catalogs and lists from which the constituent quasars are gathered, and of attaining the milli-arcsecond global alignment to the ICRF (International Celestial Reference Frame), as well as typical individual source position accuracies even to better than 100 mas.

Starting from the updated and presumably complete LQAC (Large Quasar Astrometric Catalog) (Souchay et al., 2009) list of QSOs, initial optical positions for those quasars were found in the USNO B1.0 and GSC2.3 catalogs, and from the SDSS Data Release 5. The initial positions were next placed onto UCAC2 based reference frames, followed by an alignment to the ICRF, as well as to the most precise sources from the VLBA calibrator list and from the VLA calibrator list, when reliable optical counterparts exist. Finally the LQRF axes were inspected through spherical harmonics, contemplating right ascension, declination and magnitude terms. Thus a method akin to the enlargement of the ICRF2 was used.

The LQRF contains 100,165 quasars, well represented on all-sky basis, from –83.5° to +88.5° of declination, and with 10 arcmin as the average distance between adjacent elements (Fig 5). The global alignment to the ICRF is of 1.5 mas (Fig. 6), and the individual position accuracies are represented by a Poisson distribution peaking at 139 mas on right ascension and at 130 mas on declination (Fig. 7). As a by product, significant equatorial corrections appear for all the used quasar catalogs but the SDSS DR5.

The LQRF contains J2000 referred equatorial coordinates, and is completed by redshift and photometry information from the LQAC. It is aimed to be an astrometric frame, but it is also the basis for the Gaia mission initial quasars' list, and can be used as a test bench for quasars' space distribution and luminosity function studies. The LQRF is meant to be updated after the release of new quasar identifications and newer versions of the used astrometric frames.

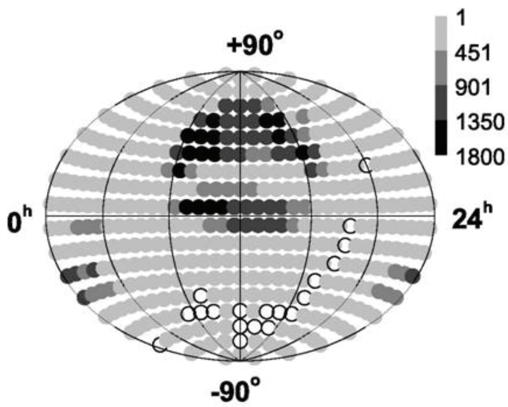


Fig. 5: Sky density of the LQRF. The counts are in bins of 10°. The void regions shown by white circles are in the galactic plane. The densest patches lie on the SDSS region.

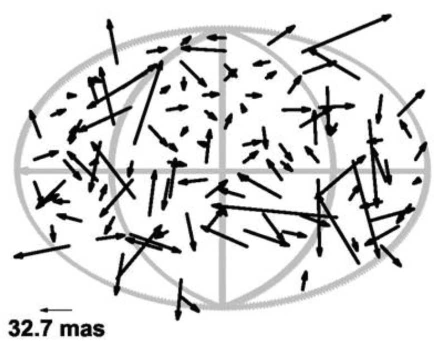


Fig. 6: Vectorial distribution of the systematic deviations (north up east right of the LQRF to the ICRF, bins of 10°. The average value is 32.7 mas, graphically represented by the off map arrow.

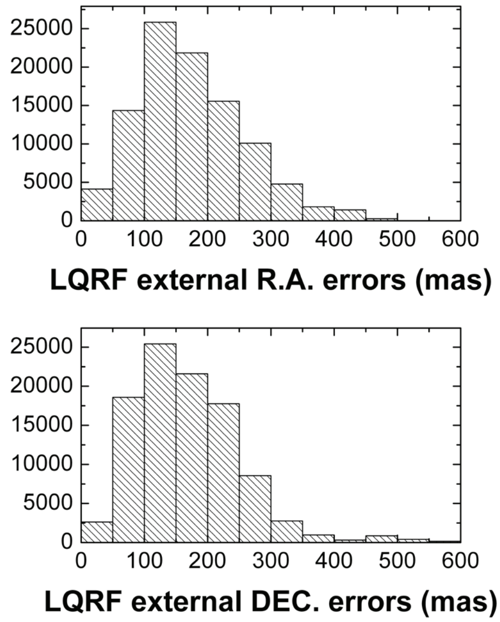


Fig. 7: Distribution of the external errors assigned to the right ascension and declination for the J2000 positions of the LQRF sources. The distributions can be reckoned as Poisson distributions peaking at 139 mas on right ascension and at 130 mas on declination.

Data bank of optical images of QSOs

In order to provide the basis for independent optical astrometry and morphology studies of quasars as the fiducial points of materialization of the ICRS, a data bank of images has been compiled during 2008. The images comprise the first and second realizations of the DSS (Digitized Sky Survey), as well as the available recent, deeper CCD frames (e.g., from the SDSS – Sloan Digital Sky Survey).

A first extract of the data bank was produced over 1,343 objects belonging to the SDSS (Fig. 8). For these, the SDSS images on filters g, r, and i, and the DSS II images on filters B, R, and I were retrieved and their morphology was analyzed. Parameters of sharpness, roundness, and normaliness were derived from the plate and CCD images, and compared against the neighbor stellar sample.

The use of those parameters allowed us to separate the stellar and non-stellar populations, with performance well adjusted (up to 88 %) to that of the SDSS. Among the QSO's an excess of about 30% of non-pointlike objects was found, indicating the signature of the host galaxy (Fig. 9).

The data bank will be made available for browsing through the IERS-ICRS site, and mirror sites from the associated institutes: SYRTE at Paris Observatory, Centro de Investigaçao em Ciencias Geo-Espaciais/FCUP (Portugal), and Observatorio Nacional/MCT (Brasil).

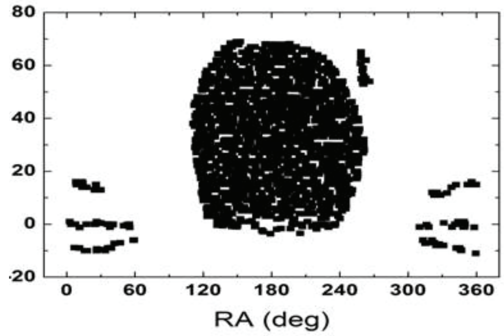


Fig. 8: Sky distribution of the 1,343 trial bench sample. It includes the extreme magnitudes, colors, and redshift objects, along with a representative DR7 population.

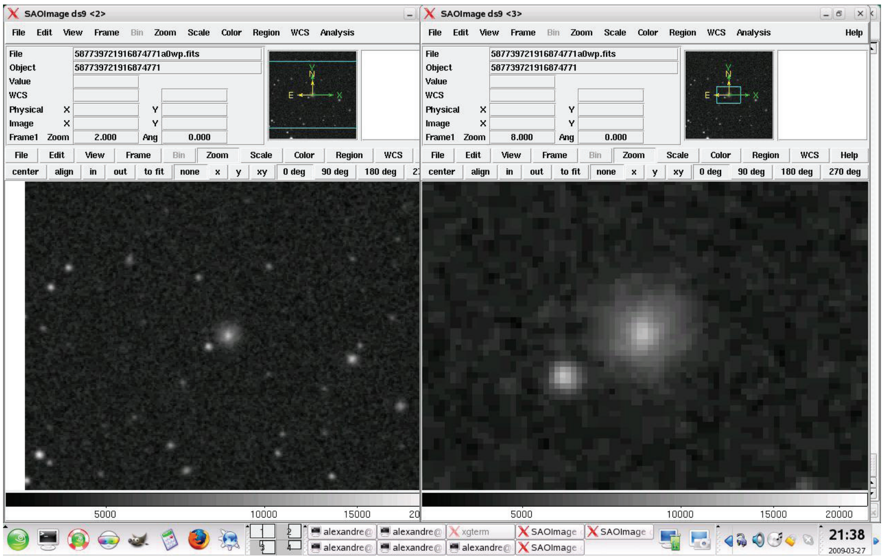


Fig. 9: Example image of QSO DR7 587739721916874771 from the DSS II red plate. The zoomed DS9 window on the right leaves evident an elliptical galaxy underneath the QSO.

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

Analysis of the Lunar Laser Ranging (LLR) provides scientific results in various domains (astronomy, gravitational physics, geodynamics, selenophysics). The LLR observations contribute also to the positioning of the dynamical reference frame with respect to ICRS.

At the lunar analysis centre of Paris Observatory (SYRTE laboratory), we define the dynamical reference frame of the solar system as the dynamical mean ecliptic and equinox J2000 related to the orbit of the Moon given by the lunar ephemerides of the solution ELP (Chapront-Touzé et al., 1997).

The LLR data (normal points) consist in measurements of the round-trip travel time of the light between a terrestrial station and a lunar reflector. According to a recent inventory of LLR observations collected since 1969 (Francou et al., 2009), we have gathered more than 18000 LLR normal points provided by four stations: Mc-

Donald (Texas) 1969–2008, OCA (France) 1984–2005, Haleakala (Hawaii) 1984–1990, Apache Point (New Mexico) 2006–2008.

The analyses of the differences between the LLR observations and the values computed with ELP give post-fit residuals around 300 picoseconds for the round-trip travel time of the light, that is to say less than 5 cm for the distance station-reflector.

The position of the dynamical mean ecliptic with respect to ICRS (J2000 epoch) resulting from LLR analyses is defined by the two angles:

- $\varepsilon^{(ICRS)}$, the inclination of the dynamical mean ecliptic to the equator of ICRS,
- $\varphi^{(ICRS)}$, 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.

Different evaluations of $\varepsilon^{(ICRS)}$ and $\varphi^{(ICRS)}$ made for various time intervals of LLR observations and using different models of precession-nutation, give very close results (Table 3).

Table 3: Evaluation of ε and φ by different authors.

Authors	Time intervals	$\varepsilon^{(ICRS)}$	$\varphi^{(ICRS)}$
Chapront J. et al. (2002)	1969–2001	23°26‘21.41100“±0.00005“	–0.05542“±0.00011“
Zerhouni W. et al. (2007)	1969–2006	23°26‘21.41081“±0.00009“	–0.05538“±0.00009“
Francou G. et al. (2009)	1969–2008	23°26‘21.41125“±0.00009“	–0.05543“±0.00009“

The uncertainties mentioned in Table 3 being formal uncertainties resulting from the least square fitting, the final values for these angles are fixed as follows:

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

$$\varphi^{(ICRS)} = o^{(ICRS)}\gamma_I^{(ICRS)} = -0.055 \text{ mas}$$

Simultaneously to the determination of the position of the dynamical reference frame, the LLR analyses have also allowed us to determine other parameters (Bouquillon et al., 2005; Chapront et al., 2006; Zerhouni et al., 2008) and to perform adjustments of the motions of Moon (Chapront et al., 2003; Manche et al., 2007).

Maintenance of the link to the solar system dynamical reference frame using Pulsar Timing analyses

In 2008, activities related to VLBI observations of millisecond pulsars (PSR) and the link between dynamical reference frames and ICRF based on PSR observations have been maintained and amplified. A PhD student began his thesis in September 2008 at the Besançon observatory on the use of PSRs in reference frame tie and detection of gravitational waves.

Rotation between planetary ephemerides: DE200, DE405 and INPOP06

In association with the Nançay Radio Telescope (NRT) and the LPCE (CNRS/University of Orléans) and in the frame of the 4-years french plan "Systèmes de reference: Raccordement de l'ICRF et du système de référence dynamique d'INPOP (Reference Systems linking the ICRF to the Dynamical System INPOP)", we developed this new investigation based on the use of millisecond pulsar timing (TOA) obtained at the NRT (Cognard, 2006). The tempo2 software (Hobbs et al., 2006) was used to proceed the TOA observations.

Coordinates estimated in using pulsar timing data (TOA) are expressed in the reference frame of the planetary ephemerides used in the reduction process. By considering only PSRs TOA, rotation matrices between dynamical frames can be estimated. The differences in (α_{TOA}, δ_{TOA}) induced by the use in the reduction procedure of different planetary ephemerides (DE200, DE405 and INPOP06) indicate small rotations of the dynamical frames of the planetary ephemerides. In Table 4, one can find the PSR coordinates used to compute the rotation matrices W between DE405 and DE200 in one hand and DE405 and INPOP06 in the other hand. We find in mas W[DE405–DE200] = [0.4 ± 3, 11 ± 4, 13 ± 3]. This matrix is close to the one deduced from estimations done by (Standish 1998a, 1998b) at J2000, S[DE405–DE200] = [1.3, 13.7, 10.3]. Between DE405 and INPOP06, we obtain W[DE405–INPOP] = [1.7 ± 0.5, 0.55 ± 0.05, 1.0 ± 0.1]. These latest rotations between DE405 and INPOP06 are statistically significant but they remain below the 1 to 10 mas uncertainties of the VLBI tracking observations of spacecrafts used to link the dynamical frame of DE or INPOP to ICRF.

Rotation between ICRF and planetary ephemerides

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

A new proposal of VLBI observations of 3 PSRs was done at the European VLBI Network (EVN) for the first semester of 2009. The rate priority being 1.6, the proposal was accepted for observation but not scheduled yet. A new proposal for the same objects was then again proposed for the first semester of 2010. Besides, new VLBI observations of PSRs have been done by other teams: Chatterjee et al. in US and Deller et al. in Australia. Based on these new positions and in using radio pulsar timing (TOA) performed at the Nançay radio telescope (NRT), we have been able to perform new link between DE405, INPOP06 and ICRF.

We note (α_{TOA}, δ_{TOA}) the pulsar coordinates obtained with pulsar timing and expressed in the reference frame of the planetary ephemerides used in the reduction process. Besides, VLBI observations of the same pulsars done in using ICRF sources as calibration sources are given directly in ICRF. Le t 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 ephemerides as well as possible drift of the dynamical reference frame if the comparisons are extended in time.

To obtain high accurate determinations, we estimate the rotation matrix in using PSRs observations presented in Table 4 and with TOA uncertainties in positions of about 1 mas. This means that we use B1937+21 and J1713+0747. As it is shown in Table 4, the data from NRT were not sufficient to obtain a good astrometry based on TOA of 0139+5814, 1300+1240 and 0454+5543.

In using the two pulsars B1937+21 and J1713+0747, we obtain in mas the rotation matrix M at J2000 M[INPOP–ICRF] = [9 ± 5, –3 ± 1, –4 ± 5]. This rotation is statisticallly significant but at the limit of accuracy of the present observations used to link planetary ephemerides to ICRF. We deduce the matrix M[DE405–ICRF] = [11 ± 6, –2.5 ± 11, –3 ±5] at J2000. We would expect smaller values (Standish 1998b). This can be seen as a systematic induced by the fact that we only use two pulsars to make the link. The link must be extended to other pulsars by adding to the NRT TOA data TOA obtained by other observatories. By adding new sets of observations, we decorrelate instrumental errors and improve the astrometric accuracy.

Table 4: Candidates of pulsars for reference frame link: Column 1 gives the name of the PSR, Columns 2 and 3 give the J2000 equatorial coordinates. Column 4 gives the RMS of TOA residuals obtained with the NRT observations and proceeded with tempo2 software. Columns 5 and 6 give the astrometric accuracies in positions obtained with NRT TOA and tempo2. The last column indicates the reference of the VLBI observations: C09 stands for (Chatterjee et al. 2009), NB98 for (Nunes and Bartel, 1998), B96 for (Bartel et al., 1996) and P94 for (Petit, 1994).

	RA [hhmmss.s]	DE [ddmmss.s]	RMS TOA [μs]	$\sigma\ \alpha$ [mas]	$\sigma\ \delta$ [mas]	VLBI
J0139+5814	01 39 19.77	58 14 31.8	62	800	70	C09
J0437-4515	04:37:15.749	-47:15:08.23	0.9	0.16	0.14	
J1909-3744	19:09:47.437	-37:44:14.32	0.3	0.1	0.2	
J1824-2452	18:24:32.00	-24:52:10.69	6	0.3	0.4	
J1300+1240	01 39 19.77	58 14 31.8	9	50	118	NB98
B1937+21	19 39 38.55	21 24 59.1	0.3	0.1	1	B96, P94
J1713+0747	17 13 49.52	07 47 37.5	0.2	2	1	C09
J1136+1551	11 36 03.30	15 51 00.7	125	19	35	
J1744-1134	17:44:29.401	-11:34:54.64	0.9	0.4	0.9	
J0454+5543	04 54 07.75	55 43 41.4	87	130	60	C09

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3.5.5 ITRS Centre

Report for 2008

This report summarizes the activities of the IERS ITRS Centre during the year 2008.

ITRF2008

The ITRS Centre, together with the ITRS Combination Centres, plans to generate a new ITRF solution (ITRF2008) and has solicited inputs from the IERS Technique Centres (TC) and their related Analysis Centres. The TCshave been requested to provide as long time series as possible and preferably covering the full history of observations of each technique. Indeed, three additional years of data are available since the ITRF2005 generation and reprocessed solutions have been expected to be available since that time which could considerably improve the consistency of the inter-technique combination.

Maintenance of the IERS network

The ITRS centre assigns DOMES numbers to geodetic tracking stations or markers as unambiguous identifications of points in space, independently from the technique of their tracking instruments.

The IERS network database, which contains the descriptions of the sites and points, is continuously updated as DOMES numbers are assigned. DOMES number request form can be found on the ITRF web site <http://itrf.ign.fr>, and should be sent to domes@ign.fr. An updated list of all available DOMES number is available at <http://itrf.ign.fr/doc_ITRF/iers_sta_list.txt>.

ITRF web site

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

The maps of the ITRF networks can be displayed depending of the measurement techniques and of the ITRF realization. Velocity vectors can be displayed as well as tectonic plates. The dynamical map can help users to familiarize with ITRF products and can be used for educational purpose. It can also be an interesting tool to select IERS sub-network depending on the measurement techniques, co-located hosted instruments or ITRF versions. ITRF94, ITRF96, ITRF97, ITRF2000 and ITRF2005 solutions are available for download.

Local ties of ITRF co-location sites

In order to improve the available local tie vectors, the ITRS product centre undertakes regularly the survey of some ITRF co-location sites in addition to every new DORIS co-located antennae that are installed. After Tahiti Observatory in October 2007, IGN has surveyed Herstmonceux co-location site in June 2008. The reports of these surveys are available at the ITRF web site at <http://itrf.ensg.ign.fr/local_surveys.php>. The local ties SINEX files are also available at that web site.

Report for 2009

This report summarizes the activities of the IERS ITRS Centre during the year 2009.

ITRF2008 preparation

The ITRS Centre collected input time series (weekly from satellite techniques and daily from VLBI) of station positions and daily Earth Orientation Parameters from the IERS Technique Centres (TC) in preparation for the ITRF2008. All the submitted solutions are combined solutions by the Combination Center of each TC and based on reprocessed individual solution generated by the Analysis Centers of each one of the four techniques (VLBI, SLR, GNSS/GPS and DORIS). The submitted solutions cover the full history of observations, except for the GNSS/GPS series which start in 1997. These solutions are archived by the ITRS Center and were analysed by the two IERS Combination Centers (IGN and DGFI). Interaction and communication between the IERS Center and the TCs were operated as necessary and as a function of the ITRF2008 pre-analysis conducted by the IERS CCs. Some IGN ITRF2008 Pre-analysis results are presented in the CC section of this report, see 3.6.1.2. The following table summarizes the final time series of station positions and EOPs submitted by the TCs.

TC	Span	Solution type	EOPs
IVS	1980.0–2009.0	Normal Equation	Full set
ILRS	1983.0–2009.0	Variance-Covariance	Polar Motion, LOD
IGS	1997.0–2099.5	Variance-Covariance	Polar motion, rate, LOD
IDS	1993.0–2009.0	Variance-Covariance	Polar motion, rate, LOD

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ITRF web site

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In preparation for the ITRF2008 combination, the IGN survey department has conducted a re-adjustment of all surveys in DORIS sites co-located with the other 3 techniques. Other few non-DORIS co-located sites for which IGN detains the raw survey data were also adjusted. The local ties generated from this re-adjustment are provided in SINEX format with full variance-covariance information.

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3.5.6 Global Geophysical Fluids Center (GGFC)

The Global Geophysical Fluid Center (GGFC) of the International Earth Rotation Service (IERS) was originally formed to provide the geodetic community with models of geodetic effects (rotation, gravity, and deformation) driven by the temporal variation of the Earth fluids. The fluids include fluid motions within the earth such as the core and mantle as well as the motions of surface fluids e.g. oceans, atmospheres, and continental water.

