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

IERS
Annual Report
2014

Verlag des Bundesamts für Kartographie und Geodäsie
Frankfurt am Main 2015

IERS Annual Report 2014

Edited by Wolfgang R. Dick and Daniela Thaller

International Earth Rotation and Reference Systems Service
Central Bureau
Bundesamt für Kartographie und Geodäsie
Richard-Strauss-Allee 11
60598 Frankfurt am Main
Germany
phone: ++49-69-6333-273/261/250
fax: ++49-69-6333-425
e-mail: central_bureau@iers.org
URL: www.iers.org

ISSN: 1029-0060 (print version)
ISBN: 978-3-86482-084-7 (print version)

An online version of this document is available at:
http://www.iers.org/AR2015

Druckerei: Bonifatius GmbH, Paderborn

Table of Contents

Appendices

1 Foreword

In 2014, the IERS continued to provide products to the scientific and operational communities. It is serving the changing needs of its users in the fields of celestial reference frames, terrestrial reference frames, Earth orientation parameters (EOPs), geophysical data, and the standards used to produce these important data sets.

The concerted effort to achieve a new terrestrial reference frame continues. The new realization, now called ITRF2014, is expected to be released in early 2016 and will provide an improvement over the existing ITRF2008.

The ICRS Centre continued to participate in the organization of the upcoming ICRF-3. It cooperated with the ICRF-3 Working Group, which held meetings in advance of the 2015 International Astronomical Union (IAU) General Assembly.

In an effort to provide better service to the community, the IERS Conventions Centre established the IERS Conventions Editorial Board. The Board provides additional resources and expertise that can be utilized to address changes to the Conventions.

The Fourth Unified Analysis Workshop, jointly sponsored by the IERS and the Global Geodetic Observing System (GGOS), was held 27 – 28 June 2014 in Pasadena, CA, USA. For a list of the issues addressed and a summary of the recommendations, see the report of the Analysis Coordinator (Chapter 3.3) and <http://www.iers.org/UAW2014>.

The IAU has finished voting on its reorganization. Based on its results, it is expected that the IERS will work predominantly with Division A: Commissions A1 Astrometry, A2 Rotation of the Earth, and A3 Fundamental Standards. The IERS looks forward to continuing its relationship with the IAU through these commissions and other components of the IAU.

There have been multiple changes of the personnel of the IERS Directing Board in 2014. Christine Hackman replaced me as the Director of the Rapid Service/Prediction Centre. Ralph Gaume stepped down as the co-director of the ICRS Centre. He was replaced by Bryan Dorland in September 2015.

Brian Luzum
Chair, IERS Directing Board, 2014

2 The IERS
2.1 Structure

From 2014 to 2015, 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 2014 and 2015.

Analysis Coordinator

Thomas Herring

Central Bureau

Director: Daniela Thaller

Technique Centres

International GNSS Service (IGS)
IGS Representatives to the IERS Directing Board:
Steven Fisher, Tim Springer
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 † (until 6 June 2015),
Daniela Thaller (since 16 July 2015)

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

International DORIS Service (IDS)
IDS representatives to the IERS:
Frank G. Lemoine (until 31 December 2014), Jérôme Saunier,
Hugues Capdeville (since 1 January 2015)
IERS Representative to the IDS Governing Board:
Brian J. Luzum

Product Centres

Earth Orientation Centre
Primary scientist and representative to the IERS Directing Board: Daniel Gambis (until 31 August 2015),
Christian Bizouard (since 1 September 2015)

Rapid Service/Prediction Centre
Primary scientist and representative to the IERS Directing Board: Brian J. Luzum (until December 2014),
Christine Hackman (since December 2014)

Conventions Centre
Primary scientists: Brian J. Luzum, Gérard Petit
Representative to the IERS Directing Board:
Brian J. Luzum

ICRS Centre
Primary scientists: Ralph A. Gaume, Jean Souchay
Current representative to the IERS Directing Board:
Ralph A. Gaume (until 16 October 2014)

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
Co-Chair: Jean-Paul Boy (since May 2014)

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
Chair: Tonie van Dam

ITRS Combination Centres

Deutsches Geodätisches Forschungsinstitut (DGFI)
Primary scientist: Manuela Seitz

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: Sten Bergstrand
Co-Chair: John Dawson

IERS/IVS Working Group on the Second Realization of the ICRF (ceased operation in 2014)
Chair: Chopo Ma

Working Group on Combination at the Observation Level
Chair: Richard Biancale

Working Group on SINEX Format
Chair: Daniela Thaller

Working Group on Site Coordinate Time Series Format
Chair: Laurent Soudarin

(*Status as of December 2015*)

2.2 Directing Board

In 2014 to 2015, the IERS Directing Board had the following members (for addresses see Appendix 2):

Chair	Brian J. Luzum
Analysis Coordinator	Thomas Herring
Product Centres Representatives	
Earth Orientation Centre	Daniel Gambis (until 31 August 2015), Christian Bizouard (since 1 September 2015)
Rapid Service/Prediction Centre	Brian J. Luzum (until December 2014), Christine Hackman (since December 2014)
Conventions Centre	Brian J. Luzum
ICRS Centre	Ralph A. Gaume (until 16 October 2014)
ITRS Centre	Zuheir Altamimi
Global Geophysical Fluids Centre	Tonie van Dam
Central Bureau	Daniela Thaller
Technique Centers Representatives	
IGS	Steven Fisher, Tim Springer
ILRS	Jürgen Müller, Erricos C. Pavlis
IVS	Chopo Ma, Rüdiger Haas
IDS	Frank G. Lemoine (until 31 December 2014), Jérôme Saunier, Hugues Capdeville (since 1 January 2015)
Union Representatives	
IAU	Aleksander Brzezinski
IAG / IUGG	Clark R. Wilson (until June 2015), Axel Nothnagel (since July 2015)
GGOS	Bernd Richter

2.3 Associate Members

Angermann, Detlef
Arias, Elisa Felicitas
Behrend, Dirk
Bergstrand, Sten
Biancale, Richard
Bianco, Giuseppe
Boucher, Claude
Boy, Jean-Paul
Bruyninx, Carine
Capitaine, Nicole
Carter, William E.
Chao, Benjamin F.
Chen, Jianli
Dawson, John
Gambis, Daniel
Garayt, Bruno
Gaume, Ralph A.
Gipson, John
Gross, Richard S.
Hugentobler, Urs
Johnston, Gary
Lemoine, Frank
Lemoine, Jean-Michel
Lestrade, Jean-François
Luceri, Vincenza
McCarthy, Dennis D.
Moore, Angelyn W.
Neilan, Ruth E.
Noomen, Ron
Pearlman, Michael R.
Petit, Gérard
Ray, Jim
Reigber, Christoph
Richard, Jean-Yves
Rothacher, Markus
Salstein, David
Shelus, Peter J.
Seitz, Manuela
Souchay, Jean
Soudarin, Laurent
Stamatakos, Nick
Veillet, Christian
Vondrák, Jan
Weber, Robert
Willis, Pascal
Yatskiv, Yaroslav S.

Ex officio Associate Members:
IAG Secretary General: Drewes, Hermann
IAU General Secretary: Benvenuti, Piero
IUGG General Secretary: Ismail-Zadeh, Alik
President of IAG Commission 1: Blewitt, Geoffrey
Chair of IAG Subcommission 1.1: Hugentobler, Urs
Chair of IAG Subcommission 1.2: Collilieux, Xavier
Chair of IAG Subcommission 1.4: Malkin, Zinovy
President of IAG Commission 3: Hashimoto, Manabu
Chair of IAG Subcommission 3.1: Bogusz, Janusz
Chair of IAG Subcommission 3.2: Shen, Zheng-Kang
Chair of IAG Subcommission 3.3: Chen, Jianli
President of IAU Division A: Lemaître, Anne
President of IAU Commission A1: Brown, Anthony G.A.
President of IAU Commission A2: Gross, Richard
President of IAU Commission A3: Hohenkerk, Catherine Y.

(*Status as of December 2015*)

3 Reports of IERS components
3.1 Directing Board

The IERS Directing Board (DB) met twice in the course of the year 2014. Summaries of these meetings are given below.

Meeting No. 58

April 27, 2014, Technical University of Vienna, Gusshausstr. 27, Vienna, Austria

Introduction and approval of agenda

The agenda was accepted. Daniela Thaller welcomed the guests and the members of the IERS Directing Board.

Formalities

The minutes of IERS DB Meeting #57 were distributed together with the agenda of DB Meeting #58.

IAG service review

Tom Herring presented the main questions raised by the undergoing review of the IAG services: How are the services working and what is written in the Terms of Reference? Is there a single point of failure or redundancy (or focused on individual institution running the service)? Certification of ICSU for the services is in progress over the next few years.

Report on GGFC activities

Tonie van Dam gave a summary of the IERS Retreat in May 2013, followed by discussions on the main topics:

- GGFC continues, new data from GFZ, but delayed.
- Working for ITRF2013 providing non-atmospheric loading model used in ITRF2013.
- Working on REFAG meeting in October, registration online on Friday.

Zuheir Altamimi will provide a full list of ITRF2013 sites to T. van Dam who will construct a model that will then be available on the IERS ftp server at BKG.

New Action Item:
#58.01 Provide a list of ITRF2013 sites to Tonie van Dam.

Report on GGOS

Hansjörg Kutterer reported on the latest GGOS activities:

- GGOS Coordinating Board (CB) Elections.
- GGOS CB semiannual meetings and GGOS Consortium annual meetings; monthly telecons.
- A GGOS reception will take place on December 14, 2014 in San Francisco.
- Unified Analysis Workshop (UAW) will take place on June 27–28, 2014 in Pasadena, USA.

Presentation of the GGOS strategic plan:

- Executive summary provided from IAG and GGOS leadership.
- Key concepts: GGOS as IAG Observing System and "integrator of services".
- GGOS's role centring upon advocacy, integration, and international relations.
- Next steps: adopt the Strategic Plan and re-align the organization; implement the plan at the Bureau Level; reporting.

Presentation on implementation of the 2011 GGOS structure and reorganization – Alignment of GGOS:

- Reporting between the GGOS components and new Bureau restructuring.
- Relation between GGOS and IERS on the strategic level and on the operational level.

A discussion on interaction between IERS and GGOS followed, particularly on the question which are the IERS core products.

For the Unified Analysis Workshop potential topics are requested from the services. Registration will be via the IGS Workshop web site.

New Action Item:
#58.02 Communicate additional possible topics for UAW if necessary.

Reports from the Technique Centres

International DORIS Service (IDS)

Frank Lemoine presented the current status of DORIS missions and network and summarized activities:

- 5 current missions + 5 future missions planned.
- Network evolution: several new stations are planned; some stations will be shut down or moved.
- Ground Antenna Characterizations: Phase variations measurements for Starec antenna in anechoic chamber; successful phase law implementation by the ACs.
- Analysis update: 6 active DORIS ACs.
- ITRF2013 contribution: 1st version (V0) has been submitted to the data server, a 2nd and 3rd version are planned to follow after EGU2014.
- Past meetings: Analysis Working Group (AWG) meetings in October 2013 and March 2014.
- Next meetings: IDS Workshop planned for October 2014 in Konstanz, Germany, IDS AWG meeting in 2015.
- IDS Governing Board: Elections for Member at Large and Analysis Coordinator in 2014.

International GNSS Service (IGS)

Tom Herring reported on IGS activities:

- IGS 2nd Reprocessing (full summary of analysis standards can be found at <http://acc.igs.org/reprocess2.html>); Main analysis features: Longer data span, updated models, frames & methodologies, sub-daily alias and draconitic errors will remain.
- Some contributions still missing, but expected soon.
- First combined solution expected for June 2014.

International Laser Ranging Service (ILRS)

Erricos Pavlis gave a report about the ILRS activities:

- New Russian stations Badary, Zelenchukskaya, Svetloe validated and Mendeleevo soon to be validated.
- Past meetings: 18th Laser Workshop in November 2013 + AWG Meeting.
- Site Log Viewer for enhanced display and comparison online at <http://ilrs.gsfc.nasa.gov/SiteLogViewer/>.
- Station Change History log now operational.
- ILRS/GGOS Study Group on tracking GNSS constellations established, campaign during the summer.
- ILRS elections for renewal of the Governing Board membership completed.
- First version of ILRS solution by the end of May/beginning July.
- ILRS Report 2011–2012 is under preparation, also the ILRS contribution to IERS Annual Report 2013.
- Future meetings: 19th Int. Workshop on Laser Ranging, October 2014 at GSFC, USA; AWG meeting in April 2014, Vienna, Austria; 20th Int. Workshop on Laser Ranging in 2015 in Potsdam, Germany; Technical Workshop in Matera, Italy in early 2015.

International VLBI Service for Geodesy and Astrometry (IVS)

Rüdiger Haas on the latest IVS activities:

- IVS Directing Board: New committee on training and education; new WG on VLBI observations of satellites.
- Past meetings: 8th IVS General Meeting and 15th IVS Analysis Workshop in Shanghai, China in March 2014.
- Upcoming meetings: 3rd Int. VLBI Technology Workshop in the Netherlands in November 2014; 8th IVS Technical Operations Workshop in Haystack, USA in May 2015; 22th EVGA Meeting and 16th IVS Analysis Workshop in Ponta Delgada, Portugal in May 2015; 9th IVS General Meeting and 2nd IVS VLBI School in South Africa in March 2016.

- CONT14 campaign starting on May 06, 2014 (17 stations at 16 sites).
- ITRF2013 contribution in work; 9–10 contributions expected from the ACs.
- Monitoring of ICRF2 defining sources and Gaia transfer sources.
- Several VGOS systems will commence operations within the next few years.

Reports from the Working Groups

IERS Working Group on Combination at the Observation Level (COL)

Richard Biancale reported on the COL activities.

- 4 years of COL working group: Goal of the WG, COL Analysis Centres.
- COL Meetings: regular annual meetings; past meeting in May 2013 in Munich, Germany; next meeting in May 2014 in Paris.
- Future of COL: homogenizing technique processing and upgrading software packages; discussion of COL activities and results at next COL meeting and at the UAW in June 2014; redefinition of combination activities within the IERS afterwards.

IERS Working Group on on Site Survey and Co-location

Sten Bergstrand reported on the current activities of the WG.

- Recent activities in the working group: a resolution on the nomenclature of space-geodetic reference points and local tie measurements.
- Coming activities: monitoring OSO VLBI antenna during CONT14 campaign; WG meeting intended at REFAG2014; establishment of GNSS/TPS combined local tie monitoring at Onsala and Metsähovi; participation in EMRP Long Distance Surveying WP5: Local Tie Metrology (2013–2016); revise WG charter.

IERS Working Group on SINEX Format

Daniela Thaller reported on the activities of the WG on SINEX Format.

- Station parameterization (e.g. post-seismic station movements) being investigated at IGN by Paul Rebischung in the frame of ITRF2013 generation.
- Clarification of the Statistics block and the definition of the number of parameters (reduced parameters and pseudo-observations).

Zuheir Altamimi pointed out that progress in the SINEX format is needed, e.g. for periodic signals and for seismic deformations to be corrected.

ITRS/ITRF

Report from ITRS Combination Center at DGFI

Detlef Angermann reported on the status of the DGFI CC.

- Presentation of the combination strategy at DGFI and the requirements for SINEX input data on normal equations and solutions.
- Summary of which information is needed from the Technique Centres in order to generate a combined solution

Report from ITRS Combination Center at JPL

Richard Gross reported on recent activities at the JPL CC:

- Continuing to develop Kalman filter-based approach to determining combined TRFs.
- Examine effects of atmospheric loading.
- Applying three-corner-hat technique to data from co-located stations.

Report from ITRS Center

Zuheir Altamimi reported on the activities of the ITRS Centre.

- UN GGIM: 5 delegates from the GGRF WG will attend an UN mission briefing in May; a short video has been produced in order to explain the concerns to the delegates (<https://vimeo.com/89695290>).
- ITRS Centre activities: new ITRF web site will be ready in 2014.
- Ongoing development by the operational entity for local surveys; Operational entity should be recognized by the IERS as fundamental component of the ITRS Centre (change the ToR?).
- New ties available for several new stations since ITRF2008.
- ITRF2013 status: new schedule: first results are previewed by End of June–July, final solution by Sep–Oct 2014.

New Action Item:
#58.03 Send video to DB.

Status of ICRS/ICRF and IAU Working Group

Ralph Gaume gave a presentation on the current activities of ICRS/ICRF.

- ICRS Centre update: maintenance of the link to Hipparcos; LQAC-3 (Large Quasar Astrometric Catalogue) scheduled mid 2014; Rotation between VLBI catalogues; Gaia launched in December 2013.
- ICRF-3: working group member list has been updated; one of the goal is amongst others to improve the X/Ka Band and the lack of sources on the southern hemisphere.
- WG meeting took place in March 2014 in Shanghai.
- Status of the VLBA: needed to improve the ICRF, but at risk for closing. Letters of support written.

Zuheir Altamimi added that VLBA stations are all co-location sites with GNSS, and to increase the observations on these sites would be positive for the ITRF. It could be helpful to send out other letters of support to the Director of the US Science Foundation who is responsible for the VLBA (also from IVS and IERS).

IERS Conventions

Gérard Petit summarized the activities on updating the IERS Conventions 2010:

- Several parts have been updated in the description of reference systems and in the conventional physical models.
- Possible directions for the evolution of the IERS Conventions:
- Update models as needed; Technique-specific conventions; Conventional treatment of non-tidal loading; Conventions to describe the models chosen in analysis; Conventions for vertical references.
- Several models have to be updated.
- Organization of the Conventions Centre: start forming the “Editorial Board” where dedicated people are responsible for one main topic or chapter each.
- What should be the role of the “Advisory Board”?

New Action Item:
#58.04 Ask people to join the Editorial Board and provide a list.

Earth orientation products

Report from Earth Orientation Centre

Christian Bizouard presented the report of Earth Orientation Centre:

- Virtual Observatory: EOP data available in XML format.
- ASCII file for TAI–UTC history.
- Need of authoritative file for leap second announcements: ongoing development at Paris Observatory for such a protocol.
- Geodetic excitation as an official IERS product? Should this product be made official?
- EOP C04 consistency with IGS and IVS.

Report from Rapid Service/ Prediction Centre

Brian Luzum reported about minor modifications to the operational software.

Annual Reports

Daniela Thaller gave an overview on the current status of the annual reports: AR 2012 has been published online and will be printed soon. The call for contributions for the IERS Annual Report 2013 will be sent out in May.

Next DB Meeting

DB meeting #59 is planned to be held before the AGU meeting on Sunday, December 14, 2014 in San Francisco.

Meeting No. 59

December 14, 2014, Hotel Marriott Marquis, 780 Mission Street, San Francisco, USA

Introduction and approval of agenda

The agenda was accepted. The Chair, Brian Luzum, welcomed the guests and the members of the IERS Directing Board.

Formalities

The minutes of IERS DB Meeting #58 were distributed together with the agenda of DB Meeting #59.

Action Items of previous DB meetings

52.01 Test loading models: Tonie van Dam reported that GGFC will not do such tests; tests will be available only if other groups are working on it (e.g., Ole Roggenbuck from BKG).

52.02 Validation procedures: Tonie van Dam reported that GGFC will not set up such procedures.

58.01 Provide a list of ITRF2013 sites to T. van Dam: Zuheir Altamimi will provide this list as soon as all ITRF input solutions are available.

58.02 Communicate additional possible topics for UAW if necessary: done

58.03 Send video to DB: done

58.04 Set up Editorial Board for Conventions Update: done

58.05 Prepare DB meeting #59: done

Changes in IERS Directing Board

Brian Luzum handed over the responsibility for the Rapid Service/Prediction Centre to Christine Hackman as of December 2014. Ralph Gaume, primary scientist of the ICRS Centre at USNO, moved to the US National Science Foundation; USNO is in the process of finding a replacement.

Possible changes in IERS Terms of Reference

A change of the ToR was proposed concerning the Chairperson of the IERS DB to be selected from the members of the DB and the IERS Associate Members. The DB decided to vote on the proposal by email.

New Action Item:
#59.02 Set up email voting for ToR.

Report on IAG REFAG2014 meeting

Tonie van Dam reported on the IAG Commission 1 Symposium 2014 on Reference Frames for Applications in Geosciences (REFAG2014):

- REFAG2014 took place on October 12–17, 2014 in Luxembourg.
- 100 participants from 24 countries met to discuss the role of global and regional reference frames in science and practice.

- 60 oral presentations and 18 posters were presented within sessions on six topics.
- The abstracts and presentations are available on the meeting website <http://iag.uni.lu>.
- Proceeding will be published in the IAG Symposia Series (Pascal Willis, Editor). About 20 papers have been proposed so far. For the IAG Proceedings, 30–40 contributions are needed.

Unified Analysis Workshop (UAW) 2014

Tom Herring summarized the UAW 2014 results.

Report

The following topics were addressed:

(1) ~1ppb scale difference between VLBI and SLR.
(2) Antenna phase centre models for DORIS systems.
(3) Time variable gravity field effects (DORIS LEO satellites).
(4) Sub-daily loading and S1/S2 loading.
(5) Update time scales for atmospheric and hydrographic loading.
(6) Diurnal and semidiurnal EOP variations.
(7) EOP parameterization for high-time resolution representation.
(8) Collocation issues.
(9) Monument stability (Large and small, physical and electrical).
(10) Intersystem observations.
(11) Error models for data and parameter estimates.
(12) Unification of gravity contributions.
(13) Combination at the Observation Level (COL) results.

A Mean Pole inconsistency for ITRF contributions was reported. Concerning monument stability it has to be checked whether In-SAR can help. J.-P. Boy will be able to study S1/S2 issues.

Formal requests to the Technique Services:

- IVS: Antenna deformation to be measured.
- IDS: Determine models for satellites in orbit (only possible empirically).
- ILRS: Effect of range bias will be studied.
- IGS: The antenna phase centre of Galileo will not be published. However, an information for one satellite would be enough and could be used to calibrate all others.

All presentations and the detailed report are available at <http://www.iers.org/UAW2014>.

Recommendations relevant for IERS

- The Chair of the IERS Conventions Centre should have a sub-group reassessing the relativity models being used by the techniques.
- Re-assess the solid-Earth pole tide model being used in operational processing and make recommendations on how to best implement and update these models in the future.

Update of the IERS Conventions

Gérard Petit presented a list of the IERS Conventions Editorial Board and reported on the following open topics:

- Chapter 6 (Geopotential): Conventional geopotential model; Solid Earth Tides; Solid Earth Pole Tides.
- Chapter 7 (Displacement of reference points): Conventional mean pole; Ocean pole tide; S1-S2 atmospheric loading; Non-tidal loading.
- Chapter 8 (Tidal variations in the Earth's rotation): Long-period tidal variations in LOD; Diurnal Earth rotation variations from ocean tides.
- Chapter 9 (Models for atmospheric propagation delays): Compatibility of the refractivity coefficients for optical and microwave techniques.
- Chapter 11 (General relativistic models for propagation): VLBI model; VLBI and SLR models in view of the persistent scale difference between the two techniques.

In general, a documentation of the impact of new models (especially a quantification) along with the Conventions would be helpful (e.g. as an extension of Tables 0.1 and 0.2 of the IERS Conventions).

Tonie van Dam proposed to publish the IERS Conventions together with the GGOS Standards and Conventions document (if the timeline of the development of both documents goes parallel).

New Action Items:
#59.03 Study S1/S2 issues.
#59.04 Documentation (quantification) of the impact of new models.

Status of ICRS/ICRF and IAU Working Group

Brian Luzum presented the status of ICRS/ICRF for Chris Jacobs.

ICRS Centre update:

- Maintenance of the link to Hipparcos with USNO Robotic Astrometric Telescope (URAT).
- Construction of the LQAC (Large Quasar Astrometric Catalogue). Objectives: Compilation of all the recorded quasars; Strategy insisting on astrometric quality; Catalogue flag (A→M) for cross-identifications; Extended photometry & redshift; Calculation of absolute magnitudes M_I & M_B; Basis

for regular updates (Gaia); Final ASCII file with VO tools in parallel; Comparisons / statistics / coherence.

Other activities of the ICRS Centre:

- Rotations between VLBI catalogues of different Analysis Centres.
- Spectroscopic follow-up of ICRF sources.
- Photometric follow-up of ICRF sources.

Gaia successfully launched on December 19, 2013, but there is a stray light problem. Final Gaia catalogue may replace VLBI catalogue as ICRF.

IAU ICRF-3 WG update:

ICRF-3 goals:

- Improving VLBA Cal Survey's 2000+ positions.
- Improving southern observations.
- Improving number, accuracy, and southern coverage of high frequency frames (24, 32, 43 GHz).
- ICRF-3 will be completed by August 2018 in time for comparisons & alignment with Gaia optical frame.

IAU WG update:

- Meetings in Shanghai in March 2014 and in October 2014 in Luxembourg.
- Proposal to extend the *defining source* concept to multiple wavelengths for ICRF-3.
- S/X, K, X/Ka observations continue.
- VLBA re-observing VCS at S/X.
- Plans for S/X-band for Southern improvements with telescopes in Parkes, DSS45, Hobart26 and HartRAO and for X/Ka-band with baselines in Argentina (Fort Irwin, Tidbinbilla, Malargüe, Robledo de Chevela).

Other issues:

- Status of VLBA: It is needed to improve ICRF2 (ICRF3), but there is a risk for closing, which would have a significant impact on ICRF3.

Proposal: UT1 in NTP messages

Brian Luzum presented NTP and its possible use for distributing UT1:

- NTP (Network Time Protocol) used to transfer time over packet-based networks.
- Client/Server model with connectionless transmissions.
- Operates on Stratum hierarchy (lower Stratum values indicate better time reference).

- NTP for UT1 transmission:
  - Could provide dedicated NTP Server broadcasting UT1.
  - Use NTPv4 Extension field to transmit values.
- User Equipment: dedicated UT1 NTP servers may be easiest solution.

Broadcasting UT1 with msec accuracy should be possible. The user list/access needs to be controlled to ensure that users understand the implications of receiving UT1 instead of UTC.

The values will be put into the "Extension Field" of NTP Packet Format for NTP version 4 only (see slides).

If USNO should do this, there should be a formal request by IERS.

New Action Items:
#59.05 Prepare and sign a letter to USNO asking to distribute UT1.

Distribution of EOP and leap seconds information

Richard Biancale made a presentation for Daniel Gambis on the Web Service for EOP and leap seconds.

Following the IAU Working Group recommendation on distributing UT1–UTC information, 4 developments are presented:

- An ASCII file is available ("Leap second file").
- EOP data available in XML format by ftp at <hpiers.obspm.fr>.
- Leap second Web Service.
- Secure protocol (via NTP) to give information on leap second announcements for servers synchronization (under development).

Report on GGOS

Bernd Richter presented a report for GGOS:

- Meetings and telecons: monthly telecons of the GGOS Executive Committee (EC); semiannual meetings of the GGOS Coordinating Board (CB) and annual meetings of the GGOS Consortium.
- Participation at the UAW in Pasadena in June 2014 and at the UN-GGIM.
- Main EC Topics: Revision of GGOS Strategic Plan with four major themes:
  - Geodetic Information and Expertise
  - Global Geodetic Infrastructure
  - Service, Standardization and Support
  - Communication, Education and Outreach.

Under development are the GGOS Component Realignment, the GGOS Component Implementation Plans and the cooperation with UN-GGIM, especially with the WG GGRF.

The following main topics have to be considered:

- Improved interaction of GGOS components, of GGOS with IAG services and of geometry and gravity.
- Improved outreach: UN-GGIM (interaction with GIAC), GEO, CEOS.
- Develop dedicated, unique GGOS products.
- Improve reporting, assure successful termination of tasks.
- Organize dedicated workshops.
- Make GGOS operational and provide better visibility.

Metadata:

- Make it mandatory for the GGOS basic products.
- Support the creation of metadata by the GGOS board and the other IAG services.
- Guidelines can be produced if necessary.

Reports from the Technique Centres

International DORIS Service (IDS)

Frank Lemoine presented the IDS report:

- DORIS Constellation Status: Currently 5 missions (Jason-2, Cryosat-2, HY-2A, SARAL and SPOT-5).
- SPOT-5 to be decommissioned by ~May 2015.
- Future missions: 5 missions (Sentinel-3A,-3B, Jason-3, HY-2B, C, D, Jason-CS A, B, SWOT).
- DORIS data modelling for ITRF2013: Time variable gravity field used: harmonic fit to 5x5 SLR+DORIS (Lemoine et al. 2011); Atmospheric loading is not applied; Non-conservative force models are updated/improved; Troposphere gradient estimation by some ACs (2–3 of 6 ACs); Beacon frequency offset now estimated by all the ACs; Phase centre antenna corrections.
- Launch of Jason-3 delayed (maybe in summer 2015).
- Network Operational Status: 58 stations of which 8 beacons are out of order (4 for more than one year).
- Network evolution:
  - Short term (next 6 months): 3 new stations in Chatham, NZ, Kitab, UZ and Socorro, MX;
  - Longer term: new stations in Goldstone, CA, Managua, Nicaragua, Chichijima & Hokkaïdo, JP, relocation of station Easter Island (Chile), closing stations in Santiago (move to San Juan, Argentina?), Port Moresby, PG and Miami, FL.
- IDS projects: Guam, US: new station planned; Wettzell, Germany: IDS GB agrees to beacon deployment.
- Publication: DORIS Special Issue (Advances in Space Research), theme: ITRF2013-related analysis and results.

- IDS workshop held in Konstanz, Germany on October 27–31, 2014, papers online at <http://ids-doris.org/>.
- Next meeting: IDS AWG meeting in May 2015.
- Analysis update: 6 ACs contributed for ITRF with the latest contribution (v7) submitted December 2014.
- Deadline Feb. 2015 only possible with data up to ~September 4, 2014 mainly due to time-variable gravity.

International GNSS Service (IGS)

Paul Rebischung reported on IGS activities:

- Analysis Centre submissions to repro2: 7 contributions from operational ACs + 2 TIGA contributions. Submission products include satellite orbit and clocks, Terrestrial frames and EOPs (daily SINEX files).
- Several re-submissions due to outliers for several ACs in their WRMS station position residuals.
- Next steps: re-submissions of 2 ACs + extensions to 2014.
- Final combined solution due by end of February 2015.
- In 2014 probably only few ACs available.
- GRGS: problem of yearly signal found (GPT-2 model); total reprocessing needed starting with observations, which is not possible for ITRF2013.

International Laser Ranging Service (ILRS)

Erricos Pavlis presented the ILRS report:

- Network operations continued without major issues.
- Recent meetings: 19th Int. Laser Workshop in Annapolis, MD, October 27–31, 2014; Fall AWG Meeting on October 26, 2014.
- ILRS Supported Missions: 3rd Indian GNSS s/c IRNSS-1C successfully launched on October 16, 2014.
- ILRS GB decided to establish a SG on Space Debris tracking, after an international interest in this activity.
- Main LLR activities: IfE LLR solution submitted for ITRF2013; proposal for a new LLR site at NTT Nasmyth (ESO) was not successful; studies on combined use of LLR, GRAIL and LRO data continue.
- ILRS AWG: Operational products delivered routinely from 8 AC/CCs; 7 ACs and 2 CCs contributed the entire 1983–2013 analysis product to ITRF2013; Focusing at present on the ITRF2014 extension.
- 2 ACs for 2014 up to September.
- Remaining input until mid-January available.
- Future ILRS Meetings: 20th Int. Workshop on Laser Ranging in 2016 in Potsdam, Germany; A technical workshop in Matera, Italy; Next AWG meeting is scheduled during the EGU 2015 week.

International VLBI Service for Geodesy and Astrometry (IVS)

Chopo Ma reported on the latest IVS activities.

Four main topics were addressed:

- IVS submission for ITRF2013/2014: 10 AC contributions with data until 2013; No significant offset of an AC for the scale parameter between the individual AC and the VTRF2013 (VLBI TRF from IVS contribution to ITRF2013); IVS combined solution submission to ITRS Centre planned for February 27, 2015 containing data including 2014 and missing sessions from 2013. For December 2014, only the R1/R4 sessions will be included.
- Recent and upcoming VLBI meetings:
  - 8th IVS Technical Operations Workshop in Haystack, USA, May 4–7, 2015.
  - 22nd EVGA Meeting, Ponta Delgada (Portugal), May 17–21, 2015.
  - 16th IVS Analysis Workshop, Ponta Delgada (Azores, Portugal), 21 May 2015.
  - 33rd IVS DB meeting, Ponta Delgada (Azores, Portugal), 22 May 2015.
  - 9th IVS GM 2016 in South Africa, March 2016.
  - 2nd IVS VLBI School, South Africa, March 2016.
- CONT14 (Continuous VLBI Campaign 2014): Observed May 6–20, 2014 (0–24h UT); 17 stations at 16 sites; Correlation completed within two months; 302,115 observations for the campaign.
- The VGOS world: 13 VGOS stations in roll-out progress; New VGOS Radio Telescopes in NY-Ålesund (NO), Zelenchukskaya (RU), Badary (RU), GGAO (US) and Ishioka (JP); RAEGE Project in progress.

ITRS/ITRF

Report from ITRS Combination Center at DGFI

Detlef Angermann reported on the status of the ITRS CC at DGFI.

- ILRS and IDS contributions analysed.
- A poster will be presented at AGU meeting: “The 2013 DGFI realization of the ITRS”.
- Analysis of the ILRS scale time series: scale difference between DTRF2013 and DTRF2008: 0.2 mm and 0.2 mm/yr.
- DTRF2013 origin in good agreement with DTRF2008 (translation < 0.7 mm, rates < 0.3 mm/yr).
- Analysis of IDS contribution: draconitics higher than those of DTRF2008 input (effect of Jason2 data?).

Report from ITRS Combination Center at JPL

Richard Gross gave an overview on the CC work at JPL:

- Recent activities:
  - Applying three-corner-hat technique to data from co-located stations.
  - Continuing to develop Kalman filter-based approach to determining combined TRFs.
  - Prepare ITRF2013 solution.
- Future plans:
  - Continue Kalman filter-based approach to determining combine TRFs.
  - Submit solution for ITRF2013 (time series of past and future station positions).

Report from ITRS Center

Zuheir Altamimi presented the status:

- ~10 additional local ties since ITRF2008.
- ITRF2013 products:
  - Usual products: Station positions, velocities and residuals, EOP.
  - Additional/new products: Geocentre motion model; post-seismic parametric models and periodic signals (amplitudes & phases) on request.
- ITRF2013 – ITRF2014 schedule:
  - I. Stick to ITRF2013 and start analysis of solutions submitted so far, together with the coming IGS solution.
  - II. Ask all the techniques to process the data for 2014.

    Go for ITRF2014 if all the technique combined solutions for 2014 are ready by Friday, 27 February 2015.
- Problems with 5 LT-SINEX files (non-invertible).
- ~3 month are needed for ITRF combination itself.

UN-GGIM GGRF resolution

Zuheir Altamimi reported on the forthcoming UN-GGIM Resolution on the Global Geodetic Reference Frame (GGRF):

- UN-GGIM objectives: the promotion of global geospatial information to address key global challenges & to support improved decision-making, like a global geodetic reference system.
- 3rd Session of the Committee of Experts took place in July 2013 in Cambridge, UK.
- Creating of a working group to develop a GGRF.
- ~30 countries + IAG are members of the WG.
- The resolution aims at encouraging member states to enhance global cooperation, to open geodetic data sharing, to

improve and maintain national geodetic infrastructure and to have multilateral cooperation.

- Next steps: referral of the draft resolution to the UN GA; developing FAQ document.

The text of the UN resolution is available at the UN-GGIM website (see <http://ggim.un.org/UN_GGIM_wg1.html>). Frank Lemoine mentioned that the tide gauges should not be forgotten in the resolution.

IERS Annual Reports

Daniela Thaller informed about the status of IERS Annual Reports:

- AR 2012: published online in April 2014, corrected version in May; printed and distributed in June 2014.
- AR 2013: Last contributions received; IGS report still missing; will be published online by December 22, 2014 and printed and distributed in January or February 2015.
- AR 2014: Call for contributions will be sent out in January 2015; proposed deadline: February 28, 2015.

New Action Item:
#59.07 Issue Call for contributions to Annual Report 2014.

Changes in address management at the Central Bureau

Daniela Thaller reported that a new IERS User and Address Management System was introduced at the IERS Central Bureau:

- Users and members of the IERS may log in to the private user area of the IERS website and may update their contact data and subscribe to newsletters and printed publications.
- New users can register directly at the IERS website.

Symposium on Earth Rotation

Richard Gross reported that the next Symposium on Earth Rotation will take place between June 27 and July 1, 2016 in Wuhan, China, similar to the last Symposium in Shanghai, China, in 2010.

Next IERS DB Meeting

The next DB meeting will be an all-day meeting and will take place on Sunday, April 12, 2015 before the EGU meeting.

New Action Item:
#59.06 Prepare next DB meeting in Vienna.

Miscellaneous

Voting for IAU Commission 19 (Earth Rotation) is not that high and Commission 19 might be merged with other commissions.

Daniela Thaller, Sabine Bachmann, Wolfgang R. Dick

3.2 Central Bureau

General activities

The IERS Central Bureau (CB), hosted and funded by Bundesamt für Kartographie und Geodäsie (BKG), organized and documented the IERS Directing Board (DB) Meetings No. 58, April 27, 2014, at Technical University of Vienna, Austria, and No. 59, December 14, 2014, at Hotel Marriott Marquis, San Francisco, California, USA (see Section 3.1. for minutes of these meetings). It also organized the 4th Unified Analysis Workshop, co-sponsored by GGOS and held on June 27–28, 2014, at California Institute of Technology, Pasadena, California, USA (see Section 4 for a report). Between the meetings the CB coordinated the work of the DB.

Members of the CB took also part in the following meetings: 8th IVS General Meeting, European Geosciences Union General Assembly 2014, ISO TC211 Meeting, IAG Commission 1 Symposium 2014 on Reference Frames for Applications in Geosciences (REFAG2014), 19th International Workshop on Laser Ranging, and AGU 2014 Fall Meeting.

IERS components maintain individually about 10 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, as well as link lists for IERS, Earth rotation in general and related fields. Throughout 2014 the web site was continually updated, several new pages and documents were added. An extended list of meetings related to the work of the IERS was maintained and updated frequently. The CB maintains also the web pages of the IERS working groups and added some new documents to these pages. For the 4th Unified Analysis Workshop a web site was created including the programme, all presentations and the recommendations.

IERS Annual Reports 2008–2009, 2010, and 2011 were printed and distributed. The CB finalized the IERS Annual Report 2012, published it online in April 2014, and distributed it in printed form. The IERS Annual Report 2013 was edited and published online in December 2014. Along with the reports of the IERS components, provided by them, the annual reports contain general information on the IERS compiled by the CB. For both reports, the CB provided also summaries of DB meetings and its own reports.

During the year 2014, 21 IERS Messages (Nos. 243–263) were edited and distributed. They include news from the IERS and of general type as well as announcements of conferences.

Address and subscription information have regularly been updated in the IERS user database. There were about 2500 users in 2014 with valid addresses who subscribed to IERS publications for e-mail and regular mail distribution. The development of a new system of address management was mainly finished (see below).

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.

The Director of the CB, Daniela Thaller, chairs the IERS Working Group on SINEX Format and is *ex officio* member of the other IERS WGs. Wolfgang Dick continued to work in the Control Body for an ISO Geodetic Register Network, which will contain standardized and proved data on reference systems, and is a member of the ISO project 19161 "Geodetic references".

IERS Data and Information System (DIS)

The IERS Data and Information System (IERS DIS) is continuously being adapted and extended by new components in order to fulfil the requirements for a modern data management and for the access to the data by the users. Besides routine work like maintenance of the data bases of users, products and web pages, in 2014 further developments of the IERS DIS concentrated on the new system for address management, the migration to a new release of the Content Management System, and the development of an interactive plot tool. Some software bugs in the data management system installed in the previous year (see report for 2013) have been fixed throughout the year 2014.