Since its creation and until 2009 the GGFC was composed of 8 Special Bureaus (SBs). Six of the SBs were defined by the fluid which was being modeled. The SB Loading and SB Gravity were different in that they provided loading effects due to time variable atmospheric pressure and geocenter observations respectively. While this structure worked well for many years, in 2008 it was found to no longer be adequate for addressing the needs of the geodetic community. In 2008, the IERS Directing Board began considering a restructuring of the GGFC with the goals of: 1) improving the reliability of products deemed necessary for IERS Product, Technique, and Combination Centers; 2) allowing for the incorporation of new and valuable datasets for these Centers; and 3) improving the ease of use of the GGFC products by the greater GGFC user community.

The biggest motivation for the reorganization came from the fact that some GGFC data sets were and still are routinely required by the IERS Product, Technique, and Combination Centers. Data sets deemed fundamental for the work of other IERS Centers needed to be promoted to the status of an operational product. Changing a product's status to operational imposes requirements on the product's reliability in time and precision that may or may not have been accepted by the present SB Chairs.

Another argument for reorganization was the problem with finding the correct 'home' within the old GGFC for new data sets that are required by the geodetic community. For example, the precision of many geodetic products rely on the regular estimates of tropospheric water vapor (TWV), making TWV a reasonable product to be provided to the community via the GGFC. However, given the old structure it was not obvious how this product should be incorporated. There were no obvious homes for a TWV product within the existing GGFC structure. SB Atmosphere is concerned with providing atmospheric angular momentum models. And SB Loading focuses on loading effects. There are no obvious homes for a TWV product within the current GGFC structure. Additional examples of data that were/are required by the community and which should have been made available through the GGFC but which did not fit into the old structure include global grids of temperature and pressure, sea surface height, sea surface temperature, etc.

In response to these new requirements, a new structure for the GGFC was proposed. The GGFC was first broken up into an Operational and a Non-operational component. The operational component would house data required for other IERS (non-GGFC) product Centers to generate their products. The Non-operational component, entitled GGFC Science and Support Products, would consist of products and/or models (environmental fluids or solid Earth) that do not change frequently, e.g. ocean and solid Earth tide models, or models of post-glacial rebound.

Figure 1 graphically represents the GGFC reorganization. The GGFC Operational Product Centers represent groups of operational products that are provided operationally and reliably, perhaps by many different individuals or teams. Each product center would be organized and maintained by a Coordinator. The Coordinators would be responsible for the overall operation of the Center, including unifying the formats, assessing the accuracy of the products, insuring the reliability of the products, etc.

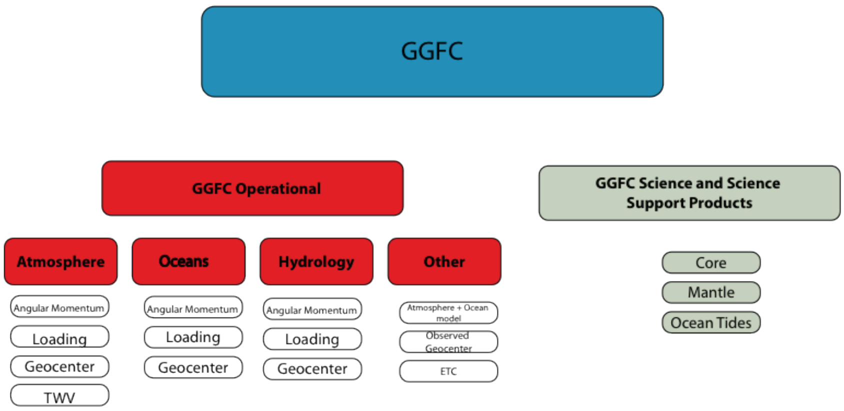

Fig. 1: The new structure of GGFC

The SBs Atmosphere, Hydrology and Oceans were already firmly established in the previous GGFC Structure. A new operational SB, Combination Products (identified as „Other“ in the figure), was established to house the new data sets that model the mass movement of combined environmental fluids such as oceans+atmosphere.

One primary goal of the restructuring was to make the GGFC more operational. To reach this goal, the DB agreed to a plan whereby a product would be accepted into the GGFC as a provisional product for a period of 2 years. During this time the submitting institution must demonstrate the reliability (precision, delay, availability, etc) of the product. At the end of this pilot phase, the performance of the institution providing the product is evaluated based on a report. If the review is negative, justifications can be given and a second trial period of 1 year can be granted. If the review is positive, the product becomes an official IERS operational product and the institution becomes an official IERS associated product center (APC).

If a product relevant to the IERS has already been produced on an operational basis for more than 2 years, the pilot phase to demonstrate the performance of the operational product generation can be skipped. The institution just has to submit a proposal for the accreditation of operational product containing:

- Description of the product
- Availability of data for generating the product
- Reliability and accuracy of the product
- Delay in making the product available operationally
- Person that is responsible for the product generation (who will be head of the associate product center (APC), if the product is accepted)
- Length of the commitment made by the institution generating the product(s).

If the proposal is declined, justifications can be given and a trial period of 1 year can be granted. If the review is positive, the product becomes an official IERS operational product and the institution becomes an official IERS associated product center (APC).

The DB also decided that the same product may be proposed by more than one institution. Such products will be coordinated by the corresponding SB chair.

Once the new structure and the process whereby products would start as provisional and would evolve into operational products was approved by the IERS DB, a Call for Special Bureau Chairs and Products was made (January, 2009).

All proposals were sent out to 5 reviewers for review. Proposals to Chair the 4 Special Bureaus were received by J. Chen (SB Hydrology), D. Salstein (SB Atmospheres), R. Gross (SB Oceans), and T. van Dam (SB Combination Products). Proposals for all the chairs were positively reviewed and accepted by the IERS DB.

Proposals for existing operational products were submitted by:

- J. Chen
  - Mass change from hydrological models and GRACE
  - hydrological angular momentum
- D. Salstein
  - atmospheric angular momentum (AAM) and related quantities from four major meteorological centers
    - NCEP

    - the Japan Meteorological Agency (JMA)
    - the United Kingdom Meteorological Office (UKMO), and the European Centre for Medium-Range Weather Forecasts (ECMWF)
  - long-term series derived from atmospheric reanalysis efforts
- R. Gross
  - ocean angular momentum
  - excitation derived from different ocean models.

All proposals for existing products were positively reviewed.

Proposals for new products were also received:

- Maik Thomas (GFZ)
  - atmospheric angular momentum from OMCT (Ocean Model for Circulation and Tides)
  - hydrological angular momentum from OMCT
  - oceanic angular momentum from OMCT
- Johannes Boehm
  - Vienna Mapping Functions
- Tonie van Dam
  - NCEP (National Center for Environmental Prediction) atmospheric loading
  - ECCO (Estimating the Circulation and Climate of the Ocean) non-tidal ocean loading
  - GLDAS (Global Land Data Assimilation System) hydrological loading
- Frank Flechner
  - GRACE dealiasing mass products

All proposals for new provisional products were positively reviewed. In October 2009, all institutes submitting proposals were informed of their proposals being accepted. The chairs of the appropriate SBs, which would be hosting the new products, were also informed. The provisional period for the new products began at this time.

In addition to the restructuring of the GGFC, a new web site was also developed (<http://geophy.uni.lu/>). The web site is currently still under development.

Tonie van Dam

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

Report for 2008

In 2008, the major focus of the ITRS Combination Centre at DGFI was on the computation of a new terrestrial reference frame within the German GGOS-D project and its comparison with the ITRF2005. Furthermore, the time series of station positions and the handling of non-linear station motions have been investigated, which is an important issue for future ITRF realizations.

GGOS-D terrestrial reference frame

GGOS-D is funded by the German Ministry for Education and Research in the frame of the programme GEOTECHNOLOGIEN. The project involves four institutions: GeoForschungsZentrum Potsdam (GFZ), Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt/Main, Institut für Geodäsie und Geoinformation, Universität Bonn (IGG-B), and DGFI. The computation of the GGOS-D terrestrial reference frame is very closely related to DGFI's work performed as ITRS Combination Centre. Input data for the terrestrial reference frame computation are VLBI, SLR and GPS observation time series, which were provided as unconstrained datum-free normal equations (see Table 1). Similar as for ITRF2005, the computation of the terrestrial reference frame consists of the two following major steps:

(1) Accumulation of the time series normal equations per technique and analysis of the time series solutions.

(2) Inter-technique combination of the accumulated multi-year normal equations per technique.

Tab. 1: GGOS-D input data used for the TRF computation.

Technique	Institutions	Software	Data	Time period
GPS	GFZ	Bernese	Daily NEQ	1994 – 2007
VLBI	IGG DGFI	CALC/SOLVE OCCAM	24 h session NEQ 24 h session NEQ	1984 – 2007 1984 – 2007
SLR	DGFI GFZ	DOGS EPOS	Weekly NEQ Weekly NEQ	1993 – 2007 1993 – 2007

GGOS-D terrestrial reference frame compared to ITRF2005

Compared to the ITRF2005 input data, there are some major improvements: (1) The observation time series of the different space techniques were homogeneously reprocessed based on unified standards and conventions; (2) For GPS consistently reprocessed observation time series were used; (3) The modelling of the observations was improved (e.g., absolute instead of relative phase centre corrections, the pole tide model was correctly applied in the VLBI software CALC/SOLVE); (4) The type of input data is nearly identical with the original observation equations and is much more appropriate for the combination than for example loosely constrained solutions or solutions with removable minimum constraints. Another advantage is, that the total number of discontinuities could significantly be reduced compared to the ITRF2005 computation. This was mainly achieved by the homogeneously processed GGOS-D data sets and the implementation of absolute antenna phase centre corrections for the GPS processing.

The results of the GGOS-D terrestrial reference frame computations were compared with the ITRF2005. Figure 1 shows as an example the discrepancies for some of the VLBI and GPS co-locations. For the GGOS-D computations the agreement of the space geodetic solutions with the local ties is better for most stations, which is evidence of the improvements compared to ITRF2005. The results are shown for the ITRF2005 solution of DGFI (ITRF2005-D).

Non-linear station motions

The time series analysis has shown non-linear variations for most of the stations, especially in the height component. Figure 2 shows the mean average shape of such annual variations for four GPS-VLBI co-location sites. These seasonal signals may be caused by atmospherical, hydrological and non-tidal oceanic loading effects, which are not reduced from the original observations. In other cases, instrumentation effects (rather than geophysical ones) may be also responsible for the observed signals.

A deficiency in the current reference frame computation is 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

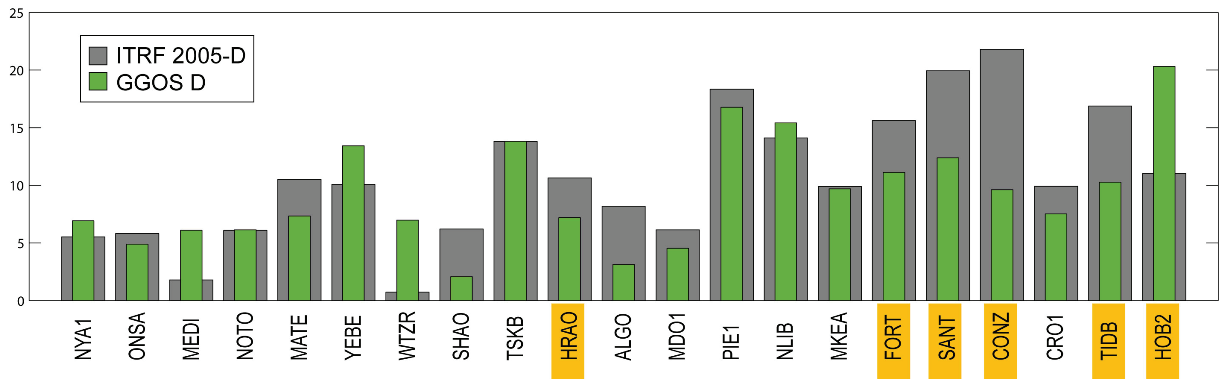

Fig. 1: Comparison of the GGOS-D results with ITRF2005-D. The 3-D difference vectors [mm] between the VLBI and GPS solutions and the terrestrial difference vectors are given for 21 co-location sites. The stations located in the southern hemisphere are highlighted.

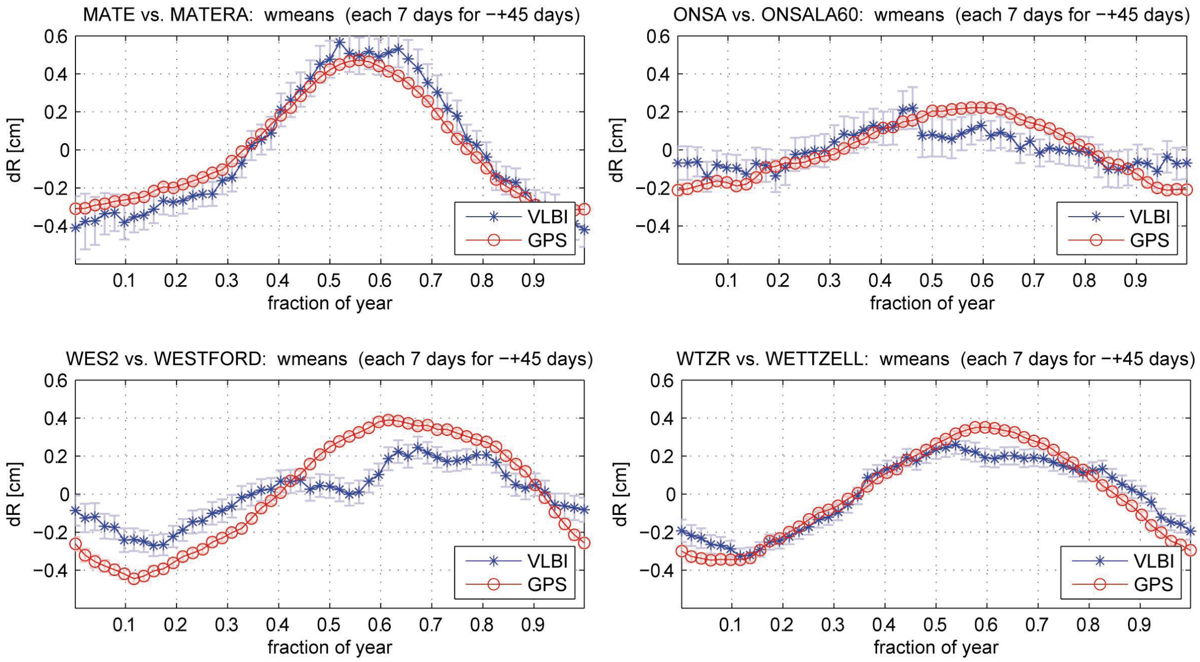

Fig. 2: Mean annual behaviour of homogeneously processed VLBI (blue stars) and GPS (red circles) height time series at four co-location sites. The figures illustrate 90 days moving weighted means and their formal errors, computed each 7 days from the daily height estimates.

combination results. Seasonal variations will affect the velocity estimations, in particular for stations with relatively short observation time spans (i.e., < 2 years). Also the alignment of epoch solutions to a reference frame with positions and constant velocities is affected by non-linear station motions. As shown in Figure 2, the shape of these non-linear motions agrees quite well between VLBI and GPS, but it differs between stations. A suitable handling (parameterization) of the seasonal variations in station positions is a challenge for future ITRF computations.

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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Report for 2009

In 2009, the focus of the ITRS Combination Centre at DGFI was on the computation of the terrestrial reference frame contribution of DGFI to ITRF2008, DGFI2008. According to the decisions of the IERS Directing Board Meeting No. 51 (2010-10-10, Paris), the individual solutions of the ITRS Combination Centres shall be named by the institution name. The label ITRF is only used for the official ITRF solution in order to avoid confusions.

The combination for DGFI2008 was performed in two major steps: (1) the analysis of input data time series and the computation of one TRF solution per technique and (2) the combination of the techniques to one combined reference frame. Fig. 1 gives a simplified flowchart of the reference frame computation at DGFI. Even if the DGFI2008 was not finished in 2009, the main part of the computation work was done during this year.

Analysis of ITRF2008 input data and computation of one multi-year solution per technique

The input data for ITRF2008 are time series of weekly or session-wise SLR, GPS, DORIS and VLBI solutions or normal equations (NEQ) provided by the individual Technique Centres IVS, ILRS, IGS and IDS. The parameters contained are station coordinates and Earth orientation parameters (EOP). The time series are

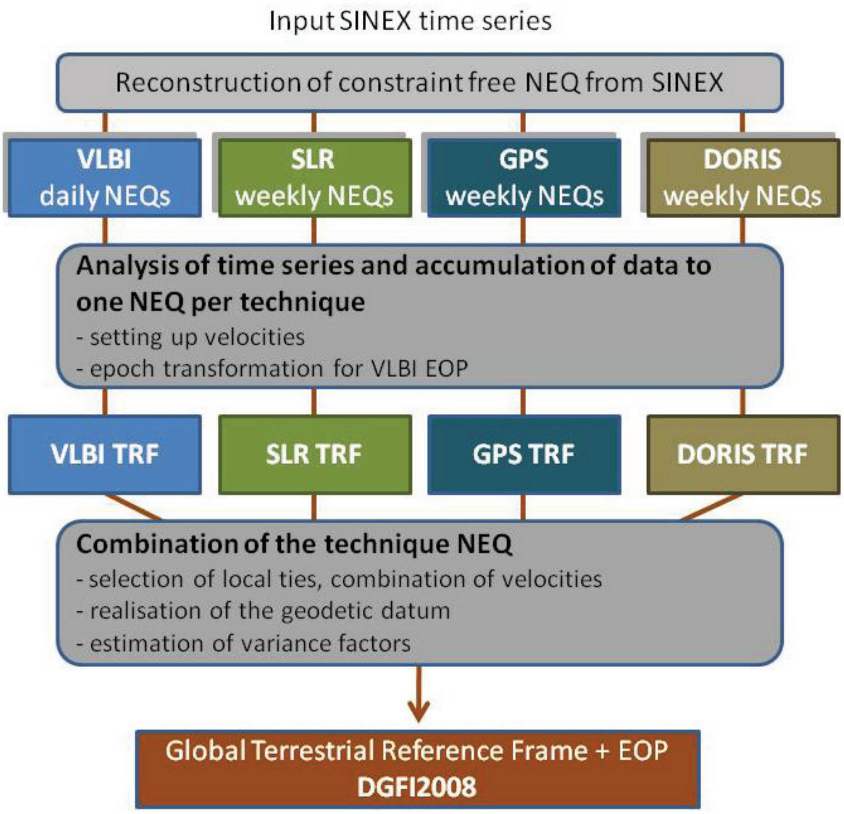

Fig. 1: Simplified flowchart of the computation of the global reference frame, the DGFI contribution to ITRF2008.

provided in SINEX format. For the first time, all input solutions are combined products computed from the contributions of at least 7 Analysis Centres. Tab. 1 gives an overview about the input data.

Tab. 1: ITRF2008 input data.

Technique	Service/TC	Time period	Temporal resolution	Data type
GPS	IGS/NRCan	1997.0–2009.0	weekly	solution
VLBI	IVS/IGG	1980.0–2009.0	24h sessions 24 h session	constraint free normal equations
SLR	ILRS/ASI	1983.0–1993.0 1993.0–2009.0	fortnightly weekly	solutions solutions
DORIS	IDS/CLS-CNES-GSFC	1993.0–2009.0	weekly	solutions

In a first step the normal equations are reconstructed from the SINEX files. In case of IVS the NEQ are provided without datum conditions and the VLBI normal equations can be directly introduced in the combination. The SLR contributions include only loose constraints, which do not have a significant effect on the reference frame solution and thus remain on the NEQ. In case of GPS and DORIS the input data are computed by applying no-net-rotation conditions which are not given in the SINEX. As both techniques shall not be contribute to the datum realization of the reference frame, singularity w.r.t. all the datum parameters (origin, orientation and scale) has to be created by setting up seven datum parameters for each NEQ.

The normal equation time series are solved by applying adequate minimum conditions. The solutions are transformed to the combined reference frame (we start with ITRF2005 and iterate this step using the combined frame DGFI2008). The residual position time series resulting from the transformations are analyzed w.r.t. discontinuities and long-term non-linear station motions (e.g. post-seismic station motions). Fig. 2 gives the number of discontinuities per technique in % of the number of available stations. GPS is the technique affected most by discontinuities.

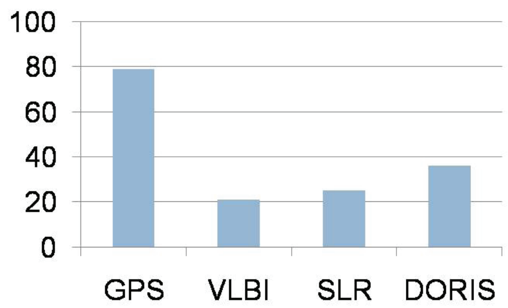

Fig. 2: Discontinuities per technique given in % of the available stations.

In addition to the station position time series also the datum parameter time series are analyzed, in particular those, which should contribute to the datum realization of the DGFI2008 reference frame: the origin and scale of SLR and the scale of VLBI. Fig. 3 shows the scale time series derived from SLR and VLBI. The data at the beginning of the time series are characterized by large standard deviations, thus the systematic effects in the early years do not have a significant impact on the mean scale and both time series are used for the scale realization of the DGFI2008.