The development of a new system of address management in cooperation with a software company was mainly finished and the software was tested in 2014. This system, which is related to the Content Management System used for the IERS web site, allows easier maintenance and gives access for users to register as well as to check and update their data through the IERS web pages. The new system went online in November 2014, after all user data had been exported from the old system and imported into the new one. Further tests have been made under live conditions. Some new users created accounts in the new system and subscribed to IERS publications. The address management system allows also to send email messages and newsletters to groups of users. Address data from the database is also used in dynamic IERS web pages.

Due to new releases of the Content Management System "Government Site Builder" used for the IERS web site and the end of support for the old release, it became necessary to move to a new release. This uses another technology so that the files could not be simply copied, and most scripts which had been developed specifically for IERS had to be rewritten. The main migration process was done by a software company, but many steps had also to be done by IERS personnel.

The IERS Plot Tool, which was developed in previous years and used to create plots of EOP data for the IERS website (Fig.

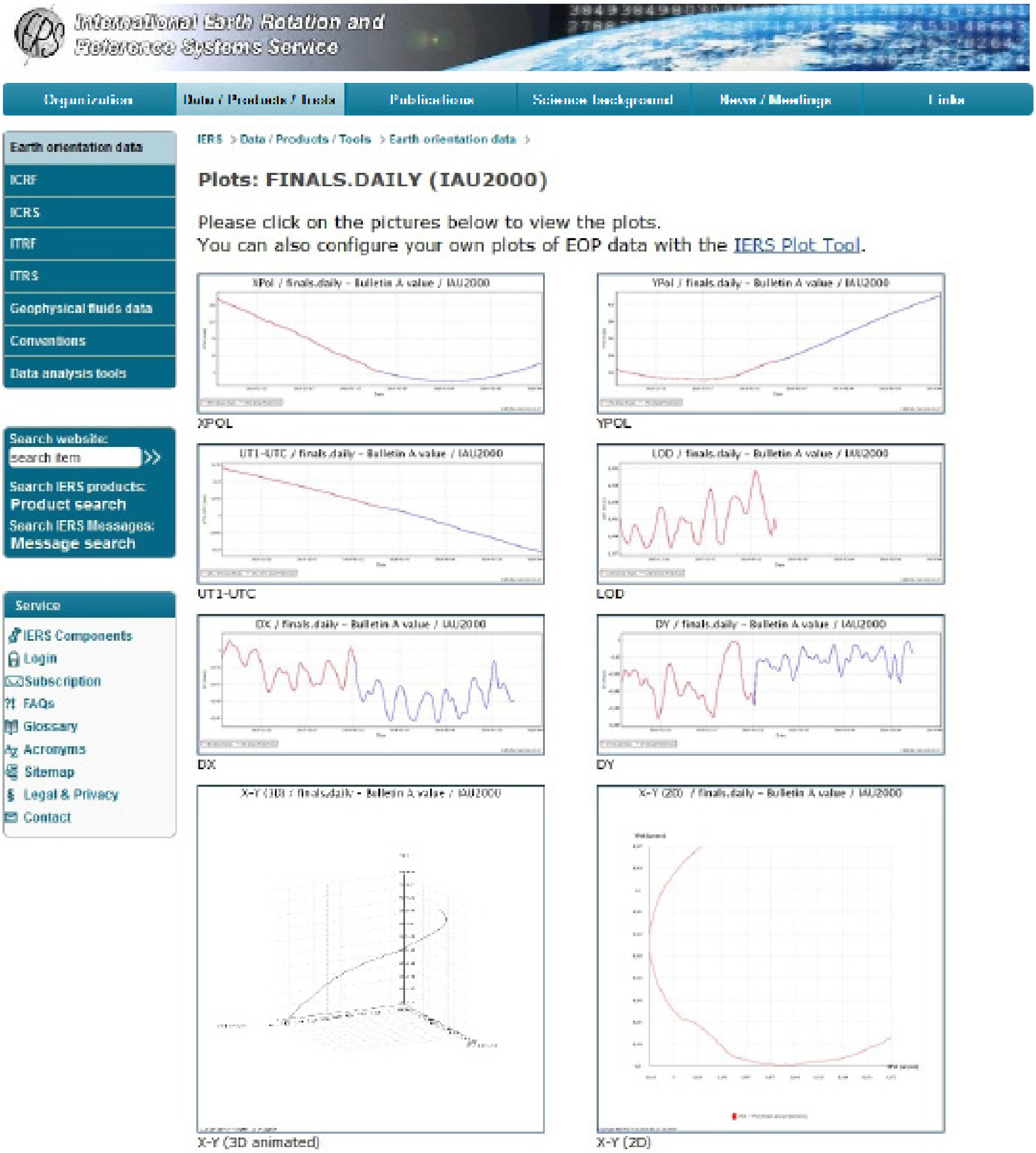


Fig. 1: Page at <www.iers.org> with plots for Bulletin A finals.daily series created with the IERS Plot Tool.

1), was improved and a web interface was created to make the tool interactive for all users. This tool allows users to configure 2D and 3D plots on the basis of IERS EOP data and to compare the different IERS EOP products on the basis of EOP 08 C04 (IAU2000A). The IERS Plot Tool was also expanded to create animated (rotating) 3D plots for the Earth orientation products. Examples are given in Figures 2 and 3.

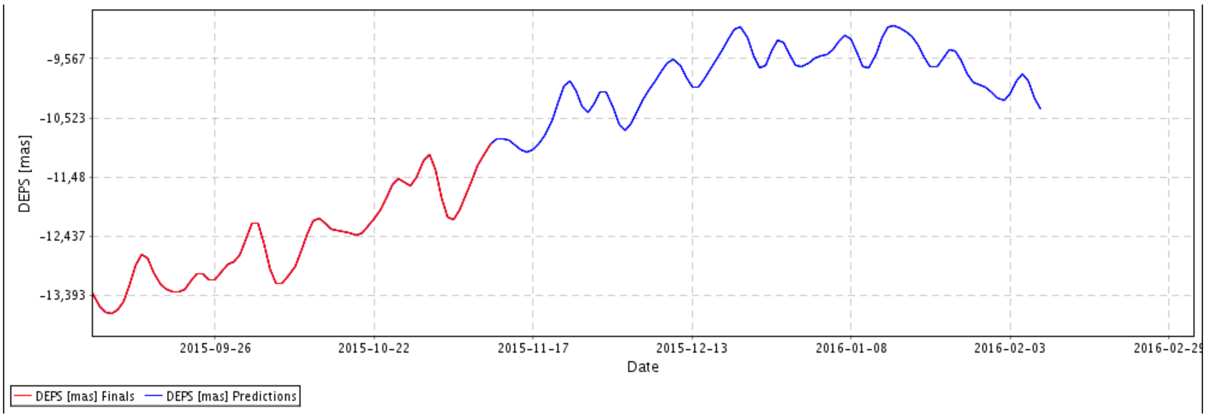


Fig. 2: Example of a plot of observed (red) and predicted (blue) values of δε (IAU 1980 model) from Bulletin A (finals.daily series) created with the IERS Plot Tool.

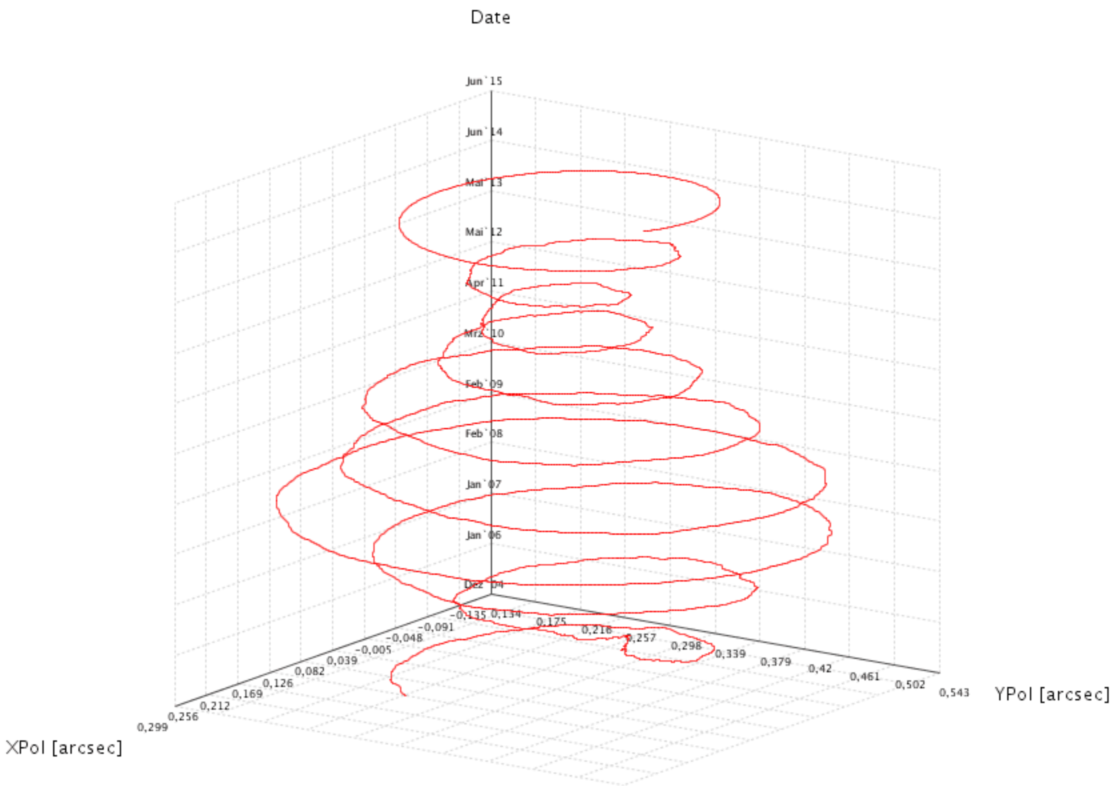


Fig. 3: Example of a 3D plot of pole coordinates x and y from Bulletin A (finals.all series) values created with the IERS Plot Tool. The web browser version of this plot rotates.

Staff in 2014

Dr. Daniela Thaller, *Director*
Sabine Bachmann, *scientist*
Dr. Wolfgang R. Dick, *scientist*
Sonja Geist, *technician*
Sandra Schneider-Leck, *technician*

Wolfgang R. Dick, Daniela Thaller, Sonja Geist

3.3 Analysis Coordinator

1. Introduction

In this report we outline the activities of the Analysis Coordinator during 2014. The main activities were running and summarizing the Unified Analysis Workshop (UAW) held in Pasadena, CA, June 27–28, 2014, in conjunction with the IGS Workshop. For a report on the UAW see Section 4. The future of the leap second continues to be addressed with no clear resolution to either retain or do away with them.

2. Action items for the Unified Analysis Workshop

Below are the main recommendations for further analysis from the 2014 Unified Analysis Workshop. There were 5 main areas investigated and in each area action items for further study were recommended. For each recommendation below we show in bold the component of the IERS that should take the lead in addressing and resolving the recommendation. It is suggested that small groups should be tasked with addressing the recommendation.

(1) Resolving the VLBI/SLR/DORIS scale differences

- There should be a re-assessment of the relativistic formulations for VLBI and satellite based systems. (Explore LLR and interplanetary tracking “scale differences”). **Conventions Center**
- Explore possible systematic height errors from radio telescope deformations. **IVS**
- Explore impact of range biases on SLR height estimates and the potential impact of blue sky (high atmospheric pressure) ranging. **ILRS**
- Explore antenna phase center model for satellite receiving antennas for DORIS system. **IDS**
- Re-accounting of atmospheric delay effects and pressure sensors. **Conventions Center**
- Exam the temporal behavior of the scale behavior within each technique to assess the variability of the scale estimates. **All Technique Centers**

(2) Geophysical Fluids: EOP

- Assessment of empirical and tide based models for diurnal and semidiurnal EOP variations. **Conventions Center**
- Assess non-tidal, high frequency EOP variations. Exam hourly estimates of EOP estimates from VLBI and GNSS after removal of tide models to assess the magnitude and consistency between the techniques. **IVS** and **IGS** to coordinate with possible ILRS contributions

(3) Geophysical Fluids: Loading

- Development of models for consistent deformation and gravity for atmosphere, hydrology and non-tidal ocean. **Global Geophysical Fluids Center**
- Assessment of error models of different loading models as a function of type and frequency. If possible, error estimates for the “signals” missing from the models should be determined. For example, hydrologic models often have 1-month time resolutions. What could be the magnitudes of the sub-monthly variations that are averaged by the models? **Global Geophysical Fluids Center**

(4) Analysis methods

- Determine the impacts of time variable gravity of the satellite-based techniques and make recommendations on how to best implement these types of models for operation data processing. **ILRS** and **IDS** lead; **IGS** to participate
- Re-assess the solid-Earth pole tide model being used in operational processing and make recommendations on how to best implement and update these models in the future. **Conventions Center**
- Gather analysis evidence for the impact of the ocean pole tide on satellite and geometric systems. For the satellite systems, make the assessment as a function of the altitude of the satellites being tracked. **ILRS** and **IGS**

(5) Monument stability

- Develop a list of monument site issues from the operators. Collocation and reference frame sites should be highest priority. Repeated site surveys (bar code leveling instrumentation and possibly tilt meter installation) if possible. **ITRS Combination Centers**

Thomas Herring

3.4 Technique Centres
3.4.1 International GNSS Service (IGS)

For various reasons it was not possible to prepare a report for the year 2014.

For IGS activities, see also the IGS web site at <www.igs.org> and the IGS Technical Report 2014 at <http://kb.igs.org/hc/en-us/articles/206257267-Technical-Report-2014>.

3.4.2 International Laser Ranging Service (ILRS)

Introduction

The International Laser Ranging Service (ILRS), established in 1998, is responsible for the coordination of Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) missions, technique development, network operations, data analysis and scientific interpretation. Here we summarize the status and developments in 2014. This year is a very special one for SLR because it marks the 50th year anniversary since the first successful tracking of a satellite target, on October 31, 1964, from a NASA Goddard tracking system deployed at what is today known as the Goddard Geophysical and Astronomical Observatory (GGAO), in Greenbelt, Maryland. The ILRS celebrated this historical event by organizing the 19th International Laser Workshop at Annapolis, Maryland over October 26–31, 2014, including a one-day visit of the Goddard campus and a tour of the GGAO facilities. The workshop's complete program including all presentations, posters and online proceedings can be found at <http://cddis.gsfc.nasa.gov/lw19/index.html>.

Network

The network of SLR/LLR stations (Figure 1), under the aegis of the ILRS, has been subject to change over the years. In 2014 the network expanded with the addition of several new sites, most of them deployed by Russia, in support of their GLONASS tracking network. Most of the new sites are filling gaps that were void of SLR stations for many decades (e.g. Brasilia, Brazil, Irkutsk, Russia, etc.). From a technical perspective, the quality

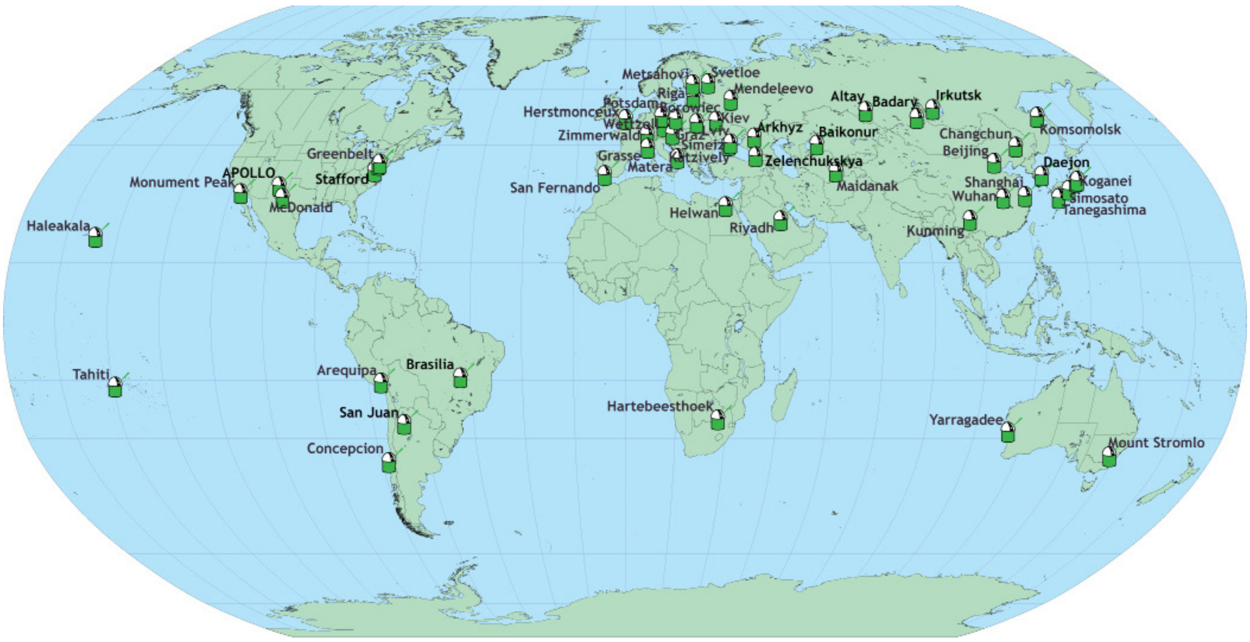


Fig. 1: The global network of SLR stations (status early 2015).

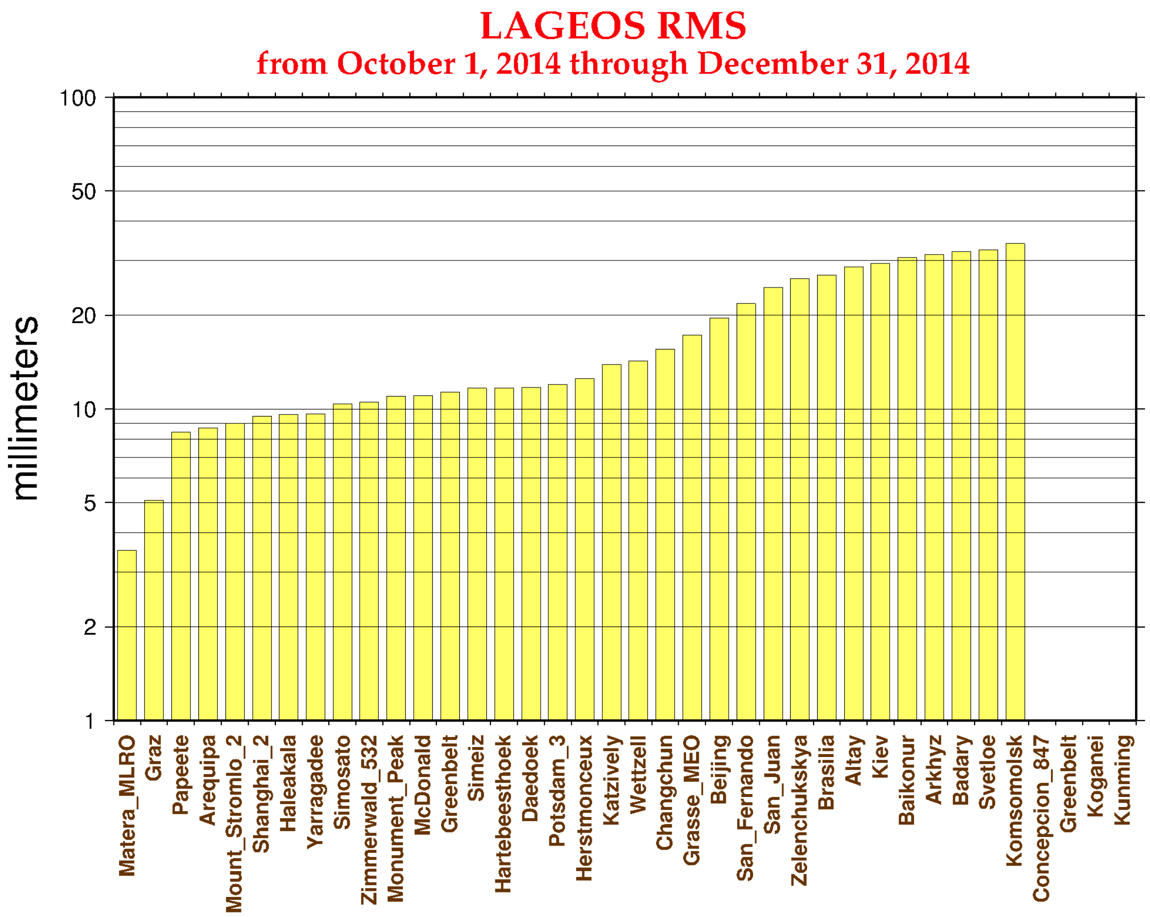


Fig. 2: Performance of the global network of SLR stations on LAGEOS (last quarter of 2014).

and quantity of the observations has improved drastically during the past decade. The single-shot precision of an average station today is better than 10 mm (for the best stations this number is a few millimeters, Figure 2). The absolute quality of the individual observations is at the 10 mm level, with a significant number of stations doing significantly better. Nearly all stations deliver normal points with a precision of 1 mm or better, a firm requirement for the GGOS-era network as outlined in the GGOS2020 document and several stations have upgraded to high repetition rate systems to meet such requirements. This allowed the modification of the Normal Point (NP) forming recipe to improve the efficiency and data yield of the network, limiting the tracking to the minimum number of single shots required to reach the 1 mm NP precision. Examination of the tracking over the past year indicates that the tracking of targets increased without loss of data accuracy or other impact on the computed orbital products. NASA is moving forward to begin the production of next generation Space Geodesy SLR systems (SGSLRs) that will replace the current network and fill

Table 1: ILRS Network Tracking Statistics for 2014.

		Number of Passes			
Site Name	**Station**	**Low**	**LAGEOS**	**High**	**Total**
Altay	1879	161	241	1,733	2,135
Arequipa	7403	2,848	501	0	3,349
Arkhyz	1886	478	321	1,016	1,815
Badary	1890	1,763	489	353	2,605
Baikonur	1887	26	396	587	1,009
Beijing	7249	925	257	556	1,738
Brasilia	7407	0	115	239	354
Changchun	7237	9,602	2,403	7,192	19,197
Concepcion	7405	115	62	3	180
Daejon	7359	983	257	393	1,633
Grasse	7845	525	468	1,273	2,266
Graz	7839	3,233	974	2,807	7,014
Greenbelt	7105	4,908	1,438	1,390	7,736
Greenbelt	7125	36	45	28	109
Haleakala	7119	1,389	564	0	1,953
Hartebeesthoek	7501	2,675	1,456	1,133	5,264
Herstmonceux	7840	3,010	1,128	2,429	6,567
Katzively	1893	1,431	273	10	1,714
Kiev	1824	1,349	326	11	1,686
Koganei	7308	73	34	76	183
Komsomolsk	1868	34	111	1,110	1,255
Kunming	7820	783	167	0	950
Matera	7941	2,569	1,634	2,588	6,791
McDonald	7080	1,015	467	439	1,921
MonumentPeak	7110	4,779	1,244	1,170	7,193
MountStromlo	7825	6,902	2,091	3,311	12,304
Potsdam	7841	2,407	550	233	3,190
SanFernando	7824	299	48	0	347
SanJuan	7406	2,149	955	711	3,815
Shanghai	7821	1,725	505	1,496	3,726
Simeiz	1873	729	243	95	1,067
Simosato	7838	1,002	374	80	1,456
Svetloe	1888	1,158	943	474	2,575
Tahiti	7124	557	223	418	1,198
Wettzell	8834	3,945	1,217	3,527	8,689
Yarragadee	7090	16,792	4,304	8,064	29,160
Zelenchukskaya	1889	440	278	897	1,615
Zimmerwald	7810	5,027	1,738	3,916	10,681
Totals:	38 stations	82,500	34,182	49,758	166,440

gaps in the network as needed. Russia's expansion and upgrade of their network continues, with new deployments announced for the next year at Havana, Cuba and Haifa, Israel. All sites will be co-located with GNSS systems primarily intended to tie the GLONASS monitoring network with that of SLR. This addition will eventually improve tremendously the tie between the SLR- and GNSS-, VLBI-implied frames.

Statistics of the SLR data collected as pass segments during the calendar year 2014 are summarized in Table 1. For each of the contributing stations the tracked passes are broken down in three categories of target orbits: Low Earth Orbiters (LEO), LAGEOS 1 & 2, and the High Earth Orbiters (HEO), GPS, GLONASS, ETALON, GIOVE-A/B, GALILEO, BeiDou, and the Moon.

Of all the active ILRS observatories (~38 in 2014), very few are technically equipped to track retro-reflector arrays on the surface of the Moon or spacecraft orbiting around the Moon. In 2014, only three LLR sites collected ranging data to the Moon: The Observatoire de la Côte d' Azur, France (430 NP), the APOLLO site in New Mexico, USA (212 NP) and the Matera Laser Ranging station in Italy (6 NP). Unfortunately, no NP data were obtained at the McDonald Observatory in Texas, USA. This means that the time series of LLR tracking that ran for four decades at McDonald was interrupted.

The measurement statistics of 2014 (Figure 3) shows that about two thirds of the data have been collected at the French MeO site near Grasse and about one third of the data at APOLLO. Figure 4 illustrates the statistics for the observed retro-reflectors, where a much better coverage of all reflectors could be achieved compared to previous years. Nevertheless, most of the data have been obtained by tracking the big Apollo 15 reflector (56%). Figure 5 shows the entire LLR data set from 1970 to 2014 indicating the

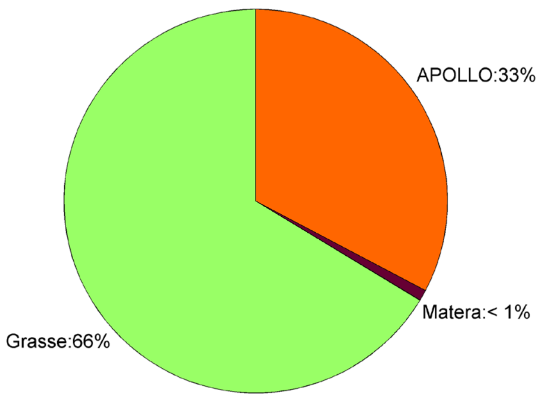


Fig. 3: Observatory statistics in 2014

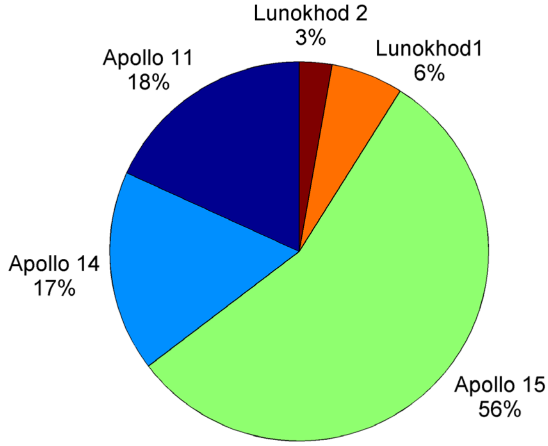


Fig. 4: Retro-reflector statistics in 2014

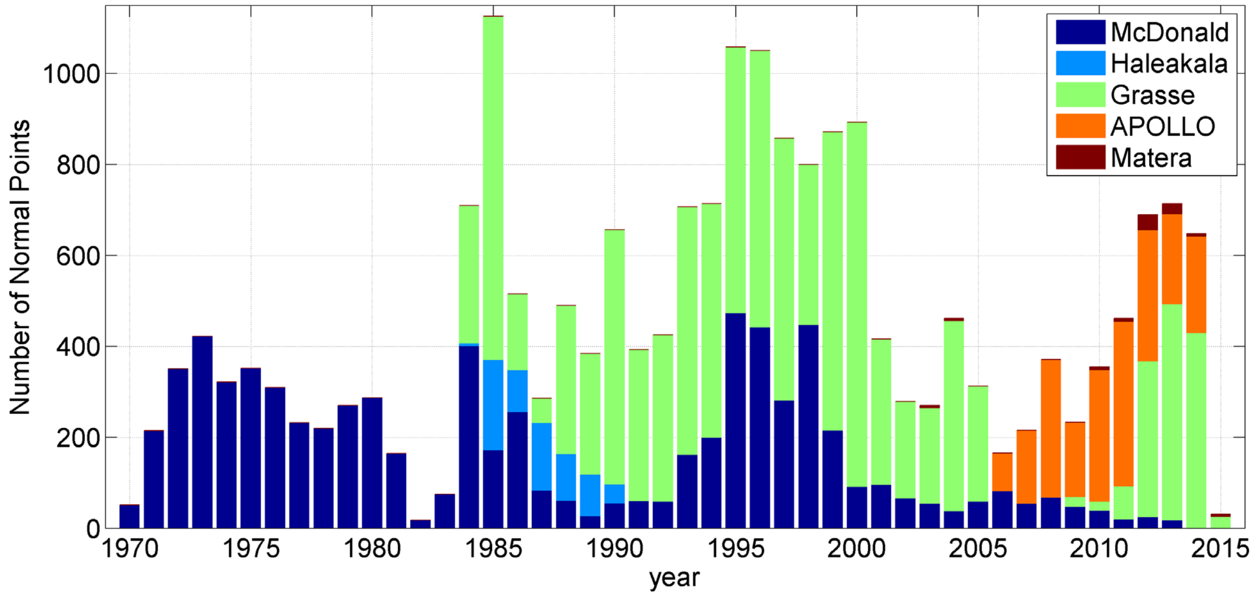


Fig. 5: Data yield of the global LLR network of stations (up to 2014). Note the increasingly significant contribution of Grasse's MeO system upon its return to operations in 2011.

amount of data collected by each of the active LLR sites in each year. It is about 21,000 normal points in total. After several years with less LLR NP, one has reached quite a good level of more than 600 NP per year in the past three years.

LLR data analysis is carried out by a few major LLR analysis centers: Jet Propulsion Laboratory (JPL), Pasadena, USA; Center for Astrophysics (CfA), Cambridge, USA; Paris Observatory Lunar Analysis Center (POLAC), Paris, France; Institute of Geodesy (IfE), University of Hannover, Germany. In the last years, the National Institute for Nuclear Physics (INFN), Frascati, Italy, and the Graduate University for Advanced Studies (SOKENDAI), Japan, increased their activities to analyze LLR data.

One general objective of LLR analysis is to achieve an accuracy level of ~1 mm, today it is still at the centimeter level. The various analysis centers continued their comparison initiative to mutually improve the various codes. Recent activities also comprise comprehensive simulations to show the potential benefit of improved tracking from further observatories and/or to new reflectors, see e.g. Hofmann et al. (2014).

Above all, LLR remains one of the best tools to support lunar science, to study the Earth–Moon dynamics and to test General Relativity in the solar system (Müller et al. 2014). LLR analysis steadily reduces the margins for a possible violation of Einstein's theory of relativity and impressively underpins its validity – now in the 100th year of its existence.

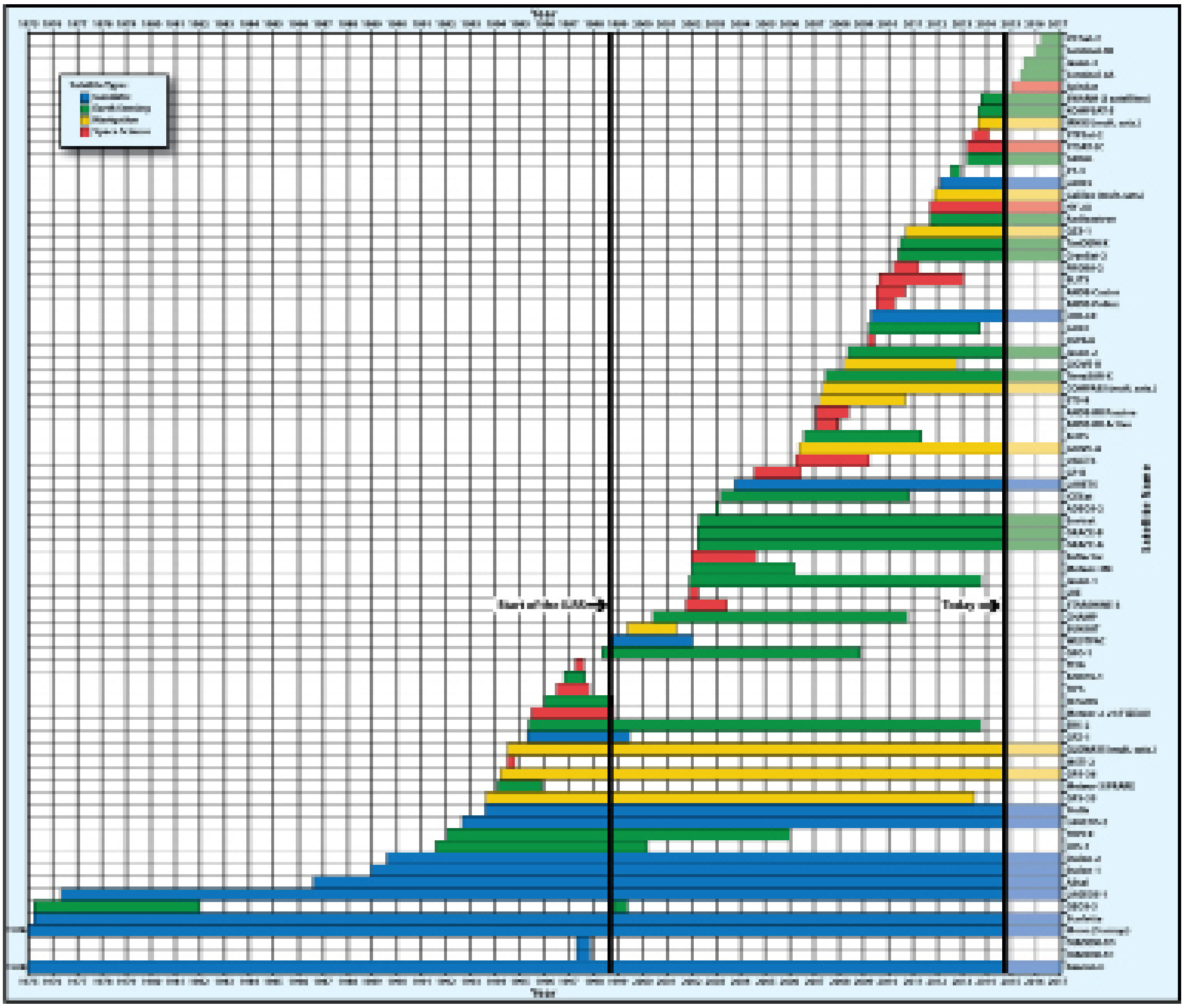


Fig. 6: The currently tracked SLR missions (status as of late 2014).

Missions

In 2014, a total of ~38 missions including the Moon (over 70 targets!) were being tracked by SLR/LLR (Figure 6). Of these, only about 1/3 are geodetic type targets (cannonball satellites), about one half are navigation satellites and the rest are mainly Earth Observation missions, along with a small number of experimental space science missions. In 2014 the steady increase of tracking multiple GNSS targets continued for a fourth year in a row and two dedicated tracking campaigns organized through the ILRS/GGOS LARGE Working Group (LAser Ranging to GNSS s/c Experiment), resulted in a further increase in data yield from such missions.

During 2014 the new missions that were launched as shown in Table 2, were primarily spacecraft of GNSS Constellations. SpinSat is an experimental mission with a rather demanding low orbit, requiring special tracking procedures and a good set of predictions,

Table 2: ILRS Supported Missions Launched or Initiating Tracking in 2014.

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (sec)	Altitude (Km)	Inclination (deg)	First Data Date
IRNSS-1B	1401701	3302	39635	9	300	42,164	29	2014-Apr-14
GLONASS-132	1401201	9132	39620	9	300	19,140	65	2014-Apr-17
Galileo-201	1405001	7201	40128	9	300	17,300-25,900		2014-Dec-05
IRNSS-1C	1406101	3303	40269	9	300	42,164	29	2014-Oct-09
SpinSat	9806714	1076	40314	1	5	425	51.6	?

including frequent updates to counter the severe atmospheric drag effects it will be undergoing.

Despite the small decrease in active stations in 2014 and a significant increase in tracked targets, the ILRS network has increased its productivity tremendously to maintain the data yield and even significantly increase it (~15%) in comparison to recent years (Figure 7). A major contributor in the recent years' data yield increase is the fact that several stations now track all GNSS satellites. The results of the first GNSS target tracking campaign

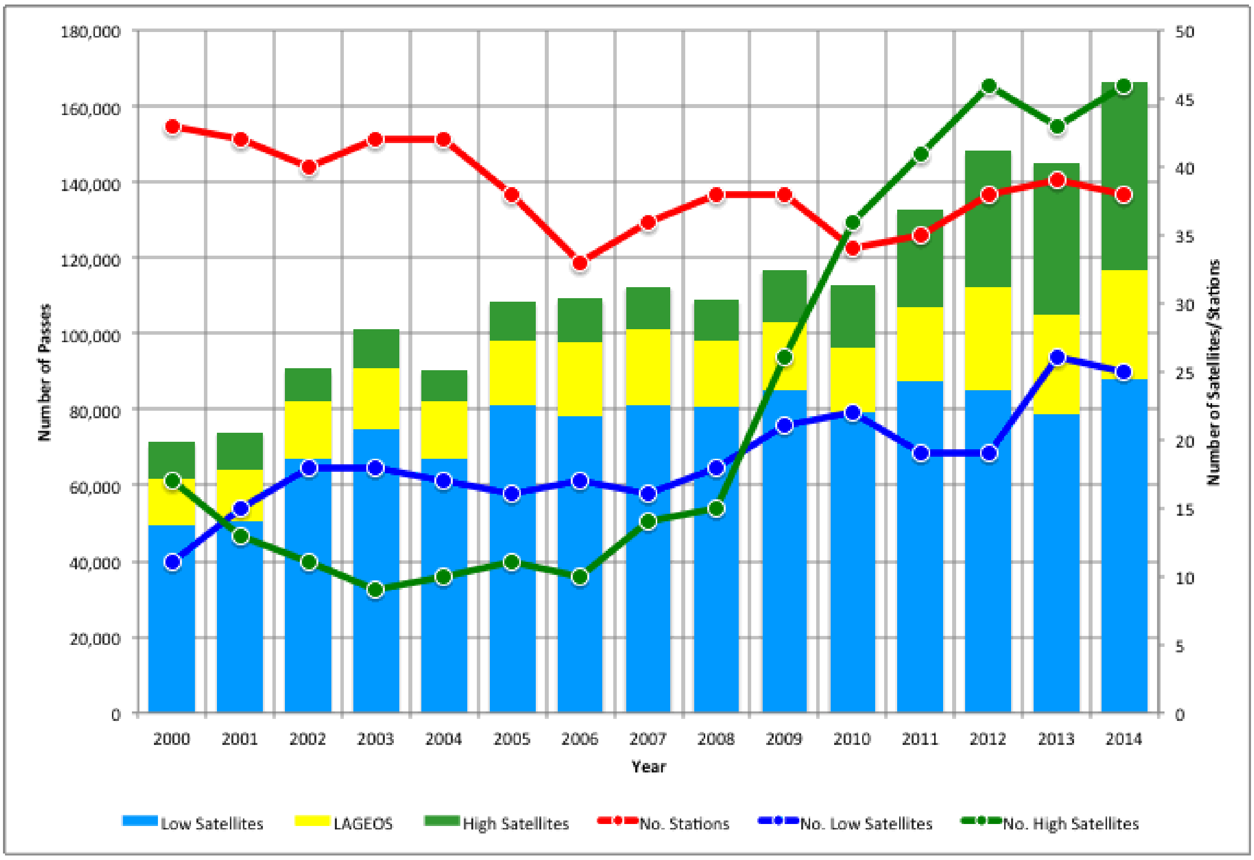


Fig. 7: ILRS network data yield by target type since 2000 (by end of 2014).

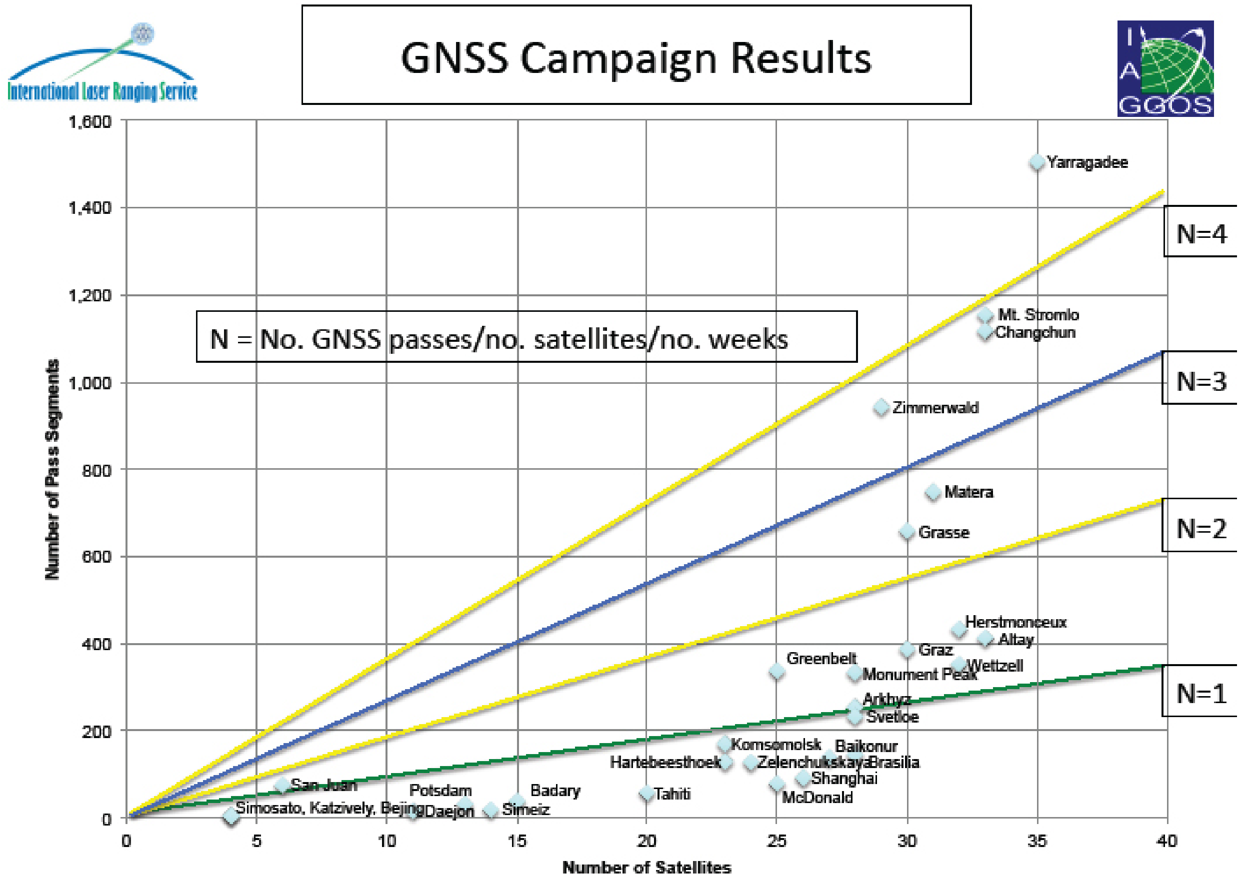


Fig. 8: Tracking data distribution statistics for the first GNSS target tracking campaign (2014).

organized by LARGE Working Group (August through September 2014) indicated that only a few sites were able to track significant number of passes on multiple targets and over the several weeks of the campaign (Figure 8). This prompted the announcement by the ILRS Central Bureau of a follow-on campaign with a more focused set of goals and more frequent reminders to the stations about the importance of meeting these goals. The second campaign started on November 22, 2014 and was initially expected to end by the end of January 2015. This time period however included holidays and less than optimal tracking opportunities, the ILRS CB thus further extended the second campaign to the end of February 2015.

Analysis and science

The Analysis Working Group (AWG) delivered a preliminary version of the ILRS contribution to ITRF2013 just prior to the European Geosciences Union meeting in April 2014. After an initial evaluation by the ITRS Combination Center (IGN), the issues identified were corrected and a new product, based on several ACs providing a

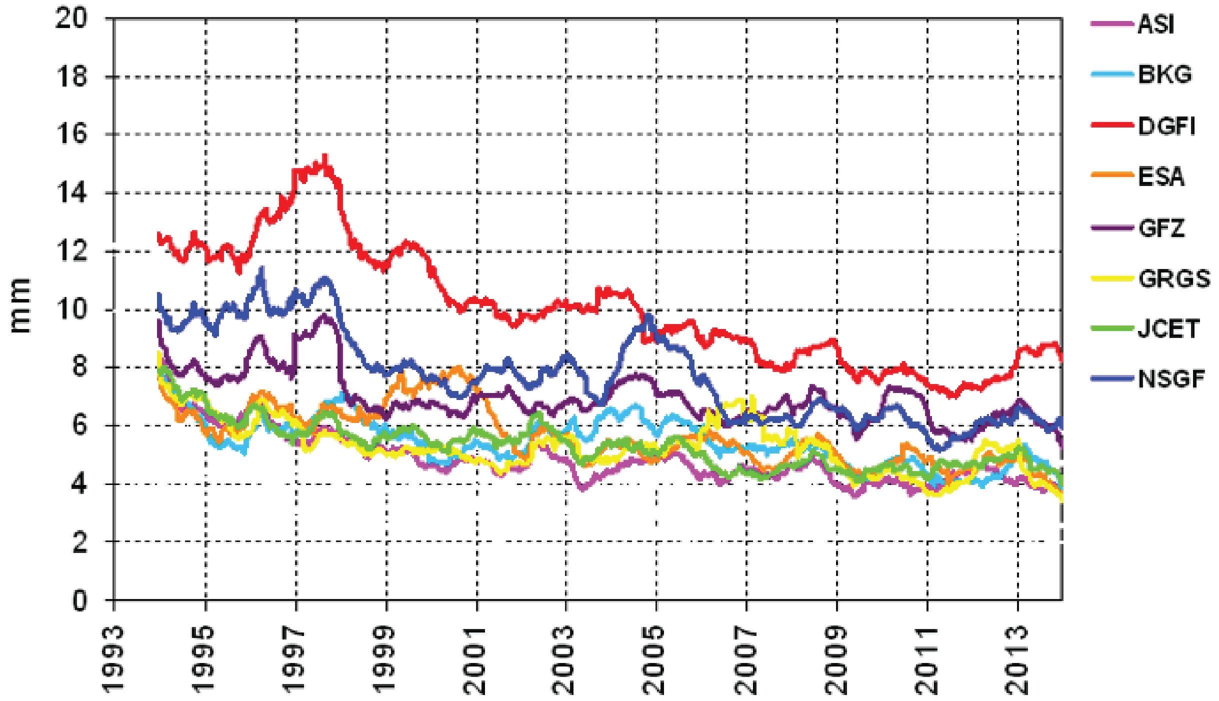


Fig. 9: Three-dimensional weighted RMS in position with respect to the official ILRS-A combination (running mean to demonstrate differences between different ACs).

complete re-analysis of the data, was submitted to the ITRS, in late October 2014, just prior to the 19th International Laser Workshop. The new submission was a significant improvement to the preliminary version, although as seen from Figure 9, there were still some intra-technique issues with some of the contributing ACs. The evaluation of this new version helped in identifying the reasons behind these inconsistencies and the three ACs involved corrected the problems and resubmitted new contributions to be included in the upcoming final combination for ITRF2014 in 2015.

Despite the issues with a few ACs, the delivered ITRF2013 product exhibited a very good quality in the definition of the origin (Figure 10) and the scale of the SLR-only TRF, which were described in a presentation of the ILRS Primary Combination Center (Luceri et al., 2014). The modeling changes and improvements that were adopted prior to the re-analysis for ITRF2013 were detailed in a follow-up presentation (Pavlis et al., 2014). A very small "step" in the time series of TY and the scale, immediately after the beginning of 2010 is under investigation, although it is generally believed to be an artifact of the station geographical distribution.

During the workshop, the ITRS presented an official solicitation for an extension of the new model to include all of 2014, renaming thereby the final product to ITRF2014. All of the ACs present at the workshop agreed to support this extension and meet the new

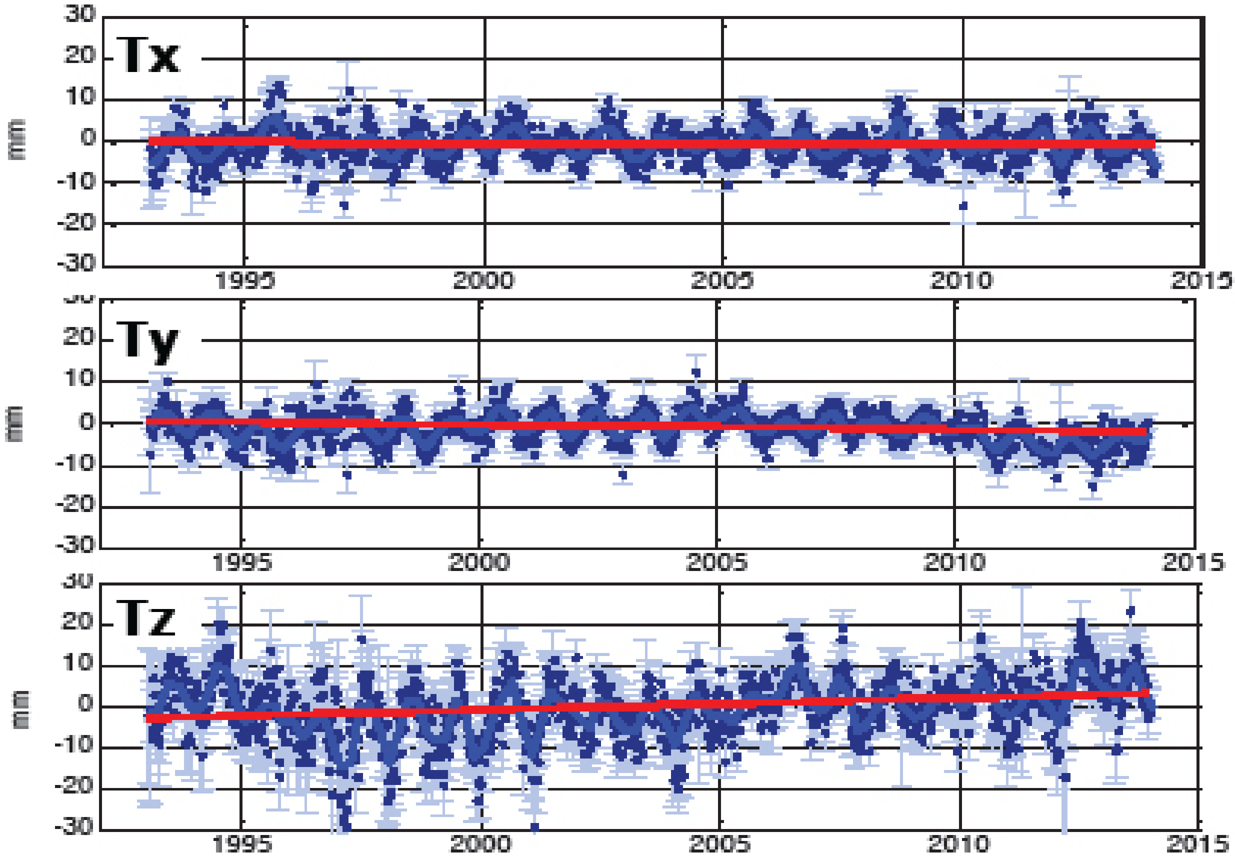


Fig. 10: Weekly variations of the origin with respect to the origin of SLRF2008 (ITRF2008).

deadline for a final ILRS product delivery date of the end of February 2014. Several Pilot Projects (PP) that were to be completed after the ITRF2013 development process, were postponed until after the delivery and finalization of ITRF2014.

Meetings

The ILRS held an extraordinary international laser workshop (19th) in Annapolis, MD, USA, October 26–31, 2014, which was already discussed in the introduction. The first day of the workshop was devoted to talks with a historical perspective, from the pioneers of the technique. NASA and ILRS presented them with awards for their contribution to the establishment of the technique fifty years ago. The awards were presented by the ILRS chairman Dr. G. Bianco of ASI/CGS, Matera, Italy and the ILRS Central Bureau director, Dr. M. Pearlman of the Smithsonian Astrophysical Observatory, Cambridge, MA (Figure 11). The AWG held two meetings in 2014, one prior to the EGU General Assembly, on April 28 (<http://ilrs.gsfc.nasa.gov/science/awg/awgActivities/index.html>), and one prior to the 19th ILW in Annapolis, on October 26 (<http://ilrs.gsfc.nasa.gov/science/awg/awgActivities/index.html>). The ILRS Governing Board met once in 2014, during the Anna-

Fig. 11: The surviving team members of the pioneering group that ran the first successful SLR experiment at Goddard, MD on the evening of October 31, 1964. With them are the ILRS Chairman (first on the left) and the ILRS CB Director (last on the right), after the special award ceremony in Annapolis, MD.

polis workshop on October 26 (<http://ilrs.gsfc.nasa.gov/about/organization/govboard/gbmeeting_reports.html>). The ILRS has already announced a Technical Workshop for 2015, to take place the last week of October in Matera, Italy. Furthermore, in 2016, the 20th International Laser Workshop will take place in Potsdam, Germany, hosted by GFZ.

Publications

Access all the presentations, posters, and proceedings papers presented at the 19th International Laser Workshop in Annapolis, MD from the official ILRS page for the workshop:

<http://cddis.gsfc.nasa.gov/lw19/Program/index.html>

Hofmann, F., J. Müller, L. Biskupek, Mai, E., and Torre, J.-M.: Lunar Laser Ranging – What is it Good for? Proceedings of the 18th International Workshop on Laser Ranging, Fujiyoshida, Japan, 11–15 November 2013, Contribution No. 13-0402, 2014 (available on ILRS meeting website).

Luceri, V. E. C. Pavlis, D. König, B. Pace, M. Kuzmicz-Cieslak, and G. Bianco: The ILRS Contribution to the Development of ITRF2013, 19th International Workshop on Laser Ranging, Annapolis, MD, October 26-31, 2014 (available on ILRS meeting website).

Müller, J., L. Biskupek, F. Hofmann, and E. Mai: Lunar Laser Ranging and Relativity. Book chapter in “Frontiers of Relativistic Celestial Mechanics”, vol. 2 (ed. by S. Kopeikin), de Gruyter, p. 99–146, 2014.

Pavlis, E. C., V. Luceri, M. Kuzmicz-Cieslak, D. König, and G. Bianco: Modeling Improvements in the ILRS Reprocess for ITRF2013, 19th International Workshop on Laser Ranging, Annapolis, MD, October 26–31, 2014 (available on ILRS meeting website).

An extensive publication list of interest to ILRS associates can be found at the ILRS website:

<http://ilrs.gsfc.nasa.gov/about/reports/biblio/bibliography.2014.html>

Erricos C. Pavlis, Jürgen Müller

3.4.3 International VLBI Service (IVS)

IVS Organization and Activities

During 2014, 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. Some highlights of the IVS organization and activities were:

Event	*Location*	*Date*
8th IVS General Meeting	Shanghai, China	March 2–7, 2014
15th IVS Analysis Workshop	Shanghai, China	March 7, 2014
31st IVS Directing Board meeting	SHAO, Shanghai, China	March 8, 2014
32nd IVS Directing Board meeting	GSI, Tsukuba, Japan	October 27, 2014
3rd International VLBI Technology Workshop	Groningen, The Netherlands	November 10–13, 2014

- In the summer of 2014 the IVS published the 2013 Annual Report. Furthermore, three IVS newsletters were published in April, August and December to keep the community informed about IVS activities.
- In March 2014 the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) was founded. It is a group which fosters VLBI activities on a regional basis, similar to the European VLBI Group for Geodesy and Astrometry (EVGA).

Network Stations and Observing Sessions

A total of 248 geodetic/astrometric 24-hour sessions were observed during the year 2014. The number of observing sessions coordinated by IVS was about ~4.7 days per week, a significant increase over previous years attributable to the increase of the number of regional AUSTRAL sessions and the observation days of the CONT14 campaign. The major observing programs during 2014 were:

IVS-R1, IVS-R4

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

Intensive

Daily 1-hour UT1 Intensive measurements were 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).

IVS-T2

Bi-monthly sessions coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn, Germany, with 15–17 stations per session. Seven of these sessions were observed to monitor the TRF with all IVS stations. On November 11, 2014, the 100th session of this series was observed. Fig. 1 depicts the distribution of the sessions and the increase in the number of telescopes participating.

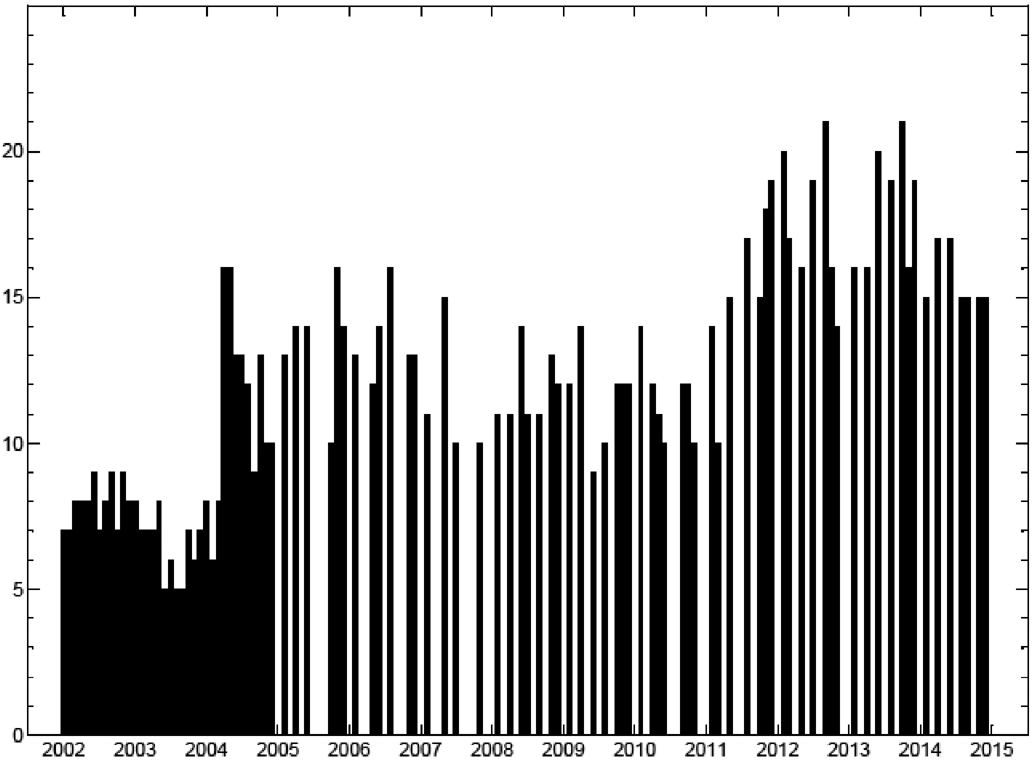


Fig. 1: Number of telescopes participating in the IVS-T2 sessions over the course of time.

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 for extending the CRF by observing 'new' sources. Twelve sessions were observed for the maintenance of the CRF in 2014.

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 6 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 2014.

IVS-OHIG The purpose of the IVS-OHIG (Southern Terrestrial Reference Frame) sessions is to tie together optimally the sites in the southern hemisphere. In 2014 six OHIG sessions were observed.

APSG The Asia-Pacific Space Geodynamics (APSG) program operated two sessions in 2014.

AUSTRAL In 2014, 73 Austral sessions were observed. The purpose is to determine the station coordinates and their evolution in the Australia (AuScope) and New Zealand geodetic VLBI network.

JADE The JApanese Dynamic Earth observation by VLBI (JADE) had five sessions during 2014. These sessions included the dedicated 32-m dish at Tsukuba and are designed to monitor the domestic network within the ITRF.

IVS-R&D Twelve research and development sessions were observed in 2014. The goals of the 2014 R&D sessions included the testing of the observing mode for the Continuous VLBI Campaign 2014 (CONT14), the observation of link sources between Gaia and the ICRF2, and the observation of the Chang'E-3 lander with VLBI.

CONT14 The continuous VLBI campaign CONT14 was observed May 6–20, 2014, and involved 17 stations worldwide. The data were correlated at the Bonn correlator.

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 Radio Astronomy in Bonn (Germany) and the correlator at the Geospatial Information Authority of Japan (GSI) in Tsukuba continued their efficient processing of the data recorded for the IVS. The majority of the 24 hour sessions were processed by the Bonn and Washington correlators. The Bonn correlator used the DiFX software correlator and processed, e.g., the R1, EURO, T2, Int3, and OHIG sessions. The Washington correlator used the Mark IV hardware correlator until October 2014 for processing, e.g., the R4, Int1, and CRF sessions. They then transitioned to using the DiFX software correlator. The Haystack correlator processed R&D sessions and some T2 sessions. The Int2 and JADE sessions were processed at the Tsukuba correlator.

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 15th IVS Analysis Workshop was held in Shanghai, China on March 7, 2014. In this workshop, the coordination of IVS routine data analysis was discussed as well as a number of individual items concerning geodetic and astrometric data analysis in the framework of the IVS. An outcome of the workshop was the request that all software packages used for IVS add the abilities to 1) estimate Earth rotation parameters (ERP) as piece-wise linear functions and 2) set the epochs of the estimates to full integer hours. The time frame for adding these abilities was set with the end of 2014.

The Combination Center at BKG/DGFI continued to perform the combination of session-based results from the individual IVS Analysis Centers on an operational basis. The combination strategy is based on the combination of normal equations; it is an adaptation of the combination process developed by IGG Bonn.

An initial set of VLBI SINEX files for the ITRF generation was submitted to the IERS ITRS Center at the beginning of December 2014. Ten IVS Analysis Centers had contributed their SINEX files to create the combined solution. One of the main tasks in 2014 was to gather the SINEX contributions and to make sure that all contributions meet the IVS analysis specifications for ITRF contributions. In the course of the year, it turned out that the ITRF could be extended by another year, including sessions until the end of 2014 (instead of 2013 as foreseen in the original ITRF call for participation). With this change, an additional IVS Analysis Center agreed to contribute.

Technology Development

The main focus of IVS technology development over the past year has been to achieve operational readiness for broadband observing as part of the VBLI Global Observing System (VGOS). This includes not only the development and proliferation of broadband systems but also the development of software and processes to enable efficient, and eventually automatic, operation of the VGOS stations and correlators. Already, a number of fully compliant (or nearly compliant) VGOS antennas have been constructed (many of these having already achieved first light and first fringes) with several more expected to come on line in the next year or two. The challenge is to ensure that signal chains are available for these antennas; that operating modes of the various systems are VGOS compliant, interoperable, and sufficiently robust against RFI; and that systems can be controlled and thoroughly monitored remotely.

Automation and remote control are very important aspects of VGOS. With the expectation of 24/7 operations and a sharp rise

Table 1: Progress in the build-out of the VGOS network as of December 2014.

Station	Recent milestone	Broadband readiness
GGAO	Test observations	now on fast RT
Westford	Test observations	now on legacy RT
Wettzell	Receiver tests	early 2015
Yebes	First fringes on X-band	late 2015
Noto	Receiver under construction	end 2015 on legacy RT
Ishioka	First fringes	end 2016 (initial S/X/Ka)
Santa Maria	RT constructed at site	2016
Badary	RT constructed at site	2015 (S/X/Ka)
Zelenchukskaya	RT constructed at site	2015 (S/X/Ka)
Kokee Park	RT being assembled at factory	2016
AuScope	Funding for upgrade secured	2016 on fast RTs
Tenerife	RT assembled at factory	2017
Ny Ålesund	Civil construction underway	2018

in the number of observations per day, it is necessary (in order to keep operating costs at a reasonable level) to make all processes (including schedule generation, station operation, correlation, fringe processing, and analysis) as automated as possible. A necessary step to achieve automation and remote control is to have a language to concisely and completely describe the instrumentation, operating modes and schedule for a session. This has been the role of the VEX language over the past decades. However, with the advent of VGOS and the new broadband systems, instrumentation and operating modes, which had not been conceived of when the original version of VEX was developed, now need to be handled. As a result, over the past few years, a new version of VEX, called VEX2, has been developed. VEX2 was completed this year; it went through a brief period of community consultation; and it is now being used to write software to control instrumentation and processes in the complete VGOS operational chain.

Dirk Behrend, Axel Nothnagel

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. Finally, we will present other activities related to meetings and publications.

1 DORIS system

1.1 DORIS satellites

During this report period (2014), the number of DORIS satellites has remained the same as the previous year at five (see Table 1).

Two missions with DORIS onboard are planned for 2015: Jason-3 and Sentinel-3A. In the same year, SPOT-5's mission will end, and with it, the last DORIS instrument of 2nd generation. Afterwards, the constellation will be only composed of DGXX receivers.

Some other DORIS missions are under development and should guarantee a constellation with at least 4 DORIS contributor satellites through 2030:

- Jason-CS (Eumetsat/ESA/CNES) is expected from 2020
- SWOT is foreseen for 2020

1.2 DORIS network

The DORIS network maintained a high level of performance: many prompt and effective maintenance operations (equipment replacement) and the return to service of Socorro eagerly awaited since several years made it possible to keep up the network availability rate with a 91% annual mean of operating stations.

As regards the ground equipment, the deployment of the remote control system allowing more rapid reaction to hardware failure

Table 1: DORIS data available at IDS Data Centers. As of December 2014

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	24-JUN-13	Remote sensing
SPOT-5	11-JUN-02	–	Remote sensing
Jason-1	15-JAN-02	21-JUN-13	Altimetry
ENVISAT	13-JUN-02	08-APR-12	Altimetry, Environment
Jason-2	12-JUL-08	–	Altimetry
Cryosat-2	30-MAY-10	–	Altimetry
HY-2A	1-OCT-11	–	Altimetry
SARAL	14-MAR-13	–	Altimetry

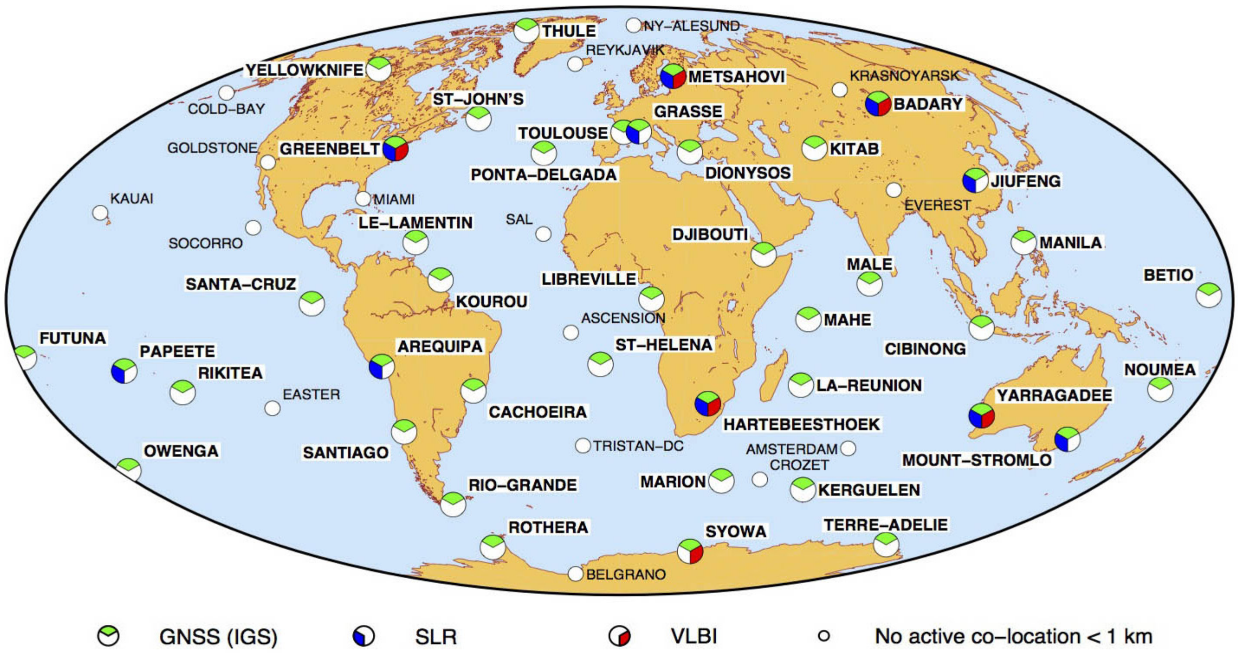


Fig. 1: The permanent DORIS network – 55 stations – and co-location with other IERS techniques (as of Dec. 2014).

is mostly complete. A new antenna type begins to roll out across the network. The letter "C" appears at the end of acronyms when this antenna type is used. This antenna is the same as the former one but the manufacturing process has been consolidated with more stringent specifications in order to better characterize the relative position of all the characteristic points of the antenna and draw up a more realistic error budget.

Efforts continued in the field to improve the monument stability at any new installation and to carry out high precision local tie surveys.

The main highlights for 2014 are:

- Due to recurring maintenance issues, two stations have been decommissioned: Gavdos (Greek island part of Crete) in March and Port Moresby (Papua New Guinea) in May 2014.
- With a view to move Easter and Santiago stations, reconnaissance in Chile.
- Major renovation with a shift of 260m in Socorro island in Mexico, back to operation after 5 years of inactivity.
- New site Owenga replacing Chatham in New Zealand.
- With a view to installing a new station, Wettzell in Germany was visited.

With regard to the off-network stations dedicated to IDS for scientific purposes, objectives and priorities have been redefined at the beginning of that year as follows:

Table 2: Composition of the IDS Governing Board (January 2013 – December 2014)

Name	Institution	Country	Mandate
Richard Biancale	CNES	France	Member at large
Pascale Ferrage	CNES	France	System representative
Frank Lemoine	GSFC	USA	Analysis Coordinator
Brian Luzum	GSFC	USA	IERS representative
Guilhem Moreaux	CLS	France	Combination Center representative
Carey Noll	GSFC	USA	Data flow Coordinator
Michiel Otten	ESOC	Germany	IAG representative
John Ries	U. Texas/CSR	USA	Member at large
Jérôme Saunier	IGN	France	Network representative
Laurent Soudarin	CLS	France	Director Central Bureau
Pascal Willis (chair)	IGN/IPGP	France	Analysis Center representative

- Wettzell, Germany: 4 techniques GGOS site; DORIS station installation planned in 2015
- Guam island, North Pacific Ocean: IGS “GUUC” + tide gauge co-location
- Sejong, Korea: future 4 techniques GGOS site

2 IDS Governing Board

In accordance with the Terms of Reference of the IDS, two positions within the Governing Board became vacant at the end of 2014: the position of Frank Lemoine as the Analysis Coordinator, and the position of John Ries as one of the Members at Large. Both have served for two terms consecutively, and therefore cannot be a candidate to a seat for another term. After the elections organized in Fall 2014, the new members elected by the IDS Associates to serve for the next four-year term 2015–2018 are:

- Hugues Capdeville (CLS)/Jean-Michel Lemoine (CNES) as Analysis Coordinator,
- Marek Ziebart (UCL) as a Member at Large.

It is important to note that Hugues Capdeville and Jean-Michel Lemoine will share together the responsibility and the work of the Analysis Coordination. From January 1st 2015, the tandem can be contact at <ids.analysis.coordination@ids-doris.org>.

The Governing Board and Central Bureau would like to friendly and warmly thanks Frank and John for their valuable contribution to the IDS. The composition of the new Governing Board is given in Table 2.

3 IDS Central Bureau

Address: <http://ids-doris.org/webservice>

3.1 DOR-O-T, the IDS Webservice

In September, the Central Bureau announces the launch of the IDS web service named DOR-O-T for DORis Online Tools (pronounced like the French given name Dorothée). The current version provides tools to browse time series in an interactive and intuitive way. It includes a network viewer to select sites and a family of plot tools to visualize the following time series: (1) station position differences at observation epochs relative to a reference position; (2) DORIS data residuals and the amount of available station observations as deduced from the CNES Precise Orbit Ephemeris processing, (3) outputs of the IDS Combination Center analysis, such as the Helmert parameters, and the WRMS. In addition to visualizing DORIS station coordinate time series, the web service also incorporates the time evolution of GNSS stations that are in co-location with DORIS, thanks to collaboration with the IGS Terrestrial Reference Frame Combination Center.

3.2 IDS Web and ftp sites

The IDS Central Bureau (CB) maintains the IDS web (<http://ids-doris.org>) and ftp (<ftp://ftp.ids-doris.org/pub/ids>) sites.

The main updates of 2014 are reported hereafter.

- The presentations of the AWG meeting held in Paris, France, March 26–27, were put on line on a dedicated page: <http://ids-doris.org/report/meeting-presentations/ids-awg-03-2014.html>
- The presentations of the IDS Workshop held in Konstanz, Germany, October 27–28, have been made available: <http://ids-doris.org/report/meeting-presentations/ids-workshop-2014.html>
- The data analysis summary of the DORIS weekly SINEX series submitted by the Analysis Centers and used for the DORIS contribution to ITRF 2014 is shown in a table: <http://ids-doris.org/contribution-itrf2013.html>
- The main events (system, station, data, Earthquake) that occurred on the DORIS space segment and ground segment are presented in one single table: <http://ids-doris.org/system/table-of-the-events.html>
- All the documents and files related to the DORIS/RINEX format is now gathered on a new page in the Analysis Coordination section: <http://ids-doris.org/about-doris-rinex-format.html>
- The list of the peer-reviewed publications related to DORIS has been enriched with 10 new references of articles published in 2014: <http://ids-doris.org/report/publications/peer-reviewed-journals.html#2014>
- The activity reports for 2013 (IDS Activity report, report for IERS) as well as the minutes of the IDS GB meetings held in 2014 (Paris, Konstanz) and several presentations in mee-

tings (IERS DB, GGOS, ...) were added on the page of the Governing Board's documents:
<http://ids-doris.org/report/governing-board.html>

- The page gathering IDS-related presentations was updated with several presentations:
  <http://ids-doris.org/report/meeting-presentations/ids-related-presentations.html>
- Some DORIS-related presentations were added:
  <http://ids-doris.org/report/publications/on-line-publications.html>

New documents and files were put on the IDS ftp site. They are listed hereafter:

- "DORIS site standard configuration" is a new document describing the standard configurations compliant with the DORIS system requirements applicable to the management of the DORIS station network:
  <ftp://ftp.ids-doris.org/pub/ids/stations/DORIS_Site_Standard_Configurations.pdf>
- "Introduction to DORIS RINEX" gives a quick description of the DORIS/RINEX format. The principle chosen in this document is to take an example of RINEX content and describe the main parameters.
  <ftp://ftp.ids-doris.org/pub/ids/data/IntroductionToDORISRINEX.pdf>
- Routines to read DORIS/RINEX files. The "tar file" contains the Fortran90 subroutines used in GINS to read the RINEX files (courtesy by Jean-Michel Lemoine, CNES).
  <ftp://ftp.ids-doris.org/pub/ids/data/DORIS_RINEX_subroutines_from_GINS.tar>
- Version #6 of the document describing the DORIS satellite models implemented in CNES POE processing. It includes updates on SPOT-5 solar panel offsets.
  <ftp://ftp.ids-doris.org/pub/ids/satellites/DORISSatelliteModels.pdf>
- Updated version of the mass and center of mass history file for Jason-1. The X value of the initial Center of Gravity was increased by 2 cm to +0.955 m to agree with the value recommended by CNES/SOD and given in the document describing the DORIS satellite models implemented in CNES POE processing.
  <ftp://ftp.ids-doris.org/pub/ids/satellites/ja1mass.txt>
- Leaflet presenting the IDS web service DOR-O-T:
  <ftp://ftp.ids-doris.org/pub/ids/DOR-O-T_Webservice_2014.pdf>

3.3 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
- DORISstations: information about station events (data gap, positioning discontinuities)

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. 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). They are both exact mirrors of each other, and so, are 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.).

The main events of the year are listed hereafter:

- In the fall of 2012, the IDS Analysis Working Group requested a test data set where data from stations in the South Atlantic Anomaly (SAA) were reprocessed by applying corrective models. Data from 2011 in DORIS V2.2 format from the Jason-1 satellite (cycles 104 through 368) were submitted to the IDS data centers in late 2012 and 2013; a set of SPOT-5 data (cycles 138 through 456, 2006 through Sept. 2014) were provided in 2013 and 2014. These files were submitted to the IDS data centers and archived in dedicated directories.
- The data centers supported the IDS Analysis Coordinator and Combination Center in the generation of the IDS contribution to ITRF2013.
- SSALTO implemented a improvements to the accuracy of the measurements in the RINEX formatted data. Therefore, all Jason-2, Cryosat-2, HY-2A, and SARAL RINEX data were reprocessed and delivery to the data centers will begin in early 2015.

5 IDS Analysis Centers and IDS Analysis Coordination

The activities of the past two years (2013–2014) have been dominated by the efforts of all the DORIS analysts to implement improvements in their processing, and to reprocess all the DORIS data, and prepare weekly SINEX files from 1993 to 2014 for the development of the IDS contribution to ITRF2013. The face-to-face meetings at the different Analysis Working Group meetings were supplemented at various times by telecons that involved the

Table 3: List of IDS Analysis Centers participating in the analysis activities in 2014.

Acronym	Analysis Center	Country	Software package
ESA	ESOC	Germany	NAPEOS
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

DORIS analysis centers and the IDS Combination. The purpose of these supplementary meetings was to try and maintain the pace of progress in assessing the model improvements, and to resolve issues associated with the reprocessing of the DORIS data. The IDS endeavored to meet the original objective of delivering a combination to the IERS by April 2014 (based on data processed through the end of 2013). It met its objective, but as it became clear that the other geodetic techniques were considerably delayed in their submissions, it allowed some updating of the submissions on the part of the ACs, and refinement of the IDS combination by the Combination Center. Near the end of the year 2014, the IERS requested that IDS process data through 2014 and submit these data by February 2015. Because of data latencies, the IDS replied that its ACs would only supply SINEX files through the end of the week of August 31, 2014. Thus ITRF2013 officially became ITRF2014.

For ITRF2014, the six active analysis centers had agreed to submit new SINEX solutions. In addition, the CNES POD center is lead DORIS analysis center. They do not submit SINEX solutions for the IDS combination, but since they have prime POD responsibility for many of the DORIS satellites, they are the source for much of the spacecraft information needed for processing. In addition, they prepare the DORIS format 2.2 data (the range-rate format) that is used by the IDS ACs. We note that in the past year we have had participation by three other institutions: GFZ, TU/Delft, the University College/London. The GeoForschungsZentrum (GFZ) has participated in several of the IDS meetings, and focused on the POD analysis for altimeter satellites. TU/Delft is analyzing data from Cryosat-2, and has made available the spacecraft quaternions for use by other team members. UCL is interested in working with individual DORIS ACs on the refinement of non-conservative force modeling for DORIS satellites. We note that a representative of the Norwegian Mapping Authority (NMA) also attended the IDS Workshop in Konstanz (Oct. 2014), and expressed an interest in analysis of DORIS data, and also in multi-technique analyses. In the future, the participation of the NMA and other potential IDS ACs should continue to be encouraged.