The NEQ are accumulated to one NEQ per technique. During this procedure station velocities are set up as additional parameters and identified discontinuities are considered by setting up new position and velocity after the event. Long-term non-linear station movements are approximated by piece-wise linear functions.

Combination of the techniques and computation of the reference frame DGFI2008

The ITRF2008 input data contain station coordinates as well as EOP. Tab. 2 gives an overview about the parameters provided by the techniques.

Whereas the EOP are common parameters, which can be combined directly, station positions can be only combined by introducing terrestrial measurements (local ties) at co-location sites. Fig. 4 shows the global distribution of the technique specific station networks of DGFI2008. The co-location sites and the type of co-location can be seen very well from the superposed symbols.

As the local ties partly show large discrepancies w.r.t. the coordinate difference vectors computed from the space geodetic techniques at co-location sites, only suitable local ties have to be used in the combination. A threshold of 32 mm was assessed as a

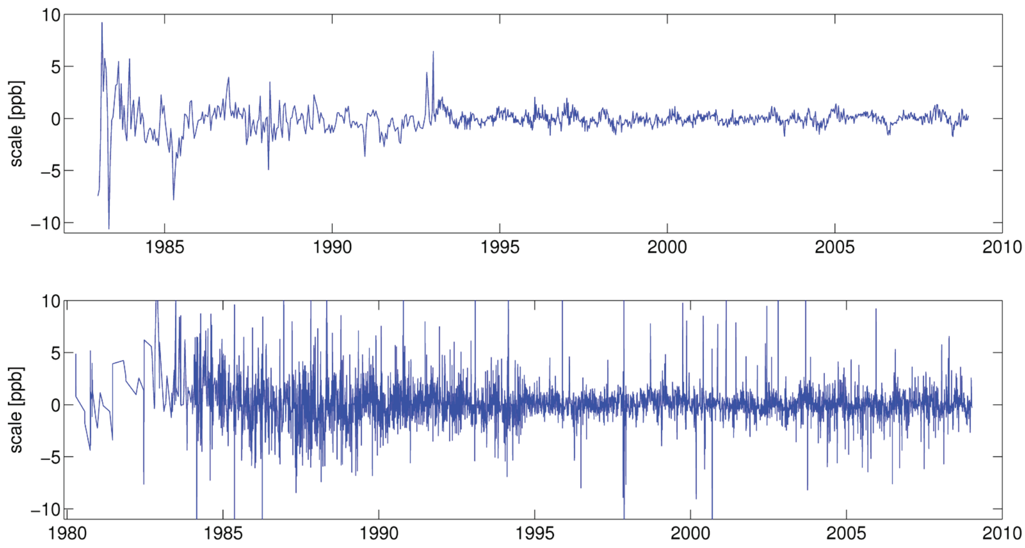

Fig. 3: Scale variation time series of SLR (upper plot) and VLBI (lower plot) w.r.t. DGFI2008.

Tab. 2: Parameters provided by the techniques in the ITRF2008 input data.

parameter	GPS	SLR 1993.0–1993.0	SLR 1993.0–2009.0	VLBI	DORIS
station coordinates	weekly	forthnightly	weekly	24h session	weekly
offsets of terr. pole	daily	3 daily	daily	24h session	weekly
Rates of terr. pole	daily			24h session	
UT1-UTC				24h session	
LOD	daily	3 daily	daily	24h session	
nutation offsets				24h session	

reliable maximum local tie misfit. Fig. 5 shows the number of local ties per continent subdivided into the different co-location types. The lowest three bars (dark blue, red and green) represent the number of co-locations including GPS stations. It becomes obviously, that at all continents co-locations including GPS stations are clearly dominant. This shows, that GPS is the technique allowing to combine the different station networks and thus is essential for the computation of a global terrestrial reference frame.

The computation of the DGFI contribution to ITRF2008, DGFI2008 was finished in 2010. Thus, the final results and comparison to ITRF2008 will be part of the Annual Report 2010.

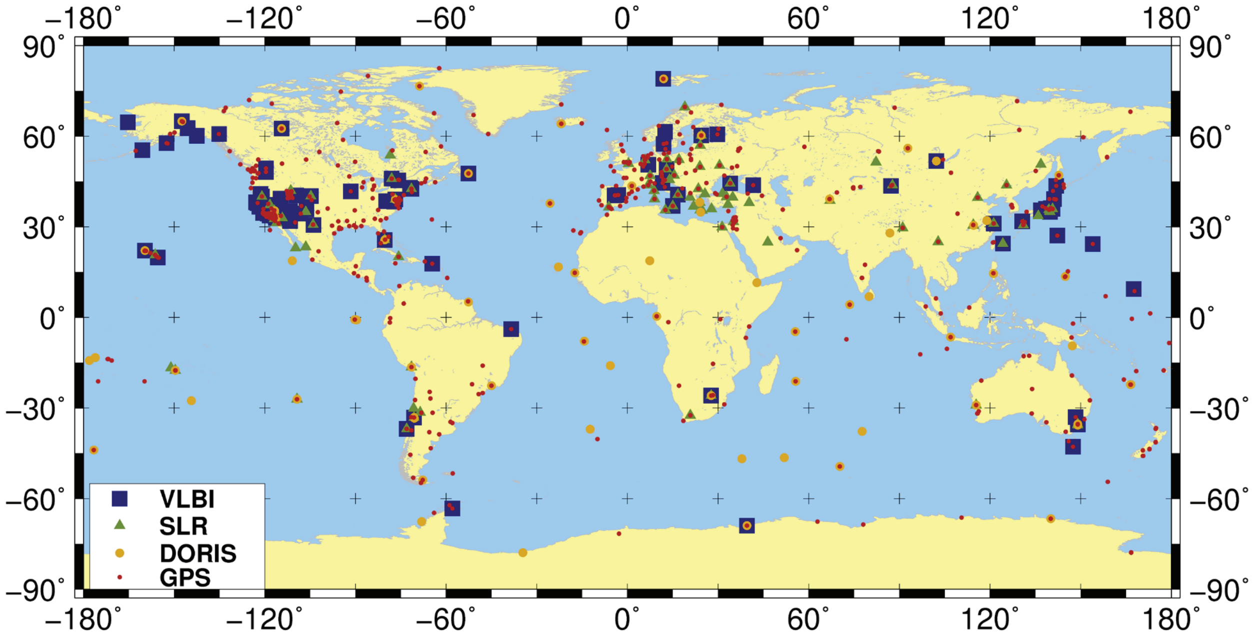

Fig. 4: Global distribution of the technique specific station networks.

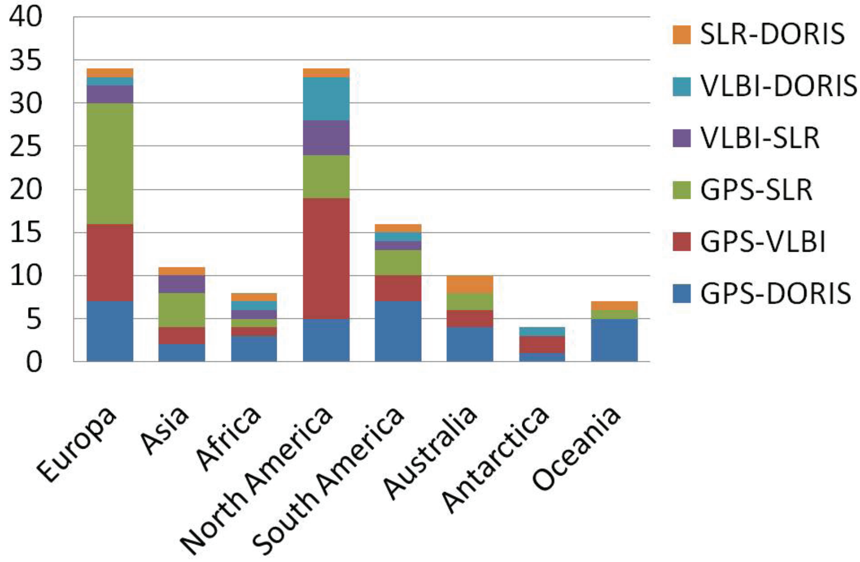

Fig. 5: Number of co-locations used in DGFI2008 per continent.

Acknowledgements

We thank the ITRS Combination Centre and the ITRS Centre at IGN, and especially Zuheir Altamimi, for the good team work and all the fruitful discussions around the ITRF2008 computation. We thank him also for providing the infrastructure for the ITRF computation and his large effort to provide all the data and information necessary.

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3.6.1.2 Institut Géographique National (IGN)

Report for 2008

This report summarizes the activities of the IGN combination centre during the year 2008. Some results are also presented in the ITRS Centre section, see 3.5.5, that complete this section.

Data analysis

With interaction of IERS Analysis Centres (AC), individual solutions from the different techniques are frequently evaluated and tested in order to improve the individual analyses as well as the ITRF combination. GPS solutions from MIT, NGS and GFZ Analysis Centres (ACs) have been analyzed to study the origin and scale information of some GPS terrestrial reference frames (Altamimi and Collilieux, 2008). Such analysis are regularly conducted for the combined solutions delivered routinely by the international technique services, namely, the International VLBI Service (IVS), the International Laser Ranging Service (ILRS), the International GNSS Service (IGS), and the International DORIS Service (IDS) (Altamimi, 2008a, 2008b, 2008c, Collilieux and Altamimi, 2008). The study of translation and scale parameter time series is of primary importance for the ITRF datum definition. Collilieux (2008) has built synthetic position time series that have been combined accordingly to ITRF combination procedure. It has been shown that translation and scale factor non-linear variations can not be fully explained by a loading displacement model. However, scale factor annual variations has been mostly understood thanks to that methodology, see Figure 1.

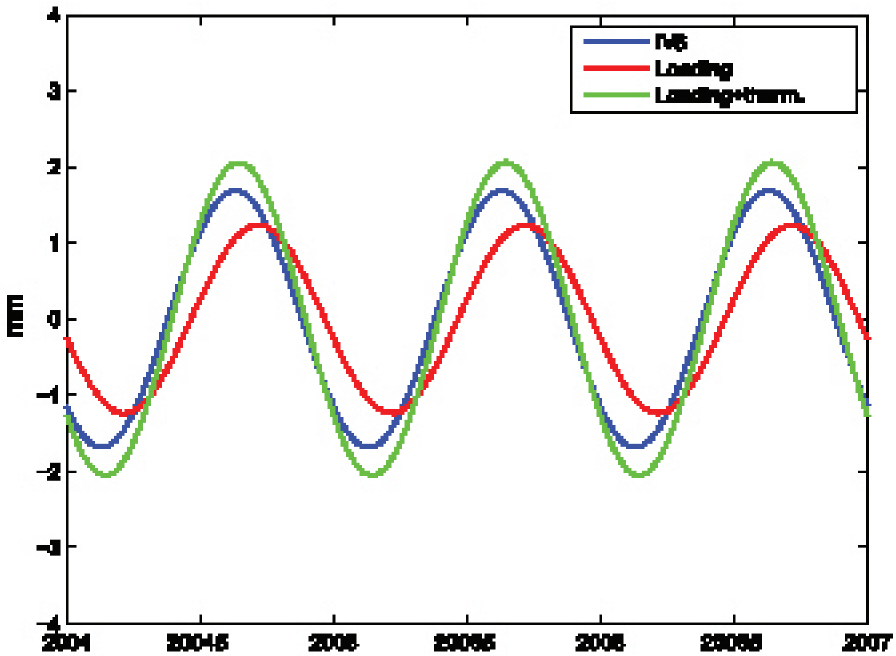

Fig. 1. Blue: IVS scale factor annual variations. Red: Scale annual variation due to loading displacement of VLBI stations (Loading model from Tonie van Dam, University of Luxembourg). Green: Scale annual variation due to loading displacement of VLBI stations and thermal deformation of VLBI telescopes.

Combination test

Combination tests have been performed to study the impact of local ties (Altamimi, 2008c). Assuming that total tie errors are at the level of 4 mm, it is proved that 16 minimum well distributed co-location sites are needed for to tie the technique global frames at the millimetre level. Ideally 32 sites are needed for redundancy and reliability.

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Report for 2009

This report summarizes the activities of the IGN combination centre during the year 2009. These activities are mainly related to the ITRF2008 pre-analysis using the TC submitted solutions presented in the ITRS Centre section, see 3.5.5.

Data analysis

With interaction and communication with the Combination Centers of the TCs, the IERS IGN Combination Center operated pre-analysis of the individual TC solutions submitted to the ITRF2008. These pre-analyses showed some deficiencies in some TC solutions and therefore the Combination Centers of the TCs generated updated solutions which caused a certain delay in the ITRF2008 production process. The first step consists in operating data analysis of each individual technique solution, allowing to evaluate the individual station behaviour regarding linear and non-linear station motions. Discontinuities in the station position time series are then localised and introduced in the accumulation (rigorously stacking) of the time series. Sites with multiple stations and discontinuities are then constrained to have a unique velocity, except sites where Earthquakes have taken place. This first step is also an efficient tool to evaluate the temporal behaviour of the frame parameters, especially the physical ones: origin and scale. The two ITRS CCs have also operated comparisons between their intra-technique cumulative solutions.

ITRF2008P combination test

A preliminary combination test was generated, called ITRF2008P and made available to the TCs for evaluation. From this preliminary combination an assessment of the ILRS SLR origin temporal behaviour is illustrated by Figure 1. This figure shows that the origin components around the three axes are much more scattered between the start of SLR data in 1983 and 1993, compared to the period afterward. This feature is to be related to the use of one satellite (LAGEOS I) data in the first period, whereas the second period makes use of the two LAGEOS satellites data.

The assessment of the scale agreement between VLBI and SLR submitted solutions is illustrated by Figure 2. From this figure we can see that the level of agreement between the two solutions is about 1ppb. The figure also shows the scale of the IDS DORIS solution, which is situated in between VLBI and SLR scales, although it is closer to VLBI than to SLR. As also illustrated by this figure, the ITRF2005 scale is about 1 ppb higher than ITRF2008P.

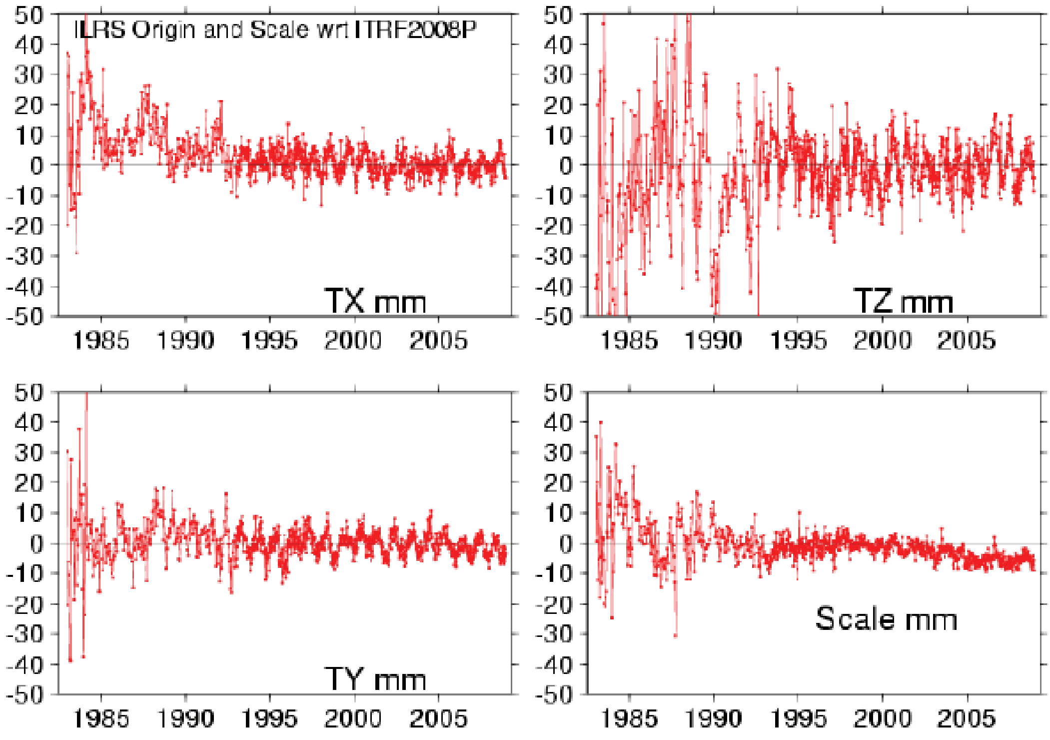

Fig. 1: ILRS SLR origin and scale factor components with respect to ITRF2008P

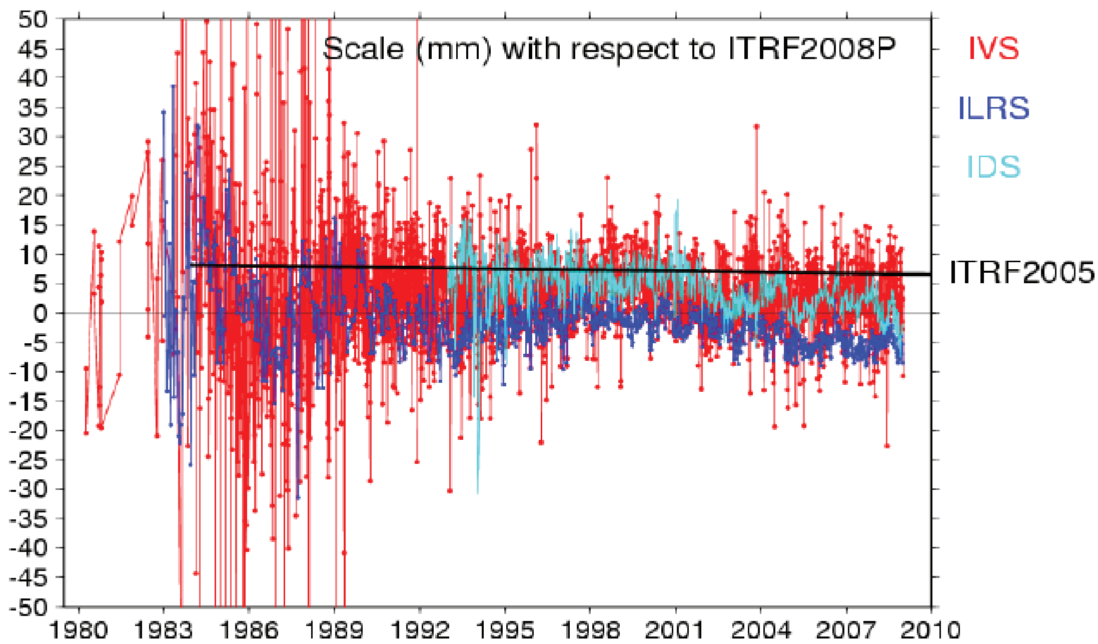

Fig. 2. VLBI, SLR and DORIS scale temporal variations with respect to ITRF2008P

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3.6.1.3 Natural Resources, Canada (NRCan)

The combination effort was limited to comparisons between the IGS official and reprocessed weekly solutions with respect to the available ITRF08P combinations. The original IGS submission for the ITRF08P was made at the beginning of February 2009 using the combined Analysis Centers (AC) reprocessed solutions. It covered the period 2000.0–2008.0 (Wks 1043–1459) and included weekly solutions for a total of 515 stations as well as daily pole positions, pole rates and LOD. A second and final contribution was possible at the end of July 2009. It covered the period of 1997.0–2009.5 (Wks 0886–1537). It included 561 stations that met the criteria of having a minimum of 2 years of data and a valid DOME#. The original 2000.0–2008.0 submission was resubmitted to account for minor improvements and new stations that met the above minimum criteria. Subsequently, older IGS reprocessed solutions from 1994.0–1997.0 (Wks 0730–0885) became available. The comparison below uses the combinations of 1994.0–1997.0 that could not be included in ITRF08, as well as the more recent solutions of 2009.5 – 2010.0 (Wks 1538–1566). This increases the independence of the comparison since the data used for comparison have not been included in the ITRF08P combination.

The first comparison includes the pole position and pole rate values for the older combined ig1 reprocessed data. Ig1 solutions are aligned to the IGS realization of ITRF2005. Figures 1a and 1b show the differences in pole position whereas Figures 2a & 2b show the differences in pole rates for the period of 1994.0–2009.5 (MJD 49354.5–55016.5). Table 1 shows some statistics of the pole position and pole rate value differences between ig1 and ITRF08P for the period of 1995.0–1997.0 (MJD 49718.5–50448.5):

Table 1: Differences between ig1 and ITRF08P

	dXp	dYp	dXpr	dYpr
	(mas)	(mas)	(mas/d)	(mas/d)
Average:	0.00	0.06	0.13	0.11
Std.:	0.22	0.22	0.68	0.69

The combinations from the 1994 period were excluded from the above statistics. A lower quality of the alignment to the reference frame was observed due to the limited number (sometimes around 10 stations) and sub-optimal distribution of available reference frame stations. Note that for the 1995.0–1997.0 period, the ITRF08P pole position estimates are available every day, while the pole rates were only available about 1/3 of the time.