The major efforts over the last two years focused on the development of the processing standards for ITRF2013(4). The details in the modeling for the ITRF-related time series submitted by the different analysis centers are reported on the IDS website at the URL: http://ids-doris.org/contribution-itrf2013.html. The major changes that were validated in 2013–2014, included the following:

(1) The implementation and validation of the phase law for the DORIS antennae in the software of the different IDS Analysis Centers; (2) The introduction of new satellites into the DORIS weekly solutions; (3) The improvement in the troposphere modeling by some of the different IDS Analysis Centers; (4) The testing of improved gravity models, and associated models for atmospheric and ocean de-aliasing; (5) The identification of discrepancies in the processing for different analysis centers through comparison of the time series of empirical accelerations.

As a conclusion, we may highlight that six DORIS Analysis Centers successfully processed 20 years of data to 11 satellites and submitted SINEX files that were combined into an IDS solution for ITRF2014. The IDS Community should not rest on its laurels, as there are still many substantive issues that remain to be addressed, even with the current data already processed.

6 IDS Combination

The IDS Combination Center spent all the year 2014 to the realization of the IDS contribution to ITRF2013. From April 17th to December 5th, the IDS Combination Center delivered to IERS 5 versions of the IDS combined SINEX files. Each version is a set of eleven hundreds of weekly SINEX files including station coordinates and earth orientation parameters, covering the time period from 1993 to 2014. These IDS series are the result of the combination of weekly solutions from six Analysis Centers (ACs) from six different institutions (ESA, Geodetic Observatory of Pecny, NASA, IGN, INASAN, CNES/CLS) using five different software packages for orbit determination. The data comes from three generations of DORIS receivers onboard of eleven satellites (Cryosat-2, Envisat, HY-2A, Jason-1/2, Saral, SPOT2/5 and TOPEX/Poseidon) supported by a beacon network of nearly sixty stations uniformly spread across the globe. Due to Jason-1 and SPOT5 USO's sensitivity to the South Atlantic Anomaly (SAA), for these 2 missions IDS made available SAA corrected data. Evaluation of the IDS contribution to ITRF2008 (series 01) and to ITRF2013 (series 07) with respect to ITRF2008 (see Figure 2) showed:

- Improvements of Tx, Ty and Tz after 2002 (lower STDs, less annual signal) thanks to time variable gravity fields use in the ITRF2013 contribution.
- Scale offset (between the IDS contributions to the 2 ITRF) due to beacons PCVs in ITRF2013 processing.

- Less scale spurious values early 1994 (SPOT2 is no more included in the combined scale) in IDS series 07.
- No more scale factor discontinuity in 2002 thanks to beacon frequency offset estimations.
- Improvement of scale stability between end of TOPEX (late 2004) and Jason-2 start (mid 2008) thanks to Jason-1 including.
- Scale factor increase mid 2012.
- Better week-to-week repeatability of Helmert parameters of ids 07 (solution more consistent).

In addition, the evaluation process also pointed out that the IDS contribution to ITRF2013 gives higher differences of mainly X-pole estimates with the IERS C04 than the IDS contribution to ITRF2008 series. The explanation of that substantial degradation could be that the new solution uses 2 ACs less than the previous one.

Last but not least, in 2014, the IDS Combination Center joined both EGU General Assembly and AGU Fall Meeting where it presented two oral presentations respectively titled "IDS contribution to ITRF2013" and "IDS and ITRF2013: Contribution and Evaluation".

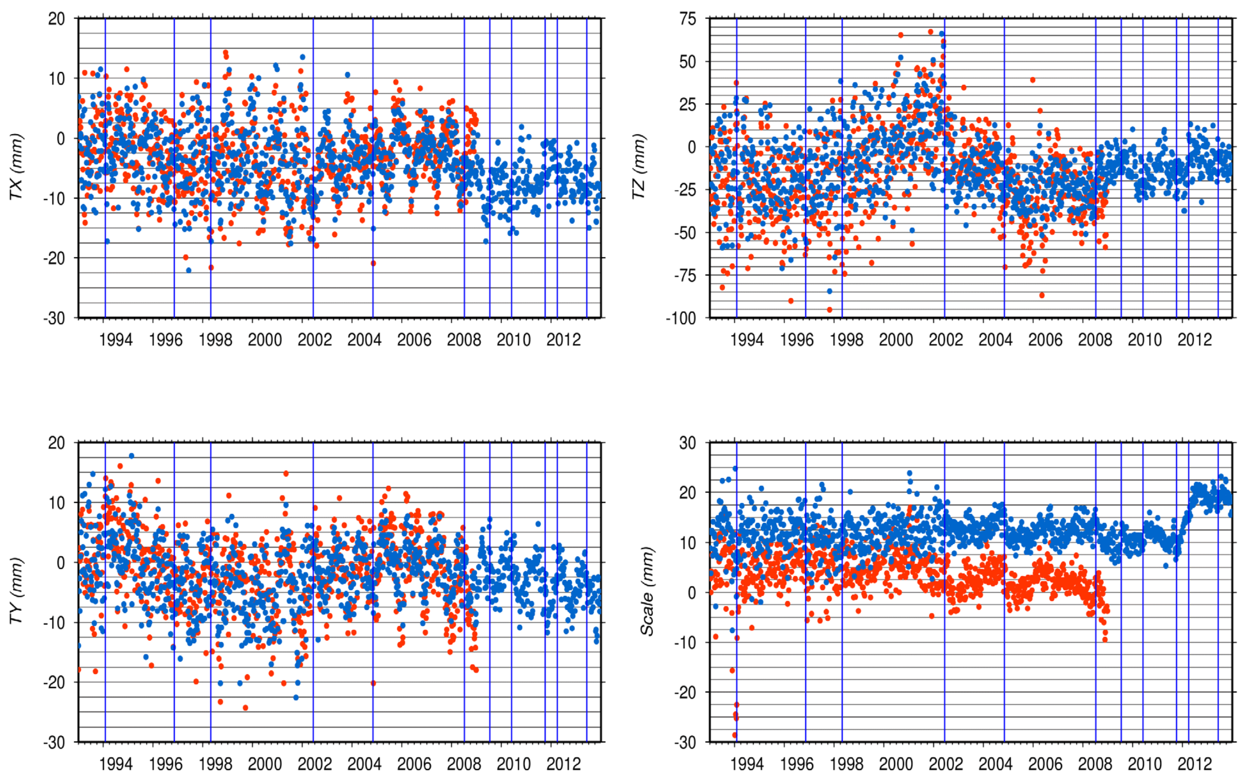


Fig. 2: Helmert parameters (translations and scale of the IDS contributions to ITRF2008 (red) and ITRF2013 (blue) with respect to ITRF2008.

7 Meetings

In 2014, the IDS organized a DORIS Analysis Working Group (AWG) meeting, in Paris, France, on March 26 and 27, as well as the IDS Workshop held in Konstanz, Germany, on October 27 and 28.

All the presentations from these meetings are made available by the Central Bureau on the IDS website at:

<http://ids-doris.org/report/meeting-presentations/ids-awg-03-2014.html>

<http://ids-doris.org/report/meeting-presentations/ids-workshop-2014.html>

8 Publications

IDS published a 2013 activity report that was 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 <http://ids-doris.org/report/publications/peer-reviewed-journals.html>.

Conclusions

Again, the DORIS community had a productive year in 2014. Like in 2013, the activities have been dominated by the efforts of all the DORIS analysts to implement improvements in their processing, to reprocess all the DORIS data, and to prepare weekly SINEX files from 1993 to 2014 for the development of the IDS contribution to ITRF2014. However there are still many substantive issues that remain to be addressed. The next work for the Analysis Centers is also the processing of the DORIS phase measurements of the DGXX instruments delivered in RINEX DORIS 3.0 format. This matter is indeed a new crucial project for IDS since this type of measurement and this format are the only ones available from the forthcoming missions (Jason-3, Sentinel 3A, …).

Laurent Soudarin

3.5 Product Centres
3.5.1 Earth Orientation Centre

This section presents over the year 2014 the activities and main results of the Earth Orientation Centre located at Paris Observatory. According to the IERS Terms of Reference, this component is responsible for monitoring Earth Orientation Parameters including long term consistency, publications for time dissemination (DUT1) and leap second announcements. Earth Orientation Parameters (EOPs: 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 firstly collected in the form of combined solutions derived by the Technique Centers (IGS, IVS, ILRS and IDS). Two main solutions are computed: a long-term solution (IERS C01) since 1846 until the end of last year and the Bulletin B / C04 given at one-day intervals and which is published monthly with a 30 day delay (Gambis, 2004; Bizouard and Gambis, 2009; Gambis and Luzum, 2011).

An important issue is the maintenance of the consistency between the EOP system and both the terrestrial and celestial reference frames. So far, Earth Orientation Parameters and the terrestrial frame are separately computed. This lead in the past to increasing inconsistencies between both systems. At the end of 2009, these inconsistencies were small but significant for polar motion (negligible for the x-pole component and about 50 microarcseconds for the y-pole component). 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. Inconsistencies are now negligible compared to the current accuracies, i.e. limited to about 10 microarcseconds for polar motion and a few microseconds for UT1.

Combined daily series: Bulletin B and C04, statistics over 2013–2014

Tables 1 to 3 present statistics in term of formal errors and Weighted Root Mean Square (WRMS) of the combined technique centres and individual solutions with respect to the combined solution Bulletin B / C04 over the period 2013–2014. Combined solutions derived by the various Technique Centres (IGS, ILRS, and IVS) are mostly used in the IERS combinations with the additions of some VLBI series for Universal Time (intensive for UT1 and standards for nutation). Statistics concerning individual series are currently given as a feedback to the analysis centres.

Table 1: Estimated accuracies of individual solutions compared to the combined solutions Bulletin B / C04 over 2013–2014. 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. Solutions contributing to Bulletin B / C04 combined solutions are referred with a star (*).

Individual solutions	Estimated uncertainties				
	Time sampling	Terrestrial Pole µas	UT1 µs	LOD µs	Celestial Pole µas
VLBI – 24 h					
EOP (AUS)	3–4d	300	15.0		150
EOP (BKG)	1–4d	150	11.0		93
EOP (GSFC)	1–4d	135	11.1		82
EOP (IAA)	1–4d	160	15.4		87
EOP (MAO)	1–4d	140	7.3		88
EOP (OPA)	1–4d	135	9.9		90
EOP (PUL)	1–4d	108	10.8		89
EOP (USNO)	1–4d	85	5.7		50
EOP (IVS) *	1–4d	105	6.7		37
VLBI – Intensive					
EOP (BKG) *	1–3 d		18.0		
EOP (GSFC) *	1–3 d		18.4		
EOP (IAA)	1–3 d		21.3		
EOP (PUL) *	1–3 d		21.0		
EOP (USNO) *	1–3 d		19.7		
SLR					
EOP (CGS)	1d	165		20.3	
EOP (IAA)	1d	300		22.6	
EOP (MCC)	1d	165		–	
EOP (PUL)	1d	110		16.6	
EOP (ILRS)*	1d	135		27.7	
GPS					
EOP (CODE)	1d	31		10.8	
EOP (EMR)	1d	45		9.6	
EOP (ESOC)	1d	40		21.3	
EOP (GFZ)	1d	75		42.2	
EOP (IAA)	1d	43		17.0	
EOP (JPL)	1d	73		8.9	
EOP (NOAA)	1d	65		17.9	
EOP (SIO)	1d	28		8.2	
EOP (IGR) *	1d	34		8.3	
EOP (IGS) *	1d	29		8.2	

Table 2: Mean and standard deviation in microarcsecond of the differences between various combined techniques solutions entering the combination and Bulletin B / C04 over 2013–2014.

EOP	IGS Comb – IERS 08C04		ILRS Comb – IERS 08C04		IVS Comb – IERS 08C04	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
X (μas)	–10	29	91	143	37	83
Y (μas)	10	29	58	131	52	88
UT1 (μs)					6	5.7
LOD (μs)	3	8	7	27		
Dψsinε (μas)					2	56
Dψ (μas)					–32	49

Table 3: Mean and standard deviation for Pole components and UT1 of the differences between combined solutions derives by both the Rapid Service/Prediction Center at USNO, the JPL and Bulletin B / C04 over 2013–2014.

EOP	Unit	Bull A – Bull B		Comb JPL – Bull B	
		Mean	Standard deviation	Mean	Standard deviation
X	μas	0	18	31	32
Y	μas	0	18	-11	18
UT1	μs	2.6	10.7	–1.0	9.9

New format of Bulletin B since January 2010

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>.

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

Content of Bulletin B / C04

According to the IERS Message 198 (<http://datacenter.iers.org/eop/-/somos/5Rgv/getTX/2/message_198.txt >) and starting on 1 December 2012, the EOP C04 series is now delivered with 30-day latency. In other words, only final definitive values are included in it.

Users needing a long-term continuous series extending up to a recent date (including rapid solution over the most recent 30 days) have two possibilities:

1) Getting the C04 solution extending until the date 30 days back and available at

<ftp://hpiers.obspm.fr/iers/eop/eopc04/eopc04_IAU2000.YY> where YY is current two digit year,

and concatenate it with the Rapid solution (Bulletin A) issued from the Rapid Service/Prediction Center available at <ftp://maia.usno.navy.mil/ser7/finals2000A.daily>.

Due to differences in the delivery times of the two products, users should exercise caution in blending the files to ensure that there is continuity between Bulletin B / C04 and Bulletin A.

2) Getting the new OPA EOP solution consisting of a continuous series derived from the concatenation of the C04 series and the OPA rapid solution available at

<ftp://hpiers.obspm.fr/iers/series/opa/eopc04_IAU2000>.

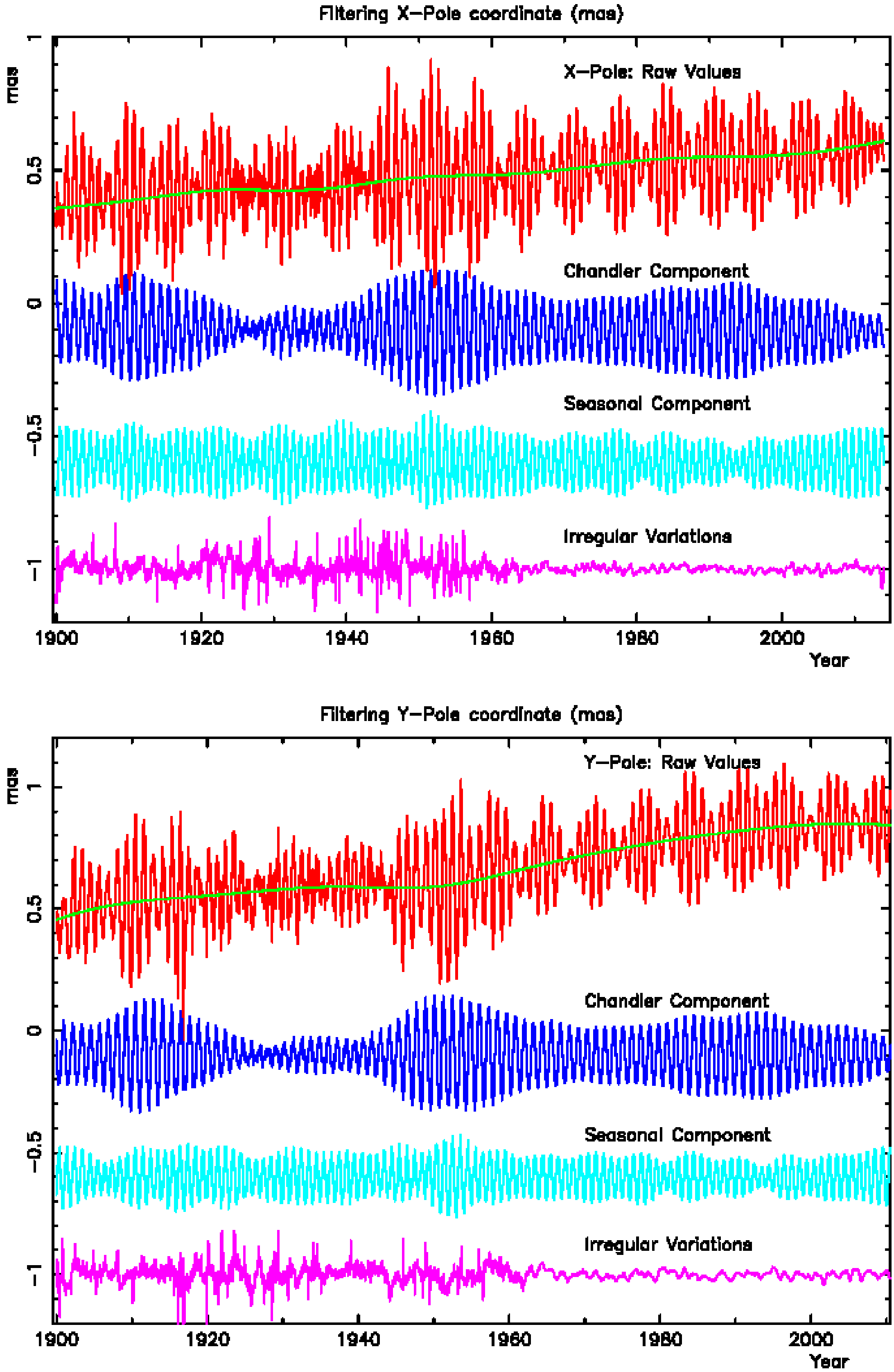
Long-term series: C 01 (1846–2014)

EOP(IERS) C01 is a series of Earth Orientation Parameters given at 0.1 year intervals from 1846 to 1889 (polar motion only) and 0.05 year interval from 1890 until now (polar motion, celestial pole offsets, UT1–UTC since 1962). For many decades, the observations were made using mostly visual and photographic zenith telescopes. Since the advent of the space era in the 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 C01 series 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.



Figs. 1a and 1b: Filtering of pole coordinates in various components.

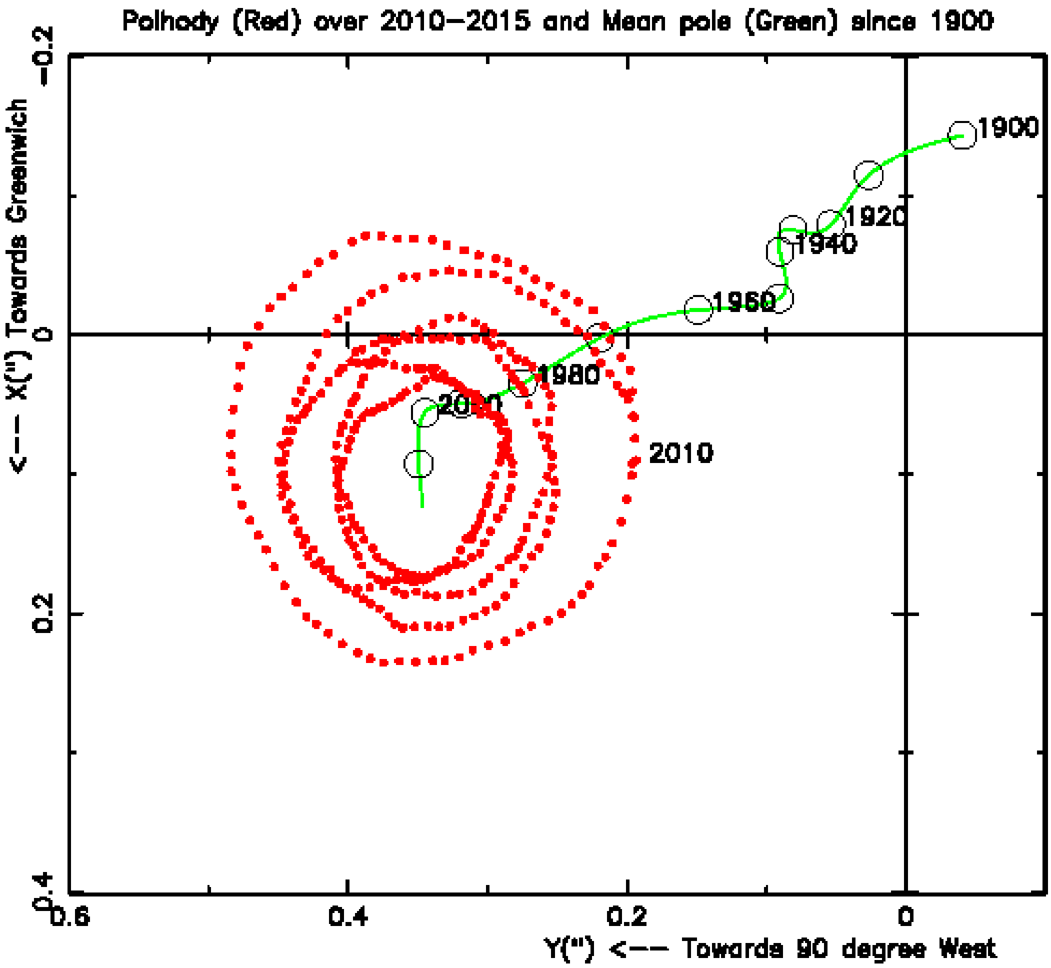


Fig. 2: Mean polar motion (1900–2015.0) and IERS C04 polhody over 2008–2015.0.

1962–2015: BIH and IERS solutions (BIH and IERS annual reports).

Figures 1a and 1b show the filtering of both pole coordinates since 1890 expressed in various components, i.e. the trend, the seasonal term and the Chandler wobble using the X-census filter (Shiskin et al., 1965).

Figure 2 shows the mean polar motion over 1900–2014 as well as the C04 polhody over 2008–2014. The change of direction of the mean pole since the beginning of the 2000s is apparent. The origin can be attributed to a change in the Earth inertia momentum probably due to the ice cap melting effect.

Mean Pole with respect to the IERS reference origin

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 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 2015.0 (Shiskin et al., 1965). Figure 2 represents the polar motion over 2008–2014 and the path of the mean pole since 1900. Until the 2000's the mean polar motion was affected by a long-term drift westward (direction 70.7 degree West, rate: 4.2 mas/yr). It appears clearly that since that epoch, the mean pole direction has changed and is directed to Greenwich meridian. Table 4 gives the IERS mean pole components.

Long term UT1/LOD (EOP C02: 1830–now)

For geophysical study, we propose a new product: a long term UT1/LOD series (with the label EOP C02). This series is extending from 1830 until now and is monthly updated.

This series is composite is available at <http://hpiers.obspm.fr/eoppc/series/longterm/eopc02.1830-now>. It is composed of the following series:

1) 1830–1955: Delta T = TE – UT = TE – TAI – (UT – TAI) from Jordi et al. (1994), and obtained from the analysis of lunar occultations – mean sampling time of 120 days.

2) 1955–1962: from Vondrak et al. (1995) UT1 time series from optical astrometry.

3) 1962–now: Combined C04 time series free from short term zonal tides (< 2 years).

Table 4: IERS mean pole components over 2000–2015.0.

Year	mean X-pole (")	mean Y-pole (")
2000.	0.055981	0.345218
2001.	0.058022	0.346532
2002.	0.060436	0.347619
2003.	0.063229	0.348490
2004.	0.066403	0.349153
2005.	0.069953	0.349618
2006.	0.073868	0.349899
2007.	0.078133	0.350008
2008.	0.082731	0.349963
2009.	0.087643	0.349779
2010.	0.092851	0.349474
2011.	0.098339	0.349062
2012.	0.104098	0.348553
2013.	0.110120	0.347955
2014.	0.116401	0.347271
2015.	0.122942	0.346502

The characteristic of the combination are:

- For optical astrometric data (Jordi et al., AICAS), prior to 1962, UT–TE / UT1–TAI series are smoothed by Gaussian filter with 365 day interpolation step.
- C04 series are smoothed using a Gaussian filter with a 200 day interpolation step.
- After filtering the total series, composed of UT–TE (prior to 1958) and UT1–TAI (after 1958), are interpolated by a cubic spline at 100 days step.
- Variation of the length of day LOD, given by LOD / D = –dUT1/dt where D = 86400 s is the duration of the day, is then obtained from a two point time derivative of the 100 day UT1 time series.

Dissemination of UT1–UTC through the use of virtual observatory

Information concerning UT1–UTC and the occurrence of the leap seconds are currently made available via IERS Bulletin D and C. However, this old-fashioned procedure does not satisfy automatic systems. We have investigated the way to develop a new service based on the concept of Virtual Observatory (VO). This concept, provided by the International Virtual Observatory Alliance (IVOA), allows scientists and the public to access and retrieve UT1–UTC information using on-line distributed computational resources. We derived the concept, using the XML-based VO Table format to build this UT1–UTC dedicated new service (Deleflie et al., 2011).

The scientific community working in different field and requiring in particular UT1–UTC on a regular and reliable basis can benefit from the VO concept. The concept of metadata allows making available a single file with a description. Such tools can enhance the visibility of earth orientation parameters as well as UT1–UTC derived by the IERS.

Development of a leap second Web service

A simple ASCII file giving the dates of insertion of leap seconds is available on the front page of the IERS EOP product Center at <http://hpiers.obspm.fr/iers/bul/bulc/Leap_Second_History.dat>.

The information about the potential introduction of a leap second is currently broadcast via Bulletin C. However, a procedure more adapted to the development of networks of servers becomes necessary and in particular, for programs like the NTP daemon which can use this file as authoritative server source. Such a procedure of providing and maintaining a leap second file via a secure protocol is now being developed at the Earth Orientation Center.

Staff

Daniel Gambis	Astronomer, Head
Christian Bizouard	Astronomer
Teddy Carlucci	Engineer
Jean Yves Richard	Engineer
Olivier Becker	Engineer
Pascale Baudoin	Secretary

References

Bizouard, C. and D. Gambis, 2009, The combined solution C04 for Earth Orientation Parameters, recent improvements, Springer Verlag series, Series International Association of Geodesy Symposia, Vol. 134, Drewes, Hermann (Ed.), pp. 265–270, DOI 10.1007/978-3-642-00860-3

Deleflie F., D. Gambis, C. Barache, J. Berthier, 2011, Dissemination of UT1–UTC through the use of virtual observatory VO, in AAS proc., AAS 11-680

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

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

Gambis,D and Luzum B., 2011, Earth rotation monitoring, UT1 determination and prediction, *Metrologia* 48 (2011) S165–S170

Jordi, C., L. V. Morrison, R. D. Rosen, D. A. Salstein, and G. Rosello, 1994, Fluctuations in the earth's rotation since 1830 from high-resolution astronomical data, Geophys. J. Int., 117, 811–818

Petit, G. and B. Luzum (eds.), 2010: *IERS Conventions (2010)*, BKG, Frankfurt am Main (IERS TN36; Website: <http://www.iers.org/TN36>)

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

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

Daniel Gambis and Christian Bizouard

3.5.2 Rapid Service/Prediction Centre

This section provides a summary of the Earth orientation parameter (EOP) results produced by the IERS Rapid Service / Prediction Center (RS/PC) for the calendar year 2014. Additionally, this section contains an overview of the combination processing techniques, the prediction processing techniques, the activities under development to improve EOP results, and the web and FTP locations available to users for obtaining results.

Combination Processing Techniques and Results

In combining the contributed observational data to generate the quick-look EOP results, the IERS RS/PC employs a smoothing cubic spline that weights each of the input data based on their reported observational errors, which is referred to as a "weighted smoothing cubic spline" (McCarthy and Luzum, 1991a). Observational data contributions are corrected for possible systematic differences in the form of offsets and rates computed with respect to the 08 C04 system of the IERS Earth Orientation Centre (EOC) at the Paris Observatory; to this end, a robust linear estimator (using the MATLAB function 'regstats') is employed which ameliorates the effect of outliers on the computed offsets and rates. The statistical weights used in the spline are proportional to the inverse square of

Table 1: Estimated accuracies of the contributors in 2014. Units are milliseconds of arc for x, y, dψ, dε, dX, and dY and milliseconds of time for UT1–UTC.

Contributor Information	Estimated Accuracy				
Name, Type	x	y	UT1	δψ (dX)	δε (dY)
ILRS SLR	0.20	0.18			
IAA SLR	0.33	0.20			
MCC SLR	0.15	0.24			
GSFC VLBI Intensives			0.020		
USNO VLBI Intensives			0.019		
GSI Intensives			0.016		
GSFC VLBI	0.11	0.11	0.007	0.53	0.13
IAA[1] VLBI	0.36	0.18	0.010	(0.22)	(0.27)
IVS[1] VLBI	0.10	0.17	0.002	(0.07)	(0.13)
USNO VLBI	0.15	0.12	0.006	0.26	0.11
IGS Final	0.01	0.02			
IGS Rapid	0.03	0.03			
IGS Ultra* (observations)	0.03	0.03	0.027*		
USNO GPS UT*			0.016*		

*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 (see Petit and Luzum, 2010).

the estimated accuracy of the individual techniques computed over the past several years. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Weights for each contributor in the algorithm may be either *a priori* values estimated by determining the standard deviation of a long history of residuals or values based on the internal precision reported by contributors. The estimated accuracies for each of the IERS RS/PC contributors to the EOP combination solutions for 2014 are provided in Table 1. These estimates are based on the residuals between the series and 08 C04 system of the IERS EOC from 2014.

For polar motion (x and y) and the celestial pole offsets (dψ, dε, dX, and dY), all the contributors (which have associated statistics in Table 1) provide direct measurements of these quantities, respectively. For UT1, some contributors provide direct measurements and others provide estimates based on quantities related to UT1. All of the Very Long Baseline Interferometry (VLBI) contributors provide direct measurements of UT1; the International GNSS Service (IGS) ultra-rapid observations (IGS ultras) provide a length-of-day-type input, which is a derivative of UT1; and the USNO GPS UT provides a UT1-like estimate based on GPS orbit modeling. The VLBI-based results have been used to correct for the length-of-day (LOD) bias in the IGS ultras and to minimize drifts in UT estimates in both the IGS ultras and USNO GPS UT. The corresponding statistics shown for the IGS ultras and USNO GPS UT are computed after the bias corrections are applied. The Atmospheric Angular Momentum (AAM) inputs do not contribute to the EOP combination solution, but provide inputs to the EOP UT1–UTC predictions out to 7 days into the future; therefore, there is no mention of AAM results in Table 1. The combination corresponds to solutions of past EOP results; whereas, predictions refer to the current and future EOP look-ahead solutions which are discussed later in the chapter.

Operationally, the spline uses the following as inputs: the epoch of observation, the observed EOP value, and the corresponding weight. 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, dψ, and dε values are computed for the midnight (00:00) UTC epoch for each day. While the celestial pole offset combination software can combine either dψ and dε or dX and dY, it uses dψ and dε for historical reasons. Therefore, the Institute of Applied Astronomy (IAA) and the International VLBI Service (IVS) VLBI dX and dY values are converted to dψ and dε in the combination process. The LOD for the combination 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

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Center combination solutions and the 08 C04 EOP solutions for 2014. 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	–0.01	0.03
y	–0.02	0.03
UT1–UTC	0.003	0.013
Bulletin A Weekly Solution (finals.data)[1]		
x	0.01	0.04
y	0.00	0.04
UT1–UTC	–0.004	0.024
Bulletin A Daily Solution (finals.daily)		
x	0.00	0.04
y	0.01	0.04
UT1–UTC	–0.017	0.036

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

at the epoch of the UT1–UTC data. 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.

Two groups of data points are excluded from the combination process. One group consists of the EOP inputs whose errors, as reported by the contributors, are greater than three times their average reported precision. The other data excluded are those inputs that have a residual that is more than four times the associated *a priori* error estimate. (The value of 4 was chosen to eliminate 4-sigma outliers and was determined via an empirical approach; email communication with Dr. Dennis McCarthy, 2015.) Also, note that since all of the observations are reported to the IERS RS/PC with the effects of sub-daily variations removed, the input data are not corrected for these effects (see IERS Gazette No. 13, 30 January 1997).

Table 2 shows the accuracies of Rapid Service/Prediction Center's combination solution for the running, weekly, and daily products compared to the 08 C04 series maintained by the IERS EOC for 2014. The running solution statistics, shown under the label "Bulletin A Rapid Solution," are the residuals of the combination solution versus the 08 C04 over the 365-day period covering 2014. The statistics for the running solution at year's end show the level of agreement between the Bulletin A running combination solution and the 08 C04 series.

The “Bulletin A Weekly Solution” results shown in Table 2 are the statistics of the residuals obtained from the Bulletin A combination values for 2014 versus the 08 C04 series. These combination values for 2014 are the concatenation of all 52 Bulletin A, 7-day EOP combination results. For each Bulletin A, there is a set of 7-day EOP combination results listed prior to the solution epoch. (For example, the Bulletin A solution computed on January 9, 2014 has EOP combination results from January 3 through January 9, 2014.)

The statistics for the daily solution, shown under the “Bulletin A Daily solution” heading in Table 2, are the differences between the EOP solution, updated daily and at each corresponding daily epoch for 2014, versus the respective 08 C04 series solution for that epoch when it becomes available. The following will illustrate the process used in generating this section of Table 2. On May 6, 2014 (MJD = 56783), an EOP solution is produced a few minutes after 17:00 UTC on that day, and the solution is contained on the EOP server at <ftp://maia.usno.navy.mil/ser7/finals.daily> (and is archived appropriately). Within that file are generally 90 past EOP combination solutions, the solution on the current day, and 90 future EOP predictions starting from MJD 56694 to MJD 56874. (Note, the number of epochs before and after the current solution day may occasionally vary depending on the most recent observational data provided.) The EOP solution on the row of the file corresponding to MJD 56783 is compared to the 08 C04 combination solution corresponding to the same date and a residual is produced. This process is repeated for each MJD of 2014, and statistics on the set of residuals are computed.

Figure 1 contains plots of the residuals between the daily rapid and the 08 C04 solutions, and the corresponding statistical results are listed in Table 2 under “Bulletin A Daily Solution (finals.daily).” These daily rapid solutions are considered the last combination or 0-day prediction results. For 2014, the RMS of the residual results for polar motion between the daily rapid solution and the 08 C04 were similar to what resulted in 2013 (see IERS Annual Report 2013, <http://www.iers.org/AR2013>, Chapter 3.5.2). The standard deviation of polar motion X improved in 2014 from 2013 by approximately 20%; the polar motion Y and UT1–UTC values from 2014 were within 10% of the 2013 values. The RMS of the residual results for UT1–UTC appear to be similar when comparing the 2013 to 2014 results; however, when examining the UT1–UTC plot shown in Figure 1 of this 2014 report, one can see a degradation in the residuals occurring in roughly the 2nd half of the year.

On June 12, 2014, the electronic transfer of VLBI data (e-VLBI) from the Kokee Park (Kk) radio telescope ceased, and this lack of e-VLBI transfer caused an increased latency in the time from VLBI intensive INT1 (Stamatakos *et al.,* 2008) observation to

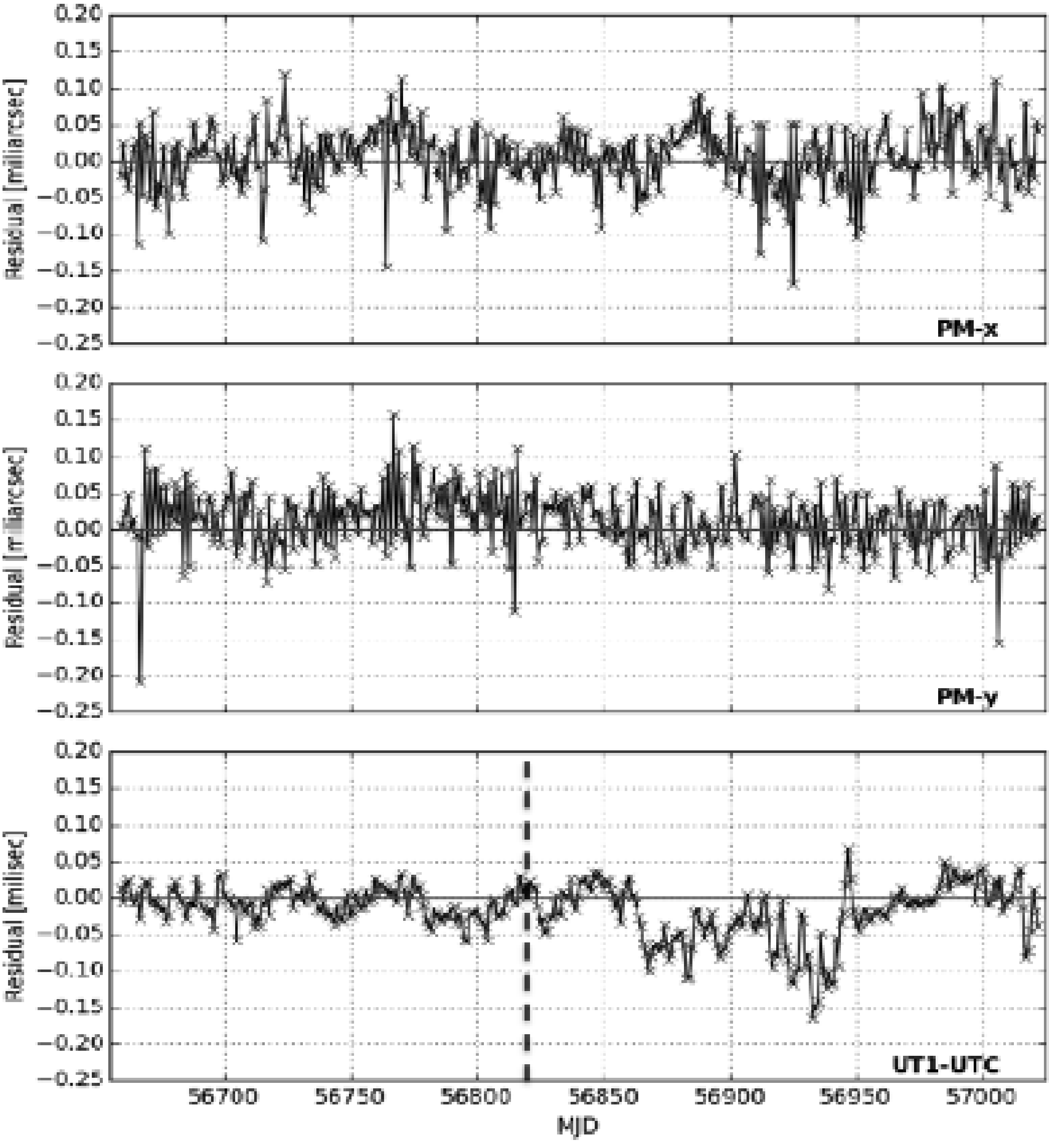


Fig. 1: Differences between the EOP solution updated daily (called the 'daily rapid solution') for 2014 and the respective 08 C04 series combination solution (produced in February 2015). The Earth Orientation Parameters shown are: a) Polar Motion X; b) Polar Motion Y; c) UT1–UTC. The vertical dotted line denotes the loss of electronic transfer capabilities from Kokee Park Observatory on MJD 56820.

correlation, fringing, analysis, and finally inclusion in the IERS RS/PC EOP solution. The INT1 observational data from Kk had to be recorded on media and shipped via FedEx to USNO instead of being electronically transferred via e-VLBI. The latency increased from about 1 day before June 12, 2014 to 2 or 3 days (and occasi-

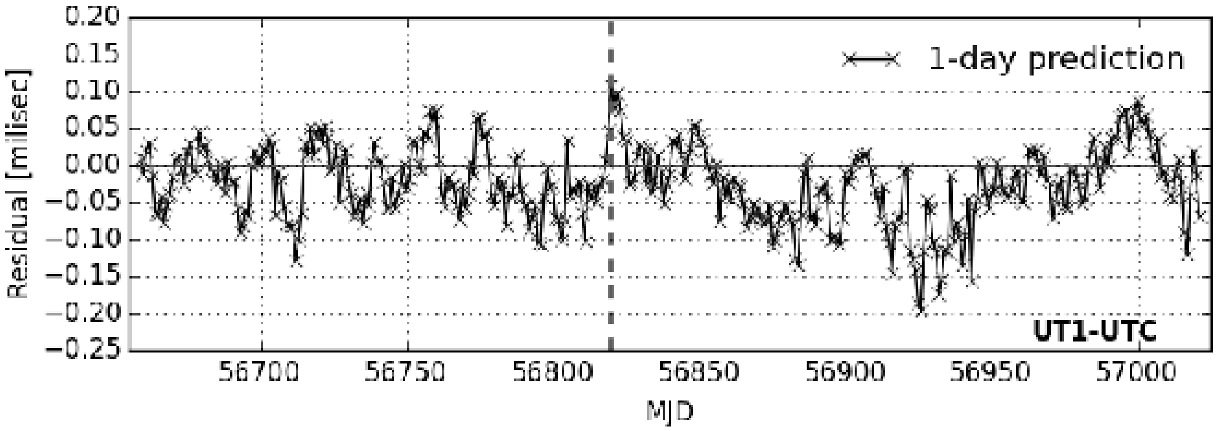


Fig. 2: Difference between the daily 1-day UT1–UTC prediction for 2014 from the 'daily rapid solution' and the respective 08 C04 series solution produced in February 2015. The vertical dotted line denotes the loss of electronic transfer capabilities from Kokee Park Observatory on MJD 56820. The effects from the loss of the electronic data transfer at Kokee Park on the daily solution (0-day prediction) can also be seen in Figure 1c.

onally longer) after that date. Also, Figure 2, which contains a plot of the UT1–UTC 1-day prediction residuals versus the 08 C04, has a similar signature to that shown in Figure 1 for UT1–UTC. (In that plot, there is a vertical line indicating when June 12, 2014 occurred.) There is a potential correlation between an increase in residuals, which is shown in Figures 1 (UT1–UTC plot) and 2, and the loss of e-VLBI when the change in UT1–UTC (with known tidal and seasonal effects removed) versus time was large. To determine the strength of this potential correlation among these effects, a larger study (beyond the scope of the analyses done for this report) is needed.

Prediction Techniques and Results

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 that are more stochastic in nature. The AR algorithm is then used to predict the stochastic process while a deterministic model consisting of the linear, annual, semiannual, and Chandler terms is used to predict the deterministic process. The polar motion prediction is the addition of the deterministic and stochastic predictions. The additional unused terms in the deterministic solution help to absorb errors in the deterministic model caused by the variable amplitude and phase of the deterministic components (T. Johnson, personal communication, 2006). For more information on the implementation of the LS+AR model, see Stamatakos *et* *al.* (2008). A deficiency with the current implementation of this algorithm occasionally causes poor quality short-term polar motion predictions. Mitigation strategies are being investigated.

The UT1–UTC prediction 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 Global Environmental Model (NAVGEM) Atmospheric Angular Momentum (AAM) analysis and forecast data (UTAAM). AAM-based predictions are used to determine the UT1 predictions out to a prediction length of 7.5 days. For longer predictions, the LOD excitations are combined smoothly with the longer-term UT1 predictions described below. For more information on the use of the UT AAM data, see Stamatakos *et al.* (2008).

The procedure for generating UT1–UTC predictions after 7.5 days 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 – resulting in a quantity called UT2R–TAI. (UT2R is a smoothed version of UT1, filtering out periodic seasonal and long period variations due to tides.) Then, to determine a prediction of UT1–UTC n days into the future, $(UT2R–TAI)_n$, the smoothed time value from n days in the past, $<(UT2R–TAI)_{-n}>$ is subtracted from 2-times the most recent value, $2(UT2R–TAI)_0$

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

The amount of smoothing used in this procedure depends on the length of the forecast. Short-term predictions with small values of n make use of less smoothing than long-term predictions. Once this value is obtained, it is possible to restore the 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 also 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.

Errors of the prediction 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 Bulletin A tabular data, but predictions derived from these formulas are significantly less accurate than the tabular predictions and are not recommended for operational use. The predictions of $d\psi$ and $d\varepsilon$ are based on the IERS Conventions (McCarthy, 1996; McCarthy and Petit, 2004).

Fig. 3: Plot of the 1-day prediction error as a function of polar motion. The prediction error is in units of milliseconds of arc. The error values correspond to the color-coded vertical bar at the right – ranging from less than 0.1 (dark blue) to greater than 0.9 (dark red) milliarcseconds.

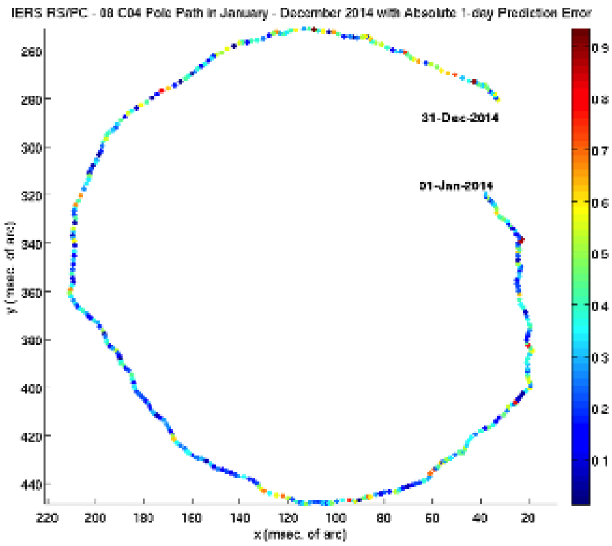


Table 3a: Root mean square of the differences between the EOP time series predictions produced by the 17:00 UTC daily EOP solutions and the 08 C04 combination solutions for 2014. Note that the prediction length starts counting from the day after the date of the solution epoch.

Days in Future	PM-x Mas	PM-y mas	UT1–UTC ms
0	.042	.043	.039
1	.305	.234	.056
5	1.68	1.16	.204
10	3.14	2.00	.481
20	5.50	3.34	1.61
40	10.1	5.32	4.51
90	21.7	12.1	14.3

Table 3b: Root mean square of the differences between the EOP time series predictions produced by the 21:10 UTC daily EOP solutions and the 08 C04 combination solutions for 2014.

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
0	.034	.034	.038
1	.272	.206	.054
5	1.63	1.13	.203
10	3.08	1.96	.483
20	5.47	3.30	1.62
40	10.2	5.27	4.50
90	21.7	12.1	14.3

Table 3c: Root mean square of the differences between the EOP time series predictions produced by the 03:10 UTC daily EOP solutions and the 08 C04 combination solutions for 2014.

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
0	.035	.035	.037
1	.265	.124	.051
5	1.77	1.20	.202
10	3.18	2.05	.482
20	5.53	3.32	1.61
40	10.1	5.24	4.49
90	21.1	12.2	14.3

Table 3d: Root mean square of the differences between the EOP time series predictions produced by the 09:10 UTC daily EOP solutions and the 08 C04 combination solutions for 2014.

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
0	.034	.035	.036
1	.154	.124	.049
5	1.47	1.20	.201
10	2.93	2.06	.481
20	5.45	3.39	1.61
40	10.1	5.27	4.50
90	21.3	12.1	14.3

** The number of days from the midnight epoch associated with the EOP solution generated at 17:00 UTC. E.g., the 1-day prediction epoch for all Nxdaily EOP solutions is shown in Figure 4.*

Table 3a shows the RMS of the differences between the 17:00 UTC Polar Motion and UT1–UTC solution predictions and the 08 C04 solutions for 2014. When comparing the 2014 results to 2013, there was a small improvement in the polar motion predictions out to 10 days – the level of improvement was approximately 5 to 10%. Unfortunately, there was almost no improvement in the short-term UT1–UTC predictions. As was previously mentioned in the discussion of Figure 1, this lack of improvement was possibly, in part, due to the loss of the e-VLBI results from Kokee Park, which is one of the two radio telescopes used in the 2-baseline INT1 intensives. As to be expected with longer-term predictions (20 days or more into the future), the comparison of 2013 to 2014 results do not follow a discernable pattern.

In previous annual reports, the prediction length (as shown in Table 3a) was determined from the epoch of the last known VLBI or IGS observation, and not based on the date of the solution epoch. It has been determined that many EOP users base their inputs on the prediction from the date of the solution epoch, and also using this new paradigm simplifies the comparison of results among the 17:00 UTC EOP solution and the 21:10, 03:10 and 09:10 UTC solutions (which are discussed below). In general, the results are very similar since on most days an observation is made either on the solution day or the day before. The statistics based upon the older paradigm could be made available upon request from ser7@maia.usno.navy.mil.

In addition to the 17:00 UTC EOP solution, three additional EOP solutions are computed each day – new solutions at 21:10, 03:10, and 09:10 UTC. These four solutions are collectively referred to as the Nxdaily solutions. At these solution times, the EOP results are recomputed and made available to users. The original solution at 17:00 UTC has been produced by the IERS RS/PC each day for over 15 years. The additional solutions are part of an ongoing effort to improve the accuracy of the EOP results by updating EOP solutions soon after new observational data are available, thereby, reducing the latency between observations and EOP solution updates. Examples of these new observational input data are e-VLBI intensives and the IGS ultras. Tables 4a and 4b illustrate the relationship between the EOP solution times and these input data.

At each Nxdaily UTC solution time listed in Tables 4a and 4b, major contributors, whose latencies between observations to availability to the EOP solution are under a few days, are listed with an associated "epoch at midpoint." IGS and VLBI solutions are determined from a span of observations and the EOP estimate is provided at the midpoint of this span. Typically IGS orbits are determined over a 24-hour period and VLBI intensives sessions span a 1-hour period. The "Contributor" column contains the most recently available input at the time of each UTC solution. Although major contributors, the 24-hr VLBI solutions are not shown in the table since the time between observations and availability to the EOP solutions is generally greater than 7 days.

Table 4a lists the most recent major input contributors for each polar motion Nxdaily solution. For example, by the polar motion 17:00 UTC <MJD> solution time, the most recently computed IGS rapid observation solution (IGS rapid), which has an epoch at midpoint of 12:00 UTC noon from the previous day, <MJD-1>, is available. In addition, there are two IGS ultras available that contain an epoch at midpoint after the IGS rapid. By 21:10 UTC <MJD>, the IGS has produced an updated IGS ultra, the 18-hr solution, and the corresponding EOP solution will use this latest data. Similarly, the 03:10 UTC and 09:10 UTC solutions will have later IGS ultra data available as shown in the table. Finally, for the next day, <MJD+1>, the sequence of IGS Rapids and Ultras will repeat – the 17:00 UTC <MJD+1> solution will have the next IGS rapid solution whose midpoint was at 12:00 UTC <MJD> along with the next 6-hr and 12-hr Ultras.

In Table 4b, a similar pattern for UT1–UTC to what was described above for polar motion is shown. In addition to the IGS contributions, the VLBI intensives series are included. While the IGS contributions have a consistent update time, the VLBI intensives updates are not as regular as the IGS updates. For example, new IGS ultra rapid observations are regularly updated every 6 hours with only a handful of missed or late solutions each year; whereas, a few VLBI intensives could be late or missing each month. So, the contributors shown for each solution are only an ideal case that occurs less than 100% of the time. (Since the e-VLBI outage occurred in June 2014 for the INT1 solutions, the corresponding rows referring to INT1 VLBI Intensives in Table 4b were not applicable from June 13 to Dec 31, 2014.) There are 3 sets of VLBI intensives that are used in the EOP RS/PC UT1–UTC solution – called INT1, INT2, and INT3 intensives. The INT1 intensives are typically only observed on weekdays, the INT2 intensives on weekends, and the INT3 intensives on Mondays. For more information about the relation of the INT1, INT2, and INT3 VLBI intensives observation times to the EOP solution see Stamatakos et al., 2012, AGU poster G51A-1084.

Within each Nxdaily EOP solution file – each called finals.daily and finals2000A.daily, but located in separate sub-directories – there are EOP solutions for polar motion, UT1–UTC and celestial pole offsets. Each has an identical format to the original 17:00 UTC solution. As shown in Figure 4, the 1-day EOP prediction from the 17:00 UTC <MJD> EOP solution will make a prediction of the EOP for 00:00 UTC <MJD+1>; the 1-day EOP prediction from the

Tables 4a and 4b: Tables describing the data available for each of the Nxdaily solutions. Note: the 24-hr VLBI solutions are not shown in the table since the time between observations and availability to the EOP solutions is generally greater than 7 days.

Table 4a: Major Contributors for the Polar Motion EOP solution at the Nxdaily Solution Update Times

1700 UTC solution		2110 UTC solution		0310 UTC solution		0910 UTC solution	
Contributor	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***
IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	IGS 0 hr Ultra	+12:00	IGS 6 hr Ultra	+18:00
IGS 6 hr Ultra	-06:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	IGS 0 hr Ultra	+12:00
IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00
		IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	IGS 12 hr Ultra	00:00
				IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00
						IGS Rapid	-12:00

Table 4b: Major Contributors for the UT1-UTC EOP solution at the Nxdaily Solution Update Times

1700 UTC solution		2110 UTC solution		0310 UTC solution		0910 UTC solution	
Contributor	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***
AAM LOD[3]		AAM LOD[3]		AAM LOD[3]		AAM LOD[3]	
INT2 / 3 VLBI intensive[1]	+08:00	INT2 / 3 VLBI intensive[1]	+08:00	IGS 0 hr Ultra	+12:00	IGS 6 hr Ultra	+18:00
IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	INT2 / 3 VLBI intensive[1]	+08:00	IGS 0 hr Ultra	+12:00
INT1 VLBI intensive[2]	-05:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	INT2 / 3 VLBI intensive[1]	+08:00
IGS 6 hr Ultra	-06:00	INT1 VLBI intensive[2]	-05:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00
IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	INT1 VLBI intensive[2]	-05:00	IGS 12 hr Ultra	00:00
		IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	INT1 VLBI intensive[2]	-05:00
				IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00
						IGS Rapid	-12:00

* IGS and VLBI solutions are determined by integrating a period of observation times. The EOP reported is the observation mid-point.

[1] INT2 and INT3 intensives are normally observed Saturday through Monday with an epoch at midpoint at approximately 08:00 UTC.

[2] INT1 intensives are normally observed Monday through Friday with an epoch at midpoint at approximately 19:00 UTC. Also, this row was not applicable after June 12, 2014 due to e-VLBI outage at Kokee Park.

[3] The AAM LOD inputs contain 7.5 days of forecast data from 00:00 to 180:00 hours.

09:10 UTC <MJD+1> EOP solution will also make a prediction of the EOP value for the same 00:00 <MJD+1> epoch.

Tables 3a through 3d contain the RMS for the 1- to 90- day prediction errors for the 17:00, 21:10, 03:10, and 09:10 UTC EOP solutions for 2014. The polar motion short-term prediction solutions should improve at each later EOP update (starting from the 17:00 UTC <MJD> to the 09:10 UTC <MJD+1> solution) since the later EOP solutions will have more recent observations. The 2014 1-day and 5-day polar motion prediction results shown in Tables 3a, 3b, 3c and 3d generally confirm this improvement, especially when comparing Table 3a and 3d results.

The percentage decrease in the 1-day polar motion error from the 17:00 to 09:10 UTC solutions (as shown in Table 3a and 3d) was significant — 50% for PMx and 47% for PMy. As expected, improvements of a consistently smaller magnitude are made between the 17:00 and 21:10 UTC and between the 17:00 and 03:10 UTC solutions, as can be seen by comparing results among Tables 3a, 3b, and 3c. The UT1–UTC 1-day predictions also show improvements from the 17:00 UTC <MJD> to the 09:10 UTC <MJD+1> solutions; however, the percentage decrease is much smaller than it was for polar motion – a decrease in error of 14%.

There are no rapid turnaround estimates of celestial pole offsets; only 24-hour VLBI solutions provide celestial pole offsets. These 24-hr solutions can be latent by one to two weeks, and therefore, it is anticipated that there will be no statistically significant difference between celestial offset prediction solutions. No tables of statistics for celestial pole offsets are presented in this report.

The predictions of celestial pole offsets (both dX/dY and $d\psi/d\varepsilon$ representations) are produced through the use of the KSV1996 model (McCarthy, 1996). In addition, a bias, based on several years of past observations compared to the 08 C04 solution, is computed and applied to ensure consistency with the 08 C04 solution. Since celestial pole offsets are based solely on VLBI data,

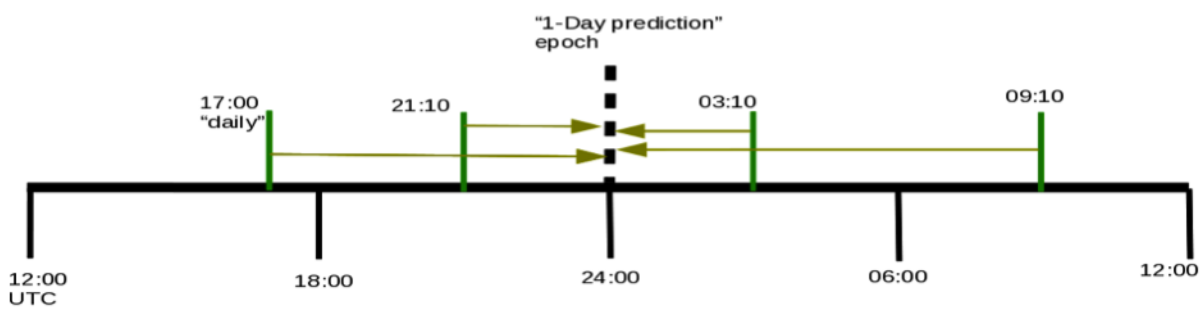


Fig. 4: Timeline of EOP 1-day prediction solutions in relation to the EOP "daily" solution produced at 17:00 UTC.

if no new VLBI 24-hour session observations are available, a new rapid combination/prediction of these angles is not determined. Therefore, the updates 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 RMS differences between the daily predictions and the 08 C04 for 2014 are provided in Table 5.

Table 5: Root mean square of the differences between the nutation prediction series produced by the daily solutions and the 08 C04 combination solutions for 2014.

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
0	.16	.16	.38	.14
1	.16	.16	.39	.15
5	.17	.17	.42	.15
10	.18	.17	.44	.16
20	.21	.19	.51	.18
40	.26	.23	.62	.23

Predictions of TT–UT1, up to 1 January 2025, are given in Table 6. 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 errors 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; Stamatakos *et al.*, 2010).

Center Activities in 2014

During 2014, several input data series to the EOP operational solution were upgraded. A list of these upgrades is as follows:

a) the U.S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) AAM input was upgraded from NAVGEM v1.1 to v1.2 in February 2014;

b) the NASA Goddard VLBI 24-hour and intensive data series was upgraded from the gsf2012a to gsf2014a series in May 2014; and

c) the USNO VLBI 24-hour and intensive data series was upgraded from the usno2012b to usno2014a series in June 2014.

In addition, it was determined that the systematic corrections for the International Laser Ranging Service (ILRS) SLR needed to

Table 5: Predicted values of TT–UT1, 2015–2025. 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)
2015 Oct 1	68.02	0.009
2016 Jan 1	68.1	0.01
2016 Apr 1	68.3	0.02
2016 Jul 1	68.4	0.02
2016 Oct 1	68.5	0.3
2017 Jan 1	68.6	0.4
2017 Apr 1	68.7	0.5
2017 Jul 1	68.8	0.6
2017 Oct 1	69.0	0.8
2018 Jan 1	69.1	0.9
2018 Apr 1	69.2	1.0
2018 Jul 1	69.	1.
2018 Oct 1	69.	1.
2019 Jan 1	70.	1.
2019 Apr 1	70.	1.
2019 Jul 1	70.	2.
2019 Oct 1	70.	2.
2020 Jan 1	70.	2.
2020 Apr 1	70.	2.
2020 Jul 1	70.	2.
2020 Oct 1	70.	2.
2021 Jan 1	71.	2.
2021 Apr 1	71.	3.
2021 Jul 1	71.	3.
2021 Oct 1	71.	3.
2022 Jan 1	71.	3.
2022 Apr 1	71.	3.
2022 Jul 1	71.	3.
2022 Oct 1	71.	4.
2023 Jan 1	72.	4.
2023 Apr 1	72.	4.
2023 Jul 1	72.	4.
2023 Oct 1	72.	4.
2024 Jan 1	72.	4.
2024 Apr 1	72.	5.
2024 Jul 1	72.	5.
2024 Oct 1	72.	5.
2025 Jan 1	73.	5.

be updated, and as a result, new corrections were included in the operational EOP solution in June 2014.

Also, efforts were continued in the following areas as well: a) using the Very Long Baseline Array (VLBA) inputs as additional UT1–UTC inputs to the EOP solution (Stamatakos *et al., 2012, AGU poster G51A-1084*), b) studying the use of the IGS Ultra-rapid predictions for enhanced polar motion and LOD inputs to the EOP solution, and c) using combined AAM and OAM models to improve polar motion predictions (Salstein *et al.*, 2014).

The IERS RS/PC replicates the USNO (Washington D.C.) EOP solutions at the Naval Observatory, Flagstaff station (NOFS). The USNO and NOFS products are generated independently, and the 17:00 UTC EOP solutions at the USNO DC and NOFS are compared each day to ensure that there are no discrepancies between the two. This redundancy provides an alternative location from which to obtain a solution should the primary facility at USNO DC be unable to deliver its EOP products, such as due to an internet outage or power outage.

The Earth Orientation transformation matrix calculator (<http://maia.usno.navy.mil/t2c36e/t2c36e.html>) was maintained throughout the year. The calculator can produce rotation matrix elements calculated using the IERS Technical Note 36 equinox-based algorithm (Petit and Luzum, 2010). This web-based product will provide both the transformation matrices as well as quaternion representations of the rotations between terrestrial and celestial reference frames.

Rapid Service Input Data Contributors and Products

A list of the inputs to the EOP combination and prediction solutions are provided in Table 7; in addition, this table indicates which EOPs are provided by each contributor.

Other data sets are available and are listed below; however, they are not used in the EOP combination and prediction solutions. They include: UT from Natural Resources Canada GPS; UT0–UTC from University of Texas at Austin Lunar Laser Ranging (LLR); UT0–UTC from JPL LLR; UT0–UTC from the Centre de recherches en géodynamique et astrométrie (CERGA) LLR; UT0–UTC from JPL VLBI; latitude and UT0–UTC from Washington [state] PZTs 1,3,7; latitude and UT0–UTC from Richmond, Florida PZTs 2,6; LOD from ILRS 1-day SLR; x, y, UT1–UTC from Center for Space Research (CSR) UT at Austin LAGEOS 3-day SLR; x and y from CSR LAGEOS 5-day SLR; x and y from Delft, Netherlands 1-, 3- and 5-day SLR; and x, y, UT1–UTC, $d\psi$ and $d\varepsilon$ from International Radio Interferometric Surveying (IRIS) VLBI.

The data described above are available from the IERS RS/PC in a number of forms. You may also request a weekly machine-readable version of the IERS Bulletin A containing the current

Table 7: Input data available for contributors to the IERS Bulletin A EOP solution.

Contributor	PM-x	PM-y	UT1–UTC	LOD	dψ	dε	dX	dY
IAA VLBI								
GSFC VLBI								
USNO VLBI								
IVS VLBI								
GSFC Int.[a]								
USNO Int.								
GSI[b] Int.								
ILRS[c]								
IAA[d] SLR[e]								
MCC[f] SLR								
IGS								
USNO GPS								
NCEP AAM								
NAVGEM AAM								
IERS EOC								
IERS RS/PC[g]								

[a] The word “Int” is an abbreviation for the word Intensive.
[b, c, d, e, f] Defined in the Acronyms section of the Appendix of this report.
[g] Both combination and prediction values are available.

365 days’ worth of predictions via electronic mail from ser7@ maia.usno.navy.mil or through <http://www.usno.navy.mil/USNO/ earth-orientation>.

Daily and Bulletin A weekly EOP solutions can be obtained from the primary Earth Orientation (EO) server at <http://maia.usno. navy.mil> and <ftp://maia.usno.navy.mil>, and from the backup EO server at <http://toshi.nofs.navy.mil> and <ftp://toshi.nofs.navy. mil>. An additional backup mirror of the daily and Bulletin A EOP data is now hosted by NASA’s Archive of Space Geodesy Data server at <ftp://cddis.gsfc.nasa.gov/pub/products/iers>.

Table 8 contains a listing of the locations and update times of several of the EOP solutions discussed in this report. The first column lists the EOP solution time in UTC. These are the approximate times when an EOP result is computed; the actual solution time may occur as much as one hour later than what is listed. The second column contains the subdirectory under each FTP or web address listed in the above paragraph where an EOP solution resides. For example, at <http://maia.usno.navy.mil>

there exists a subdirectory called “ser7” (i.e., <http://maia.usno.navy.mil/ser7>) where the daily EOP solution computed at 17:00 UTC will be updated each day. Similarly, at <ftp://cddis.gsfc.nasa.gov>, there exists a subdirectory called “eop0300utc” (i.e., <ftp://cddis.gsfc.nasa.gov/pub/products/iers/eop0300utc>), where an EOP solution update computed at approximately 03:10 UTC will be uploaded each day.

Table 8: EOP server locations and update times.

EOP solution time (UTC)[1]	Subdirectory Location	Approximate time solution is posted[1]
17:00	ser7	17:15[2]
21:10	eop2100utc	21:15
03:10	eop0300utc	03:15
09:10	eop0900utc	09:15

[1] *Solution times are the approximate times when an EOP result is computed; actual solution time may occur as much as one hour later than what is listed.*

[2] *This time represents the approximate time updated EOP solutions, found at http://maia.usno.navy.mil, ftp://maia.usno.navy.mil, http://toshi.nofs.navy.mil, and ftp://toshi.nofs.navy.mil, will be available. For ftp://cddis.gsfc.nasa.gov/pub/products/iers, the solution is posted at 18:00 UTC, which is approximately 45 minutes after the “maia” and “toshi” servers have data posted. The additional time is needed to allow the EOP solution to finish at USNO and to be verified by EOP personnel before the mirroring is performed to post the solution to CDDIS.*

Center Staff

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

Dr. Christine Hackman	Director; Head, Earth Orientation Department
Nick Stamatakos	Operational program manager, research, and software maintenance; Chief, Earth Orientation Combination and Prediction Division
Merri Sue Carter	Assists in daily operations and support; Research Astronomer
Nathan Shumate	Assists in daily operations and support, research, and software maintenance; Astronomer
Maria Davis	Assists in daily operations and support, research, and software maintenance; Astronomer

References

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

Johnson, T.J., Luzum, B.J., and Ray, J.R., 2005, Improved near-term Earth rotation predictions using atmospheric angular momentum analysis and forecasts, *J. Geodynamics*, **39**(3), 209–221.

Kammeyer, P., 2000, A UT1-like Quantity from Analysis of GPS Orbit Planes, *Celest. Mech. Dyn. Astr.*, **77**, 241-272.

Luzum, B.J., Ray, J.R., Carter, M.S., and Josties, F.J., 2001, Recent Improvements to IERS Bulletin A Combination and Prediction, *GPS Solutions,* **4**(3), 34–40.

McCarthy, D.D. and Luzum, B.J., 1991a, Combination of Precise Observations of the Orientation of the Earth, *Bulletin Geodesique,* **65**, 22–27.

McCarthy, D.D. and Luzum, B.J., 1991b, Prediction of Earth Orientation, *Bulletin Geodesique,* **65**, 18–21.

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

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

Petit, G. and Luzum (eds.), 2010, IERS Conventions (2010), *IERS Technical Note* No. 36, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main, Germany.

Salstein, D., Stamatakos, N., “New Atmospheric and Oceanic Angular Momentum Datasets for Predictions of Earth Rotation/Polar Motion”, G13A-0521 POSTER at the *American Geophysical Union Meeting*, San Francisco, California, December 2014.

Stamatakos, N., Luzum, B., Wooden, W., 2008, “Recent Improvements in IERS Rapid Service/Prediction Center Products,” in *Proc. Journées Systèmes de Référence Spatio-Temporels*, Paris, 17–19 Sept. 2007, 163–166.

Stamatakos, N., Luzum, B., Stetzler, B., Wooden, W., and Schultz, E., 2009, “Recent Improvements in IERS Rapid Service/Prediction Center Products,” in *Proc. Journées Systèmes de Référence Spatio-Temporels*, Dresden, 22–24 Sept. 2008, 160–163.

Stamatakos, N., Luzum, B., Stetzler, B., Shumate, N., and Carter, M.S., 2011, “Recent Improvements in IERS Rapid Service/Prediction Center Products,” in *Proc. Journées Systèmes de Référence Spatio-Temporels*, Paris, 20–22 Sept. 2010, 184–187.

Stamatakos, N., Luzum, B., Stetzler, B., Shumate, N., Carter, M.S., and Tracey, J., 2012, “Recent Improvements in IERS Rapid Service/Prediction Center Products for 2010 and 2011,” in *Proc. Journées Systèmes de Référence Spatio-Temporels*, Vienna, 19–21 Sept. 2011, 125–129.

Stamatakos, N., Luzum, B., Zhu, S., and Boboltz, D., 2012, “Further Analysis of a New Geodetic VLBI Data Source and its Applications,” G51A-1084, *AGU Fall Meeting*, San Francisco, 3–7 Dec. 2012.

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

Wooden, W.H., Johnson, T.J., Kammeyer, P.C., Carter, M.S., and Myers, A.E., 2005, Determination and Prediction of UT1 at the IERS Rapid Service/Prediction Center, *Proc. Journees Systemes de Reference Spatio-Temporels*, Paris, 20–22 Sept 2004, 260–264.

Nicholas Stamatakos, Maria Davis, Nathan Shumate, Merri Sue Carter, Christine Hackman

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 IERS Conventions in electronic form, after approval of the IERS Directing Board. In the meantime, interim versions are 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.

In 2014, the operation of the Conventions Center has been reorganized with the creation of an Editorial Board with roughly twelve members, where each member typically has responsibility for one chapter of the IERS Conventions, providing editorial support to the Center. Independently, the former “Advisory Board for the IERS Conventions updates” chaired by Jim Ray since 2005 has been discontinued. Planned updates to the Conventions are distributed for comments through the Directing Board and the Technique Service coordinators.

Over 2014, the work accomplished or in progress includes the following:

1. Technical content of the IERS Conventions

Work started on the updates to the IERS Conventions (2010) soon after the publication of this new reference edition. Note that the published IERS Conventions (2010) is available in electronic form (<http://tai.bipm.org/iers/conv2010/>) and as IERS Technical Note 36 (<http://www.iers.org/TN36>). The list below summarizes the updates made in 2014. See <http://tai.bipm.org/iers/convupdt/convupdt.html> (or the site at <http://maia.usno.navy.mil/conv2010/convupdt.html>) for details.

- Provided draft revision to implement new conventional mean pole coordinates for Chapter 7 (Displacements of reference points).
- Provided draft revision to Chapter 9 (Models for atmospheric propagation delays) to improve access to data and to modify the section on ionospheric effects.

2. Conventions software

The FCNNUT program was updated for the latest free core nutation values.

3. Planned Changes

A study group was established to review compatibility of models for VLBI and SLR in an effort to reduce the discrepancy in scale observed by the two techniques. Discussions continued regarding the update of the conventional geopotential model (Chapter 6), notably its time-varying part (low degree coefficients, seasonal variations). Associated topics such as conventional models for the geocenter motion in the ITRF and the IERS mean pole were also covered. Investigation into non-tidal displacement of reference markers continues and may lead to a new section for Chapter 7. In response to concerns regarding the quality of existing models for diurnal and semi-diurnal EOP variations in Chapter 8, efforts to identify improved models continued. In addition to improvements in content, the IERS Conventions Center is considering the electronic content of the document, version control, and other ways to improve the quality and usability of the IERS Conventions.

4. Dissemination of information

The Conventions web pages at the BIPM (<http://tai.bipm.org/iers/>) and the USNO (<http://maia.usno.navy.mil/conv2010/>) were maintained.

Past updates to the IERS Conventions (2003), from 2004 until the release of the IERS Conventions (2010), were archived separately from the current updates, at <http://tai.bipm.org/iers/conv2010/convupdt/convupdt.html>.

5. Conventions Center staff

Felicitas Arias (BIPM)
Merri Sue Carter (USNO, until March 2015)
Maria Davis (USNO, since March 2015)
Brian Luzum (USNO), co-director
Gérard Petit (BIPM), co-director
Nick Stamatakos (USNO)

Brian Luzum, Gérard Petit

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 behavior 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 and 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).

At the XXVII General Assembly of the IAU held in Rio de Janeiro, Brazil, a second realization of the International Celestial Reference Frame (ICRF2; Fey, Gordon and Jacobs 2009) was adopted as the fundamental celestial reference frame as of 1 January 2010. ICRF2 is again based on the radio wavelength astrometric positions of compact extragalactic objects determined by the technique of VLBI. 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 International VLBI Service for Geodesy and Astrometry (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 (NRAO) 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.

ICRF2 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. Maintenance of ICRF2 will be made using a set of 295 new "defining" sources selected on the basis of positional 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.

ICRS Centre personnel are involved in a program to extend the ICRF to higher radio frequencies than those currently used. At these higher radio frequencies, e.g., K-band (24 GHz), Ka-band (32 GHz), and Q-band (43 GHz), contributions to source position uncertainties from intrinsic source structure and from the Earth's ionosphere will be less than that at the radio frequencies currently used for astrometric/geodetic VLBI. VLBA observations to extend the ICRF to K-band and Q-band continued in 2014. These observations are part of a joint program between the National Aeronautics and Space Administration (NASA), the USNO, the NRAO and Bordeaux Observatory. Preliminary results of these high frequency reference frame observations can be found in Charlot et al. (2010) and Lanyi et al. (2010). Results of observations to determine the position/structure stability of four ICRF2 quasars can be found in Fomalont et al. (2011).

At the IAU General Assembly in Beijing in August 2012, ICRS Centre personnel organized an effort to establish an IAU Working Group on ICRF3. The effort was well received by the IAU. A steering committee was established which met in Beijing and subsequently in October 2012 in Bordeaux. The steering committee wrote a charter for the working group, established Working Group membership, and selected a Working Group chair. The IAU subsequently accepted all these, and formally established the Working Group. In 2014 the ICRF3 Working Group pursued new observations that filled some gaps and improved weaknesses of ICRF2, prepared a progress report to the IAU General Assembly in 2015, and pursue the completion of ICRF3 in 2018.

In the coming decades, there will be significant advances in the area of space-based optical astrometry. Missions such as the European Space Agency's (ESA) Gaia mission, which launched 19 December 2013, are expected to achieve astrometric positional accuracies beyond that presently obtained by ground-based radio interferometric measurements. Whether future versions of the ICRF transition back from the radio to the optical depends at least partially upon the relative astrometric accuracy of future radio- and optical-based reference frames.

Assessment of VLBI realisations of the ICRF

Eight catalogs were submitted respectively by Geoscience Australia (aus2015a/b), the Federal Agency for Cartography and Geodesy (BKG Leipzig) and Institute of Geodesy and Geoinformation of the University of Bonn (IGGB) (bkg2014a), the Space Geodesy Center (CGS) of Matera (cgs2014a), the NASA Goddard Space Flight Center (GSFC) (gsf2014a), the Institute of Applied Astronomy (IAA) of the Russian Academy of Sciences (RAS) (iaa2014a), the Paris Observatory (opa2015a), and the US Naval Observatory (usn2015a). All these catalogs provide right ascension (α) and declination (δ) of extragalactic radio sources, as well as their respective uncertainties, the correlation coefficient between α and δ, and the number of sessions and delays. Note that bkg2014a, cgs2014a, gsf2014a, opa2015a, and usn2015a were produced with the same geodetic VLBI analysis software package SOLVE developed at NASA GSFC. Both aus2015a/b and iaa2014a were produced with OCCAM.

Table 1 displays the total number of sources of each catalog, as well as the number of ICRF2 sources (out of 3414) and ICRF2 defining sources (out of 295). Some catalogs do not provide values for one or two defining sources, likely because they do not process a few sessions that were present in the session list processed to generate the ICRF2 catalog. We recommend that in the future, the analysis centers pay attention to their session list in order to get values for all 295 ICRF2 defining sources. As well, none of the catalogs provide values for all 3414 ICRF2 sources.

Table 1: Number of sources by categories and median error. Unit is µas. Values for right ascension are corrected from the cosine of the declination.

	No. Sources			Median Error	
	Total	ICRF2	Def	RA	Dec
aus2015a	3383	3170	295	676.5	965.0
aus2015b	3406	3191	295	576.0	817.0
bkg2014a	3340	3110	294	281.4	429.4
cgs2014a	969	961	294	44.3	50.1
gsf2014a	3740	3408	294	264.0	400.0
iaa2014a	2946	2799	293	445.6	690.3
opa2015a	3684	3378	295	283.5	440.2
usn2015a	4048	3410	295	230.0	333.3

The median error reported in Table 1 reveals an error in declination larger than in right ascension by a factor of ~1.5. The error is substantially smaller for SOLVE solutions. The smaller error for cgs2014a is likely originating in the fact that the solution provides only well observed sources with low positional standard error.

Frame orientation

We evaluate the consistency of the submitted catalogs with the ICRF2 by modeling the coordinate difference (in the sense catalog minus ICRF2) by a 6-parameter transformation as used at the IERS ICRS Centre in previous comparisons:

$$A1 \tan \delta \cos \alpha + A2 \operatorname{tg} \delta \sin \alpha - A3 + DA\,(\delta\text{-}\delta_0) = \Delta\alpha,$$
$$-A1 \sin \alpha + A2 \cos \alpha + DD\,(\delta\text{-}\delta_0) + BD = \Delta\delta,$$

where A1, A2, A3 are rotation angles around the X, Y, and Z axes of the celestial reference frame, respectively, DA and DD represent linear variations with the declination (which origin δ_0 can be arbitrarily chosen but was set to zero in this study), BD is a bias in declination, and $\Delta\alpha$ and $\Delta\delta$ coordinate differences between the studied and the ICRF2 catalogs. The 6 parameters were fitted by weighted least squares to the coordinate difference of the defining sources (upper part of Table 2) and ICRF2 sources (lower part of Table 2) found in the catalog. The standard deviation of the offsets to ICRF2 after removal of the systematics of Table 2 is reported in Table 3 together with the median offset.

Though rotations around the X-axis (angle A1) remain almost statistically non significant (within 3 sigmas), all catalogs show significant misorientation around A2 larger than 10 μas (4 sigmas). We note also that solutions aus2015a/b show significant misorientation of the frame around the Z-axis close to 50 μas whereas it remains reasonable for other catalogs. The largest deviation from ICRF2 axes is observed for the bias in declination. Values of BD are indeed significantly larger than those reported in the 2013 Annual Report for solutions bkg2013a and opa2013a (to be compared to bkg2014a, and opa2015a, respectively). Generally, all SOLVE solutions have declination biases larger than 30 μas in absolute value, which is significantly larger than the ICRF2 axis stability of 10 μas measured at the time of the ICRF2 release in 2009 (Fey et al., 2015). This fact may indicate some systematics in source declinations with respect to solutions of the previous years.

Zonal errors

Figure 1 displays the offset to ICRF2 (in the sense catalog minus ICRF2) averaged over declination bins of 5 degrees. Solutions opa2015a, usn2015a, and bkg2014a exhibit zonal errors characterized by large declination offsets at low declinations, which may reflect the large values of BD found in the coordinate difference to ICRF2. A similar effect is also visible but less pronounced for cgs2014a and gsf2014a.

Table 2: Rotation parameters with respect to ICRF2. A1, A2, A3 and BD are in µas. DA and DD are in µas per degree.