The ITRF05 and ITRF08P are aligned in orientation and rates. Although the ITRF08P frames and the IGS05 frame realization should also be aligned, Rebischung et al. (2010) estimated the transformation between the two frames. Using their transformation and propagating it back to 1996.0, the estimated rotations are about RX = +0.031 mas and RY =+0.036 mas with formal uncertainty at the 0.03 to 0.04 mas level in both directions. Taking into account the estimated frames mis-alignment, the average pole position differences become:

RX – dYp = 0.031 – 0.06 = –0.029 mas

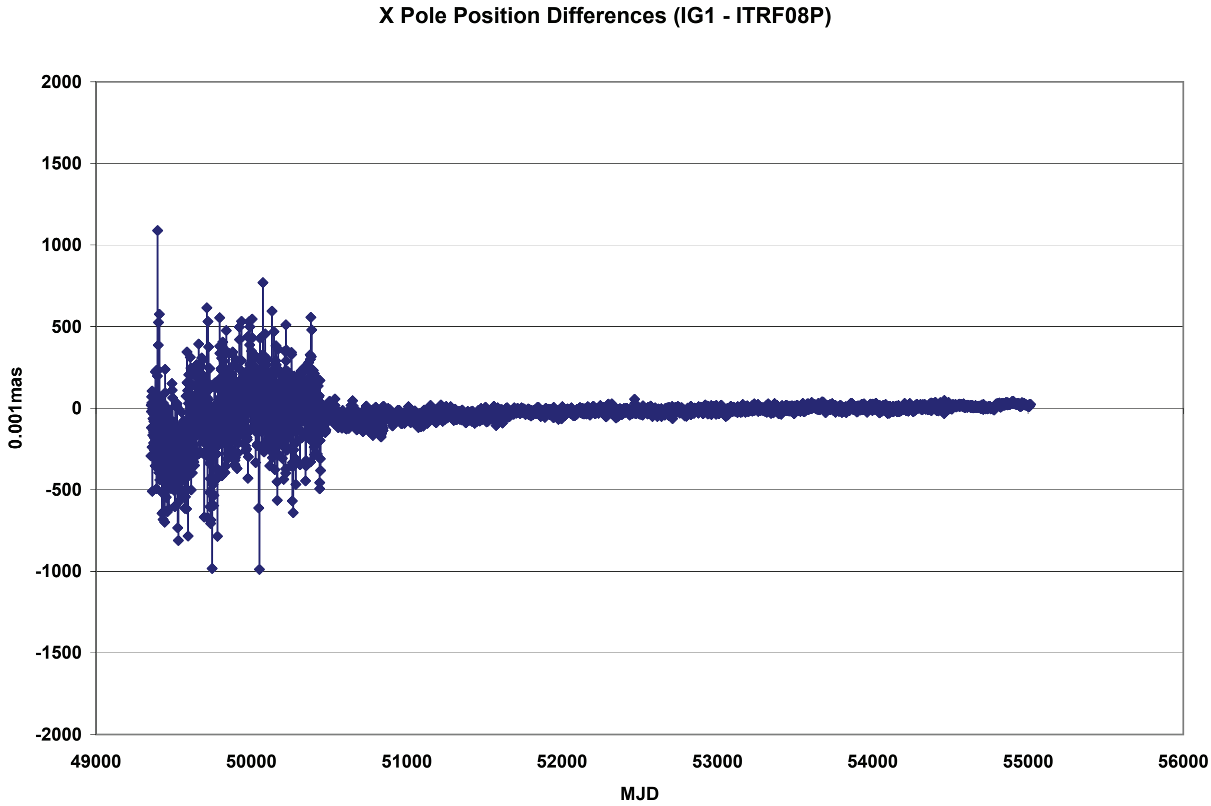
RY – dXp = 0.036 – 0.00 = 0.036 mas

The average pole position differences are about at the same level as the formal uncertainty of the transformation parameters and smaller than the above standard deviations, suggesting that there is no significant misalignment in the pole position (and rates) between ITRF08P and the IGS weekly combined reprocessed solutions. The effect of the transformations on the pole rate statistics is negligible.

Given the relatively good accuracy of the ig1 pole position with respect to the ITRF08P combined for the 1995.0–1997.0 period, it is also possible to assess the ITRF08P formal sigmas. During that period, the formal sigmas of the daily IGS pole position were between 0.05 and 0.1 mas. For simplicity, let's assume 0.075 mas for that period. From the above information, the relative noise contribution of the ig1 pole position estimates to the total noise can be estimated to be ~35%. The same exercise was repeated with the 1994 ERPs and the 1995–1996 pole rates, but due to the reduced differentiation between the ITRF08P and the ig1 noise level at that time (see Figures 1 and 2), the results are less reliable. The normalized residuals of the pole position differences ((ITRF08P-IG1)/sigma (ITRF08P)) was also estimated. The normalized sigmas are 1.35 and 1.42 for the X and Y pole components. Now, if we remove the ig1 noise contribution from the normalized differences (and sigmas), we get 0.88 and 0.92. This suggest that the combined ITRF08P pole position formal sigmas for the 1995.0–1997.0 period is close (i.e. within 10%) of the expected values. Since the ITRF08P is combined rigorously, this also suggests that the formal sigmas for the other parameters are also close to the expected values.

Comparisons can also be done between the ITRF08P station coordinates and the igs reprocessed weekly solutions. Similarly to the above pole comparison, this comparison uses data that were not included in ITRF08P, namely, just before and just after the period included in ITRF08P.

First, the igs official weekly solutions were used for the period of 2009.5–2010.0 (Wks 1538–1566) and compared to the ITRF08P.



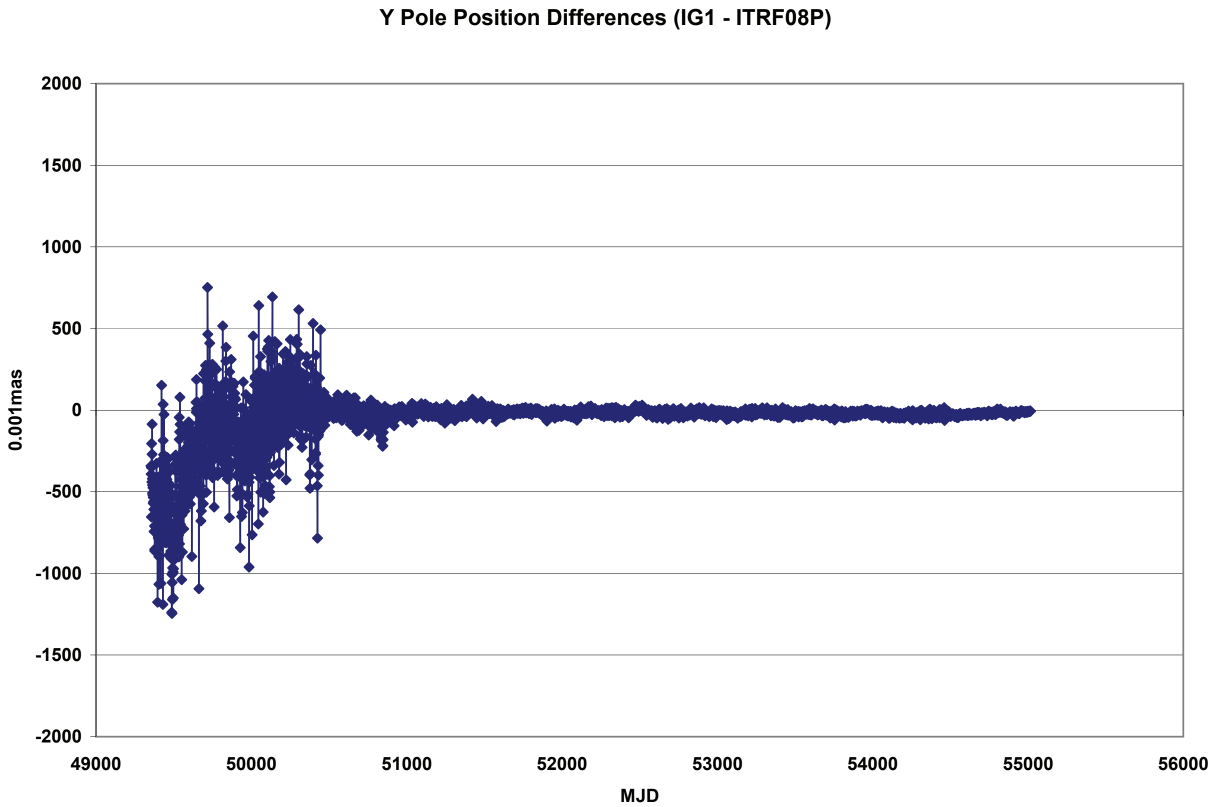
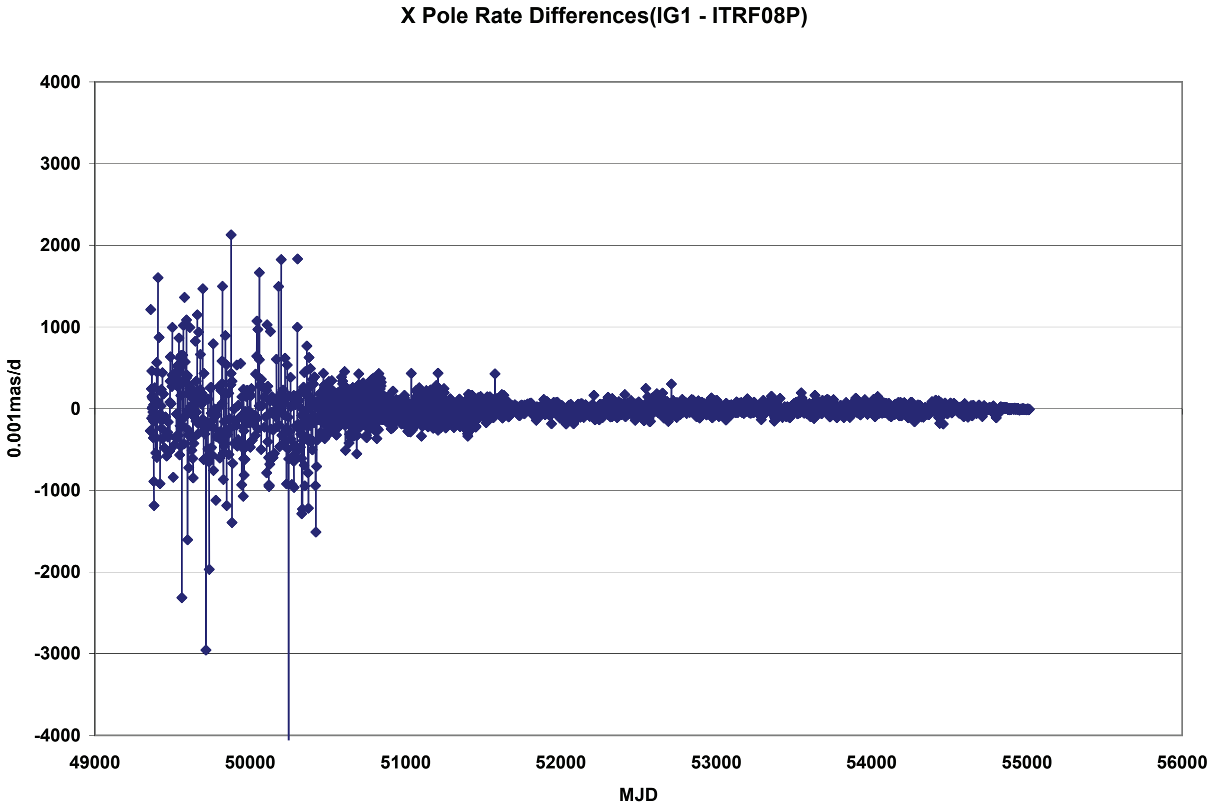


Fig. 1: Daily X and Y (top and bottom) pole position differences between the IGS combination of the reprocessed solutions and the ITRF08P combination.



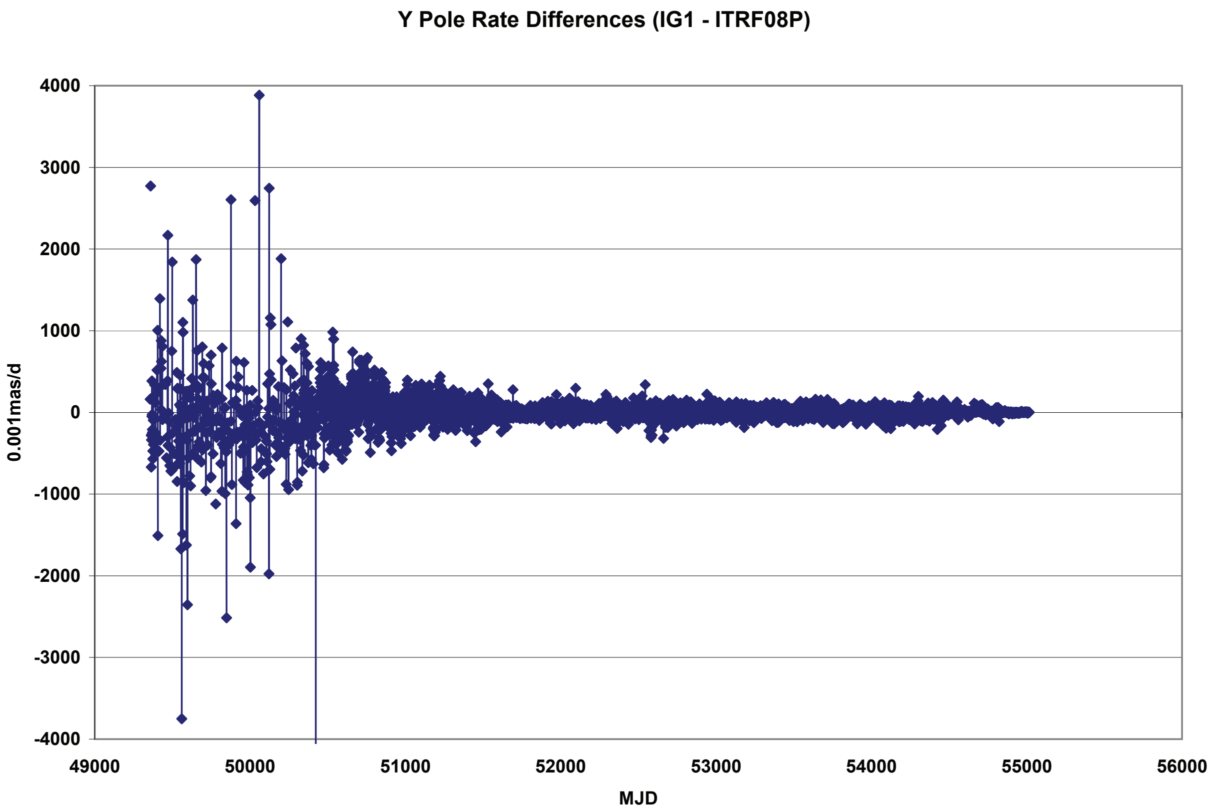


Fig. 2: Daily X and Y (top and bottom) pole rate differences between the IGS combination of the reprocessed solutions and the ITRF08P combination.

The igs weekly solutions were aligned to ITRF08P and residuals were computed, resulting in about 7000 station position differences. 13 stations were removed from the comparison mainly due to discontinuities. The average differences in the N, E, and H components were 0.4 ± 2.0 mm, 0.2 ± 2.5 mm and –0.1 ± 4.9 mm respectively. This confirms the excellent agreement of the observed station coordinates and the ITRF08P when extrapolated forward in time.

Similar comparisons were done using the older reprocessed ig1 weekly solutions. First we compared the period of 1995.0–1997.0 (Wks 0782–0885). Weekly solutions were aligned to ITRF08P propagated to the corresponding ig1 week. 20 stations were removed from the comparison, again mainly due to discontinuities. Residuals were computed for about 10200 station position differences. The average differences and standard deviations in the N, E, and H components were respectively 0.4 ± 3.0 mm, 0.0 ± 3.3 mm and 0.7 ± 7.1 mm. Second, we compared the period of 1994.0–1995.0 (Wks 0730–0781) using the same procedure as above. The average differences and standard deviations in the N, E, and H components were 0.2 ± 3.1 mm, 0.0 ± 3.7 mm and 0.0 ± 8.7 mm (~1700 station position differences). The 1994 results are quite acceptable despite the reduced number of ACs that contributed and the reduced number of stations available. So, the agreement between the ITRF08P extrapolated backward and the ig1 reprocessed combinations is also good for the older data set.

In summary, the ERP comparison (ITRF08P-IGS) for 1995–1996 agrees within the expected noise level. The formal ITRF08P sigmas on ERPs are consistent with the observed noise level. There is also a good agreement of the observed IGS station positions with the ITRF08P predicted positions outside the combination period. Those statistics are also consistent with similar results obtained by Rebischung et al. (2010) when the IGS05 was compared to ITRF08P.

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Rémi Ferland

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, ASI-CGS consolidated its role as a Combination Center (IERS CRC, ILRS CC).

Combination research activity and products

In 2008, 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 EOPs.

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. The ILRSA solutions, based on the individual solutions from 8 ACs, contain:

1. Weekly coordinates of the worldwide SLR tracking network
2. Daily EOPs (xpole, ypole, LOD), ITRF2005-framed for IERS Bulletin B

The latency of the combined weekly product goes from a minimum of 4 days to a maximum of 10 days for the EOP parameters: to provide IERS with a faster, constant-latency SLR product, with comparable accuracy level to the weekly one, a daily product has been set up. The ILRS ACs have been requested to generate a 7-day arc solution every day, with a one day latency with respect to the data acquisition; one day after, ILRS CCs generate the combined solutions, along the same strategies implemented in the weekly product. Since February 2008, 5 ILRS ACs (ASI, BKG, GFZ, JCET, NSGF) have been concurring to the generation of this new product, in a pre-operational phase (i.e. not public, just sent

Fig. 1: ILRSA Daily EOPs residuals and latency

to USNO). Several analyses, performed during 2008 have verified that ILRS is able to provide routinely a daily EOP product with high quality level, with constant latency lower than the minimum latency of the ILRS weekly solution.

Grouping the EOP residuals for the period February-September 2008 according to their latency, the following behavior is visible in any component:

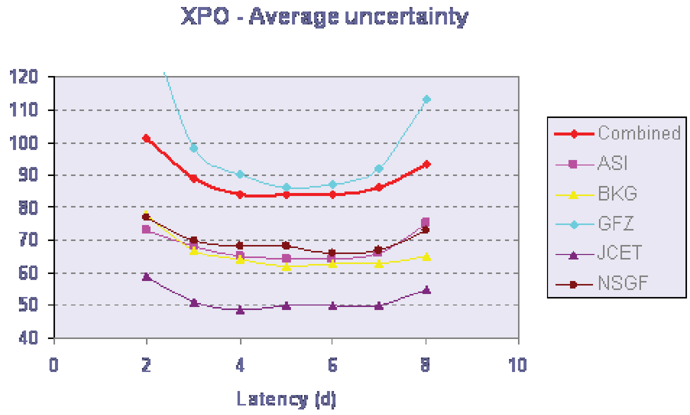

Fig. 2: ILRSA Daily EOPs and latency

The 'edge' effect is visible, the lowest latency estimates (2 day) show a lower accuracy, due to a lack of data for the last analysed day, as well as possible different analysis strategies (e.g. constraints) for the terminal days. For these reasons, at the present state-of-the-art, the best trade-off between accuracy and latency seems to be represented by the 3-day latency EOP estimates.

2. 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) covering 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.

In 2008, a special version of the velocity combined solution (presented at the WEGENER 2008 Meeting) included also an independent CGS GPS solution based on the Precise Point Positioning analysis approach.

The cross-check of the two independent GPS solutions allows to detect discrepant behavior for sites processed by both solutions or compared to geographically correlated sites and to apply a recovery processing to anomalous sites, eventually edited from the solution.

The following sites are assumed as colocated and the velocity is merged among techniques: Matera (SLR, VLBI, GPS), Medicina (VLBI, GPS), Noto (VLBI, GPS), San Fernando (SLR, GPS), Athens (SLR, GPS).