	A1	A2	A3	DA	DD	BD
Defining sources						
aus2015a	2.2	20.9	49.0	-0.2	-0.4	-10.8
+-	3.7	3.7	3.4	0.1	0.1	3.5
aus2015b	1.7	28.9	52.6	-0.7	-0.5	-17.9
+-	3.9	3.9	3.6	0.1	0.1	3.8
bkg2014a	6.4	13.9	-12.6	0.2	0.9	-53.0
+-	3.5	3.4	3.1	0.1	0.1	3.4
cgs2014a	8.6	19.1	-12.1	0.1	0.1	39.6
+-	3.5	3.5	3.2	0.1	0.1	3.5
gsf2014a	-4.6	11.4	-8.8	0.1	0.6	-38.1
+-	3.4	3.4	3.0	0.1	0.1	3.3
iaa2014a	-3.9	12.1	-1.1	-0.1	0.5	1.0
+-	3.7	3.6	3.4	0.1	0.1	3.7
opa2015a	-8.9	18.9	-3.3	0.1	1.0	-57.8
+-	3.4	3.4	3.1	0.1	0.1	3.3
usn2015a	-9.1	18.1	-2.3	0.2	0.9	-50.9
+-	3.4	3.4	3.1	0.1	0.1	3.3
All common sources						
aus2015a	10.0	14.1	38.0	-0.0	-0.3	-6.0
+-	4.4	4.5	4.1	0.2	0.1	4.1
aus2015b	15.7	25.9	38.4	-0.6	-0.4	-15.8
+-	4.7	4.8	4.5	0.2	0.1	4.4
bkg2014a	10.5	16.5	-13.0	0.2	1.0	-53.7
+-	4.5	4.6	4.2	0.2	0.1	4.3
cgs2014a	10.4	18.8	-9.2	0.2	0.3	37.9
+-	4.5	4.6	4.2	0.2	0.1	4.3
gsf2014a	-2.3	14.5	-8.2	0.1	0.7	-36.0
+-	4.5	4.6	4.2	0.2	0.1	4.2
iaa2014a	-0.9	11.3	-1.8	0.1	0.6	-1.7
+-	4.7	4.8	4.4	0.2	0.1	4.6
opa2015a	-3.8	18.7	-8.7	0.1	1.1	-56.3
+-	4.5	4.6	4.2	0.2	0.1	4.2
usn2015a	-4.5	21.2	-8.5	0.0	1.1	-53.4
+-	4.5	4.6	4.2	0.2	0.1	4.2

Table 3: Statistics after removal of systematics given in Tables 2. Unit is µas. Values for right ascension are corrected from the cosine of the declination.

	Standard Deviation				Median Offset			
	Defining		All		Defining		All	
	RA	Dec	RA	Dec	RA	Dec	RA	Dec
aus2015a	165.0	130.4	165.3	132.1	256.4	419.6	267.9	427.4
aus2015b	68.8	69.2	107.2	119.2	261.1	495.4	264.9	409.8
bkg2014a	48.3	59.4	401.2	419.1	117.3	223.1	118.9	211.4
cgs2014a	47.8	58.9	282.1	520.5	48.9	72.4	50.7	67.0
gsf2014a	48.7	57.1	517.9	771.1	78.7	143.8	79.1	132.8
iaa2014a	49.6	60.9	310.6	304.3	35.6	34.7	180.6	253.5
opa2015a	56.6	62.2	491.5	718.6	51.8	76.5	54.7	82.5
usn2015a	56.7	63.1	546.1	774.4	119.4	232.8	124.6	219.2

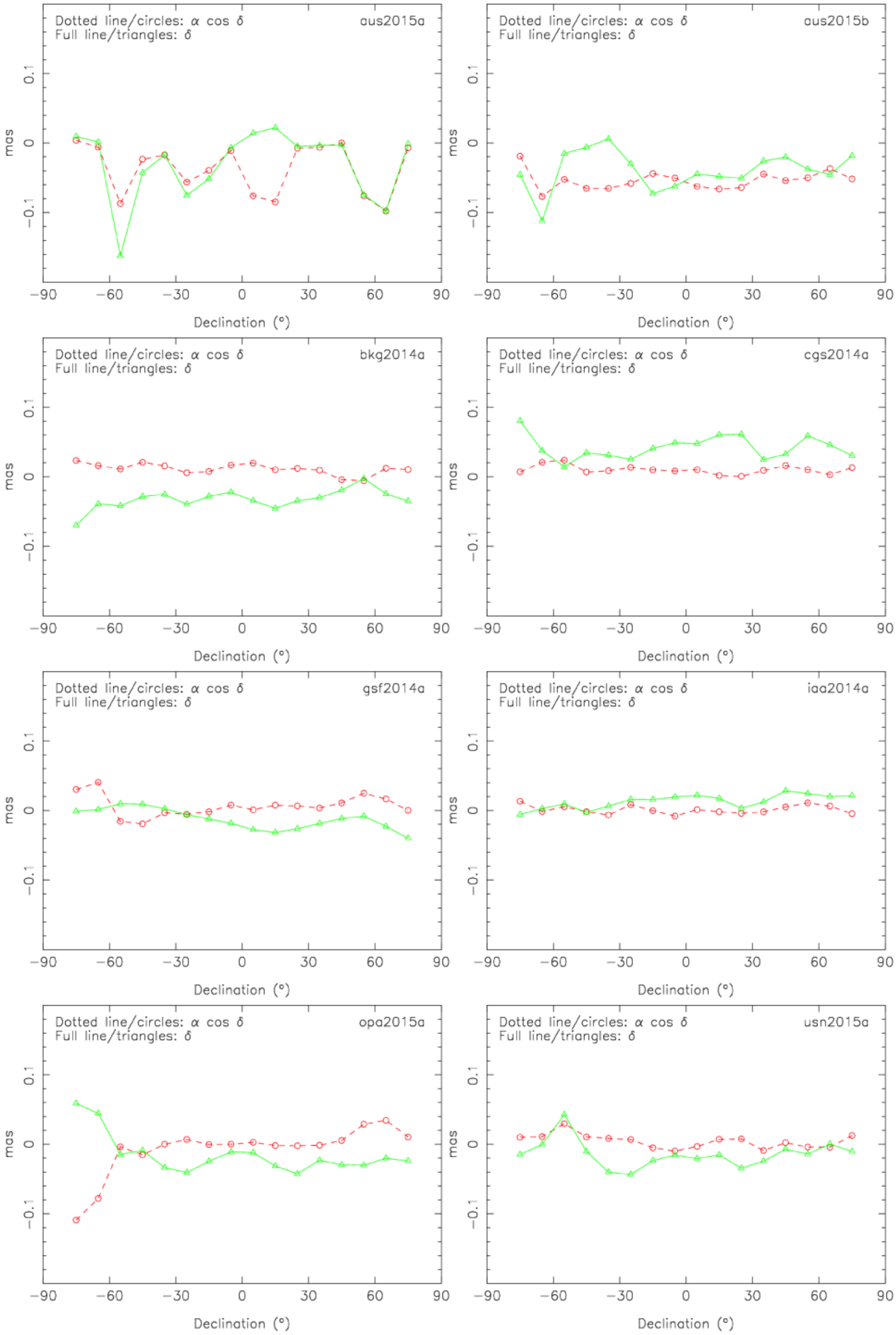


Fig. 1: Offset to ICRF2 for right ascension (dotted line with circles) and declination (full line with triangles) by bins of declination of 5 degrees.

Standard error and noise

Figure 2 illustrates how the overall formal error, defined as the square root of $\sigma_{\alpha\cos\delta}{}^2+\sigma_\delta{}^2+c\sigma_{\alpha\cos\delta}\sigma_{\alpha\delta}$ where σ is the formal error listed in the catalogs and c is the correlation coefficient between estimates of α and δ as provided in the catalogues, varies with the number N of observations. The circled dots represent defining sources. The figure for aus2015a clearly shows that the defining sources have underestimated formal errors likely due to an over-constrained solution. (As stated in the technical document delivered with the catalog, a strong no-net rotation condition imposed to these sources.) The formal error of the same sources in solution aus2015b, in which the no-net rotation condition is less severe, appears to be at a level comparable to other sources.

Figure 2 also shows how the error on delays is propagated to the estimated source coordinates. For white noise measurements, the formal error on source coordinates is expected to decrease as $N^{-0.5}$. The figure reveals that this regime exists for N between ~100 and ~10000. For N lower than a hundred observations (e.g., VCS sources or sources observed in only one session) the formal error varies as N^{-1}. Beyond 10000 observations, the formal error generally tends towards a limit lower than ~10 μas. Such a deviation is visible for all catalogs except aus2015a/b for which the formal error seems to continue to decrease closely to $N^{-0.5}$. The deviation for large N observed for all other catalogs is likely the signature of non-Gaussian correlated errors: as N increases, thermal baseline-dependent error tends to zero and the station-dependent error arising from time- and space-correlated parameters becomes dominant (see, e.g., Gipson 2006 or Romero-Wolf et al. 2012).

A last test was performed to assess the consistency between the formal errors and the offset to ICRF2. This test was motivated by the consideration that, although the ICRF2 is not the "truth", it nevertheless provides accurate values of well-observed sources. As a consequence, for most of the sources, the addition of new observations after 2009 should not perturb significantly the estimated position but only improve the formal error. For formal errors lower than 0.1 mas, one sees that the scatter is over the diagonal, indicating a possible underestimation of the formal errors. To quantify this scale factor, one can estimate it together with an error floor so that a realistic error Er (i.e., that explains the observed offset to ICRF2) is given by

$$Er = ((E\ s)^2 + f^2)^{-0.5}$$

where E is the error, s a scale factor and f a noise floor. Values of s and f estimated over sources whose offset to ICRF2 is smaller than 1 mas are reported in Table 4. Uncertainties are ~10 μas on f and ~0.01 on s. SOLVE solutions tend to have scale factors larger than unity while OCCAM catalogs have scale factors smaller than 1. Note that the noise floor does not represent the catalog

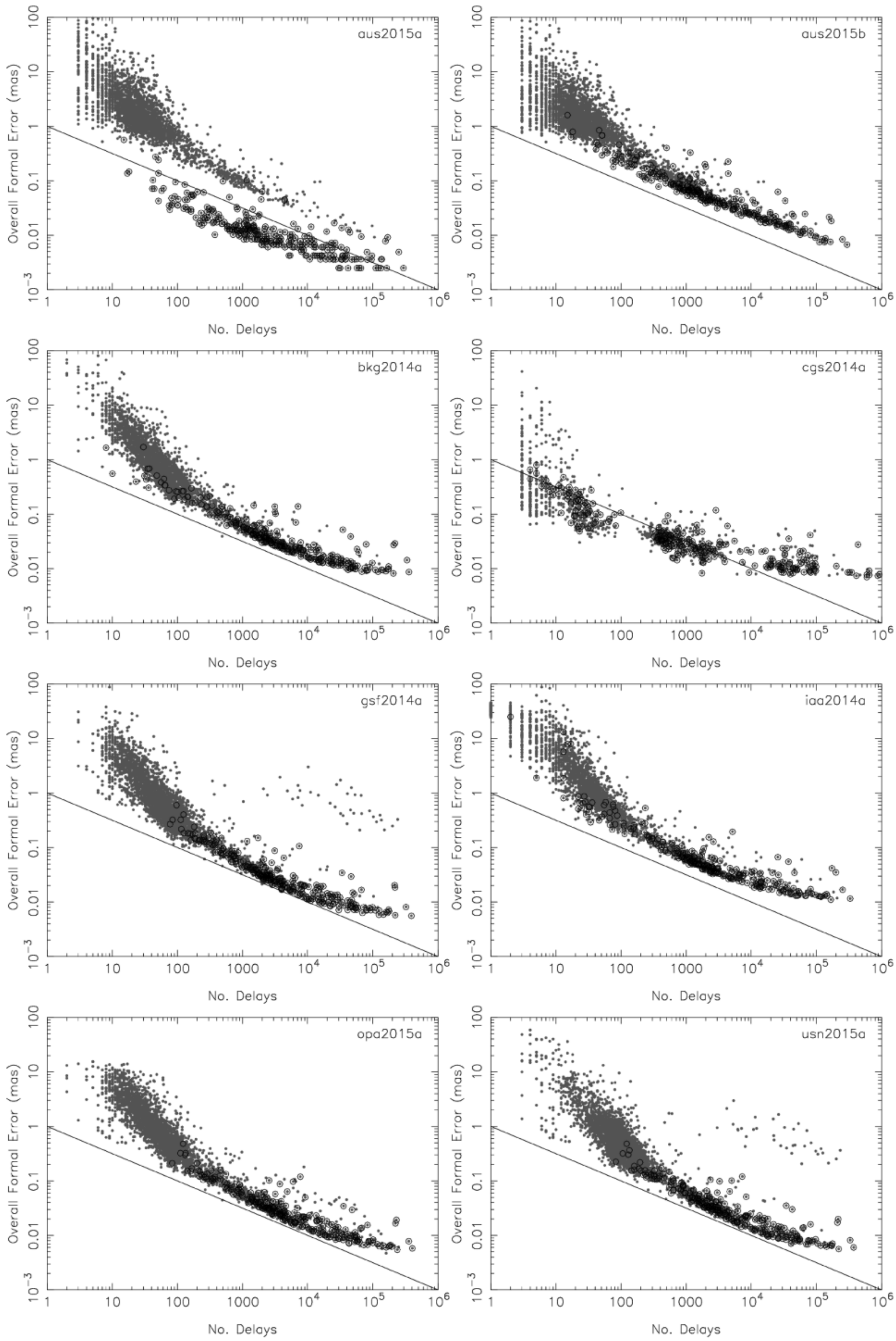


Fig. 2: Overall formal error as a function of the number of observations. The circled dots represent defining sources. The solid line indicates a decrease as $N^{-1/2}$ where N is the number of delays.

Table 4: Noise floor (µas) and scale factor estimated for sources with offset lower than 1 mas. Values for right ascension are corrected from the cosine of the declination.

	-- Floor --		-- Scale --	
	RA	Dec	RA	Dec
aus2015a	97.3	117.5	0.79	0.79
aus2015b	70.4	71.2	0.96	0.93
bkg2014a	45.6	62.5	1.26	1.11
cgs2014a	36.4	48.7	2.70	2.38
gsf2014a	47.7	60.3	1.14	1.06
iaa2014a	44.4	52.1	0.99	0.83
opa2015a	50.8	62.4	1.27	1.11
usn2015a	53.7	65.6	1.67	1.47

internal error since one considers the offset to ICRF2: the quantity f therefore contains the internal noise of the ICRF2. The global noise lies between 50 and 120 µas. If one assumes 40 µas for the ICRF2 internal noise (Fey et al., 2015), it means that the analyzed catalog internal noises are larger by a factor between 1 and 3.

Conclusions and recommendations

The above results lead to some recommendations for analysis centers who plan new submissions in the future. First, it is recommended to include all ICRF2 sources in the processed session list, in order to get values of, at least, all 3414 ICRF2 sources. Second, analysis centers should focus on understanding several points: (i) the significant systematics in orientation (~50 µas) showing up in Table 2, (ii) the zonal errors appearing in Fig. 1 for some solutions, and (iii) the non-Gaussian errors dominating for large number of observations discussed previously. About the latter item, one should understand particularly why aus2015a/b OCCAM solutions decreases differently than SOLVE catalogs for larger numbers of delays. In the future, the correction of this defect should be achieved by better modeling and parameterization of clock and troposphere correlated errors (Lambert 2014).

Monitor source structure to assess astrometric quality

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 VLBA images of 782 sources at radio frequencies of 2.3 GHz and 8.4 GHz. Additionally, the RRFID contains 1867 images of 285 sources at frequencies of 24 GHz and 43 GHz. Imaging of additional radio sources has been temporarily suspended due to lack of available resources. 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 more than 3500 VLBA images of 1100 sources mostly at radio frequencies of 2.3 GHz and 8.4 GHz, but includes images for some sources at 24 GHz and 42 Ghz. The BVID can be accessed from the Analysis Center web page or directly at <http://www.obs.u-bordeaux1.fr/BVID/>.

Linking the ICRF to frames at other wavelengths

The link between the ICRF and other celestial reference frames is fundamental to prepare the future ICRF as well as the future connection between the ICRS and the GCRS (Gaia Celestial Reference System). During the reporting period (2014) ICRS Centre personnel continued to make progress with several astrometric star catalogs (e.g URAT), the extragalactic link to ICRF sources, and the preparation for the Gaia astrometric space mission.

Optical Representation of the ICRS: Gaia

The ICRS/ICRF paradigm is based on a frame formed by very distant extragalactic sources that is assumed to have no global rotation. By definition, this frame is considered to be kinematically non-rotating. To present date the versions of the ICRF (IERS Tech. Notes 23/1997 and 35/2009) were formed by VLBI positions of selected radio-loud quasars. The Gaia astrometric solution will be referred to a kinematically non-rotating frame thanks to the global zero-proper motion constraint set on the clean subset of quasars detected by Gaia. The positional accuracy of the individual sources will depend on their magnitude, but at least for the (forecasted) 30,000 QSOs brighter than G=18 this would be better than 80 µas and 60 µas/yr formal error per source coordinate (position and proper motion, respectively). This astrometric solution should supersede the VLBI based versions of the ICRF, and bring the primary representation of the ICRS to the optical wavelength at the time of issuing of the Gaia final solution, to be published around 2020 (Mignard, 2012). In preparation for what is currently called the Gaia Celestial Reference Frame (GCRF), the Gaia Initial QSO Catalog has been prepared (Andrei et al., 2012a,b).

The Gaia Initial QSO Catalog (GIQC)

The latest version of the Gaia Initial QSO Catalog (GIQC) produced by the Gaia Coordination Unit 3 (CU3), workpackage GWP-S-335-13000, contains 1,248,372 objects, of which 191,372 are considered and marked as “defining” ones, because of their observational history and the existence of spectroscopic redshift. Also objects with strong, calibrator-like radio emission are included in this category. The “defining” objects represent a clean sample of quasars. The remaining objects aim to bring completeness to the GIQC at the time of its compilation. For the whole GIQC the average density is 30.3 sources per sq.deg. Practically all sources have an indication of magnitude and of morphological indexes, and 90% of the sources have an indication of redshift and of variability indexes. Besides presenting morphological variability, and classification indexes (plus a one-letter comment on the source main feature), the GIQC is being used to define the astrometric reference frame for the 2016 release of the preliminary Gaia catalog. QSOs are used as well for surveillance of stability of the measurements. The GIQC was part of two publications: Smart & Nicastro, A&A vol. 570 pp. 87 (tables at CDS); Michalik et al., A&A in preparation.

Optical Images of the QSOs linking the VLBI and the Gaia Celestial Reference frames

The connection between the International Celestial Reference Frame, currently defined by Very Long Baseline Interferometry (VLBI) observations of quasars, and the future Gaia Celestial Reference Frame (GCRF) is demanded for continuity reasons, since it is foreseen that the GCRF will be the future materialization of the International Celestial Reference System. Each quasar candidate to be used for this alignment should be scrutinized so that the ones that are retained for the link represent the top precision astrometry that can be reached by VLBI and Gaia observations. On the VLBI side specific observations are already being made. In the optical window long term campaigns follow the sources variability (see more on this topic elsewhere in this report). The program obtains optical images with high SNR, using preferably the B and R Johnson filters, for the candidate sources appropriate for the link. The main goal is to establish whether there is an apparent underlying host galaxy, and to which level are the corresponding isophotes. If prominent, the source must be flagged in the Gaia observations, because its centroid ought to be determined with special care for the sake of precision and to be properly compared against the VLBI centroid.

At this point there are already collected good quality images of the optical counterpart of QSOs – in particular the ICRF sources, with special effort toward those that have been regularly radio surveyed either for future implementation at high frequencies and/or those that will be the link sources between the ICRF and the Gaia CRF. Observations have been taken at the LNA/Brazil, CASLEO/Argentina, NOT/Spain, LFOA/Austria, Rozhen/Bulgária, and ASV/Serbia. In complement images are also collected from the Sloan Digital Sky Survey (SDSS) and from the Digitized Sky Surveys (DSS). An image data bank is planned to be made publicly available through the IERS ICRS Centre. The photometry analysis is centred on the morphology, since there remain still cases in which the host galaxy is overwhelming, and many cases in which a non-stellar PSF modelling is required. On basis of the neighbour stars we assign magnitudes and variability whenever possible. Moreover, since Gaia will not obtain direct images of the observed sources, the morphology and magnitude becomes useful as templates onto which assembling and interpreting the one-dimensional and uncontinuous line spread function samplings that will be delivered by Gaia for each QSO.

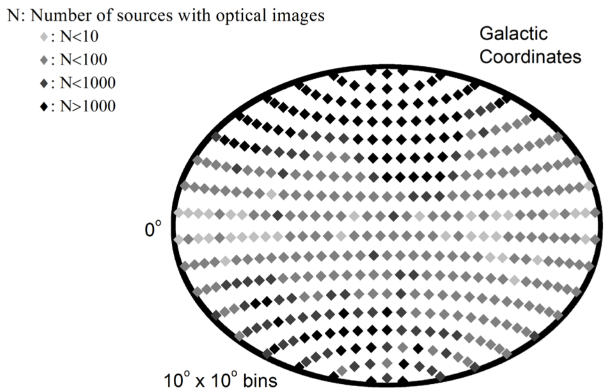


Fig. 3: Sky distribution of the QSOs for which specific observations were made by this program – that is, the images from the SDSS and the DSS do not appear in this plot.

An observational program for identification of the reference sources in radio/optical has also continued at several large optical facilities (PI: Oleg Titov). This program focuses on the future link between the radio reference frame produced by VLBI and the optical reference frame which will be produced by Gaia, and comprises several large optical facilities: 3.58-meter New Technology Telescope (NTT, ESO) in Chile; 2.5-meter Nordic Optical Telescope at Canary Islands (NOT) in Spain; two 8-meter Gemini Telescopes in Chile and Hawaii. Spectroscopic observations at optical wavelengths of the reference radio sources to determine redshifts, and, thus, confirm their extragalactic nature are undertaken. Redshifts of ~300 reference radio sources have been measured to date. They were added to the OCARS database (<http://www.gao.spb.ru/english/as/ac_vlbi/ocars.txt>).

The morphology indexes

In the GIQC as well as in the LQAC (see below) morphological indexes were assigned to each object on basis of the departure of the images from a purely stellar PSF, defined by the stars nearby to each quasar. A morphological departure indicates that the isophotes from the host galaxy must be considered in order to reach maximum precision in the determination of the centroid of the target. A pilot study compared 1,343 quasars in images from the SDSS (r images) and the DSS (R plates). The outcome has shown that the DSS images were able to detect quasars for which the host galaxy signature was sensed in the SDSS images, using the SHARP, SROUND, and GROUND, PSF parameters in IRAF's DAOFIND task. Thus the images of all quasars in the GIQC were

Table 5: Telescope and filter origins of the sources depicted in the plot. Also shown the available contents of the ICRF2 and the GIQC.

Country	Brasil	Brasil	Áustria	Bulgaria	Spain	Argentina	Chile
Telescope aperture	1.6m	0.6m	2m	0.6m	2m	2.2m	2.2m
N QSOs	350	495	12	133	190	103	497
Average <Nobs>	6	5	6	35	9	8	8
Magnitude	327	462	12	128	190	6	497
Redshift	281	403	11	123	179	6	404
GIQC-def	305	412	11	121	160	2	180
GIQC-can	11	15	0	1	2	0	19
GIQC-other	34	68	1	11	28	4	298
ICRF2-def	107	150	11	55	62	0	10
ICRF2-vcs	5	7	0	0	2	0	52
ICRF2- non vcs	185	238	0	63	34	0	29
Non ICRF2	53	100	1	15	92	103	406
u	0	0	0	0	0	0	0
B	0	49	0	0	183	94	497
g	0	0	0	0	0	0	0
V	278	413	12	0	0	1	0
C	101	92	0	133	6	0	0
R	36	48	12	0	183	102	497
I	8	0	0	0	0		0

searched for in the B, R, and I plates of the DSS. For each of the 3 DAOFIND parameters, in each of the 3 colors, a morphological index was produced as the z-ratio of the parameter value for the quasar to the mean parameter ratio for the surrounding stars, normalized by the standard deviation in that mean. Thus, in all, there are up to 9 morphological indexes for each quasar. Typically about 10% of the quasars are found with departures larger than 2 in the z-ratio. The departures are clearly more important in the R plates than in the B plates (Souchay et al., 2012).

The variability indexes

Variability is a prominent characteristic of quasars, mostly due to the violent processes of infall of matter to the massive central black hole (Taris et al., 2012b). As the objects that will materialize the GCRF will be those with the most accurate and stable positions (which are therefore critical, defining, properties), there is evidence that flux variations at different time scales correlate with variations of the astrometric location of their photocentres. Therefore, photocentre angular variations at different wavelengths are possibly the results of common phenomena occurring in the vicinity of the central engine of QSOs: the base of relativistic jets, the broad emission line regions, or accretion disks (Popovic et al., 2012).

Typically Gaia will take about 80 measurements of each quasar during the five years mission, a couple of times in successive fields (or slightly more if the quasar happens to occupy the nodus of a transit great circle), and then come back to the target after a month and a half. Such cadence is very well suited to single out the peculiar quasar variability in comparison to other variable sources (Kelly et al., 2009; Andrei et al., 2012c). At the same time, if an associated astrometric jitter is not accounted for, the error budget of the quasar increases beyond what can be attributed to photon noise.

Accordingly variability indexes were produced on basis of the mass of the central black hole and the absolute luminosity of the quasar. With these elements the radius of the accretion disk and that of the dust torus region were calculated, as apparent angular sizes accounting for the cosmological redshift correction. Those two radii, the accretion disk one in micro-arcseconds and the torus one in milli-arcseconds, are given as the indexes to indicate the likeness of an astrometric jitter that would impact the stability of the centroid during the Gaia mission.

Optical monitoring of extragalactic radiosources to ensure the link between ICRF and the future Gaia celestial reference frame

After four years of observation, a huge amount of optical images of some AGN's selected to ensure the link between the ICRF and the future Gaia celestial reference frame have been gathered (without taking into account the data mining). They come from small robotic telescopes, medium size or large optical facilities spread all over the world. In 2014 four large telescopes (CFHT, NOT, MPG 2.2 and Rozhen 2m) provided high resolution optical images dedicated to morphology analysis while four smaller ones (OHP, the two TAROT and Zadko) provided images dedicated to photometry. The first results of the optical monitoring campaign were published (Taris et al., 2012a, 2013).

All the optical images will be made available to the astronomers by means of a database currently under construction in the frame of the ICRS Centre. These observations will be also of interest in the context of the Gaia Initial QSO Catalogue (GIQC) and for astrophysical studies (emission regions, gravitational lensing, photocenter scattering, constraints for binary black holes models).

The Large Quasar Astrometric Catalog

The ICRS Centre is in charge of the LQAC (Large Quasar Astrometric Catalog), a whole sky compilation of information on known QSOs, as well as of its regular up-dates. The second release of the LQAC, LQAC-2 (Souchay et al., 2012), was published as a CDS catalog. It contained 187,504 quasars. A third release, LQAC-3, is in preparation in 2014. Its publication is scheduled for the end of 2015. Basically, the LQAC delivers complete information (when available) as a set of optical magnitudes and radio fluxes, the redshift, original and consolidated equatorial coordinates, together with re-calculated absolute magnitudes and morphological indexes (see IERS Annual Report, 2010, 2012).

Link Between Optical and Radio Reference Frames

Work continued to assess the potential magnitude and explanation for offsets in position between extra-galactic reference frame objects in the optical and in the radio. Analysis of data obtained at CTIO from 1997 to 2004 that used a combination of simultaneous UCAC astrograph and CTIO 0.9 m observations in the same bandpass, indicates systematic differences in positions between the optical and radio positions of ICRF2 sources exceeding 100 mas in some cases with suspected general, random offsets of most sources of order single mas (see Zacharias and Zacharias, 2014). If this new and potentially significant source of error holds for alignment sources common to both Gaia and the ICRF, then the optical/radio system alignment error of a significant fraction of a milliarcsecond could result. Results of the reference frame link work were presented at the Extra-Galactic Science with Gaia (EGSG) meeting, held at Observatoire de Paris-Meudon. Additional analysis of this issue, along with new optical and radio observations will be conducted in 2015 and beyond, and the results communicated to the Gaia team and ICRF3 working group.

It is important to keep in mind that the angular resolution of Gaia is about 10 times higher than the ground-based optical morphology investigations mentioned above. Therefore Gaia “sees” a different “blob” of light (AGN core area + host galaxy) than those ground-based imaging data which, in turn, is different from what is seen at radio wavelengths.

A completely different approach for the link between the Gaia (optical) and current ICRF (radio VLBI based) reference frames has been suggested (Zacharias & Zacharias, 2014) in case the link via QSOs is found to be insufficient. Observations of thermal radiation of ordinary stars with ALMA are planned and a positional accuracy on the mas level per star is estimated (Fomalont, priv. com.). Stars, although subject to proper motions, could in principle provide the desired reference frame link between the GCRF and ICRF because the Gaia internal observations are already inertial (non-rotating due to observations of QSOs and galaxies). The radio observations of stars would allow alignment of the positional zero-point of the coordinate systems.

ICRF2 Work

ICRF2 work continued, with the ICRF2 journal paper nearing completion. The ICRF2 journal paper will be published in 2015.

URAT1 Catalog release

The USNO Robotic Astrometric Telescope (URAT) astrometry program continued its northern hemisphere observations. The first 2 years of data (Fig. 4) were reduced and validated using both external and internal (USNO) references for comparison. The first catalog release (URAT1), scheduled for early 2015, will include data for approximately 228 million primarily northern hemisphere (DEC north of –15 deg) stars spanning the magnitude range of R=3–18.5. Validation using ICRF2 counterparts in the visible indicates systematic errors at or below the 10 mas level (see Fig. 5), with random error estimated at between 5 and 30 mas, as a function of magnitude due to signal-to-noise levels. URAT1 represents the most accurate star catalog released to date that covers hundreds of millions of stars; field "beta" testers (including asteroid occultation observers) report significant improvements in their results have been obtained by using URAT1 in place of UCAC4. Sky coverage of URAT observations were extended to include the area around Pluto in support of NASA's Pluto fly-by mission "New Horizons". These data will be incorporated into the URAT1 catalog.

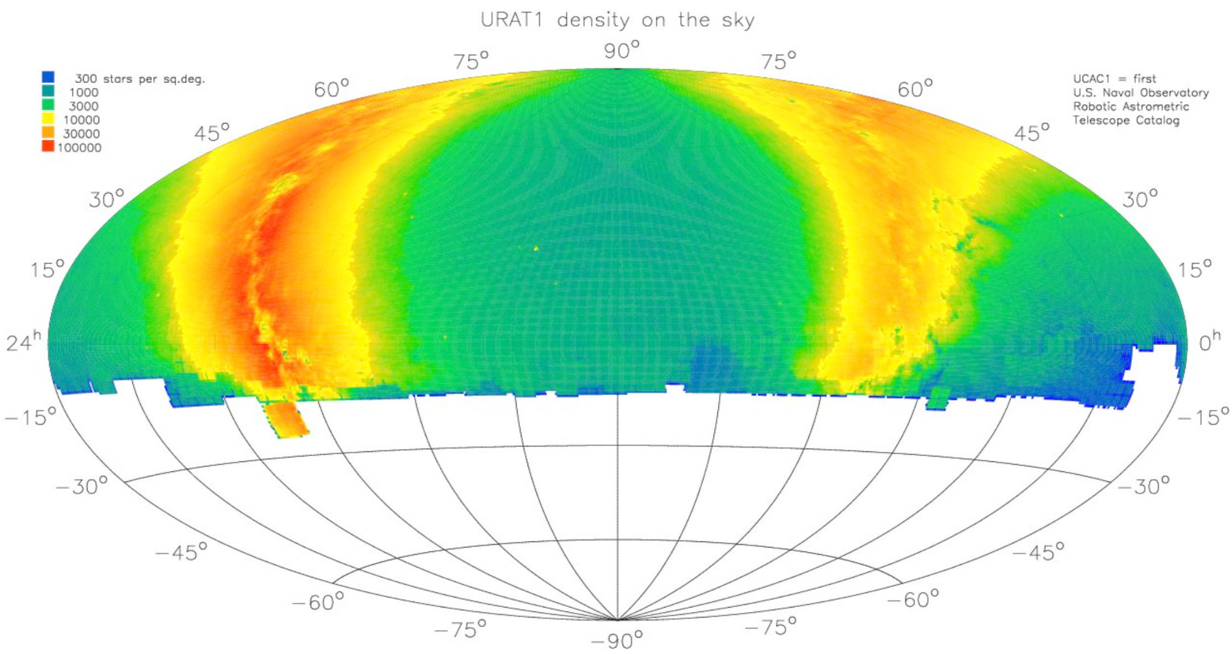


Fig. 4: URAT sky overage as of late 2014. The 2015 URAT1 release will consist of approximately 228 million stars covering the sky north of approximately –15 deg DEC. URAT1 includes observations from April 2012 to June 2014, along with extensive validation using a variety of sources.

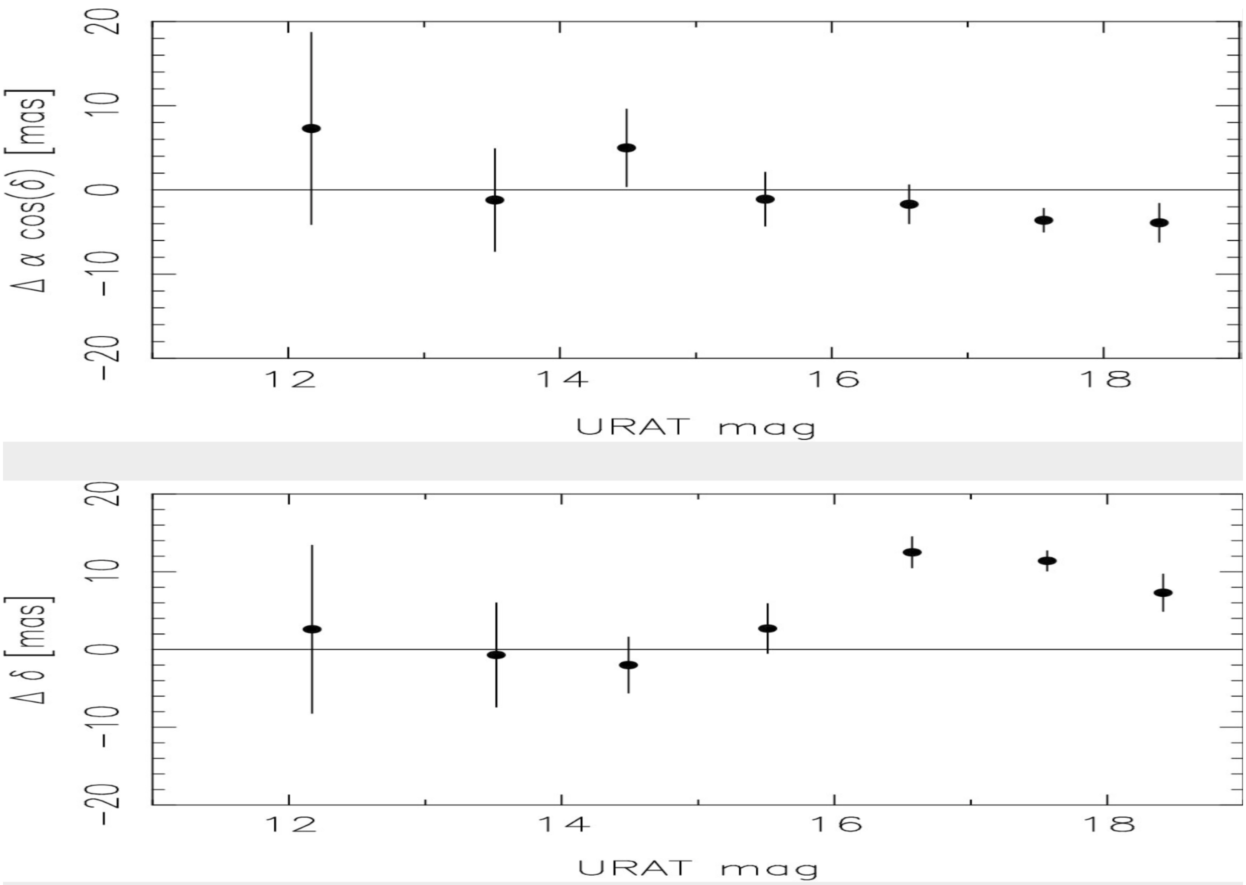


Fig. 5: Differences between URAT1 and ICRF2 sources. Oval indicates mean for all sources in magnitude bin; span indicates sample deviation. (Top) RA cos(DEC); (bottom) Dec. The data are consistent with URAT1 systematic errors at the 10 mas or smaller level.

The URAT1 catalog will be released electronically in 2015 along with an accompanying journal article describing the instrument, data reduction methodology and validation results. Future work will include release of additional northern hemisphere data, and deployment of a modified URAT telescope to the southern hemisphere to conduct a bright star (magnitude range *R*= –1.5–17) survey over the 2015–2016 time period. The URAT data will be used to supplement Gaia optical data for the brightest stars, and will serve as the preferred current epoch optical catalog until the future release of the Gaia catalog covering the same magnitude range at better astrometric accuracies (currently planned for the 2017–2018 timeframe). Eventually, it is anticipated that URAT data will be superseded by Gaia results except at the bright end.

Staff

Dorland, Bryan, Director (USNO)
Souchay, Jean, Co-director (OP)

Andrei, Alexandre, Assoc. Astronomer (OP, Obs. Nat. Rio, Brasil)
Arias, E. Felicitas, Assoc. Astronomer (BIPM / OP)
Barache, Christophe, Engineer (OP)
Bouquillon, Sébastien, Astronomer (OP)
Fey, Alan, Astronomer (USNO)
Lambert, Sébastien, Astronomer (OP)
Taris, François, Technician (OP)
Titov, Oleg, Astronomer (OP, Geoscience Australia)
Zacharias, Norbert, Astronomer (USNO)

References

Andrei, A. H.; Anton, S.; Barache, C.; Bouquillon, S.; Bourda, G.; Le Campion, J.-F.; Charlot, P.; Lambert, S.; Pereira Osorio, J. J.; Souchay, J.; Taris, F.; Assafin, M.; Camargo, J. I. B.; da Silva Neto, D. N.; Vieira Martins, R.; 2012a; SF2A-2012: Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics. Eds.: S. Boissier, P. de Laverny, N. Nardetto, R. Samadi, D. Valls-Gabaud and H. Wozniak, pp. 61–66

Andrei, A. H.; Anton, S.; Barache, C.; Bouquillon, S.; Bourda, G.; Le Campion, J.-F.; Charlot, P.; Lambert, S.; Pereira Osorio, J. J.; Souchay, J.; Taris, F.; Assafin, M.; Camargo, J. I. B.; da Silva Neto, D. N.; Vieira Martins, R.; 2012b; Memorie della Societa Astronomica Italiana, v. 83, p. 930

Andrei, Alexandre Humberto; Souchay, Jean; Martins, Roberto Vieira; Anton, Sonia; Taris, Francois; Bouquillon, Sebastien; Assafin, Marcelo; Barache, Christophe; Camargo, Julio Ignacio Bueno; Coelho, Bruno; da Silva Neto, Dario Nepomuceno; 2012c; IAU Joint Discussion 7: Space-Time Reference Systems for Future Research at IAU General Assembly, Beijing. Online at <http://referencesystems.info/iau-joint-discussion-7.html, id.31>

IERS Technical Note No. 23; 1997; C. Ma and M. Feissel (eds.): Definition and realization of the International Celestial Reference System by VLBI astrometry of extragalactic objects

IERS Technical Note No. 35; 2009; Alan L. Fey, David Gordon, and Christopher S. Jacobs (eds.): The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry

Kelly, B.C., Bechtold, J., Siemiginowska, A.; 2009; Astrophysical Journal 698, 895.