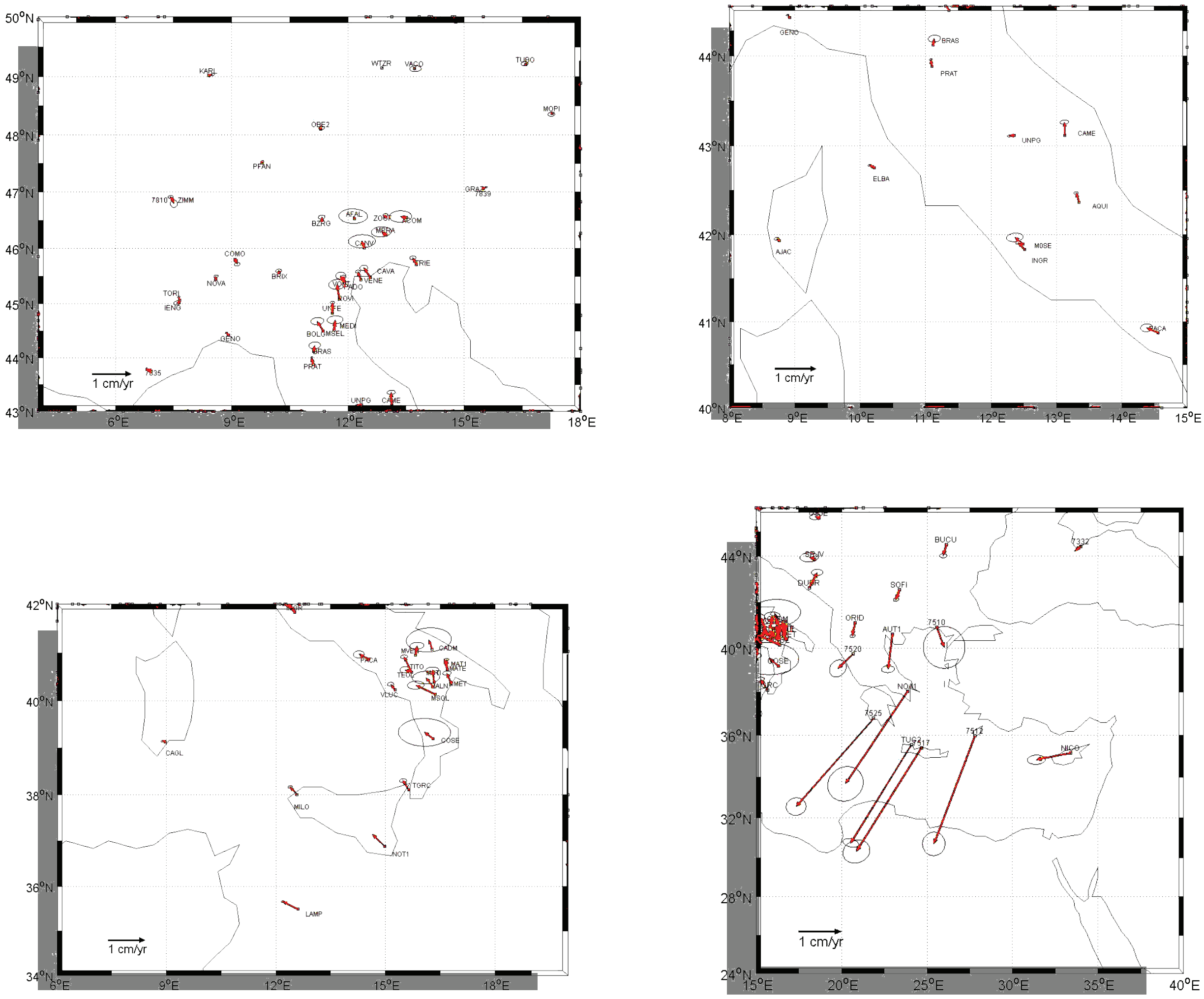

Fig. 3: Italian and Aegean residual velocity field from ASIMed2008

The obtained velocity field seems to be in agreement with the main expected tectonic behavior for this area.

The Aegean spreading can be confirmed as far as the substantial stable behavior of the Iberian peninsula, apart from its southern part.

Italy shows small, but significant residual motions; this evidences that, more or less, the whole Italian territory acts as a complex plate boundary, where African and Eurasian plates are converging, and the presence of the Adriatic micro plate (or African promontory?) complicates the overall scenario.

3. 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 Wednesday along with the operational weekly SLR solution, stacked and compared whenever possible with the atmospheric excitation functions from the IERS SBA, under the IB and non-IB assumption, including the “wind” term.

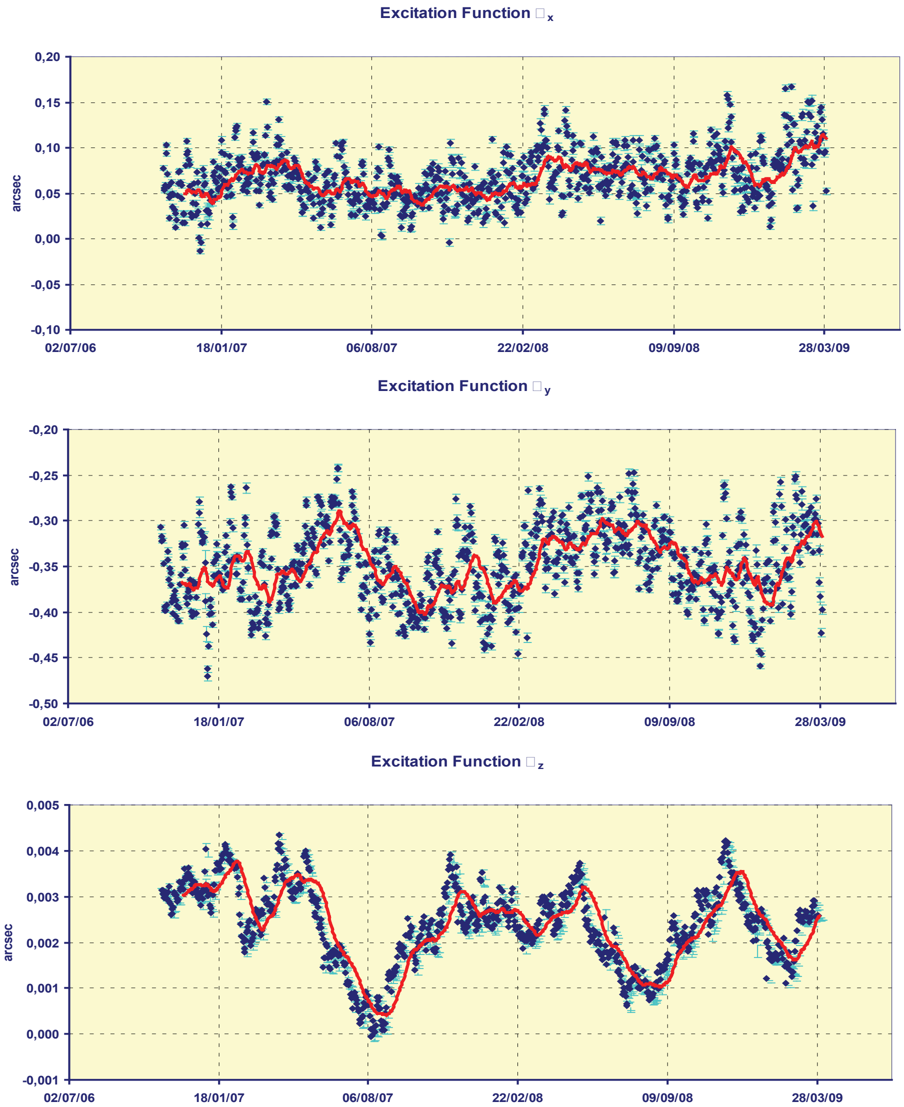

Fig. 4: ASI EOP Geodetic Excitation Functions 2007-2008 from SLR solutions

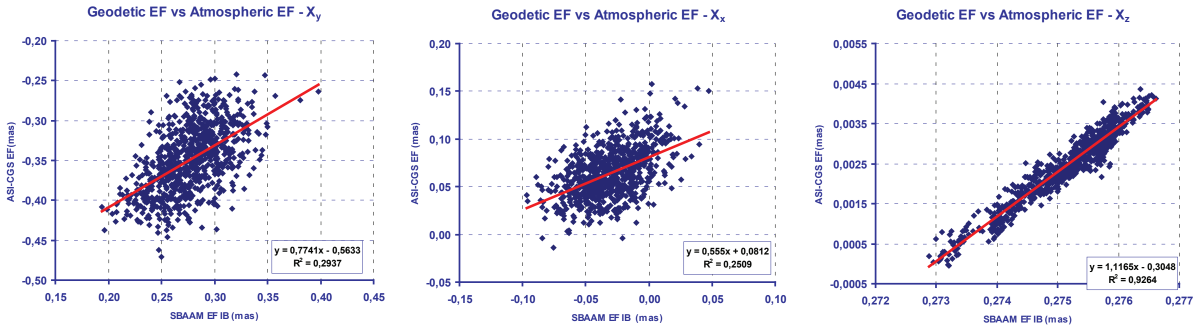

Fig. 5: Linear regression of Excitation Functions 2007-2008 from ASI SLR and SBA values

The atmospheric and geodetic excitation functions show clear similarities, not considering the expected systematic differences, especially in the z component, as it is shown in the following plots (a systematic bias has been removed from the atmospheric values).

Giuseppe Bianco, Vincenza Luceri, Cecilia Sciarretta

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

Introduction

The CRC is an integral part of the Center for Earth Dynamics Research (CEDR) that joins four Czech research institutions active in astronomy and geosciences. The combination research was based on combining non-SINEX particular solutions of different techniques (GPS, VLBI, SLR, Doris) to determine the Earth orientation parameters simultaneously with station coordinates. Our PhD student, Vojtěch Štefka, is responsible for solving this problem.

Combination of EOP and station coordinates

We used 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 (Štefka et al. 2008a). The results were compared with IERS C04 series, with the rms differences between the two solutions being 0.129 mas, 0.102 mas and 0.0536 ms for polar coordinates *x, y* and UT1-UTC, respectively. Our numerical solutions of the combination were originally based on solving full normal equation matrix, which was a rather time consuming task. Therefore, a more effective algorithm of solving sparse systems of linear equations from the GNU Gama package (Čepek and Pytel 2005, <http://www.gnu.org/software/gama>) was implemented and applied to six-year series of observations (Štefka et al. 2008b). This decreased the necessary computation time by about one order. Instead of rigorous constraints, additional pseudo-observations were used to ensure the smoothness of EOP. Time series of EOP and station coordinates obtained by this method were then compared with IERS C05 solution and ITRF2005, respectively (Štefka et al. 2009). The rms differences between our combination and IERS C05 in 4-year interval were 0.141 mas, 0.146 mas and 0.169 ms for polar coordinates *x, y* and UT1-UTC, respectively. Time series of station coordinates proved good agreement with the trends in ITRF2005.

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Jan Vondrák, Vojtěch Štefka, Ivan Pešek, Jan Kostelecký

3.6.2.3 Deutsches Geodätisches Forschungsinstitut (DGFI)

The activities of the IERS Combination Research Centre at DGFI concentrated on contributions to the IERS Combination Pilot Project, the IERS Working Group on Combinations at the Observation Level and to the project GGOS-D.

IERS Combination Pilot Project

DGFI provides individual SLR and VLBI solutions and combined SLR solutions to the ILRS and IVS, respectively, which serve also as input for the IERS Combination Pilot Project. 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. The computation of weekly combined solutions is done with the DGFI software DOGS-CS.

IERS WG on Combination at the Observation Level

The focus of this IERS working group is on inter-technique combinations at the level of observations. This implies the common processing of the different space geodetic observations (VLBI, SLR, GPS, DORIS) by using a uniform software, the same modeling and standards. A proposal of creating such a WG was discussed at the IERS DB45 and a charter was proposed by R. Biancale at the IERS DB46 in Vienna, 2008. It was suggested that GRGS and DGFI will take over the joint responsibilities to initiate the activies. Other groups are welcome to participate in this WG. Existing close cooperation and future joint venture of DGFI with IAPG/FESG at Technische Universität München (TUM) involves TUM in the WG. In 2008 an initial work plan has been set up and test data sets have been exchanged between GRGS and DGFI for the inter-technique combinations.

DGFI contributions to GGOS-D

DGFI's work within the GGOS-D project is very closely related to the research performed as IERS Combination Research Centre. GGOS-D is funded by the German Ministry for Education and Research in the frame of the programme GEOTECHNOLOGIEN. The project involves four institutions: GeoForschungsZentrum Potsdam (GFZ), Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt/Main, Institut für Geodäsie und Geoinformation, Universität Bonn (IGG-B), and DGFI. Within the GGOS-D project, homogeneously processed observation time series have been generated for the different space geodetic observation techniques, as the basis for the computation of a GGOS-D terrestrial reference frame and for the generation of consistent, high-quality time series of geodetic-geophysical parameters. DGFI performed the following major activities within GGOS-D:

- VLBI and SLR observation time series have been homogeneously processed based on the unified standards and models

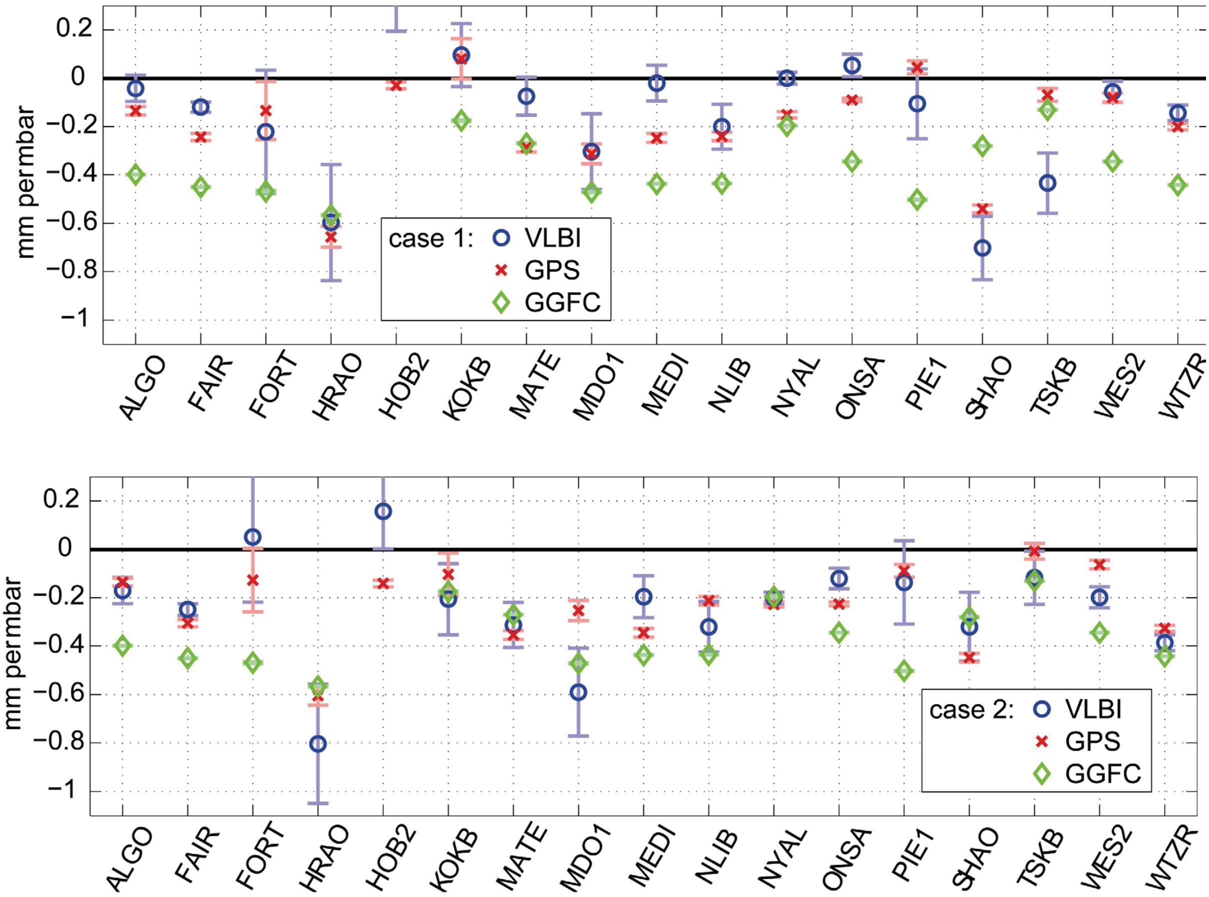

Fig. 1: Atmospheric loading regression coefficients and their formal errors, determined from VLBI (blue circles) and GPS (red crosses) height time series (top/bottom: Case 1 / 2), and coefficients provided by the GGFC (green diamonds).

that were implemented in the software packages OCCAM and DOGS-OC.

- The GGOS-D terrestrial reference frame has been computed from a combination of the VLBI, SLR and GPS long-time series. The work is closely related to the ITRS Combination Centre at DGFI and is therefore reported in Chapter 3.6.1.1.
- Time series of geodetic-geophysical parameters have been generated from the GGOS-D observation series.

As an example we provide results which have been obtained from the consistently processed VLBI and GPS observations. The work has been done in cooperation with GFZ Potsdam and TU Munich. Among other investigations, loading coefficients have been estimated from the GPS and VLBI height time series. The solutions were run twice: Case 1: Niell Mapping Function (NMF) and constant a-priori zenith delay; Case 2: Vienna Mapping Function (VMF) and a-priori zenith delay from ECMWF. As shown in Figure 1 the agreement of the loading coefficients with those provided by the GGFC (Global Geophysical Fluids Centre) significantly improves for Case 2.

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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Barbara Meisel, Manuela Seitz, Volker Tesmer

3.6.2.4 Forsvarets forskningsinstitutt (FFI)

No report submitted.

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 2008, the combination process for the two IVS EOP series (rapid and quarterly solutions) has been continued exclusively on the basis of datum-free normal equations in SINEX format and the output has been tested thoroughly. The advantages of this combination strategy are (1) that the full variance-covariance information of the individual input solutions is rigorously carried over and (2) that one common terrestrial reference frame 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 $d\psi$, $d\omega$ w.r.t. the IAU2000A model) are extracted into separate files. These results are then added to the two EOP time series, the rapid solution file (ivs08r1e.eops) and the quarterly solution file (ivs08q4e.eops), in the IVS EOP Exchange format. Companion files containing the nutation offsets in the X, Y paradigm are routinely generated through a standard transformation process (ivs08r1X.eops, ivs08q4X.eops).

In 2008, it became obvious that a new TRF for the IVS EOP determinations had to be computed for several reasons. ITRF2005, used in 2007 and 2008, has a noticeable deficit due to the pole tide error which had been made in the IVS contribution to ITRF2005. The post-quake movements of GILCREEK in ITRF2005 lacked the continuity of the piece-wise linear elements, thus, introducing discontinuities. In addition, only limited observations for the sites of SVETLOE, ZELENCHK and BADARY had been available for ITRF2005 or no observations had been available yet. Of course, all other stations took their benefit from more data in the new computations as well.

The new TRF (VTRF2008) has been computed from the individual combined SINEX files of all geodetic VLBI sessions available. These have been pre-reduced for EOP so that only the coefficients for the site coordinate parameters remained. In a stacking process, these sets of normal equations have then been combined to a full TRF normal equation system for site positions and velocities. The subsequent inversion process provided the complete TRF including its variance-covariance information. VTRF2008 is being used for all IVS combinations since December 2008. In addition, VTRF2008 had also been selected by the "IERS Working Group on the Second Realization of the ICRF" as its conventional terrestrial reference frame.

The work reported here has partly been funded by the German Bundesminister für Bildung und Forschung (BMBF) under the Geotechnologien Project "Beobachtung des Systems Erde aus dem Weltraum", FKZ 03F0425D.

Axel Nothnagel, Thomas Artz, Sarah Böckmann

3.6.2.6 GeoForschungsZentrum Potsdam (GFZ)

Introduction

The IERS Combination Research Center (CRC) at GFZ performed most of the work concerning the combination of space geodetic techniques in the framework of the project GGOS-D. The major features of this project are the high degree of standardization of the modeling and parameterization between the software packages that were 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 project GGOS-D has been financed by the German Ministry of Education and Research (BMBF) as part of the large program “Geotechnologien – Observation of the Earth from Space”. More about the project GGOS-D may be found in the IERS Annual Report 2007, Section 3.7.2 “WG on Combination”.

In the following a few of the results of this project will be shown:

- Assessment of the quality of local ties using Earth Rotation Parameters (ERPs)
- Assessment of the quality of local ties using troposphere gradients
- Atmospheric loading effects in VLBI and GPS height time series

More information about the project and its results may be found in Rothacher et al. (2011), more information about all the projects in the Geotechnologien Program is contained in the Springer book by Flechtner et al. (2010) and its predecessor by Flury et al. (2006). See also the references below for further publications in this context.