Michalik, D.; Lindegren, L.; 2014; arXiv:1511.01896.

Popovic, L. C.; Jovanovic, P.; Stalevski, M.; Anton, S.; Andrei, A. H.; Kovacevic, J.; Baes, M.; 2012; Astronomy & Astrophysics 538, id. A107, 11 pp.

Smart, R. L.; Nicastro, L.; 2014; Astronomy & Astrophysics 570, id. A87.

Souchay, J.; Andrei, A. H.; Barache, C.; Bouquillon, S.; Suchet, D.; Taris, F.; Peralta, R.; 2012; Astronomy & Astrophysics 537, id. A99, 13 pp.

Taris, François; Andrei, Alexandre; Anton, Sonia; Barache, Christophe; Coelho, Bruno; Klotz, Alain; Lambert, Sébastien; Souchay, Jean; Vachier, Frédéric; 2012a; IAU Joint Discussion 7: Space-Time Reference Systems for Future Research at IAU General Assembly-Beijing. Online at <http://referencesystems.info/iau-joint-discussion-7.html>, id. P9

Taris, F.; Andrei, A.; Souchay, J.; Klotz, A.; Vachier, F.; Bouquillon, S.; Anton, S.; Côte, R.; Suchet, D. ; 2012b; Memorie della Societa Astronomica Italiana 83, p. 986

Taris, F., Andrei, A.H., Klotz, A.; Vachier, F.; Côte, R.; Bouquillon, S.; Souchay, J.; Lambert, S.; Anton, S.; Bourda, G.; Coward, D.; 2013; Astronomy & Astrophysics 552, id. A98

Zacharias, N. & Zacharias, M.; 2014, Astronomical Journal 147, 95

Bryan Dorland, Jean Souchay, Alexandre Andrei,
E. Felicitas Arias, Christophe Barache,
Sébastien Bouquillon, Alan Fey, Sébastien Lambert,
François Taris, Oleg Titov, Norbert Zacharias

3.5.5 ITRS Centre

This report summarizes the activities of the IERS ITRS Centre during the year 2014.

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>. The IERS site information is available to the users through the ITRF web site interface (see below).

At the occasion of the ITRF2014 analysis, several new stations, mainly GNSS permanent stations where added to the ITRF network and database.

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 epoch in any ITRF version if their coordinates are provided in the requested ITRF version.

The maps of the ITRF networks can be displayed depending of the measurement techniques and of the ITRF 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, ITRF2005 and ITRF2008 solutions are available for download.

Preparation for a new ITRF web site

The ITRS Centre has started in 2011 the initial study analysis and preparation for a new design of the ITRF web site. It will be designed to provide more ITRF-related information to the users using more user-friendly interfaces. The specification document is finalized and the development started in 2013. The new web site is expected to be operational beginning 2016.

Local ties of ITRF co-location sites

The ITRS Centre collects all new surveys operated by either IGN or the hosting agencies of ITRF co-location sites. The reports of these surveys are posted at the ITRF web site and are available to users at <http://itrf. ign.fr/local_surveys.php>. The local ties SINEX files used in the ITRF combinations are also available on that web site.

At the occasion of the ITRF2014 analysis, several new local tie SINEX files and corresponding reports were submitted to the ITRS Centre. These new survey results will be made available via the ITRF web site after the release of the ITRF2014.

Other activities

- Participation in most meetings of the analysis working groups of the Technique Centres (in 2014: IDS, IGS, ILRS).
- Convening and organizing EGU and AGU sessions.
- Participation in the 9th meeting of the International Committee on GNSS held in Prague, 10 – 14 November 2014.
- Participation in the UN-GGIM related meetings, May and August 2014.

Zuheir Altamimi, Xavier Collilieux,
Bruno Garayt, Laurent Métivier

3.5.6 Global Geophysical Fluids Center (GGFC)

The International Earth Rotation and Reference Systems Service (IERS)'s Global Geophysical Fluids Center (GGFC) provides the geodetic community with models of geodetic effects (earth rotation, gravity, and deformation) driven by the temporal redistribution of the Earth geophysical fluids. These include fluid motions within the Earth system such as the core and mantle, as well as the motions of surface fluids (e.g. oceans, atmospheres, and continental water).

The GGFC is composed of four operational entities: the Special Bureau for the Atmosphere (SBA, Chair, D. Salstein), the Special Bureau for the Oceans (SBO, Chair, R. Gross), the Special Bureau for Hydrology (SBH, Chair, J.-L. Chen), and the Special Bureau for the Combination Products (SBCP, Chair, T. van Dam). The Atmosphere, Hydrology and Oceans SBs have been firmly established since the creation of the GGFC in 1998. The operational SB, Combination Products, was established in 2009 to house the new data sets that model the mass movement of combined environmental fluids such as oceans+atmosphere. There is a GGFC non-operational component, the GGFC Science and Support Products. This component serves as a repository for models and data used regularly in data processing but that do not change often. The GGFC is still actively searching for a Chair for this component.

Up to the latest realization of the International Terrestrial Reference System (ITRS), namely ITRF2008 (Altamimi et al., 2011), technique contributions were requested not to include non-tidal loading models in the geodetic data processing. Attempts have been made to consider non-tidal loading corrections as a posteriori corrections to construct a multi-technique combined reference frame (Collileux et al., 2010). However, the improvement, while conclusive at some stations, has not been systematically observed. In the meantime, more and more scientific studies have included NT-ATML a priori corrections as a standard, as currently done by the International VLBI Service (IVS) for their operational products. Thus, the question is raised whether the application of NT-ATML corrections alone could improve the determination of the Terrestrial Reference Frame (TRF). Indeed, while some published studies quantifying the effects of NT-ATML corrections on positions and velocities can be found for most of the techniques, NT-ATML corrections have never been applied over the same period of time for the four techniques using the same model. While results have been supplied recently for a combination of GPS and SLR data (Sośnica et al., 2013), the impact on a combined coordinate dataset including all technique measurements has never been studied.

In addition, software and technique specific induced effects were never fully investigated regarding this specific issue. Following a recommendation of the Unified Analysis Workshop 2011 that took place in Zurich, the IERS decided to launch a campaign to assess the effect of NT-ATML corrections on the TRF. Space geodetic solutions, i.e. sets of station coordinates, EOPs, additional parameters and their covariances were requested over a period of five years. The GGFC and the various analysis centers contributed data with NT-ATML applied and not applied to the ITRF to evaluate the impact of NT-ATML corrections on estimated station positions, velocities and EOPs as a result of a combination of multi-technique solutions. The issue of applying mean daily/weekly NT-ATML corrections to solutions versus using the loading model at the observation level in the data processing was also revisited for the four space geodetic techniques. This method of correcting co-ordinates after the observation adjustment has the advantage of not requiring a full data reprocessing. Such a comparison has already conducted for VLBI and GPS only.

Special Bureau for the Oceans

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure are a major source of polar motion excitation and also measurably change the length of the day. The changing mass distribution of the oceans causes the Earth's gravitational field to change and causes the center-of-mass of the oceans to change which in turn causes the center-of-mass of the solid Earth to change. The changing mass distribution of the oceans also changes the load on the oceanic crust, thereby affecting both the vertical and horizontal position of observing stations located near the oceans. As part of the IERS Global Geophysical Fluids Center, the Special Bureau for the Oceans (SBO) is responsible for collecting, calculating, analyzing, archiving, and distributing data relating to nontidal changes in oceanic processes affecting the Earth's rotation, deformation, gravitational field, and geocenter. The oceanic products available through the SBO website at <http://euler.jpl.nasa.gov/sbo> are produced primarily by general circulation models of the oceans that are operated by participating modeling groups and include oceanic angular momentum, center-of-mass, and bottom pressure. Through the SBO website, oceanic data can be downloaded and a bibliography of publications pertaining to the effect of the oceans on the solid Earth can be obtained. Additional information about the SBO can be found in an unpublished manuscript available through the SBO Publications website at <http://euler.jpl.nasa.gov/sbo/sbo_publications.html> and in the SBO chapter of IERS Technical Note 30, Proceedings of the IERS Workshop on Combination Research and Global Geophysical Fluids (http://www.iers.org/TN30).

During 2014, the SBO website was maintained and products from the ECCO/JPL ocean model were updated. Daily values of oceanic angular momentum, oceanic excitation functions, and oceanic center-of-mass from the kf079 (simulation) and kf080 (data assimilating) runs of the ECCO/JPL ocean model are now available from 01 January 1993 through 31 December 2014. These values can be extended back to 01 January 1949 using the corresponding values from a 50-year-long simulation run of the ECCO/JPL ocean model whose results are also available through the SBO website.

In addition, a link is provided to the ECCO/JPL website at <http://ecco.jpl.nasa.gov> from which grids of modeled ocean-bottom pressure can be obtained, a link is provided to the GGFC website at <http://geophy.uni.lu/ggfc-oceans/ECMWF-loading.html> from which grids of ocean loading determined from the ECCO/JPL modeled ocean-bottom pressure can be obtained, and a link is provided to the GLObal Undersea Pressure (GLOUP) data bank of ocean-bottom pressure observations at <http://www.ntslf.org/files/acclaimdata/gloup/gloup.html>. Finally, a link is provided to the GFZ Helmholtz Centre Potsdam's Effective Angular Momentum Functions (EAM) website at < http://www.gfz-potsdam.de/en/section/earthsystemmodelling/services/data-products/> from which consistent estimates of atmospheric, oceanic, and hydrologic angular momentum can be obtained.

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

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

Special Bureau for the Atmosphere

The Special Bureau for the Atmosphere (SBA) is concerned with the atmospheric information that is needed for a number of geodetic issues. The SBA was an outgrowth of the earlier Sub-bureau for Atmospheric Angular Momentum prior to the creation of the GGFC, and can be accessed at <https://www.aer.com/science-research/earth/earth-mass-and-rotation/special-bureau-atmosphere>.

Calculations of atmospheric angular momentum (AAM) are made from a number of global meteorological operational analyses and reanalyses, and are archived at the SBA. Long-term archives are at Atmospheric and Environmental Research in the file <http://ftp.aer.com/pub/anon_collaborations/sba/>. AAM from analyses and forecasts are updated daily at NOAA on <http://ftp.cpc.ncep.noaa.gov/long/aam/>. On-line readme files on these two sites are useful in documenting the data sets.

Operational atmospheric analyses are fields determined from observations during the epoch they are valid from the resident atmospheric analysis system in use at that time. Thus the systems, the main components of which are atmospheric forecast models and data assimilation systems, have changed over the years. In contrast, atmospheric reanalysis systems use a constant analysis system to reprocess the historical atmospheric observational data. Thus the earlier periods are analyzed with a more advanced system than existed during their era, and the whole record of reanalysis is more suitable for long-term studies. The reanalyses were developed for consistent climate studies, and we use them here for long-term geodetic studies.

The AAM and related data are from the following large meteorological centers: US National Centers for Environmental Prediction, NCEP (formerly known as the National Meteorological Center); the Japan Meteorological Agency, JMA; the United Kingdom Meteorological Office, UKMO; and the European Center for Medium-Range Weather Forecasts (ECMWF). The ECMWF AAM is not updated daily in the on-line service but rather by links by our contributors, as noted below.

The SBA has on-line links from a number of contributors listed on the website; these include a number of atmospheric data related to surface loading, path delays, and gravity. The specialized ECMWF fields are accessed this way. Cooperating institutions are: the Geoforschungszentrum, Potsdam, Germany; Vienna University of Technology, Austria; University of Luxembourg, Goddard Space Flight Center, University of Strasbourg, France, and the University of New Brunswick, Canada.

During 2014, the SBA updated all fields from AAM; the updates were performed by Dr. Y. Zhou of the Shanghai Astronomical Observatory, China.

We participated in the recent GGFC workshop presenting analysis of the archived analyses, and possible addition of other analyses to the datasets, including the U.S. Navy's NAVGEM analysis and forecasts.

Special Bureau for Hydrology

The Special Bureau for Hydrology (http://www.csr.utexas.edu/research/ggfc/) provides internet access to data sets of terrestrial water storage (TWS) variations from major climate and land surface models and GRACE (Gravity Recovery and Climate Experiment) satellite gravity measurements. The web site contains TWS estimates from five numerical models, the NCEP (National Center for Environmental Prediction) reanalysis, the ECMWF (European Center for Medium Range Weather Forecasting) reanalysis, the CPC (Climate Prediction Center) Land Data Assimilation System (LDAS), the NASA's Global Land Data Assimilation System

(GLDAS), and the NOAA LadWorld land dynamics model. Global gridded TWS changes estimated from GRACE time-variable gravity observations are also provided in our online data archive (at <http://www.csr.utexas.edu/research/ggfc/dataresources.html>). The NASA GLDAS and GRACE data products are updated on a regular basis.

SBH also provides fully normalized gravity spherical harmonic coefficients (in the same definition as the GRACE products) up to degree and order 100, computed from the GLDAS-estimated TWS changes. This product offers the convenience for hydrologists who want to compare GRACE estimates and model predictions in a more consistent way by applying similar truncation and spatial filterings to both GRACE and model estimates. This data set is highly welcomed by the hydrological community.

In addition, TWS change estimates from historical GRACE release-01 and release-04 products are also provided in our online data archive (at <http://www.csr.utexas.edu/research/ggfc/dataresources.html>). Some other data sets available in the SBH online data archive include daily hydrological excitations of polar motion and length-of-day computed from the NCEP/NCAR Reanalysis and the list of global major artificial reservoirs and their compacities.

During 2014, we have updated the monthly GLDAS TWS estimates to extend the coverage from January 1979 to December 2014. GLDAS gravity spherical harmonic coefficients have also been updated to cover the period January 2002 to December 2014. GRACE release-05 monthly TWS estimates with decorrelation and 300 km and 500 km Gaussian smoothing applied have been updated to extend the coverage to August 2014.

Combinational Products

Here we provide updated information on the AOD Products used to estimate loading.

- GRACE non-tidal high-frequency atmospheric and oceanic mass variation models are routinely generated at GFZ as so-called Atmosphere and Ocean De-aliasing Level-1B (AOD1B) products to be added to the background static gravity model during GRACE monthly gravity field determination. AOD1B products are 6-hourly series of spherical harmonic coefficients up to degree and order 100, which are routinely provided to the GRACE Science Data System and the user community with only a few days time delay.
- The GRACE AOD1B products were accepted by the International Earth Rotation and Reference Systems Service (IERS) Global Geophysical Fluid Center (GGFC) as Provisionary Products in 2009 and have been given the status of GGFC Operational Products in May 2012.

- The most recent AOD1B product version for the period 2000 till today is release 05 (RL05) which is based on ECMWF operational data.
- In March 2015 GFZ has also generated and delivered AOD1B RL05 products for 1979–2000 based on ERA-interim data.
- Details can be found at <http://www.gfz-potsdam.de/aod1B>.

GGFC Operational Products	**Principal Investigator**	**Proposed GGFC Operational Center**
• UNB Vienna Mapping Function Service • <http://unb-vmf1.gge.unb.ca/Products.html>	M. Santos	University of New Brunswick
• AAM analysis (and forecast*) series from: ○ NCEP Reanalysis (1948–) ○ NCEP operational (1976–)*, also known as NMC ○ JMA operational (1993–)* ○ UKMO operational (1986–2006; and also to present)* ○ ECMWF operational (1988–01.2000) ○ ECMWF ERA-40 reanalysis (1959–2002)	D. Salstein	Atmospheric and Environmental Research
• Vienna Mapping Function Service • AAM series from 6-hourly ERA-40 and operational analysis data starting in 1980 • AAM series from 10-day forecast data • Cartesian coordinates of the center of mass of the atmosphere and total mass of the atmosphere at 6-hourly intervals • Atmospheric loading ECMWF • Atmospheric gravity coefficients: thin layer approach and vertical integration approach	J. Boehm and M. Schindelegger	Technical University of Vienna
• Global Mass Change Fields From GRACE (RL 05 & 04, 1x1 deg) • GLDAS Monthly Water Storage (1x1 deg) • Gravity Spherical Harmonics from GLDAS Monthly Water Storage Change • NOAA LadWorld Monthly Water Storage (1x1 deg) • CPC Monthly Water Storage (1x1 deg) • Daily hydrological excitations of polar motion and LOD from NCEP/NCAR Reanalysis • List of Major Artificial Reservoirs with Water Capacity Exceeding 10 km^3 • http://geophy.uni.lu/ggfc-hydrology.html	J.L. Chen	University of Texas at Austin GGFC Special Bureau for Hydrology
• Atmospheric loading: NCEP (2.5 deg; 6-hr) • <http://gemini.gsfc.nasa.gov/aplo/> • Continental water loading: GLDAS • <http://lacerta.gsfc.nasa.gov/hydlo/>	D. MacMillan	Goddard Space Flight Center

• Site displacements due to atmospheric pressure loading • Low degree harmonic time series from LAGEOS[1] • <ftp://gfzop.gfz-potsdam.de/nt-atml/>	J.-C. Raimondo R. Koenig	Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences
• High resolution atmospheric loading (3-hr; 0.5 deg): ECMWF (Operational)+IB and ECMWF+MOG2D • ERA Interim+IB 6 hours • Continental water loading: GLDAS/NOAH (3hr), ERA interim (6 hours) • Effects on gravity and tilt • <http://loading.u-strasbg.fr>	J.-P. Boy	Ecole et Observatoire des Sciences de la Terre; University of Strasbourg
• Atmospheric loading (NCEP 2.5 x 2.5; 6 hourly) • <http://geophy.uni.lu/ggfc_atmosphere/NCEP-loading.html> • GLDAS continental water storage loading (2.5 x 2.5; monthly) • <http://geophy.uni.lu/ggfc-hydrology.html> • ECCO bottom pressure (2.5 x 2.5; 12 hourly) • <http://geophy.uni.lu/ggfc-oceans.html> • GRACE AOD ATM + OBP mass data (1.8 x 1.8 deg; 6 hourly) see Section on Combination Products • GRACE AOD ATM + OBP loading effects (2.5 x 2.5 deg; 6 hourly) • <http://geophy.uni.lu/ggfc-combination/about-2.html> • S1/S2 tidal loading calculator • <http://geophy.uni.lu/ggfc-atmosphere/tide-loading-calculator.html>	T. van Dam	University of Luxembourg
• Hydrological Loading from LSDM water (0.5 x 0.5; 24 hr) • <http://www.gfz-potsdam.de/en/section/earthsystemmodelling/services/hydl/>	R. Dill	GFZ
• AAM, HAM, OAM (ECMWF operational, ECMWF forecasts, ERA-Interim, ERA40) • <http://www.gfz-potsdam.de/en/section/earthsystemmodelling/services/data-products/>	M. Thomas	GFZ
• GRACE AOD dealiasing products (6 hourly) • <http://www.gfz-potsdam.de/en/section/earthsystemmodelling/services/aod1b-product/>	F. Flechner	GFZ

[1] The system is not operational yet as we decided to augment our data basis to the ensemble of geodetic satellites (AJISAI, STARLETTE, STELLA, and LARES in addition to the LAGEOS satellites). We expect to become operational by June/July. Also in this case we'll provide the products via site.

Many of the centers above also provide products that will soon become provisional products in the GGFC archive, e.g. GSFC (MacMillan) provides Atmospheric gravity (deg/order 72/72, 20/20), loading from ECCO bottom pressure (1 deg, 12-hr) and raytraced VLBI troposphere delays. These products have not yet been tested and compared with existing products.

For information on submitting proposals for GGFC operational products, please go to <http://geophy.uni.lu/ggfc-about/to-submit-new-proposals-for-products.html> or contact T. van Dam (tonie.vandam@uni.lu).

References

Altamimi, Z., X. Collilieux, and L. Métivier (2011): ITRF2008: an improved solution of the International Terrestrial Reference Frame, Journal of Geodesy, Vol. 85, pp. 457–473, doi: 10.1007/s00190-011-0444-4

Collilieux, X., Z. Altamimi, D. Coulot, David, T. van Dam, and J. Ray (2010): Impact of loading effects on determination of the International Terrestrial Reference Frame, Advances in Space Research, Vol. 45, pp. 144–154, doi: 10.1016/j.asr.2009.08.024

Sośnica, K., D. Thaller, R. Dach, A. Jäggi, and G. Beutler (2013): Impact of loading displacements on SLR-derived parameters and on the consistency between GNSS and SLR results. Journal of Geodesy, Vol. 87, 751–769, doi: 10.1007/s00190-013-0644-1

Tonie van Dam, Jean-Paul Boy, David Salstein, Richard Gross, Jian-Li Chen

3.6 ITRS Combination Centres
3.6.1 Deutsches Geodätisches Forschungsinstitut (DGFI)

With effect from January 1st, 2015 the Deutsches Geodätisches Forschungsinstitut has become an institute of the Technische Universität München (TUM). It is now called Deutsches Geodätisches Forschungsinstitut at TU Munich (DGFI-TUM).

In 2014, the focus of the work of the ITRS Combination Centre (CC) at DGFI-TUM was on the ITRS realization DTRF2014. DGFI-TUM is one of three ITRS Combination Centres which will provide a new ITRS realization in 2015. First data series from DORIS and VLBI were provided by the Technique Centres and analysed by the CC in 2014.

DGFI combination strategy for DTRF2014

The ITRS realization strategy of DGFI-TUM is based on the combination of datum free normal equations which are reconstructed from the input SINEX series provided by the Technique Centres. The ITRS realization consists of two main parts: (1) the technique-wise analysis of the input data and the generation of one combined NEQ per technique and (2) the combination of the technique NEQs (Fig. 1). In 2014 the first step was performed for the first iterations of VLBI and DORIS input data series.

In ITRF computation many correction models are applied considering tidal-related effects on station positions. The ITRF2014 will be the first ITRF that considers non-linear signals in station position time series which are mainly caused by non-tidal loading. DGFI-TUM plans to apply loading data provided by the GGFC and derived from atmospheric, hydrologic and oceanic models. The DGFI-TUM combination strategy is based on the combination of datum-free normal equations which are corrected for loading signals directly after their reconstruction from the SINEX files. Beside the application of loading corrections, the identification and consideration of discontinuities in station position time series and the analysis of datum parameters are important steps of the first part.

Analysis of VLBI data

VLBI data are provided as datum-free session NEQs by the IVS. The VLBI series is the longest in ITRF2014 and includes 35 years of data from 1980 – 2015. The NEQs contain daily station positions, pole coordinates and rates, LOD, UT1–UTC and nutation offsets. Altogether 159 stations are included from which 52 are reduced because of too short or sparse observation time series. The analysis of the station positions provided 43 discontinuities mainly caused by earthquakes.

The VLBI scale is analysed in detail as it is planned to use it for DTRF scale realization. Figure 2 shows the scale time series

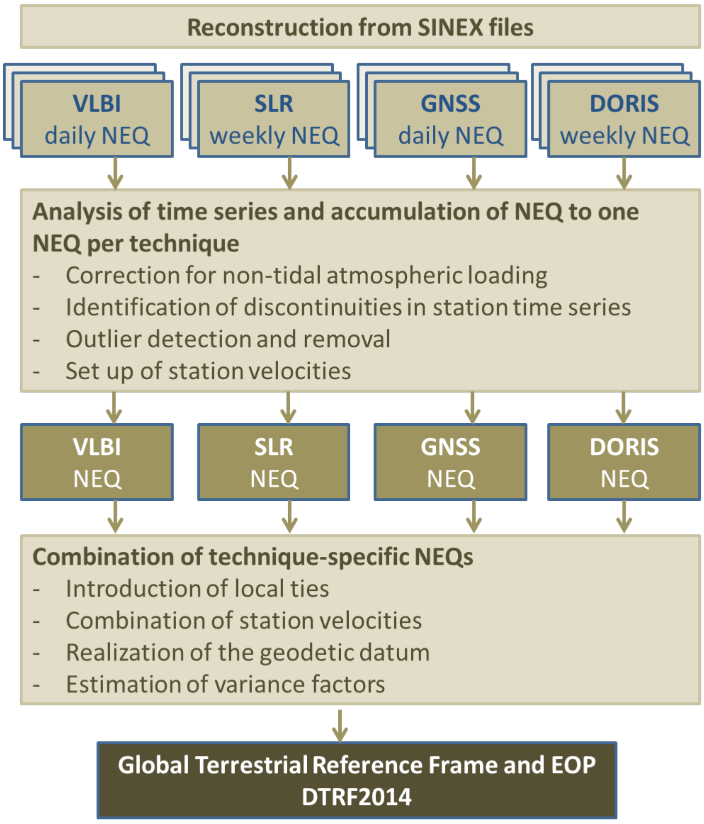


Fig. 1: Combination strategy applied by ITRS CC DGFI-TUM.

derived from similarity transformations of the session solutions to the VLBI-TRF solution. Except for the first years, which are characterised by large standard deviations, no long-term signals, offsets or trends are found. Therefore, the complete VLBI series can be used for scale realization.

The transformation of the VLBI-TRF solution to DTRF2008 shows a good agreement providing a difference for the scale of –1.2 ± 0.3 mm and for the scale rate of –0.04 ± 0.09 mm/yr.

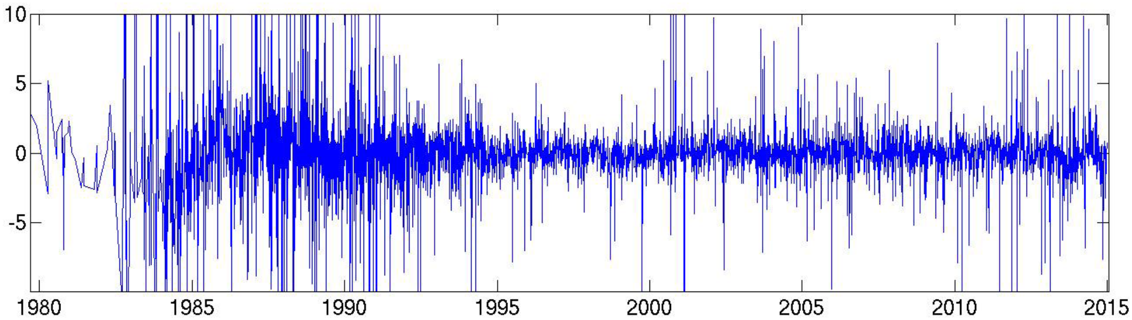


Fig. 2: VLBI scale time series derived from similarity transformations of VLBI session solutions to the VLBI-TRF solution.

Analysis of DORIS data

The DORIS data are provided as weekly solutions together with the full statistical information. However, the applied datum-related constraints are not given in the SINEX files and therefore seven parameters of a similarity transformation have to be set up for each NEQ. It should be mentioned that – compared to the solution level – all stations have to be considered for these similarity transformations at NEQ level.

The DORIS data covers the time span 1993–2015 (22 years). The solutions contain weekly station positions and daily pole coordinates. IDS provided three iterations of the input series which are all analysed by DGFI-TUM. Significant improvements of the weekly solutions are reached which lead to smaller RMS values of the parameter time series. In total 160 stations are included in the DORIS data from which 14 are reduced because of short time series. The analysis of the station position time series provided a list of 55 discontinuities, which was iterated and discussed with the IDS Combination Centre.

Even if the datum provided initially by the DORIS observations is not used to realize the DTRF datum, the scale parameter series is shown in Figure 3 as it very nicely represents the large improvement of the DORIS data compared to ITRF2008. The large drift in the input series for ITRF2008 of –1.8 mm/yr could be removed. The increasing scale values at the end of the ITRF2014 input data might be related to some new DORIS satellites launched at this time.

References

Bloßfeld M., Seitz M., Angermann D.: Non-linear station motions in epoch and multi-year reference frames. Journal of Geodesy 88(1): 45–63, Springer, doi: 10.1007/s00190-013-0668-6, 2014

Boßfeld M., Seitz M., Angermann D.: Epoch reference frames as short-term realizations of the ITRS – datum stability versus sampling. IAG Symposia 143, online first, doi: 10.1007/1345_2015_91, 2015

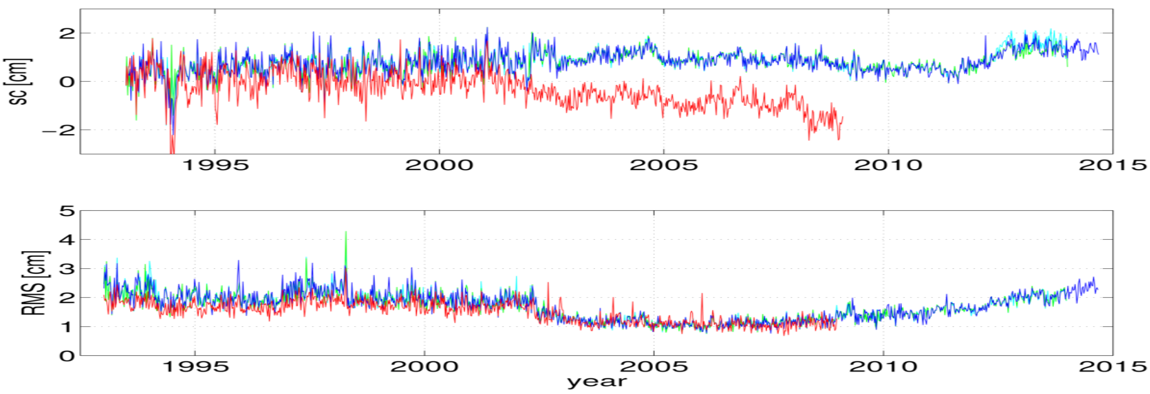


Fig. 3: DORIS time series derived from similarity transformations of weekly DORIS solutions to the DORIS-TRF solution (Blue, green: two DORIS input series for DTRF2014, red: DTRF2008).

Bloßfeld M., Seitz M., Angermann D., Moreaux G.: Quality assessment of IDS contribution to ITRF2014 performed by DGFI-TUM, Advances in Space Research (in review)

Seitz M., Angermann D., Gerstl M., Bloßfeld M., Sánchez L., Seitz F.: Geometrical reference systems. In: Freeden W., Nashed M.Z., Sonar T. (Eds.) Handbook of Geomathematics (Second Edition), Springer, pp. 1–35, ISBN: 978-3-642-27793-1, doi: 10.1007/978-3-642-27793-1_79-2, 2015

Seitz M.: Comparison of different combination strategies applied for the computation of terrestrial reference frames and geodetic parameter series. In: Kutterer H., Seitz F., Alkhatib H., Schmidt M. (Eds.), The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS'11), IAG Symposia 140: 57–64, doi: 10.1007/978-3-319-10828-5_9, 2015

Manuela Seitz, Detlef Angermann, Mathis Bloßfeld,
Michael Gerstl, Horst Müller

3.6.2 Institut National de l'Information Géographique et Forestière (IGN)

This report summarizes the activities of the IGN combination centre during the year 2014. These research activities are mainly related to the preparation for the ITRF2014.

Research and development activities

The members of the IGN CC, often in cooperation with other scientists, conduct research and developments activities relating to the ITRF in particular and reference frames in general. R&D activities include ITRF accuracy evaluation, mean sea level, loading effects, combination strategies, and maintenance and update of CATREF software. Scientific results of specific data analysis and combination are published in peer-reviewed journals, as listed in the references' section, but also presented at international scientific meetings.

Preparation for ITRF2014

Specific new developments were achieved and validated in preparation for the ITRF2014: CATREF software was enhanced and upgraded to include periodic terms of the station position time series, such as in particular annual, semi-annual terms for all techniques and draconitic signals for satellite techniques, especially GNSS. These new developments are intended to be applied to the technique solutions which were submitted to the ITRF2014.

Other developments were also finalized and validated, such as modelling of post-seismic deformations for sites affected by major Earthquakes, as well as an improved strategy for the detection of discontinuities in the technique station position time series.

First and early results of the ITRF2014 input data analysis were presented at various conferences in 2014.

Publications

Abbondanza, C, Z. Altamimi, T. M. Chin, R. S. Gross, M. B. Heflin, 2015, Three-Corner Hat for the assessment of the uncertainty of non-linear residuals of space-geodetic time series in the context of terrestrial reference frame analysis, Journal of Geodesy, 89(4), 313–329, doi: 10.1007/s00190-014-0777-x

Métivier, L., X. Collilieux, D. Lercier, Z. Altamimi, and F. Beauducel, 2014, Global coseismic deformations, GNSS time series analysis, and earthquake scaling laws, J. Geophys. Res. Solid Earth, 119(12), 9095–9109, doi:10.1002/2014JB011280.

Rebischung, P., Z. Altamimi and T. Springer, 2014, A collinearity diagnosis of the GNSS geocenter determination, Journal of Geodesy, 88(1), 65–85, doi:10.1007/s00190-013-0669-5

Wu, X., C. Abbondanza, Z. Altamimi, T. M. Chin, X. Collilieux, R. S. Gross, M. B. Heflin, Y. Jiang, and J. W. Parker, 2015, KALREF—A Kalman filter and time series approach to the International Terrestrial Reference Frame realization, J. Geophys. Res. Solid Earth, 120(5), 3775–3802, doi:10.1002/2014JB011622.

Zuheir Altamimi, Xavier Collilieux,
Laurent Métivier, Paul Rebischung

3.6.3 Jet Propulsion Laboratory (JPL)

CATREF, the software package used at IGN France to produce the well-known ITRFs, has been installed at JPL and has been used to reproduce ITRF2005. A Kalman filter and smoother algorithm has been developed and coupled to the CATREF software. This Kalman filter-based software package, KALREF, has been used to produce ITRF2005-like and ITRF2008-like reference frames that compare favorably with ITRF2005 and ITRF2008, respectively (Wu et al., 2015). It has also been used to solve for time-variable weekly coordinates, as well as a model of secular, periodical and stochastic motion components. In addition, KALREF has been used to define a nearly instantaneous reference frame by specifying constant frame parameters and combining different technique data weekly. It is currently being used to determine a solution for the IERS using the input SINEX files that were produced by the Technique Centers for ITRF2014.

A simulation tool to study the effect of network geometry on reference frame determination is being developed. The tool is based on synthetic station position and reference frame parameter (geocenter, scale) data. It has been used to study the effect of station distribution, number of stations, availability of site tie measurements, etc. on the reference frame. Preliminary conclusions indicate that reasonable TRFs can be determined from a network of about 30–40 well-distributed, co-located stations as long as accurate site ties are available at each site.

The Three Corner Hat (TCH) technique has been used to determine the uncertainties of estimates of positions of stations at co-located sites. For 16 co-located sites used in ITRF2008, the median (north, east, up) uncertainties are found to be (1.1, 1.2, 2.8) mm for the GPS stations, (2.2, 2.0, 6.2) mm for the VLBI stations, (8.5, 7.6, 9.0) mm for the SLR stations, and (9.2, 11.7, 10.6) mm for the DORIS stations (Abbondanza et al., 2015).

References

Abbondanza, C., Z. Altamimi, T. M. Chin, R. S. Gross, M. B. Heflin, J. W. Parker, and X. Wu, Three-Corner Hat for the assessment of the uncertainty of non-linear residuals of space-geodetic time series in the context of terrestrial reference frame analysis, *J. Geodesy*, *89*(4), 313–329, doi:10.1007/s00190-014-0777-x, 2015.

Wu, X., C. Abbondanza, Z. Altamimi, T. M. Chin, X. Collilieux, R. S. Gross, M. B. Heflin, Y. Jiang, and J. W. Parker, KALREF – A Kalman filter and time series approach to the International Terrestrial Reference Frame realization, *J. Geophys. Res. Solid Earth*, *120*(5), 3775–3802, doi:10.1002/2014JB011622, 2015.

Richard S. Gross

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

Following the 2013 workshop in Paris, the focus of the working group has shifted slightly. At the workshop it was evident that there are several interpretations and implementations of common terms both in and between the space geodetic techniques. An important conclusion from the workshop was therefore that in order to merge the results from different techniques in an efficient way, the terminology used for site surveying needs to be consistent both within and between the techniques. The original working group thus appears to now have grown to a size where more formal measures are needed in order to avoid confusion been the participants. Considering the importance of site surveying in order to produce an ITRF on the observational level, the terminology is therefore the first issue to address for the group. Consequently, a core of designated points of contact (POC) has been established with each of the IERS Technique Centres (TCs). The role of these POCs is foremost to make sure that each TC is represented and speaks with one voice, and that questions can be directed with some accountability. The group will thus continue to be open to in- and output from other participants than the POCs.

Additionally, the working group is also part of the GGOS structure under its IERS name.

Projects, WG meetings

A terrestrial (i.e. robotic total station) monitoring system adapted to the telescope's observation schedule was successfully operated by the Frankfurt surveying team at the Onsala Space Observatory during the full two weeks of IVS CONT14.

An open working group meeting was held in conjunction with the REFAG2014 conference in Luxembourg. The working group background was presented, as well as the new group structure. The need for a common terminology and understanding of definitions between users was further accentuated. A rework of the resolution proposal on Local Ties from the 2013 workshop in Paris was also initiated.

Working group points of contact

The spirit of being an open working group is still kept, but in order to maintain accountability and make sure to have a response from all services, the following representatives have been designated as point of contacts for the respective TC.

- IDS – Jerome Saunier, IGN, France
- IGS – Ralf Schmid, TUM, Germany
- ILRS – Erricos C. Pavlis, UMBC, USA
- IVS – Rüdiger Haas, Chalmers, Sweden

- NASA SGP – Jim Long, NASA, USA

Additionally, surveying teams at IGN (FRA), GA Australia (AUS), NLS (FIN), Uni Bonn (GER), FRA-UAS (GER), SP (SWE), USGS (USA) have been identified. The need to establish cooperation with other nationalities (e.g. Chinese, Japanese and Russian) is considered an important future task.

Work ahead

With the POCs appointed, the next step is to establish a common terminology that is acceptable for all IAG Services. An outreach to surveying teams in e.g. China, Japan and Russia is also anticipated, as well as initiating a surveying plan based on the results from ITRF2013. An inventory of current surveying statuses at different sites would also be beneficiary.

References of publications relevant to the WG

Artz, T., A. Springer, A. Nothnagel. A complete VLBI delay model for deforming radio telescopes: the Effelsberg case. Journal of Geodesy, Volume 88, Issue 12, pp. 1145–1161

IVS:
8th IVS General Meeting, Shanghai, China, March 2–7, 2014
<http://ivscc.gsfc.nasa.gov/publications/gm2014/index.html>

Kodet J., K.U. Schreiber, C. Plötz, A. Neidhardt, G. Kronschnabl, R. Haas, G. Molera Calvés, S. Pogrebenko, M. Rothacher, B. Männel, L. Plan, A. Hellerschmied. Co-locations of Space Geodetic Techniques on Ground and in Space.

Krásná H., M. Nickola, J. Böhm. Axis Offset Estimation of VLBI Telescopes.

Ma C., S. Merkowitz, B. Luzum. The Impact of NASA's SGP and USNO on VGOS.

Männel B., M. Rothacher, J. Kodet, U. Schreiber, R. Schmid. GLONASS Satellites Simultaneously Observed by VLBI, GNSS and SLR.

Nothnagel, A., A. Springer, E. Heinz, T. Artz, P. de Vicente. Gravitational Deformation Effects: The Yebes 40-m Telescope Case.

Ning T., R. Haas, G. Elgered. Determination of the Telescope Invariant Point and the Local Tie Vector at Onsala using GPS Measurements.

Li J., F. Xiong. Local Survey at the Shanghai Tianma 65-m Antenna.

Ipatov A., I. Gayazov, S. Smolentsev, D. Ivanov, G. Ilin, N. Shuygina, Y. Bandarenko. Co-location of Space Geodetic Techniques at the "Quasar" VLBI Network Observatories.

ILRS:
19th International Workshop on Laser Ranging, Annapolis MD, USA, October 27–31, 2014
<http://cddis.gsfc.nasa.gov/lw19/Program/index.html>

Appleby G., J. Rodriguez, R. Sherwood, T. Shoobridge, M. Wilkinson. Relative height surveying of geodetic monuments at the SGF, Herstmonceux, UK.