Assessment of the quality of local ties using Earth Rotation Parameters (ERPs)

The local ties forming the link between the station positions of the individual techniques play a crucial role in the inter-technique combination. As a criterion for a good selection of local ties the pole coordinates were considered. In a first step all available local ties were introduced into the combination, but the ERPs were not combined, i.e., for each observation technique (GPS, VLBI and SLR) an individual pole time series was estimated. Under ideal circumstances, all three pole time series should agree. Discrepancies between the pole time series could then be attributed to individual local ties that were then removed from subsequent computations. Figure 1 shows the iterative process for the selection of appropriate local ties between GPS and VLBI co-locations.

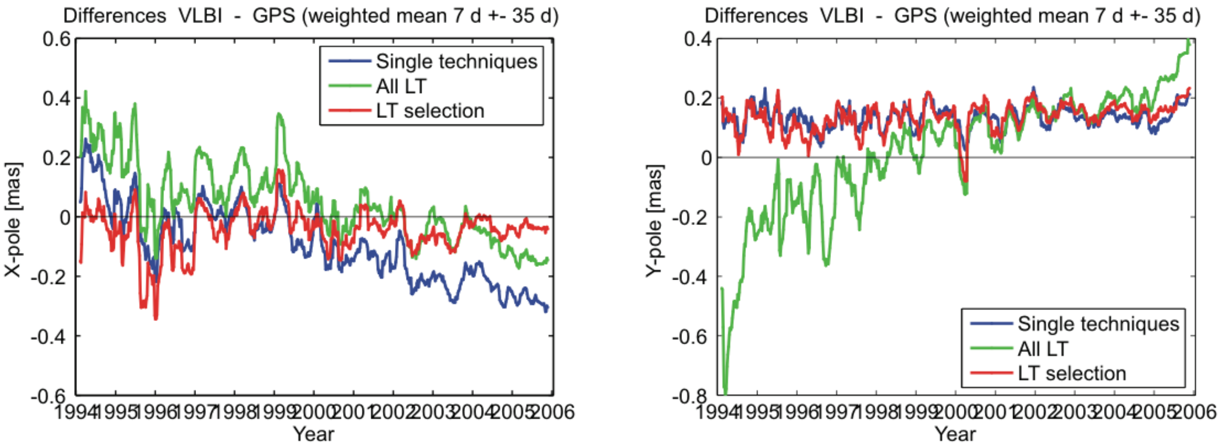

*Fig. 1***:** *Differences in the pole coordinates as indication for the quality of the local ties used.*

Assessment of the quality of local ties using troposphere gradients

The known correlation between station coordinates and troposphere parameters may also be used to assess the local ties selected for linking the space geodetic techniques VLBI and GPS. Based on the data of the CONT'02 campaign these relationships were studied in detail. Figure 2 shows the troposphere gradients in the north direction for the station Kokee Park. If all local ties available between VLBI and GPS are applied in the combined solution (called „G+V: 8 LT"), the estimates of the troposphere gradients change for both, GPS and VLBI, compared to the estimates resulting from the two single-technique solutions („VLBI-only", „GPS-only"). If, however, the local tie for Kokee Park is not introduced into the combination, („G+V: 7 LT"), the gradient estimates are almost identical to those based on the single-technique solutions. This is a clear sign that discrepancies are present between the local tie and the difference between the coordinate estimates for Kokee Park derived from VLBI and GPS data.

The smaller discrepancies between the zenith total delays derived from GPS and VLBI, when an accurate common reference frame is used, also show the high correlation between station coordinates and troposphere parameters (here heights and troposphere zenith delays), that can be exploited to assess the quality of the local ties used.

Atmospheric loading effects in VLBI and GPS height time series

In this study, a simple but very direct approach was used for the modeling of deformations caused by atmospheric loading. The changes of the local pressure values (Δp) are multiplied by a coefficient (coef) that is valid locally, in order to obtain the corresponding change in the height component: Δh = coef * Δp. The changes in the local atmospheric pressure were computed from ECMWF pressure fields by a bi-linear interpolation.

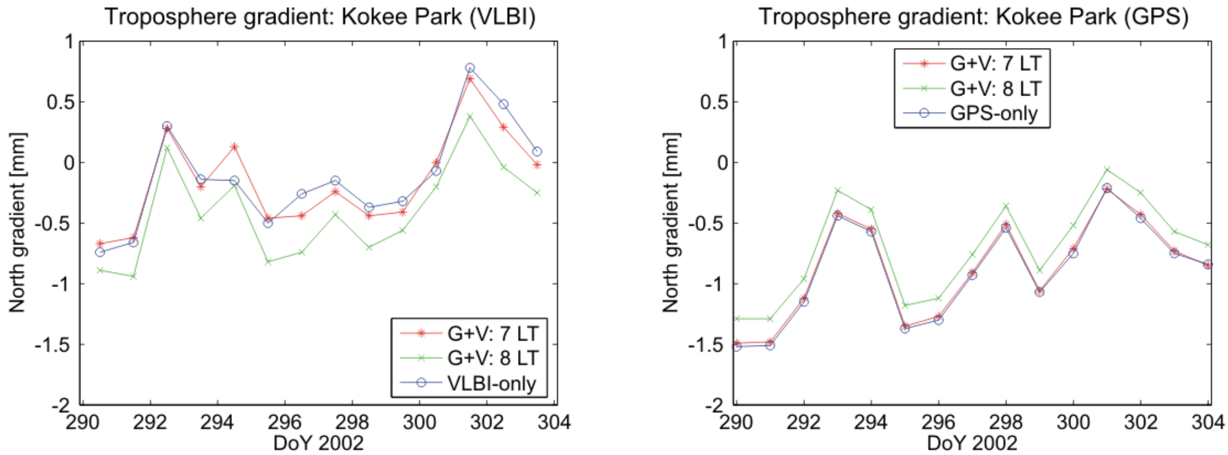

Fig. 2: *Influence of problematic local ties on the troposphere gradients of GPS and VLBI for the station Kokee Park.*

Using the height time series of individual stations, a coefficient was estimated for each station using the method of least squares. These coefficients, estimated for each station, indicate how strongly the Earth surface deforms at the measurement stations in the case of pressure variations. If a station is located, e.g., close to the coast, almost no effect (coef ~ 0) will be expected, whereas noticeable effects (coef < 0) are to be expected in the interior of continental plates.

An analysis has been performed, whether the state-of-the-art GGOS-D reprocessing solutions indeed deliver variations in the height time series that can more adequately be interpreted as deformations caused by atmospheric loading than variations in height time series that are, as usually done, generated using simpler modeling approaches. This would theoretically be expected, because, when using the simple, common approaches with, e.g., constant a priori zenith delays, part of the atmospheric loading signals might be absorbed into the tropospheric parameters.

The VLBI height time series generated by DGFI and the GPS height time series generated at GFZ with the Bernese GPS Software were considered here. Both series were produced twice:

(1) once using the simpler common modeling approaches like the NMF (Niell Mapping Function) and a priori zenith delays (ZD) that are constant in time, and

(2) a second time using the best possible models according to the standards defined within the GGOS-D project, as e.g. the VMF1 (Vienna Mapping Function 1) and a priori ZD computed using atmospheric models of the ECMWF derived from real meteorological data.

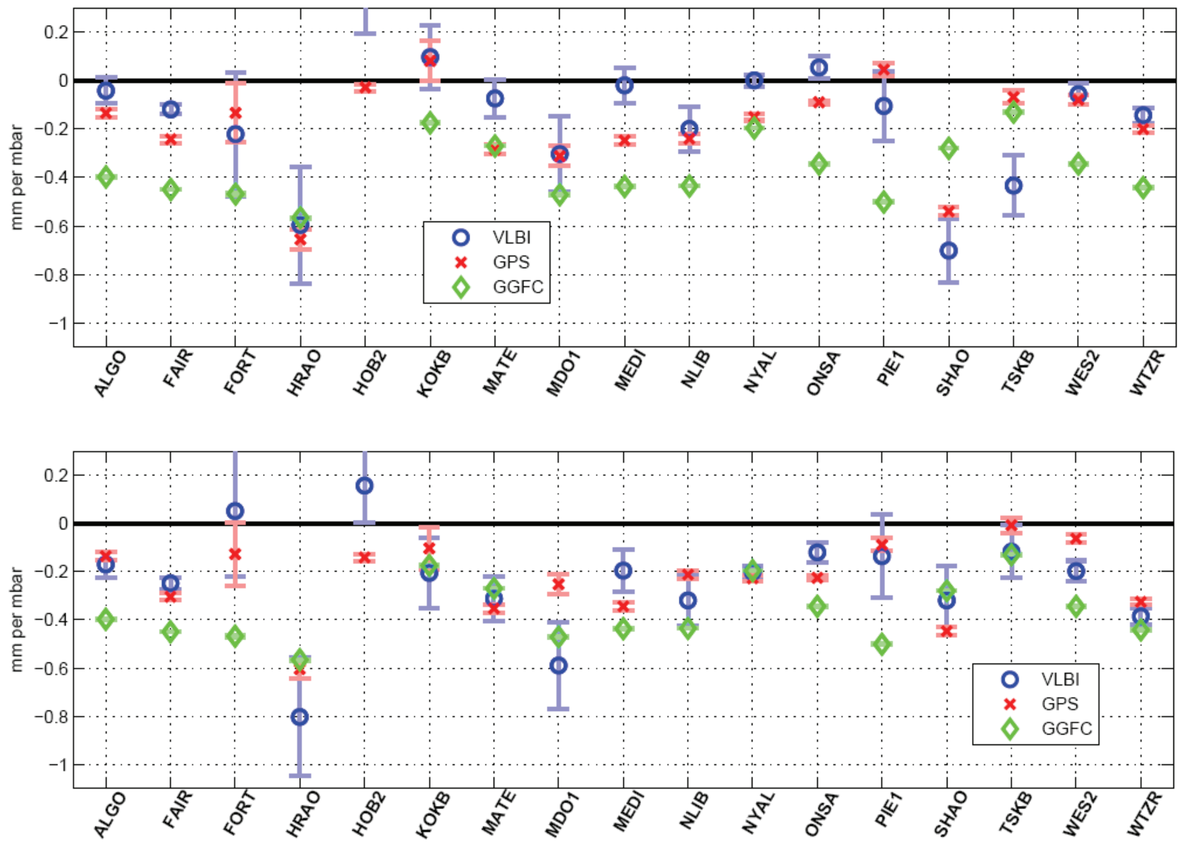

Fig. 3: Atmospheric loading coefficients and their a posteriori RMS values estimated from height time series derived from VLBI (blue circles) and GPS (red circles), for solution types 1 (left) and 2 (right), and, for comparison purposes, the coefficients available at the GGFC (Global Geophysical Fluids Center) (green diamonds).

The coefficients derived from the VLBI and GPS height time series are shown in Figure 3. In addition, coefficients computed in exactly the same way, i.e. using the regression equation Δh_{GGFC} = coeff * Δp_{NCEP}, but using the height time series made available by the Global Geophysical Fluid Center (GGFC), are displayed in Figure 3 for comparison purposes. Δp_{NCEP} is thereby the change in the local air pressure from 1980 to 1997 according to NCEP and Δh_{GGFC} is the crustal deformation computed using the local air pressure changes, the convolution with Green's functions and the assumption of an inverted barometric behavior.

Figure 3 shows that the modeling approach used for the generation of the second GGOS-D solution labeled (2) is better than that of the first solution (1): first of all, the coefficients derived from VLBI and GPS time series are clearly in better agreement for approach (2) (the WRMS of the differences is 0.134 and 0.083 mm/mbar for solution type (1) and (2), respectively). Secondly, with approach (2), also the agreement with the coefficients available at the GGFC is considerably improved: the WRMS values for the differences VLBI-GGFC amount to 0.301 and 0.154 mm/mbar for approaches (1) and (2), respectively, and 0.232 and 0.161 mm/mbar for the differences GPS–GGFC.

Acknowledgements

This work was partly funded by the project “GGOS-D” within the Geotechnologien-Projekt of the Deutsches Bundesministerium für Bildung und Forschung (BMBF, Federal Ministry of Education and Research), under the promotional reference 03F0425A.

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3.6.2.7 Groupe de Recherches de Géodésie Spatiale (GRGS)

The main points concerning the GRGS activities in the combination domain are:

- New server at OP SYRTE, a Dell PowerEdge 1950 bi-quad core Xeon E5335 2Ghz 16 Go RAM and 1 To disc, was installed in 2008 and geodesy software such as GINS, DYNAMO and CATREF were tested at the beginning of 2009.
- A discussion forum (<http://grgs.obspm.fr/forum/>) on the combination at observation level was created for our community concerning geodetic techniques for GRGS participants and extended to all other analyses centres in English language.
- SINEXtool software was upgraded in order to convert normal equation in GINS format to SINEX format. SINEXtool is managed by Sylvain Loyer (CNES-CLS Toulouse).
- Test of daily linearity constraints procedure of Dynamo software applied to the solutions or to the corrections on polar motion and universal time.
- Test of the influence of the continuity constraints on celestial offset solutions derived from GRGS VLBI observations. We observed the discrepancy of the celestial pole offset correction with respect to IAU1980 model with linearity constraint equal to various values $0 \pm \sigma$ ($\sigma \in$ [3m, 30cm, 3cm, 3mm]). We noted the decreasing of RMS on correction for the celestial pole offset corrections (ε, ψ) from 2.7mas to 125µas.
- Weekly VLBI normal equations from GRGS have been analysed with the new quasar coordinates parameters with respect to ICRF2 reference frame, complemented by the hourly troposphere parameters and the Earth Orientation Parameters, polar motion and Universal Time at 6h intervals and celestial pole offset at 12h intervals. Troposphere parameters estimated contribute to increase the RMS of EOP corrections with respect to C04 series as a priori reference solution.
- Participation to the realization of the new terrestrial reference frame ITRF2008 with the combination of GPS, VLBI, SLR, DORIS geodetic techniques at the normal equations level. GPS, DORIS, SLR and VLBI normal equations, over 2007–2008 period, were processed on a weekly basis (100 weeks). Atmospheric loadings are removed, tropospheric parameters are reduced, EOP 6h intervals are linearly constrained over each successive day and the weekly reduced normal equations weighted by an empirical factor are stacked. These successive steps were collected in a routine to generate the

unconstraint multi-technique combined normal equations, with daily EOP and weekly station coordinates parameters. All these normal equations of multi technique combination spanning the 2007–2008 period were converted into the SINEX format and delivered to the ITRF2008 contribution and put on the ftp server <ftp://hpiers.obspm.fr/iers/eop/grgs/GRGS/itrf2008/>. The GRGS contribution to the new realization ITRF2008 was analysed by the ITRS Center for techniques alone (SLR, VLBI, DORIS) as well as for global combination. The transformation parameters, i.e. translation, scale and rotation, were weekly estimated with respect to ITRF2005.

- EOP solutions: polar motion, universal time, nutation offset and station coordinates solutions were calculated from unconstraint weekly normal equations issued from GPS, DORIS, SLR and VLBI combination over 2007–2008 period.
- Transformation parameters for geodetic techniques GPS, DORIS, SLR, VLBI were determined over 2007–2008 period to estimate the consistency between the geodetic space reference frame versus ITRF2005.
- Zenithal Bias Delays (ZTD) were estimated by multi technique combination at the normal equation level. GPS, DORIS and VLBI geodetic techniques allow the determination of this troposphere parameter. Nutation offsets and polar motion were fixed in the process.
- Combination at normal equation level of GPS and VLBI have been made over 2 years to estimate the polar motion and universal time UT1 at 6h intervals and nutation offsets at 12h intervals.
- Combination of GPS normal equation and VLBI normal equation spanning the same 2 years period for estimation of nutation offsets parameters 12h intervals.
- Station coordinates and transformation parameters weekly determined by combination of GPS, DORIS, SLR and VLBI at normal equation level for the 2007–2008 period. Cartesian positions versus ITRF2005 of collocated techniques at Hartebeesthoeck station (4 techniques) and Wettzell (3 techniques) were compared.
- 26 EOP solutions of combined geodetic techniques were produced in 2009 and 144 EOP solutions in 2010, put on the ftp server <ftp://hpiers.obspm.fr/iers/eop/grgs/GRGS/solutions/>.
- DYNAMO routine computed the weight of combined normal equations “dynamo_w” using Helmert’s algorithm have been tested and a new routine “sigmas_et_residus_moyens” was

applied to the DYNAMO output files resulting from normal equation processing. This new routine estimates for each type of measurements their uncertainty (a priori RMS), the weighting associated and the sum squared of the weighting observation minus calculated.

- Weighting factors applied for GPS, DORIS, SLR and VLBI for generation of weekly unconstraint combined normal equations, were estimated using the rate of the sigma a priori and the square of the empirical weighting. These weighting factors were used by IGN for the calculation of our contribution to ITRF2008 realization.
- Using the "COMPSTA" software in order to compare the station coordinates and rates for each geodetic technique versus to ITRF2005 the space reference frame used and to estimate the seven transformation parameters (TX, TY, TZ, S, RX, RY, RZ) during the 2007–2008 periods of available measurements and solutions extracted.
- Analysis of local ties constraints applied to the station coordinates estimation for weekly unconstraint normal equations. 26 collocated stations were used to constraint the normal equation for station coordinates parameters spanning the 2007-2008 period. Station coordinates corrections in Cartesian (X, Y, Z) and spherical coordinates (φ, λ, h) and rates for Wettzell site with VLBI, SLR, GPS collocated stations and for Ny-Alesund site with VLBI, DORIS, GPS collocated stations have been compared over the 2007–2008 period with respect to ITRF2005.
- Weekly transformation parameters were estimated for each technique and for combination techniques. The stability of these parameters has been compared using the Allan variance. For translation and scale transformation parameters the combination technique exhibits the best long term stability (> 100d). For rotation parameters the stability of combined referential frame shows a good compromise.
- Stacking of VLBI weekly normal equations during the period of 2007-2008 was performed to estimate UT1 and nutation offsets at 12h. The same stacking of weekly normal equations was performed to GPS, DORIS and SLR to estimate the polar coordinates. The following table shows the results obtained.

Table 1: Statistics for EOP corrections in respect to C04 series at 12h obtained by stacking the weekly NEQ derived from the different techniques over 2007-2008

	GPS	VLBI	SLR	DORIS
Number of weeks	97	97	89	97
Number of unknowns	27269	4742	6858	18131
X-Pole WRMS / µas	41.6	–	281	463
Y-Pole WRMS / µas	38.4	–	220	350
UT1 WRMS / µs	–	18.3	–	–
Eps WRMS / µas	–	389	–	–
Psi.sin(ε_0) WRMS / µas	–	345	–	–

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3.6.2.8 Institut Géographique National (IGN)

Impact of loading effects

Station positions estimated from space geodesy observations have been shown to exhibit significant non-linear variations, especially at the annual signal. Altamimi and Collilieux (2008) have shown that repeatability of GPS positions time series can be fully explained by a combination of noise models and loading displacements. As a consequence, the impact of the inclusion of loading models in the combination process has been studied in an ITRF-like combination involving Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI) and Global Positioning System (GPS) data. Collilieux et al. (2010) have shown that such a method clearly reduce spurious annual signals observed in translation and scale factors. The combination residuals also slightly reduce although this conclusion can not be generalized to all sites.

ITRF and EOPs consistency

The availability of frame time series is fundamental to insure the mutual consistency between a secular Terrestrial Reference Frame (TRF) and a set of Earth Orientation Parameters (EOPs) (Altamimi et al., 2007, Altamimi et al., 2008). Indeed, EOPs are dependent on the underlying terrestrial reference frame and thus EOPs can be compared to previous values only if they refer to the same TRF. EOP alignment is efficiently achieved if a set of core stations is used to define the orientation of the station position set. Coulot et al. (2010) have developed an original and rigorous method that allows choosing the reference set of stations to be used thanks to a multi objective genetic algorithm. This method has been applied to SLR data and evidenced an improvement of 10% of the SLR EOP time series accuracy (about 25 µas) compared to the method currently used (Coulot et al., 2010).

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 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 (LAGEOS1 and 2), 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 their proper weight to be used. To ensure a better consistency of this combined reference frame, the use of other common parameters like zenithal biases or multi-technique satellite orbital parameters will be investigated.

SLR geocenter motion

SLR network translations with respect to ITRFs are often chosen as references for geocenter motion studies. But due to the SLR network sparseness, this estimation is biased, notably at the annual frequency. Collilieux et al. (2009) have evaluated this bias at the level of 1.5 mm scatter with annual error up to 1 mm on X and Z component. An adequate combination of GPS and SLR results allows producing more reliable estimations of the geocenter motion by mitigating this bias.

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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 2008, three such reference series were generated: (1) SPACE2007, consisting of values and rates for polar motion and UT1 spanning September 28, 1976 to March 29, 2008 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) COMB2007, consisting of values and rates for polar motion and UT1 spanning January 20, 1962 to March 29, 2008 at daily intervals, was generated by additionally including the BIH optical astrometric measurements with the space-geodetic measurements used to generate SPACE2007; and (3) POLE2007, consisting of values and rates for just polar motion spanning January 20, 1900 to March 22, 2008 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 COMB2007. These three reference series can be obtained by anonymous ftp to <ftp://euler.jpl.nasa.gov/keof/combinations/2007>. A report describing the generation of these series (Ratcliff and Gross, 2009) 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 2008 were largely concerned with a comprehensive review of the models and procedures used by KEOF to combine and predict Earth orientation parameters (Chin et al., 2009). This bottom-up review included an examination of the available EOP measurements, of the stochastic and observation models used by KEOF, and of the Kalman filter algorithm employed by KEOF. A number of possible ways to improve KEOF's performance were identified, including:

- refining the polar motion excitation models, including use of nonidentical random walk models for the x- and y-components as well as enhancements with AR-1 models and additional annual/semi-annual periodic components;
- incorporating all or part of the 1- to 7.5-day lead time AAM forecast data from NCEP in addition to the 5-day lead-time data that is currently being used;
- incorporating GPS polar motion rate measurements as well as additional GPS length-of-day measurements;
- using the Rauch-Tung-Striebel smoother in place of the backward filtering and forward–backward combination procedures currently used by KEOF.

Many of these improvements are currently being implemented in KEOF.

Acknowledgments

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Richard Gross

3.7 IERS Working Groups

3.7.1 Working Group on Site Survey and Co-location

Report for 2008

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 relate to:

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 standard 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;
- 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;
- 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.

Meetings

A meeting was held in 2008, at the AGU2008 meeting in San Francisco, US, jointly with the GGOS Networks and communication working group. 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 co-location vectors in near real time. The current survey methodology is episodic and as such will not pick up variations to the co-location 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 1–5mm 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 co-located 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 0.5mm level.

Plans are also being developed for local tie infrastructure at the Yarragadee site which will have a 12m 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. Local surveys were carried out at Tahiti and Herstmonceux sites.

Change of Working Group Chair

In October 2008 the IERS DB asked Pierguido Sarti (IRA-INAF, Italy) to set up a new charter and to revise the list of the WG members in prevision of a transfer of the chairmanship of the WG. At the end of 2008 the WG chair was transferred from Gary Johnston (Geoscience Australia) to Pierguido Sarti (IRA-INAF, Italy).

Report for 2009

A new WG charter was prepared by the new WG chair Pierguido Sarti and submitted for approval to the IERS Directing Board meeting No. 48, held in Vienna on the 19th April 2009. The new charter was approved as follows.

Charter of the IERS Working Group on co-location and local ties – Jointly with IAG Sub-Commission 1.2

Introduction

Tie vectors are nowadays fundamental for the computation of global terrestrial reference frames: the combination of the individual techniques-specific reference frames relies on the accuracy of tie vectors as well as the number and distribution of co-location sites. In order to be useful, tie vectors must be provided with full variance covariance information and must be accurate to the 1 mm level. Variance covariance computation strictly attains to the data processing phase of the tie vector; it can be rather simply achieved and should be regarded as a mandatory task of any local tie. An accurate estimation of the tie vector is more difficult to obtain and many efforts must be taken during the whole local tie process. The accuracy of a tie vector is usually (and indirectly) assessed through a comparison with the space geodetic solutions in the combination phase: the residuals of the combination are analyzed and used to identify discrepancies between space geodetic and terrestrial measurements. If, on the one hand, these discrepancies simply highlight a disagreement for a specific co-location site, on the other hand, they are the starting point for a rigorous investigation on the wide variety of causes that might originate from technique specific problems. It should be noticed that the whole process is characterized by the unavoidable complication of reliably coupling measurements of different nature (space geodetic and terrestrial) related to different reference points (electronic and conventional points, respectively).

Local tie surveys are usually performed combining terrestrial measurements of angles, distances and height differences and aim at computing differential coordinates between space geodetic instruments expressed in a topocentric frame. In order to do so, terrestrial measurements are performed and combined according to a geometric model (whose complexity and flexibility can vary considerably) apt at realizing the *conventional* definition of the instrument's reference point. Regardless of the way the observations are acquired, processed and conditioned (all these aspects obviously impact the tie vector estimation) it should be noticed that it is impossible to directly observe the instrument's electronic reference point with terrestrial techniques (i.e. the antenna's phase centre for GPS, VLBI and DORIS and the photodetector for SLR). Furthermore, the tie vector is naturally expressed with respect to a topocentric frame and, in order to be useful, it must be accurately transformed into a global frame.

Space geodetic observations are acquired at the electronic reference point and are commonly referred to the conventional reference point by means of specific corrections and models that are assumed to properly realize the connection. Many factors may influence the stability of the electronic point and any inconsistency related to this very delicate connection phase obviously reflects on the combination's residuals. Addressing, investigating and understanding electronic point instabilities has been a major concern for the whole geodetic community and it is a mandatory task when tie vectors and space geodetic measurements are combined.

The WG on site surveys and co-locations aims at enhancing the cooperation between the groups involved in local tie surveys and their adjustment, the combination centres, the users of tie vectors and the space geodetic techniques services (i.e. IGS, ILRS, IVS and IDS), with the purpose of bringing together all necessary capabilities apt to improve present day situation.

Cooperation with GGOS activities and its branches should be sought and established.

Goals and Objectives

The WG should spread the knowledge related to local surveys and their adjustment among the national agencies in charge of co-location sites maintenance.

1. Site surveys standards:

a. Revise the local tie surveying activity developed so far. Identify open issues and promote research and discussion.

b. Set guidelines related to on-field operations.

c. Spread the know how among the community and the national agencies in charge of co-located sites maintenance.

2. Tie vector estimation:

a. Set guidelines on tie vectors computational standards and their transformation into global frame.

b. Provide local tie vectors with full variance-covariance information in SINEX format.

c. Develop a concrete action plan to improve local ties for future ITRF realizations.

3. Site surveys activities:

a. Promote local tie surveying wherever needed.

b. Remotely assist site surveying activities.

c. Provide computational support.

4. Coordination and research:

a. Liaise with technique combination centres.

b. Liaise with technique services.

c. Promote a joint effort aimed at focussing on the most recent combination residuals of the global frame for investigating local inconsistencies at co-location sites and identify actions to be taken to improve the performances of tie vectors within ITRF like combinations.

Working Group Members

The WG member list was prepared right after the approval of the charter and can also be found at the IERS WG web site <http://www.iers.org/WGSiteSurvey>.

Claudio Abbondanza (IRA-INAF, Italy, since 2011 JPL, USA)
Zuheir Altamimi (IGN, France)
Pippo Bianco (ASI, Italy)
Xavier Collilieux (IGN, France)
John Dawson (Geoscience Australia)
Bruno Garayt (IGN, France)
Rüdiger Haas (Chalmers, Sweden)
Maria Hennes (Univ. Karlsruhe, Germany)
Michael Lösler (Univ. Karlsruhe, since 2011 BKG, Germany)
Jim Long (Honeywell, USA)
Chuck Meertens (UNAVCO, USA)
Valerie Michel (IGN, France)
Axel Nothnagel (Univ. Bonn, Germany)
Mike Pearlman (Harvard-Smithsonian, USA)
Jean-Claude Poyard (IGN, France)
Jim Ray (NGS, USA)
Pierguido Sarti (IRA-INAF, Italy)
Jerome Saunier (IGN, France)
Ralf Schmid (TU Muenchen, Germany)
Manuela Seitz (DGFI, Germany)
Luca Vittuari (Uni. Bologna, Italy)
Alex Woods (Geoscience Australia)

Meetings

The first 2009 WG meeting took place during the AGU Fall Conference on Wednesday, December 16th, 2009 at Hotel Palomar in San Francisco (USA). The following items were discussed.

Site Survey Standards

Guidelines for surveyors: During the meeting the necessity of defining the guidelines regarding local tie practice has been pointed out several times. This would assure a minimum standard in tie vector measurements with the aim of estimating eccentricities to the highest precision achievable. Several methods nowadays exist and different groups claim to possess the know-how for optimal tie vector computation. Nowadays only a few tie vector surveying methods have been compared and proved to be consistent. As a matter of fact, tie vectors are submitted to ITRF Combination

Centres adopting a variety of non homogeneous methods which largely depend on the know-how of the local teams carrying out the local surveying operations. The issue must be discussed in the next Vienna meeting during EGU 2010 in order to agree on common surveying methods which may be routinely adopted as conventional IERS reference procedures for tie vector computation. Specific guidelines must be described, supplied and circulated in a document which should be used as quick reference manual. Operatively, the WG must identify a sub-group of WG members experts on tie surveying technical issues for the compilation of a reference manual.

Tie Vector Estimation

Software: Exchange of tie vector estimation software has to be promoted among the local tie groups and existing software must be made readily available. A validation phase must precede the former step and has to be supported.

Site Surveys activities

Critical co-location sites: ITRF2008 residuals will provide verification of critical co-locations in need of urgent actions such as re-measurements/re-computation of the tie vector. Specific action will be taken accordingly to support new local tie measurements or re-analyse data with existing software.

Coordination and Research

Who does what? The role of local agencies and their surveyors must be harmonised with IERS standards and combination requirements. Technique Services are crucial to endorse documentation eventually produced by this WG and must be actively involved in the finalisation of conventional IERS reference procedures related to tie vector estimation.

Output format: Software should allow to save and to output the full tie vector information (components and full variance-covariance matrix) in the native topocentric frame. Also, when available, information on local geoidal undulation should be provided. These aspects are crucial to align topocentric and local geodetic frames and to carry out a thorough investigation on combination residuals. *Alignment:* Local to global frame tie vectors alignment remains an aspect which needs deep and further investigation.

Terminology: As research progresses, the lack of a univocal reference terminology on local tie issues is evident. Definitions are needed on specific procedures, items and quantities which relate to tie vector surveying, estimation and alignment. Particularly, the definition of space geodetic instrument reference point is ambiguous (e.g. stochastic, conventional, electronic). This part can be treated and included in the reference manual.

PCV & technique-dependent biases: As the knowledge of gravitational deformations of VLBI telescopes improves, a new lexicon on phenomena and quantities must be clearly set. PCV files similar to GPS might be needed in the future for VLBI in order to account for gravitational deformation of VLBI telescopes. This task can be fulfilled liaising with IVS and other services. Finally range biases in SLR and their signature in the misclosure between terrestrial and space geodetic results must be investigated in the near future. It is agreed that these corrections are responsibility of the technique services and cannot be relied upon tie surveying and computation procedures, i.e. the tie aims at connecting conventional-to-conventional reference points.

Survey activities

In August 2009 John M. Gipson (NVI Inc.) issued an invitation for a proof-of-concept demonstration involving a Robotic Total Station and a VLBI antenna at the Goddard Geophysical Observatory in Greenbelt, Maryland. The demonstration was carried out on Wednesday, September 23 at 2:00 and aimed at illustrating a 1 hour automated, straight-forward, fast, and, unassisted method for measuring the position of the VLBI/SLR conventional reference point.

Pierguido Sarti

3.7.2 Working Group on Combination

The major three items that will be addressed in this report are (1) the follow-up on the GGOS/IERS Unified Analysis Workshop of December 2007, (2) the research going on in the German GGOS-D project and similar projects, and (3) the new IERS Working Group on the “Combination on the Observation Level”.

A huge amount of combination work was also done for the preparation of the new ITRF2008, but this is part of the reports of the ITRS Center and the ITRF CCs, see Sections 3.5.5 and 3.6.1.

Follow-up on the Unified Analysis Workshop 2007

This section will give a summary of some of the major action items that were discussed and agreed upon during the GGOS/IERS UAW in December 2007:

- **Role of the IERS Combination Research Centers (CRC):** as discussions during the UAW 2007 made evident, the role of the IERS CRC was not well-defined. Not many of them actually contributed to the development of strategies for a rigorous combination of the space geodetic techniques, but were rather concentrating on their own specific research field. As a consequence of these and other discussions the IERS CRC were discontinued as of January 2009.
- **Need of a IERS WG on Combination on the Observation Level:** This IERS WG has since been established, see below.
- **SINEX extension for more flexible parameterizations:** Two proposals were made at the UAW 2007, but there was no consensus on how to proceed. Since then, as an action item of the second UAW in 2009 (see Section 4.3) an IERS WG for the “SINEX Format” has been established that is now dealing with these issues.
- **Generation of a SINEX meta data block:** A SINEX meta data block has been defined by Wolfgang Schwegmann (BKG) to be used for meta data exchange for solutions. A proposal for a meta data XML file has also been prepared. Meta data information is very important for the GGOS Portal.
- **Unique format for Earth gravity field coefficients:** A unique format for the exchange of gravity field coefficients has been agreed upon by the GOCE High-Level Processing Facility (HPF) and the International Center for Global Earth Models (ICGEM). This format has international acceptance and should be used. The format description may be found at the ICGEM: <http://icgem.gfz-potsdam.de/>.

- **Recommendation to fundamental stations:** at a fundamental station (co-location sites of more than one technique) at least 2 (better 3 GNSS receivers) with 2 resp. 3 antennas should be operated in parallel to be able to monitor any discontinuities due to antenna and receiver changes. Not too much progress has been made here.
- **Unique documentation of Analysis Center (AC) modeling and parameterization standards for all space geodetic techniques:** A unique standard has not yet been achieved. This is certainly a task for the GGOS Bureau on Standards and Conventions.

A short report on the meeting that followed the UAW of 2007 at the EGU 2008 is given in Section 4.1.

GGOS-D project and similar activities

The GGOS-D project, running from 1 September 2005 to 31 August 2008, was one of the major activities aiming at a rigorous combination of the different space geodetic techniques. Four institutions were involved: GeoForschungsZentrum (GFZ) Potsdam, Deutsches Geodätisches Forschungsinstitut (DGFI), Bundesamt für Kartographie und Geodäsie (BKG), and the Institute of Geodesy and Geoinformation (IGG) at the University of Bonn. An overview of the major results of the GGOS-D project may be found in Rothacher et al. (2011). Further information is available at <http://www.ggos-d.de> and in some of the papers listed at the end of this report.

A similar activity is taking place in the Group de Recherche Géodésie Spatiale (GRGS), a group formed by about 10 institutions, among them CNES, IGN, OP, etc. This group mainly works on the software packages GINS and CATREF and the combination on the observation level. More information may be found at <http://grgs.obs-mip.fr/>.

New IERS Working Group “Combination on the Observation Level”

During the Unified Analysis Workshop in December 2007 in Monterey, Richard Biancale made the proposition to establish a new IERS Working Group on “Combination on the Observation Level”. There was a general agreement and therefore the new WG was installed in with Richard Biancale as the chair. The kick-off meeting of the WG took place on October 22, 2009. Since it did not make any sense to have two WGs working on the topic of combination, the old IERS WG on Combination was resolved at the same time.

Meetings and Workshops

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

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Markus Rothacher

3.7.3 Working Group on Combination at the Observation Level

During 2009, a Kick-off meeting was organized at the “Centre for Space Research” of Poland in Warsaw, 21–22 October. A working group was created in the frame of IERS, the “Combination at the Observation Level” IERS COL-WG. Its main objective is to bring together groups able to do combinations of space geodetic techniques at the observation level in order to improve the accuracy, the time resolution and the overall consistency of the products. A major task of the WG COL is to study methods and advantages of combining space geodetic techniques (DORIS, GPS, SLR, VLBI), searching for an optimal strategy to solve for geodetic parameters and to intercompare the solutions obtained by different software, Bernese for AIUB, DOGS / OCCAM for DGFI, NAPEOS for ESOC and GINS / DYNAMO for GRGS. Participants have decided to pursue the activity of research on multi-techniques combination at the observation level. Five analyses centres – AIUB from Bern, DGFI from Munich, ESOC from Darmstadt, GFZ from Potsdam and GRGS from Toulouse – have scheduled different steps of processes. The first step consisted in choosing a period of test of benchmark during the CONT08 comparison campaign extended from 10th to 30th August 2008. Over this period, each analysis centre had to deliver weekly normal equations of different geodetic techniques including daily EOP, weekly station coordinates, and weekly quasar coordinates for VLBI and hourly troposphere delays. The format for all normal equations spanning the three weeks is the normalised SINEX format.

For the communication in the COL-WG, an electronic “Forum Multi-technique Combinations” was established at the Paris Observatory at <http://grgs.obspm.fr/forum/>. This forum is open to anyone willing to participate in the work of the COL-WG. Registration is firstly required.

The minutes and the presentations of the Kick-off meeting are available at the “Forum Multi-technique Combinations” and at the working group’s web site at <http://www.iers.org/WGCOL>.

Members of the COL-WG are:

Richard Biancale, France (Chair)
Daniel Gambis, France (Co-Chair)
Zuheir Altamimi, France
Sarah Böckmann, Germany
Richard Gross, USA
Rolf König, Germany
Jean-Michel Lemoine, France
Frank Lemoine, USA
Sylvain Loyer, France

Mykhailo Lytvyn, Ukraine
Maria Mareyen, Germany
Arnaud Pollet, France
Jean-Yves Richard, France
Manuela Seitz, Germany
Laurent Soudarin, France
Tim Springer, Germany
Daniela Thaller, Switzerland

Richard Biancale, Daniel Gambis, Jean-Yves Richard

3.7.4 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 web site <http://www.iers.org/IERS/EN/Organization/About/History/Prediction/prediction.html>). The question was addressed 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 104).

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. In general, the survey results confirmed the terms of reference under which the IERS RS/PC operates.

However, the survey also revealed that there is a need for increased accuracy, and subsequent efforts of the WGP concentrated on examining algorithms and incorporating potential new sources of data to address that need. In addition, the growing interest in daily and sub-daily predictions will require more timely measurements of EOP quantities and some increased processing capability.

IERS Workshop on EOP Combination and Prediction

As a fitting conclusion to the WGP, the IERS Workshop on EOP Combination and Prediction was held in Warsaw, Poland on 19–21 October 2009. The goal of the workshop was to define the current state-of-the-art for EOP predictions. The workshop looked at all aspects of predictions, including sessions on both data and algorithms as well as sessions devoted to the geophysical causes of the variations in Earth orientation.

At the end of the 3-day workshop, twenty recommendations were generated in an effort to help the EOP community direct its resources towards areas that were likely to be most beneficial. These recommendations touch on all aspects of the combination and prediction process. Papers from the Workshop were published in Volume 45, No. 2 of *Artificial Satellites* (2010) (see this report, Section 4.2).

It should be noted that one of the recommendations of the IERS Workshop was to “investigate the feasibility of initiating operational ensemble EOP predictions,” a task which has been taken up by the newly formed IERS EOP Combination of Predictions Pilot Project. For more information on the Pilot Project, please see <http://maia.usno.navy.mil/eopcppp/eopcppp.html>.

William Wooden and Brian Luzum

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

Introduction

The IERS/IVS Working Group was established after the 2006 IAU General Assembly to make use of the significant improvements in data and analysis since the ICRF became the fundamental frame for all astrometry at the beginning of 1988. The goal was to produce a second realization of the ICRF for IERS/IVS consideration and for submission to the IAU Working Group charged with providing oversight on behalf of the general astronomical community.

Working Group Charter

The purpose of the working group is to generate the second realization of the ICRF from VLBI observations of extragalactic radio sources, consistent with the current realization of the ITRF and EOP data products. The working group will apply state-of-the-art astronomical and geophysical models in the analysis of the entire relevant S/X astrometric and geodetic VLBI data set. The working group will carefully consider the selection of defining sources and the mitigation of source position variations to improve the stability of the ICRF. The goal is to present the second ICRF to relevant authoritative bodies, e.g. IERS and IVS, and submit the revised ICRF to the IAU Division I working group on the second realization of the ICRF for adoption at the 2009 IAU general assembly.
Members

Members

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
L. Petrov, USA
O. Sovers, USA

Meetings

The Working Group held the following meetings:

2008 March 5; St. Petersburg, Russia
2008 September 25-26; Dresden, Germany
2008 December 4-5; Washington DC, USA
2009 March 27-28; Bordeaux, France

Preparation for the XXVII IAU General Assembly

After the Bordeaux meeting the Working Group organized the work of the members into IERS Technical 35. Additional contributions were provided by C. Barache, S. Böckmann, A. Collioud, J.M. Gipson, D. Gordon, S.O. Lytvyn , D.S. MacMillan, and R. Ojha. A.L. Fey and D. Gordon acted as editors. The IERS Central Bureau published the online version for consideration by the IVS, IERS and the IAU Working Group, each of which approved the work in a timely manner. At the IAU General Assembly members of the Working Group presented the ICRF2 to Division 1, Commission 8 and Commission 19 and participated in drafting Resolution B3 on the Second Realization of the International Celestial Reference Frame. This resolution was adopted by the General Assembly on Aug. 13, 2009 with an effective date of 1 January 2010.

Preparation of IERS Technical Note 35

After the formal adoption of the ICRF2 the Working Group collaborated with the IERS Central Bureau to prepare the Technical Note for publication in hard copy. Additional editorial review was provided by C.S. Jacobs before the final text was sent to the printer.

Chopo Ma

4 IERS Workshops
4.1 GGOS Unified Analysis Workshop, Follow-Up Meeting

The first GGOS Unified Analysis Workshop (UAW) took place in Monterey, California, USA, from December 6 to 8, 2007 (see report in Section 4.2 of the IERS Annual Report 2007). 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. To make a review of the status of work, a Follow-Up Meeting was organized at the Technical University of Vienna, Austria, on April 15, 2008.

At the beginning of the meeting, Markus Rothacher reviewed the status of the Action Items from the first UAW. Proposals for SINEX file name conventions and for the SINEX meta data block were presented by Axel Nothnagel and Bernd Richter, respectively. Markus Rothacher explained the final details of SINEX V2.20 with respect to extended parameterization. Johannes Böhm set out a proposal by him and Harald Schuh concerning reference pressure for GGOS.

Most of the presentations are available at <http://www.iers.org/UAW2008>.

Wolfgang R. Dick

4.2 IERS Workshop on EOP Combination and Prediction

The IERS Workshop on EOP Combination and Prediction was held in Warsaw on 19–21 October 2009. The main goal of this Workshop was to provide the current state-of-the-art for EOP predictions in terms of data sets and algorithms as well as to discuss recommended actions for improving EOP predictions, including improving the IERS rapid combined series. The scientific program which consisted of three sessions was devoted to EOP observations, models, their combined solutions and excitation functions as well as prediction techniques and algorithms. The Workshop was attended by about 50 participants and about 40 papers and 5 posters were presented. At the Workshop the discussion about recommended actions was summarized with 20 recommendations concerning e.g. EOP tidal models, IERS precession/nutation model, a priori tropospheric gradient models, latency of IVS intensive and IGS rapid EOP products, systematic errors in EOP, EOP + TRF consistency, modern Earth rotation theory, fluid excitation functions time series and their forecasts as well as required EOP prediction length and accuracy. The proceedings of this Workshop were published by VERSITA in a special issue of Artificial Satellites (Vol. 45, No. 2) on November 1, 2010 [1].

Reference

[1] http://versita.metapress.com/content/q18285534556/?p=3fde944efa804882a991a1628ebd43db&pi=0

Wiesław Kozek

4.3 Second GGOS Unified Analysis Workshop

After the GGOS Unified Analysis Workshop (UAW) in Monterey, California, USA, in December 2007 and a Follow-Up Meeting in Vienna in April 2008, the Second GGOS Unified Analysis Workshop was organized in San Francisco, California, USA, on December 11–12, 2009. As in the case of the first UAW, the participation in the UAW 2009 was based on invitation, i.e., the IAG Services decided on the persons to represent them during the workshop.

Workshop Scope and Goals

An important goal of GGOS 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 to rigorously combine the various space geodetic techniques (e.g. with the realization of ITRF2005, making use of a new approach based on time series of weekly/session SINEX files), there are still many deficiencies (missing parameters), inconsistencies and systematic effects to be addressed.

The workshop was intended to be a forum for the exchange of information and results concerning both,

- problems common to more than one service and
- problems specific to an individual service.

For a successful combination of the space geodetic techniques, experts of a certain technique have to be familiar with the critical issues of the other techniques. Therefore, the workshop was organized to increase the common understanding of the individual techniques as they contribute to GGOS.

Sessions

The workshop was organized in four sessions. Their titles, chairs, scopes and goals were the following:

Session 1: Products by the Services, GGOS Portal and Metadata

Chaired by R. Neilan, co-chaired by B. Richter B. and C. Noll

In this session each of the Services presented its present status of product generation, i.e., the products themselves, the standards, models, parameterizations, and processing strategies used. A list of the deficiencies and problems encountered by the various techniques was of special importance here and the Services described, how they are intending to improve these issues and what new strategies are considered to improve the technique and products in general. In addition, the metadata flow from the Services to the GGOS Portal (meta data format) was an important topic. Also an updated version of SINEX including necessary updates was considered.

Goals:
- Understand the processing details and problems of the individual techniques
- Information about the improvements planned by each of the techniques
- Discuss ways to improve the deficiencies and cure problems in the future
- Define formats, data structures and data flows for metadata for the GGOS Portal
- New version of SINEX

Session 2: Modelling Deficiencies and Modelling Based on External Data

Chaired by J. Böhm, co-chaired by T. van Dam

The geodetic/geophysical models used in data analyses still show significant deficiencies and are not really fully consistent among techniques and analysis centres. The various modelling problems (antenna effects, atmosphere, loading effects, etc.) were addressed and possible solutions/improvements were discussed. Of special importance is the fact, that in the future, the modelling of the observations will depend more and more on large amounts of external data (e.g., meteorological models for mapping functions and a priori delays, ocean models for non-tidal loading effects, hydrological models for hydrological loading, etc.). This can be considered a paradigm change in reference system definition and realization, because these external data sets will have to be available for all high-precision realizations of the frame, be it in post-processing or (near) real-time applications. The benefit from corrections based on external data and the implications thereof were addressed.

Goals:
- Improve the accuracy and consistency of the geodetic/geophysical models used
- Assess the benefits of correction models based on large external data sets
- Discuss the implications of the paradigm change (from corrections based on *simple* mathematical formulas to corrections based on large amounts of external data)

Session 3: Combination Strategies, Common Parameters and Combined Products

Chaired by H. Schuh H., co-chaired by R. Biancale R. and Z. Altamimi

One topic of this session were combination strategies to be used for various combined products of the IERS or GGOS (e.g., including troposphere parameters, quasar coordinates, gravity field coefficients, clocks, …). Important issues were, among others, the weighting of the observations and variance component estimation, constraining of parameters, rank deficiencies, datum definition strategies, combination of UT1 and LOD, nutation offsets and rates (VLBI + satellite techniques), definition of the parameterization for parameters common to more than one technique, standards for a priori values/models to be used for these parameters as well as standards for the time resolution (weekly, daily, sub-daily, …) and reference epochs of parameters. Combination on the observation level was also considered.

Session 4: Network Simulations and Analyses

Chaired by M. Pearlman, co-chaired by J. Ries and E. Pavlis

One of the GGOS recommendations (see GGOS2020 book) is the establishment of a global, well-distributed network of core sites, where all the major observation techniques are co-located. Simulations and analyses are therefore important to assess the number of sites necessary, some reasonable locations and what results are to be expected if, e.g., new observation techniques are implemented (kHz-SLR, twin telescopes, combined GPS/GLONASS/GALILEO receivers).

Goals:

- Assess network characteristics required to fulfil demanding requirements (e.g., 1 mm reference frame, 0.1 mm/y stability)
- Identify improvements to be achieved with technological innovations (technique-specific and local ties)

The detailed programme, the position papers of the sessions, the presentations, and the Action Items are available at <http://www.iers.org/UAW2009>.

Markus Rothacher, Wolfgang R. Dick

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 is elected by the DB for a term of four years with the possibility of re-election for one additional term. 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 and PC chairs 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 GGOS.

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 10, 2010

Appendix 2: Contact addresses of the IERS Directing Board

Chair

Chopo Ma
(address see below)

Analysis Coordinator

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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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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 <www.iers.org/products>.

Earth orientation data

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

Monthly earth orientation data
Web access:
http://hpiers.obspm.fr/eop-pc/index.php?index=bulletins
ftp access: `hpiers.obspm.fr` - directory `iers/bul/bulb_new`

Long term earth orientation data
http://hpiers.obspm.fr/eop-pc/index.php?index=eoptable
ftp access: `hpiers.obspm.fr` - directory `iers/eop`

Leap second announcements
Web access:
http://hpiers.obspm.fr/eop-pc/index.php?index=bulletins
ftp access: `hpiers.obspm.fr` - directory `iers/bul/bulc`

Announcements of DUT1
Web access:
http://hpiers.obspm.fr/eop-pc/index.php?index=bulletins
ftp access: `hpiers.obspm.fr` - directory `iers/bul/buld`

Conventions

Web access:
IERS Conventions 2010:
http://tai.bipm.org/iers/conv2010/conv2010.html

International Celestial Reference Frame

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

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://geophy.uni.lu/

Publications

IERS Messages
http://www.iers.org/Messages

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

http://hpiers.obspm.fr/eop-pc/index.php?index=bulletins
(Bulletins B, C, D)
http://www.iers.org/Bulletins

IERS Technical Notes
http://www.iers.org/TechnicalNotes

IERS Annual Reports
http://www.iers.org/AnnualReports

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

IERS Components

Directing Board
Web page: http://www.iers.org/DB

Analysis Coordinator
Web page: http://www.iers.org/AC

Central Bureau
Web page: http://www.iers.org/CB

Product Centres

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

Rapid Service/Prediction Centre
Web site: http://www.usno.navy.mil/USNO/earth-orientation

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://geophy.uni.lu/
Special Bureaus:
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Special Bureau for Hydrology
Web site: http://www.csr.utexas.edu/research/ggfc/
Special Bureau for the Atmosphere
Web site: http://www.aer.com/scienceResearch/diag/sb.html
Special Bureau for Combination
Web site: http://geophy.uni.lu/

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/

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Working Group on Prediction
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Appendix 5: Acronyms

AAM	Atmospheric Angular Momentum
AAS	American Astronomical Society
AC	Analysis Centre
AC	Analysis Coordinator
AGN	Active Galactic Nucleus [or Nuclei]
AGU	American Geophysical Union
ANDE-RRA	Atmospheric Neutral Density Experiment Risk Reduction - Active [component]
ANDE-RRP	Atmospheric Neutral Density Experiment Risk Reduction – Passive [component]
AOD	atmospheric and oceanic dealiasing
APC	associated product center
APKIM	Actual Plate KInematic and crustal deformation Model
APSG	Asia-Pacific Space Geodynamics
AR	autoregressive
ASI	Agenzia Spaziale Italiana
AUS	= AUSLIG
AUSLIG	Australian Surveying and Land Information Group (now: Geoscience Australia)
AWG	Analysis Working Group
BIH	Bureau International de l'Heure
BIPM	Bureau International des Poids et Mesures
BKG	Bundesamt für Kartographie und Geodäsie
BLITS	Ball Lens In The Space [spacecraft]
BMBF	Bundesministerium für Bildung und Forschung, Germany
BNC	[GGOS] Bureau on Networks and Communication
BVID	Bordeaux VLBI Image Database
CATREF	Combination and Analysis of Terrestrial Reference Frames
CB	Central Bureau
CC	Combination Centre
CCD	Charge-Coupled Device
CDAS	Chinese VLBI Data Acquisition System
CDDIS	NASA Crustal Dynamics Data Information System
CEDR	Center for Earth Dynamics Research
CERGA	Centre d'Etudes et de Recherches Géodynamiques et Astronomiques
CfP	Call for Participation/Proposals
CGS	Centro di Geodesia Spatiale, ASI
CICGE	Centro de Investigação em Ciências Geo-Espaciais
CIP	Celestial Intermediate Pole
CLS	Collecte Localisation Satellites
CMS	Content Management System
CNES	Centre National d'Etude Spatiale
CODATA	Committee on Data for Science and Technology
CODE	Centre for Orbit Determination in Europe
CoG	center of gravity to effective reflection surface
CONT	continuous VLBI session
COSPAR	Committee on Space Research
CPP	IERS Combination Pilot Project
CRC	Combination Research Centre
CRD	Consolidated Laser Ranging Data Format
CRD	CRF deepsouth [sessions]
CRF	Celestial Reference Frame
CRMS	CRF mediansouth [sessions]
CSR	Center for Space Research, University of Texas
DB	Directing Board
DBBC	Digital Base Band Converter
DBE	digital backend
DDA	AAS Division on Dynamical Astronomy
DE	JPL Development Ephemeris
DE, DEC	declination
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 Radi-

	opositioning Integrated on Satellite
DSS	Digitized Sky Survey
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
ELP	Ephemeride Lunaire Parisienne
EMR	Energy, Mines and Resources Canada (replaced by NRCan)
ENSG	Ecole Nationale de Sciences Geographiques
EO	Earth orientation
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
EVGA	European VLBI Group for Geodesy and Astrometry
e-VLBI	Electronic transfer VLBI
EVN	European VLBI Network
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FCUP	Faculdade de Ciências da Universidade do Porto
FESG	Forschungseinrichtung Satellitengeodäsie, Technical University of Munich
FFI	Forsvarets forskningsinstitutt
FFT	Fast Fourier Transformation
FIR	finite impulse response
FSUE	[Russian] Federal State Unitary Enterprise
FTLRS	French Transportable Laser Ranging Station
FTP, ftp	File Transfer Protocol
GA	General Assembly
GA	Geoscience Australia
GAOUA	Main Astronomical Observatory of the Ukrainian Academy of Sciences
GCRS	Geocentric Celestial Reference System
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GFZ	GeoForschungsZentrum Potsdam
GGF	global geophysical fluids
GGFC	Global Geophysical Fluids Centre
GGFC-OC	GGFC Operational Component
GGFC-SSC	GGFC Science Support Component
GGOS	Global Geodetic Observing System
GGOS-D	GGOS – Deutschland (Germany)
GINS	Geodesy by Simultaneous Digital Integration [software]
GIQC	Gaia Initial Quasar Catalogue
GLDAS	NASA's Global Land Data Assimilation System
GLONASS	GLObal'naya NAvigatisionnay Sputnikovaya Sistema [Global Orbiting Navigation Satellite System, Russia]
GMF	Global Mapping Function
GNAAC	Global Network Associates Analysis Center
GNSS	Global Navigation Satellite System
GNU	GNU's Not Unix
GOCE	Gravity field and Ocean Circulation Explorer
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
GSC	GSFC Analysis Center
GSC2.3	[HST] Guide Star Catalog 2.3
GSFC	Goddard Space Flight Center
GSI	Geographical Survey Institute
HEO	High Earth Orbiter
HPF	GOCE High-Level Processing Facility
HST	Hubble Space Telescope
h/v	hight/vertical
IAA	Institute of Applied Astronomy, St. Petersburg
IAG	International Association of Geodesy
IAS	International Altimetry Service
IAU	International Astronomical Union
ICESat	Ice, Cloud, and land Elevation Satellite

ICGEM	International Centre of Global Earth Models
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
ICSU	International Council for Science
IDS	International DORIS Service
IERS	International Earth Rotation and Reference Systems Service (formerly: International Earth Rotation Service)
IGFS	International Gravity Field Service
IGGB	Institute of Geodesy and Geoinformation of the University of Bonn
IGN	Institut Géographique National
IGR	IGS rapid (orbit)
IGS	International GNSS Service (formerly: International GPS Service)
ILRS	International Laser Ranging Service
ILRSA	ILRS official solution
INA	= INASAN
INAF	Istituto Nazionale di Astrofisica
INASAN	INstitut AStronomii Rossijskoj Akademii Nauk (Institute of Astronomy of the Russian Academy of Sciences)
INPOP	Intégrateur Numérique Planétaire de l'Observatoire de Paris
IPIE	Institute for Precision Instrument Engineering
IRA	Istituto di Radioastronomia
IRIS	International Radio Interferometric Surveying
ISO	International Organization for Standardization
ISO TC	ISO Technical committee
ISO/TS	ISO Technical specification
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
KASI	Korea Astronomy and Space Science Institute
KEOF	Kalman Earth Orientation Filter
LAREG	Laboratoire de Recherche en Geodesie
LCA	LEGOS in cooperation with CLS
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LEO	Low Earth Orbit(er)
LLR	Lunar Laser Ranging
LOC	Local Organizing Committee
LOD	Length of Day
LOLA	Lunar Orbiter Laser Altimeter
LPCE	Laboratoire de Physique et Chimie de l'Environnement
LQAC	Large Quasar Astrometric Catalog
LQRF	Large Quasar Reference Frame
LR	laser ranging
LRO	Lunar Reconnaissance Orbiter
LS	least-squares
MAG	magnitude
MAO	= GAOUA
mas	milliarcsecond(s)
µas	microarcsecond(s)
MCC	Russian Mission Control Centre
MCT	Ministério da Ciência e Tecnologia, Brasília
MeO	Métrologie Optique [Grasse SLR /LLR system]
MERIT	Monitoring Earth Rotation and Intercomparison of Techniques
MIT	Massachusetts Institute of Technology
MJD	Modified Julian Day
MLRO	Matera Laser Ranging Observatory
MPIfR	Max-Planck-Institut für Radioastronomie / Max Planck Institute for Radio Astronomy
ms	millisecond(s)
µs	microsecond(s)
NASA	U.S. National Aeronautics and Space

	Administration
NCEP	U.S. National Centers for Environmental Prediction
NCL	University of Newcastle upon Tyne
NEQ	normal equation
NERC	Natural Environment Research Council, UK
NGS	U.S. National Geodetic Survey
NGSLR	[NASA's] Next Generation SLR
NMF	Niell Mapping Function
N.N.	Nomen Nominandum [vacant, to be nominated]
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
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
OAM	oceanic angular momentum
OATo	Osservatorio Astronomico di Torino
Obs.	Observatory, Observatoire
OCA	Observatoire de la Côte d‘Azur
OICETS	Optical Inter-Orbit Communications Engineering Test Satellite
ON/MCT	Observatório Nacional, Ministério da Ciência e Tecnologia
OP, OPA	Observatoire de Paris
OS	Observing System
OV/UFRJ	Observatório do Valongo, UFRJ
PC	Product Centre
PCV	Phase-Center Variations
PDR	Potsdam Dresden Reprocessing / GeoForschungsZentrum Potsdam & Technical University of Dresden
PM	Polar Motion
POD	Precise [or Precision] Orbit Determination
PP	Pilot Project
ppb	parts per billion (10^{-9})
PSF	point spread function
PSR	pulsar(s)
PZT	Photographic Zenith Tube [or Telescope]
QSO	Quasi-Stellar Object [quasar]
RA, R.A.	right ascension
RC	Research Centre
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
RS/PC	IERS Rapid Service/Prediction Center
RT e-VLBI	Rapid turn-around e-VLBI
SAI	Sternberg Astronomical Institute
SB	Special Bureau
SBA	Special Bureau for the Atmosphere
SBC	Special Bureau for the Core
SBCP	Special Bureau for Combined Products
SBH	Special Bureau for Hydrology
SBO	Special Bureau for the Oceans
SCCID	Strategic Coordinating Committee for Information and Data
SCID	Strategic Committee on Information and Data
SDSS	Sloan Digital Sky Survey
SDSS DR	SDSS Data Release
SIM	NASA’s Space Interferometry Mission
SINEX	Solution (Software/technique) INdependent EXchange Format
SIO	Scripps Institution of Oceanography
SLR	Satellite Laser Ranging
SOC	Scientific Organizing Committee
SOFA	Standards Of Fundamental Astronomy
SPBU	St Petersburg University
SPM	Yale/San Juan Southern Proper Motion Program
SYRTE	(Laboratoire) Systèmes de Référence Temps-Espace
TAI	Temps Atomique International (International Atomic Time)
TC	Technique Centre

TDB	Barycentric Dynamical Time
TEMPO	Time and Earth Motion Precision Observations
TIGA	Tide Gauge Benchmark Monitoring
TN	[IERS] Technical Note
TOA	time of arrival
ToR	Terms of Reference
TRF	Terrestrial Reference Frame
TT	Terrestrial Time
TU	Technical University
TUM	Technical University of Munich
TWV	total water vapor / tropospheric water vapor
U.	University
UCAC	USNO CCD Astrograph Catalog
UEZO/RJ	Centro Universitário Estadual da Zona Oeste, Rio de Janeiro
UFRJ	Universidade Federal do Rio de Janeiro
UKMO	United Kingdom Meteorological Office
ULR	University of La Rochelle, France
UNAVCO	University Navstar Consortium
UNESCO	United Nations Educational, Scientific and Cultural Organization
Univ.	University
URAT	USNO Robotic Astrometric Telescope
URL	Uniform Resource Locator
USNO	United States Naval Observatory
UT, UT0, UT1, UT1R	Universal Time
UTAAM	NOAA AAM analysis and forecast data
UTC	Coordinated Universal Time
UTGPS	Universal Time-like quantity using Global Position System
V2C	VLBI2010 Committee
V2PEG	VLBI2010 Project Executive Group
VDIF	VLBI Data Interchange Format
VEX	VLBI Experiment Documentation
VLA	Very Large Array
VLBA	Very Long Baseline Array, NRAO
VLBI	Very Long Baseline Interferometry
VMF, VMF1	Vienna Mapping Function
WDC	World Data Centre(s)
WDS	ICSU World Data System
WDSSC	WDS Scientific Committee
WDS-TT	World Data System Transition Team
WG	working group
WGP	IERS Working Group on Prediction
Wks	weeks
WRMS	Weighted Root Mean Square
XML	eXtensible Markup Language
yr	year
ZD	zenith delay(s)