Eckl J., I. Prochazka, J. Blazej, J. Kodet, K. U. Schreiber. Geometry bias in a short baseline ground calibration.

Merkowitz S. M., J. Esper, L. Hilliard, D. D. Lakins, F. G. Lemoine, J. L. Long, C. Ma, D. R. McCormick, J. F. McGarry, B. P. Michael, C. Noll, M. D. Shappirio, E. C. Pavlis, M. R. Pearlman, D. A. Stowers. NASA's Next Generation Space Geodesy Network.

IDS:

IDS Workshop 2014, Konstanz, Germany, October 27–28, 2014 <http://ids-doris.org/report/meeting-presentations/ids-workshop-2014.html>

Saunier J. DORIS Network 2014 Status Report.

Saunier J., C. Tourain, A. Auriol. Ground Antenna Position: Initiating an Error Budget

EUREF Symposium 2014, Vilnius, Latvia, June 04–06, 2014 <http://www.euref.eu/symposia/2014Vilnius/Symposium2014-Vilnius.html>

Brockmann E., D. Ineichen, P. Mahler. GNSS and Tachymetry for Monitoring the Stability of Permanent Reference Stations

Sten Bergstrand

3.7.2 Working Group on Combination at the Observation Level

This Working Group COL was created in 2009. Its main objective is to bring together groups able to perform combinations of space geodetic techniques (DORIS, GNSS, SLR and VLBI) at the level of observations (similar to the Normal Equation level) searching for an optimal strategy to simultaneously solve for geodetic parameters, in particular Earth Orientation Parameters, terrestrial and celestial reference frames and tropospheric delays. This implies to improve the accuracy, the time resolution and the overall consistency of the geodetic products derived.

The activities of the Working Group over 2014 were mainly focused to the participation of the French COL/GRGS to the ITRF2014 realization. At an internal meeting, the GRGS discussed on the strategy to apply at the different levels of analysis: processing of the individual techniques and the combinations.

- Organization of storage space for the normal equations delivery
- Test on the exchange of binary files between centers
- Update on the preparation of the normal equations derived from the processing of the individual techniques: VLBI, SLR, GPS, DORIS
- Update on the adoption of the IERS Conventions for models
- Particular point on the construction of DORIS weekly solutions from solutions initially derived over 3.5 days, keeping information on satellites for further studies (SAA)
- Test period: each technique is required to provide the NEQs on the test period of 2009 if possible before the end of 2014
- List of stations to take into account (DOME numbers)
- Compatibility of DYNAMO with the file containing the discontinuities of station positions and what is the procedure for the database management.

Computation and analysis of normal equations derived by the GRGS for ITRF2014

In the beginning of 2014, different GRGS groups involved for each technique have made available 12 years (2002 – 2013) of weekly normal equations (NEQs) which were then processed at the Paris combination center. Table 1 shows the different techniques delivered by the GRGS Analysis Centers and their contribution to this campaign. Table 2 shows the parameters to be considered for this comparison campaign and their a priori values

Table 1: Techniques used for combination, GRGS Normal Equations (NEQs) and Parameters

GPS: CNES-CLS Toulouse	DORIS: CNES-CLS Toulouse	VLBI: OB LAB Bordeaux	SLR: IMCCE GRGS Paris	LLR: IGN-LAREG GRGS Paris
4372 daily NEQ, Period January 1st 2002 to December 30th 2013 GPS week **1147** to **1773**	NEQ per 3,5d arc length & per satellite: **106/106** Jason2, **99/99** Jason1, **104/104** Envisat, **58** Spot2, **104** Spot4, **107** Spot5 over the whole year 2009	From week 48th of 2008 to week 5th of 2010 session R1 (XA) & R4 (XE) producing **125** weekly NEQ	2009: 74 weekly NEQ LAGEOS-1, 74 NEQ LAGEOS-2, 74 NEQ ETALON-1, 74 NEQ ETALON-2	7-January-1990 to 8-December-2013 820 weekly NEQ
GPS – Glonass Constellation , between 23 and 55 GNSS satellites	**Doris Laser:** Envisat, Jason-1, Jason-2 **Doris Doppler**: Envisat, Jason-1, Jason-2, spot2,4,5		Lageos1&2 Etalon-1&2	
Pole PX, PY and Rates PXR, PYR 1pt /d @12h, **UT1-TAI, LOD** 1pt/d @12h, **Nutation** corrections IAU2000) NX, NY 1pt/d @ 12h **Stations** coordinates SX, SY, SZ 1/d **Tropospheric** parameters for collocated sites (zenith delays & N/E gradients) 12pt/d @ 02h (00,02,04,06,08,10,12,14,16,18, 20,22h)	**Pole**: PX, PY, **UT1-TAI** 4pt/d @ 0h,6h,12h,18h **Nutation** NX, NY 2pt/d @ 00 12h **Stations** SX, SY, SZ 1/week **Tropospheric Zenithal Delays** MZB 12pt/d @2h East & North gradients 1pt/d Center of mass correction CDX,CDY,CDZ on satellites 1p/sat *Global station bias 1pt/arc *Doppler frequency offset @ 2h. *Orbital elements EX, EY, EZ, EXP, EYP, EZP 1pt /arc *Atmospheric drag and lift *Solar pressure 1pt/arc. *Orbit Biases *Radiation forces 1 to 8: -specular reflectivity of panel -diffuse reflectivity of panel *Emissivity of panel 1 à 8 per arc *Gravity field coefficients normalized: GCN cosinus, GSN sinus degree 0 a 40	**Pole** : PX, PY 4pt/d @ 00,06,12,18h **UT1-TAI** : PT 4pt/d @ 00,06,12,18h **Nutation** : NX, NY 4pt/d @ 00,06,12,18h **Stations** : SX,SY,SZ @1/week **Quasars** : QRA, QDE @ 1/week **Tropospheric zenithal delays** MZB @ 02h *Clock error for VLBI stations @1H	**Pole & UT**: PX, PY PT 4pt/d @ 00,06,12,18h **Stations**: SX, SY, SZ 1pt/week @12:00 **Station range Bias** MRB *Orbital elements EX, EY, EZ, EXP, EYP, EZP 1pt /arc *Solar pressure 1pt/week/sat *Orbit Biases 1pt/week/sat *Gravity field coefficients normalized: GCN cosinus, *GSN sinus degree 0 a 40 *Oceanic tides coefficients normalized	**Pole & UT**: PX, PY , PT 4pt/d @ 00,06,12,18h **(Nutation** : NX, NY @00H - 12H not available) **Stations & *Lunar Reflectors**: SX, SY, SZ 1/week@12:00

Table 2: Recommended geodetic parameters for the GRGS multi-technique combination

Parameters	SINEX format	GINS format	Sampling	Initial values
Polar motion	**XPO, YPO**	PX, PY	PWL @ 12Hr	IERS EOP 08-C04 series Interpolated @12h
Delta time UT1-TAI	**UT1**	PT	PWL @ 12Hr	IERS EOP 08-C04 series Interpolated @12h
Nutation angles X, Y corrections to the IAU2000A/2006 model	**NUT_X, NUT_Y**	NX, NY	PWL @ 12Hr	Set to 0.0
Station coordinates	**STAX, STAY, STAZ**	SX, SY, SZ	1/w @ mid epoch	ITRF2008
Radio sources coordinates right ascension & declination	**RS_RA, RS_DE**	QRA, QDE	1/w @ mid epoch	ICRF2
Added parameters not used for ITRF2013 purposes but proposed for GRGS studies				
Zenithal Troposphere Delay for wet component limited for stations	**ZBIAS**: Adjustment of the wet component to the model	MZB	Every 2-hours: 00, 02, 04, …20, 22hr per day	GPT/GMF model for radio waves and Mendles/Pavlis for optical waves
Troposphere gradient north & east limited for selected stations	**TGETOT, TGNTOT**	MGE, MGN	1 pt/d @ 00Hr	
Possible parameters for future investments				
Polar motion rate	**XPOR, YPOR**	PXR, PYR	1pt/d @ 12Hr	Set to 0.0
Length of Day LOD	**LOD**	PTR	1pt/d @ 12Hr	IERS EOP 08-C04 LOD Interpolated @12h
Rate for nutation angle	**NUTR_X, NUTR_Y**	NXR, NYR	1pt/d PWL @ 12Hr	Set to 0.0

Strategy to prepare the normal equations derived from the individual techniques

1. Stacking the weekly Normal Equations for DORIS, GNSS, SLR, LLR, VLBI techniques

The daily GNSS NEQs are stacked to generate the weekly NEQs with respect to the GPS week numeration. The DORIS NEQs for satellites ENVISAT, Jason-1 and 2, SPOT-3, 4 and 5 and by arcs of 3.5 days long are stacked without any weighting. The weekly SLR and LLR NEQs are stacked using the Helmert weighting method. The VLBI NEQs session R1 and R4 are weekly stacked with respect to the GPS week numeration.

2. Reduction of parameters

For each weekly NEQ, tropospheric parameters which do not belong to a selection of tied stations and outside the list of recommended parameters are reduced (Table 3).

3. Systematic Effects

In order to combine the different geodetic techniques, we need to consider the systematic effects of their terrestrial referential frame relatively to the a priori TRF. To take into account inconsistencies between techniques, Helmert parameters are introduced, i.e translations and scale for satellites systems and scale factor for VLBI technique. Station coordinates for each technique are transformed into a common reference frame R_c by applying the Helmert parameters by the transformation equation:

$$X_{Tech} = X_{Tech\_ITRF} + A.\Theta_{Tech}$$

The station parameters of each technique expressed in the ITRF2008 referential frame, X_{Tech_ITRF}, are reduced from the normal equation, the station parameters X_{Tech} and systematic effects, handled by Θ_{Tech}, are kept for estimation. For more details see IERS Annual Report for 2012.

Combination of DORIS, GNSS, SLR/LLR, VLBI Normal Equations

1. Stacking DORIS, SLR/LLR, VLBI Normal Equations without GNSS

NEQs are stacked using the Helmert weighting algorithm. Table 3 shows for a dedicated week the weighting factors applied to the variance.

Table 3: Weighting factor computed by the Helmert algorithm for DORIS SLR/LLR and VLBI weekly NEQ available – here for GPS week 1514

Technique	DORIS	SLR/LLR	VLBI
Weighting factor	0.0072	1.246	0.043

2. Cancellation of Earth Orientation Parameters measurements outside the considered week

In order to cancel the influence of EOP measurements outside the week processed, we introduce a constraint consisting to force the outside EOP to equal to their a priori, or the EOP corrections to be null for dates outside the nominal week processed:

$$d[EOP(tk)] = 0 \pm \sigma \text{ with } \sigma \text{ very small (0.1mm)}$$

This process is applied on the weekly DORIS, SLR/LLR, and VLBI NEQs. GNSS weekly NEQs are not concerned by this process.

3. Linear constraint on sub-daily EOP corrections and reduction to 1 point per day at 12h

The sub-daily EOP (sampling 6h) resulting of the weekly stacking NEQs DORIS, SLR/LLR and VLBI, are daily linearly constrained between 0h to 24h, and then all EOP except those of 12h are reduced from the NEQ. DORIS, SLR/LLR, VLBI NEQs provide daily EOP at 12h and ready for combination with GNSS NEQ containing EOP also at 12h.

4. Stacking GNSS with combined DORIS, SLR/LLR, VLBI Normal Equations

DORIS, SLR/LLR, VLBI NEQs are then stacked with the GNSS NEQ using unitary weighting factor. This NEQ weekly stacked constitutes Normal Equations delivered.

5. Combination solutions

Additional constraints are added to the combined NEQs before the inversion, such as the No Net Rotation condition on quasars set (NNR), minimal constraints on DORIS, GNSS, SLR and VLBI network stations respectively (7 transformation parameters: 3 Translations, 1 scale factor, and 3 Rotations), stability constraints on station coordinates and loose constraints on tropospheric parameters.

Preliminary results have been obtained over January 2009. They show a good consistency for pole components and for the terrestrial frame. The computation of combined Normal Equations over the whole period is planned for the year 2015.

Participants in the Working Group activities

D. Gambis, J.-Y. Richard, C. Bizouard, Observ. de Paris/GRGS
R. Biancale, J.-M. Lemoine, CNES/GRGS
A. Pollet, D. Coulot, IGN-LAREG/GRGS
S. Loyer, L. Soudarin, CLS
F. Deleflie, IMCCE
G. Bourda, A. Bellanger, Observatoire de Bordeaux
M. Seitz, R. Heinkelmann, M. Gerstl, H. Müller, M. Blossfeld, DGFI
R. Schmid, TUM
D. Thaller, M. Mareyen, S. Bachmann, BKG
R. König, D. König, GFZ
T. Springer, D. Svehla, ESA/ESOC
H. Krasna, K. Teke, TUW
C. Sciarretta, ASI/e-GEOS
M. Kudryashova, ORB
F. Lemoine, GSFC

References

Richard J.-Y., Gambis D., Biancale R., Bizouard C., Handling systematic effects before combining space techniques at the level of normal equations, EGU General Assembly 2013, held 7–12 April, 2013 in Vienna, Austria, id. EGU2013-7604

Richard J.-Y., Biancale R., Gambis D., Bizouard C., Carlucci T., IERS COL-WG Project at GRGS, COL meeting, PARIS, October 2013

Richard J.-Y., Gambis D., Bizouard C., Carlucci T., Biancale R., Combinaison de Techniques Géodésiques au niveau des Observations, AS GRAM 2014, Bordeaux, 2–4 April 2014

Richard J.-Y., Biancale R., Gambis D., Bizouard C., Carlucci T., IERS COL-WG project at GRGS COMBINATION CENTRE, 17th June 2014

Richard J.-Y., Bellanger A., Biancale R., Bizouard C., Bourda G., Bouquillon S., Coulot D., Deleflie F., Francou G., Gambis D., Lemoine J.M., Loyer S., Pollet A., Soudarin L., Combination at the Observation Level: contribution to ITRF2013, EGU General Assembly 2014, held 27 April – 02 May, 2014 in Vienna, Austria, id. EGU2014-2213-4

Daniel Gambis, Richard Biancale, Jean-Yves Richard

3.7.3 Working Group on SINEX Format

The IERS Working Group (WG) on SINEX Format was established in early 2011. The Charter of the Working Group is available on the website dedicated to the working group and maintained at the IERS Central Bureau: <http://www.iers.org/WGSINEX>. Information related to the working group's activities are available there as well, such as agenda and minutes of the meetings held so far.

During the year 2014 there was no special meeting of the working group. All discussions on possible format revisions and additions have been done via email communication.

The latest version of the SINEX format is v 2.02. A full format description is available at: <http://www.iers.org/IERS/EN/Organization/AnalysisCoordinator/SinexFormat/sinex.html>.

The SINEX format is used by all four space-geodetic techniques to provide their products. To ensure that all technique-specific needs are covered by the SINEX format, representatives from each Technique Centre are members of the SINEX Working Group. Additionally, representatives of the IERS ITRS Combination Centres, the IERS Working Group on Site Survey and Co-location, the IERS Conventions Centre, and the IERS Central Bureau are involved in the working group. The IERS Analysis Coordinator is an ex-officio member of the working group in order to cover the needs of the combined IERS products.

The major part of the requested format updates is related to the new method of generating the ITRF, i.e., the handling of non-linear station motions together with the parameterization of the post-seismic behaviour of stations: Periodic signals (especially annual and semi-annual signals), exponential and logarithmic functions will be estimated together with linear velocities. As all these functions together represent the ITRF, the relevant parameters need to be stored in the SINEX file.

Please refer to the IERS Annual Report 2013 for more details.

The next release of an ITRF has been extended from ITRF2013 to become ITRF2014 (see the summary of the IERS DB Meeting No. 59 in this volume, section "Report from ITRS Centre"). Due to this extension, the activities for updating the SINEX format with the new parameterizations could not be finished in 2014. IGN (Institut National de l'Information Géographique et Forestière) as the IERS product centre for the terrestrial reference frame (ITRS Centre) continued to work on the new parameterization in SINEX.

Daniela Thaller (on behalf of the WG)

3.7.4 Working Group on Site Coordinate Time Series Format

The Working Group is a unified WG, both an IERS WG (<http://iers.org/WGSCTSF>) and IAG WG 1.1.1 (<http://iag.uni.lu/index.php?id=175>) of Sub-Commission 1.1 (Coordination of Space Techniques).

Goals and objectives

The major goals and objectives of the WG are:

1) Define a common exchange format for coordinate time series of all geodetic techniques (DORIS, GNSS, SLR, VLBI, …)
2) Examine what type of time series is required (geocentric, detrended, reference frame, …)
3) Define the data and meta-data that should be included in the format
4) Ensure that the format contains the necessary information to be easily used or converted for the web tools of the IAG Services (GGOS, IERS, IDS, IGS, ILRS, IVS)

WG Members

In order to have the best possible interaction with the groups working with station coordinate time series, the working group is composed by time series providers and users.

- Bernd Richter (BKG), GGOS portal manager
- Thomas Herring (MIT), IERS Analysis Coordinator
- Xavier Collilieux (IGN), ITRS Combination Center
- Manuela Seitz (DGFI), ITRS Combination Center
- Laurent Soudarin (CLS), IDS representative
- Paul Rebischung (IGN), IGS representative
- Erricos Pavlis (Univ. of Maryland, Baltimore County), ILRS representative
- John Gipson (NASA), IVS representative
- Médéric Gravelle (Univ. La Rochelle), user (SONEL)
- Yehuda Bock (Scripps Institution of Oceanography), user (SOPAC GPS webservice)
- Simon Williams (Proudman Oceanographic Laboratory), user (CATS software)
- Xiaoping Wu (JPL), user

WG activity

The first meeting of the WG was organized in San Francisco at AGU, on December 6th, 2012. Despite a very short time of meeting, we had rich discussions on some important issues concerning the data: time scale, reference system, coordinate system, … The metadata are of prime importance in the format because they will give the necessary information to identify the time series and to make them easily used. They were briefly discussed. S. Bachman, representing GGOS, informed us of the existence of ISO standards for Geospatial metadata, and of the metadata search engine included in the GGOS portal.

The second meeting of the WG was held in Vienna at EGU, on April 10th, 2012 with a few participants because of travel restrictions for our NASA colleagues and the meeting of GGOS Bureau of Networks and Communications at TU Vienna at the same time. A list of existing formats at IAG services and GPS time series providers were presented. Several issues concerning the time series were discussed (epoch, time tag, accuracy, correlations, …).

The activity of the WG was presented in the session “Unification of product formats” at the IERS Retreat held in Paris in May 2013. The purpose of the session was to discuss the benefits of common formats for the IERS data products, especially for EOP estimates and position time series. It was expressed that there is a clear need to have a standardized format to allow easy comparison. There were not any particular recommendations concerning position time series, just that the WG must continue developing a common format and investigate methods for web access to these files (including graphical presentations). Meeting summary and presentations are online at <http://www.iers.org/Retreat2013.html>.

A third meeting took place in Vienna, on April 15th, 2015, at EGU. Based on a non exhaustive list of existing formats at IAG services and GPS time series providers, metadata and data have been examined. The next step is to define the necessary elements for the time series exchange format (metadata content, data table, mandatory and optional inputs) as well as the units, the coordinate system, the date and time system.

Laurent Soudarin

4 Unified Analysis Workshop

The 4th Unified Analysis Workshop (UAW) was held on June 27–28, 2014 at the California Institute of Technology in Pasadena, California, USA. It was organized mainly by the IERS Analysis Coordinator and the IERS Central Bureau and co-sponsored by GGOS.

Aims of the workshop and issues to be addressed

The following topics were the mains ones to be addressed at the Unified Analysis Workshop. Papers were invited that would address these areas and follow-up after the workshop should lead to resolution or a better understanding of the issues. There is no specific order to the issues listed below but some are more critical to be addressed than others.

(1) ~1 ppb scale difference between VLBI and SLR. This issue is critical to the ITRF realization and should be addressed as thoroughly as possible.

(2) Antenna phase center models for DORIS systems. The recent implementation of phase center models for the DORIS ground transmitters has increased the scale difference between DORIS results and the ITRF2008 scale. It is likely this difference will persist with ITRF2013 as well.

(3) Time variable gravity field effects (DORIS LEO satellites). Although the IDS raised this issue, it also has impacts on the ILRS and even GNSS orbits could be affected by time variable low degree gravity field coefficients.

(4) Sub-daily loading and S1/S2 loading. Two issues are involved here: (a) the coefficients of the S1 and S2 loading signals and how they vary during the year, and (b) the effects of any remaining sub-daily variations after the S1 and S2 terms are removed.

(5) Update time scales for atmospheric and hydrographic loading: Frequency dependence and signal to noise ratio of loading?

(6) Diurnal and Semidiurnal EOP variations. Impact of new models available from the IVS and how these model impact geodetic parameter estimates.

(7) EOP parameterization for high-time resolution representation: Is piece-wise linear adequate for current accuracies?

(8) Collocation issues, ground- and space-based: Assessment of where we stand at the moment.

(9) Monument stability (large and small, physical and electrical): UNAVCO and NASA SGP have been studying this issue and there are measurements that try to address this issue.

(10) Intersystem observations (e.g. VLBI of satellites, SLR of GNSS systems): Assessment of current status, future prospects and likely impacts on geodetic parameter estimates.

(11) Error models for data and parameter estimates: What are the impacts and best methods for determining correlations within and between geodetic systems and how do account for these correlations so that error estimates on geodetic parameters are more robust and realistic?

(12) Unification of gravity contributions: How do we start addressing the integration of gravity services with the geometric services to ensure consistent models and results?

(13) Combination at the Observation level results. Update on current status and long term impact of these approaches.

Schedule of Talks

Friday, June 27

Session 1: VLBI/SLR scale I

Zuheir Altamimi: Current estimates of scale differences between techniques

John Ries: The Scale of the Terrestrial Reference Frame from VLBI and SLR

Johannes Boehm, Hana Krana, and Matt King: GIA effects on VLBI scale rate

Erricos C. Pavlis, V. Luceri, M. Kuzmicz-Cieslak, and K. Evans: Modeling Changes for the ILRS Reanalysis for ITRF2013

Session 2: VLBI/SLR scale II

Dan MacMillan: VLBI Scale Effects

Vincenza Luceri, B. Pace, E. Pavlis, and G. Bianco: SLR systematics and TRF scale

Graham Appleby and Jose Rodriguez: Accuracy assessment of the ILRS network and potential impact on ITRF scale

A. Auriol, F. Boldo, C.Jayles, and C. Tourain: DORIS Ground Antenna Characterization

Saturday, June 28

Session 3: Geophysical Fluids I EOP and Loading

Daniela Thaller, Ole Roggenbuck, Gerald Engelhardt, and Sonja Geist: Geophysical fluids: Models and their impact on space-geodetic solutions

John Gipson: High Frequency Tidal EOP from Space Geodesy and Ocean Modeling

Jan M. Hagedoorn, H. Schuh, M. Madzak, and W. Bosch: Short Period Ocean-Tidal variations in Earth rotation

Session 4: Geophysical Fluids II S1/S2

Shailen Desai, Willy Bertiger, Bruce Haines, and Richard Ray: Self-Consistent Treatment of Tidal Variations in the Geocenter for Satellite Geodesy

Johannes Böhm, Hana Krásná, and Michael Schindelegger: S1/S2 Loading Effects

Session 5: Analysis methods

Richard Biancale, Daniel Gambis, Manuela Seitz: After 4 years of COL activities

Frank G. Lemoine: Time-variable gravity effects on LEO satellites
John Gipson: What Do Our Time-Tags Refer to?

Session 6: Monument Stability

Jérôme Saunier: Monument Stability: DORIS Network Experience Feedback

Thomas Herring: UNAVCO/GGAO monument study

Workshop website and recommendations

The workshop program, summary, and presentations are available online at <http: //www.iers.org/UAW2014>. For a list of recommendations from this UAW see the report of the IERS Analysis Coordinator in Chapter 3.3 or the UAW website.

Thomas Herring, 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 ICSU World Data System (WDS).

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: IDS, IGS, ILRS, IVS, 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 elected by the Board for a term of four years with the possibility of re-election for one additional term. Eligible candidates are members of the DB and IERS Associate Members.

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. If a DB member cannot participate in the meeting, he/she can designate a proxy to attend the meeting and vote in the place of the absent DB member. Any appointment of a proxy by a DB member shall be in writing to the CB prior to the meeting, and is valid only for the meeting.

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

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

WORKING GROUPS

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

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

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

- Draft charter clearly specifying:
  - Proposed goals (two pages at maximum),
  - Proposed structure of the group or project,

  - o Working plan including schedule / deadlines including the anticipated end of work,
- Candidate for a chairperson to be appointed by the DB (optional),
- Initial list of members,
- Proposed plans for an operational phase (if applicable),
- Draft IERS message to inform the IERS community.

IERS ASSOCIATE MEMBERS

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

IAG General Secretary

IAU General Secretary

IUGG General Secretary

President of IAG Commission 1

Chair of IAG Subcommission 1.1

Chair of IAG Subcommission 1.2

Chair of IAG Subcommission 1.4

President of IAG Commission 3

Chair of IAG Subcommission 3.1

Chair of IAG Subcommission 3.2

Chair of IAG Subcommission 3.3

President of IAU Division A

President of IAU Commission A1

President of IAU Commission A2

President of IAU Commission A3

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 6, 2015

Appendix 2: Contact addresses of the IERS Directing Board

Chair

Brian J. Luzum
(address see below)

Analysis Coordinator

Thomas Herring
Massachusetts Institute of Technology
77 Massachusetts Avenue
Building 54-618
Cambridge, MA 02139
USA
phone: +1-617-253-5941
fax: +1-617-253-6385
e-mail: tah@mit.edu

Product Centres Representatives

Earth Orientation Centre Representative

Christian Bizouard
Observatoire de Paris
61, avenue de l'Observatoire
75014 Paris
France
phone: +33-1-4051-2335
fax: +33-1-4051-2291
e-mail: christian.bizouard@obspm.fr

Rapid Service/Prediction Centre Representative

Christine Hackman
U.S. Naval Observatory
Earth Orientation Department
3450 Massachusetts Avenue, NW
Washington, DC 20392-5420
USA
phone: +1-202-762-1444
fax: +1-202-762-1563
e-mail: brian.luzum@usno.navy.mil

Conventions Centre Representative

Brian J. Luzum
U.S. Naval Observatory
Scientific Director
3450 Massachusetts Avenue, NW
Washington, DC 20392-5420
USA
phone: +1-202-762-1513
fax: +1-202-762-1563
e-mail: brian.luzum@usno.navy.mil

ICRS Centre Representative

Bryan Dorland
U.S. Naval Observatory
Astrometry Department
3450 Massachusetts Avenue, NW
Washington, DC 20375
USA
phone: +1-202-762-0134
fax: +1-202-762-1516
e-mail: bryan.dorland@usno.navy.mil

ITRS Centre Representative

Zuheir Altamimi
Institut National de l'Information Géographique et Forestière (IGN)
Laboratoire de Recherche en Géodésie (LAREG)
Bâtiment Larmarck A
5, rue Thomas Mann, Case courrier 7011
75205 Paris Cedex 13, France
phone: +33 1 57 27 53 28
fax: +33 1 57 27 84 82
e-mail: altamimi@ensg.ign.fr

Global Geophysical Fluids Centre Representative

Tonie van Dam
Faculté des Sciences, de la Technologie et de la Communication
University of Luxembourg
162a, avenue de la Faïencerie
1511 Luxembourg
Luxembourg
phone: +352-46-66-44-6261
fax: +352-46-66-44-6567
e-mail: tonie.vandam@uni.lu

Central Bureau Representative

Daniela Thaller
Bundesamt für Kartographie und Geodäsie
Richard-Strauss-Allee 11
60598 Frankfurt am Main
Germany
phone: +49-69-6333-273
fax: +49-69-6333-425
e-mail: daniela.thaller@bkg.bund.de

Technique Centers Representatives

IGS Representatives

Steven Fisher
Jet Propulsion Laboratory
Communications, Tracking and Radar Division (33)
Mail Stop 238-540, 4800 Oak Grove Dr.
Pasadena, CA 91109, USA
phone: +1-818-354-3435
fax: +1-818-354-8545
e-mail: Steven.Fisher@jpl.nasa.gov

Tim Springer
European Space Operations Centre
Navigation Support Office
GMV, OPS-GN, Robert-Bosch-Strasse 5
64293 Darmstadt, Germany
phone: +49-6151-902029
fax: +49-6151-903129
e-mail: Tim.Springer@esa.int

ILRS Representatives

Jürgen Müller
Leibniz Universität Hannover
Institut für Erdmessung
Schneiderberg 50
30167 Hannover, Germany
phone: +49-511-762-3362
fax: +49-511-762-4006
e-mail: mueller@ife.uni-hannover.de

Erricos C. Pavlis
Goddard Earth Science and Technology Center (GEST/UMBC)
University of Maryland, Baltimore County
1000 Hilltop Circle
Baltimore, MD 21250, USA
phone: +1-410-455-5832
fax: +1-410-455-5868
e-mail: epavlis@umbc.edu

IVS Representatives

Chopo Ma
Planetary Geodynamics Laboratory, Code 698
NASA's Goddard Space Flight Center
Greenbelt, MD 20771, USA
phone: +1-301-614-6101
fax: +1-301-614-6522
e-mail: Chopo.Ma@nasa.gov

Rüdiger Haas
Chalmers University of Technology
Onsala Space Observatory
439 92 Onsala, Sweden
phone: +46 31 772 55 30
fax: +46 31 772 55 90
e-mail: rudiger.haas@chalmers.se

IDS Representatives

Hugues Capdeville
CLS
8-10 rue Hermes, Parc Technologique du Canal
31520 Ramonville Saint-Agne, France
phone: +33 5 61 39 37 06
fax: +33 5 61 75 10 14
e-mail: ids.analysis.coordination@ids-doris.org

Jérôme Saunier
Réseaux et Services Internationaux
Service de Géodésie et Nivellement
Institut National de l'Information Géographique et Forestière
2, avenue Pasteur, 94165 Saint Mande Cedex, France
phone: +33 1 43 988 363, fax: +33 1 43 988 450
e-mail: jerome.saunier@ign.fr

Union Representatives

IAU Representative

Aleksander Brzezinski
Space Research Centre
Polish Academy of Sciences
Bartycka 18a
00-716 Warsaw, Poland
phone: ++48-22-381 6287
fax: ++48-22-840 3131
e-mail: alek@cbk.waw.pl

IAG / IUGG Representative

Axel Nothnagel
Institut für Geodäsie und Geoinformation (IGG)
Universität Bonn
Nußallee 17
53115 Bonn, Germany
phone: +49-228-73-3574
fax: +49-228-73-2988
e-mail: nothnagel@uni-bonn.de

GGOS Representative

Bernd Richter
Bundesamt für Kartographie und Geodäsie
Richard-Strauss-Allee 11
60598 Frankfurt am Main
Germany
phone: +49-69-6333-345
fax: +49-69-6333-441
e-mail: bernd richter@bkg.bund.de

(*Status as of December 2015*)

Appendix 3: Contact addresses of the IERS components

Analysis Coordinator

Thomas Herring
Massachusetts Institute of Technology
77 Massachusetts Avenue, Building 54-618
Cambridge, MA 02139, USA
phone: +1-617-253-5941
fax: +1-617-258-6385
e-mail: tah@mit.edu

Central Bureau

IERS Central Bureau
Bundesamt für Kartographie und Geodäsie
Richard-Strauss-Allee 11
60598 Frankfurt am Main
Germany
phone: +49-69-6333-273/261/314/250
fax: +49-69-6333-425
e-mail: central_bureau@iers.org

Director: Daniela Thaller
Scientific Assistant: Wolfgang R. Dick

Technique Centres

International GNSS Service (IGS)
IGS Central Bureau
Jet Propulsion Laboratory (JPL)
M/S 238-540, 4800 Oak Grove Drive
Pasadena, CA 91109, USA
phone: +1-818-354-2077
fax: +1-818-393-6686
e-mail: igscb@igscb.jpl.nasa.gov

IGS Representatives to the IERS Directing Board:
Steven Fisher, Tim Springer
IERS Representative to the IGS Governing Board:
Claude Boucher

International Laser Ranging Service (ILRS)
ILRS Central Bureau
NASA's Goddard Space Flight Center (GSFC), Code 690.5
Greenbelt, MD 20771, USA
phone: +1-301-614-6542
fax: +1-301-614-6099
e-mail: cb@ilrs.gsfc.nasa.gov

ILRS Representatives to the IERS Directing Board:
Jürgen Müller, Erricos C. Pavlis
IERS Representative to the ILRS Directing Board:
Daniela Thaller

International VLBI Service for Geodesy and Astrometry (IVS)
IVS Coordinating Center
NASA's Goddard Space Flight Center (GSFC), Code 698.2
Greenbelt, MD 20771, USA
phone: +1-301-614-5939
fax: +1-301-614-6099
e-mail: ivscc@ivscc.gsfc.nasa.gov

IVS Representatives to the IERS Directing Board:
Rüdiger Haas, Chopo Ma
IERS Representative to the IVS Directing Board: Chopo Ma

International DORIS Service (IDS)
IDS Central Bureau
CLS
8-10, rue Hermes, Parc Technologique du Canal
31526 Ramonville CEDEX, France
phone: +33 5 61 39 48 49 / 5 61 39 47 50
fax: +33 5 61 39 48 06
e-mail: Laurent.Soudarin@cls.fr
IDS representatives to the IERS:
Hugues Capdeville, Jérôme Saunier
IERS Representative to the IDS Governing Board: Brian Luzum

Product Centres

Earth Orientation Centre
Observatoire de Paris
61, Avenue de l'Observatoire
75014 Paris
France
phone: +33-1-4051-2335
fax: +33-1-4051-2291
e-mail: services.iers@obspm.fr, christian.bizouard@obspm.fr

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

Rapid Service/Prediction Centre
U.S. Naval Observatory, Earth Orientation Department
3450 Massachusetts Avenue, NW
Washington, DC 20392-5420
USA
phone: +1-202-762-1444
fax: +1-202-762-1563
e-mail: christine.hackman@usno.navy.mil

Primary scientist and representative to the IERS Directing Board: Christine Hackman

Conventions Centre
U.S. Naval Observatory, Earth Orientation Department
3450 Massachusetts Avenue, NW, Washington, DC, USA
phone: +1-202-762-0242
fax: +1-202-762-1563
e-mail: brian.luzum@usno.navy.mil

Bureau International des Poids et Mesures
Pavillon de Breteuil, 92312 Sèvres Cedex, France
phone: +33-1-45077067
fax: +33-1-45077059
e-mail: gpetit@bipm.org

Primary scientists:
Brian J. Luzum (USNO), Gérard Petit (BIPM)
Current representative to the IERS Directing Board:
Brian J. Luzum

ICRS Centre
U.S. Naval Observatory, Astrometry Department
3450 Massachusetts Avenue, NW
Washington, DC, USA
phone: +1-202-762-0134
fax: +1-202-762-1516
e-mail: bryan.dorland@usno.navy.mil

Observatoire de Paris, SYRTE
61, Avenue de l'Observatoire
75014 Paris, France
phone: +33-1-40512322
fax: +33-1-40512291
e-mail: Jean.Souchay@obspm.fr

Primary scientists:
Bryan Dorland (USNO), Jean Souchay (Obs. Paris)
Current representative to the IERS Directing Board:
Ralph A. Gaume

ITRS Centre
Institut National de l'Information Géographique et Forestière (IGN)
Laboratoire de Recherche en Géodésie (LAREG)
Bâtiment Larmarck A
5, rue Thomas Mann, Case courrier 7011
75205 Paris Cedex 13, France
phone: +33 1 57 27 53 28, fax: +33 1 57 27 84 82
e-mail: itrf@ign.fr

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

Global Geophysical Fluids Centre
Tonie van Dam
Faculté des Sciences, de la Technologie et de la Communication
University of Luxembourg
162a, avenue de la Faïencerie
1511 Luxembourg, Luxembourg
phone: +352-46-66-44-6261, fax: +352-46-66-44-6567
e-mail: tonie.vandam@uni.lu

Primary scientist and representative to the IERS Directing Board: Tonie van Dam

Special Bureau for the Oceans
Richard S. Gross
JPL, Mail Stop 238-600, 4800 Oak Grove Drive
Pasadena, CA 91109-8099, USA
phone: +1-818-354-4010, fax: +1-818-393-4965
e-mail: Richard.Gross@jpl.nasa.gov

Special Bureau for Hydrology
Jianli Chen
Center for Space Research
University of Texas at Austin
Austin, TX 78712, USA
phone: +1-512-232-6218, fax: +1-512-471-3570
e-mail: chen@csr.utexas.edu

Special Bureau for the Atmosphere
David A. Salstein
Atmospheric and Environmental Research, Inc.
131 Hartwell Avenue
Lexington, MA 02421-3126, USA
phone: +1-781-761-2288, fax: +1-781-761-2299
e-mail: salstein@aer.com

Special Bureau for Combination
Tonie van Dam
(address see above)

ITRS Combination Centres

Deutsches Geodätisches Forschungsinstitut (DGFI)
Manuela Seitz
Deutsches Geodätisches Forschungsinstitut an der TUM
Alfons-Goppel-Straße 11
80539 München, Germany
phone: +49-89-23031-1294
fax: +49-89-2303-1240
e-mail: manuela.seitz@tum.de

Institut National de l'Information Géographique et Forestière (IGN)
Zuheir Altamimi
Institut National de l'Information Géographique et Forestière (IGN)
Laboratoire de Recherche en Géodésie (LAREG)
Bâtiment Larmarck A
5, rue Thomas Mann, Case courrier 7011
75205 Paris Cedex 13, France
phone: +33 1 57 27 53 28, fax: +33 1 57 27 84 82
e-mail: altamimi@ensg.ign.fr

Jet Propulsion Laboratory (JPL)
Richard S. Gross
Jet Propulsion Laboratory
Mail Stop 238-600, 4800 Oak Grove Drive
Pasadena, CA 91109-8099, USA
phone: +1-818-354-4010, fax: +1-818-393-4965
e-mail: Richard.Gross@jpl.nasa.gov

Working Groups

Working Group on Site Survey and Co-location

Sten Bergstrand
SP Technical Research Institute of Sweden
Measurement Technology
Box 857
SE-501 15 Borås, Sweden
phone: +46 10 516 50 00, direct: +46 10 516 57 73
fax: +46 10 516 56 20
e-mail: sten.bergstrand@sp.se

Working Group on Combination at the Observation Level

Richard Biancale
Groupe de Recherches de Géodésie Spatiale
CNES/GRGS
18, Avenue Edouard Belin
31055 Toulouse Cedex, France
phone: +33-61332978
fax: +33-61253098
e-mail: richard.biancale@cnes.fr

Working Group on SINEX Format

Daniela Thaller
Bundesamt für Kartographie und Geodäsie
Richard-Strauss-Allee 11
60598 Frankfurt am Main
Germany
phone: +49-69-6333-273
fax: +49-69-6333-425
e-mail: daniela.thaller@bkg.bund.de

Working Group on Site Coordinate Time Series Format

Laurent Soudarin
Collecte Localisation Satellites (CLS)
8-10 rue Hermès
Parc Technologique du Canal
31520 Ramonville Saint-Agne
France
phone: +33-5-61-39-48-49
fax: +33-5-61-39-48-06
e-mail: laurent.soudarin@cls.fr

(*Status as of December 2015*)

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://www.usno.navy.mil/USNO/earth-orientation/eo-products
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://www.usno.navy.mil/USNO/earth-orientation/eo-products/weekly/bulla (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:
Special Bureau for the Oceans
Web site: http://euler.jpl.nasa.gov/sbo/
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://www.igs.org/

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

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

International DORIS Service (IDS)
Web site: http://ids-doris.org/

ITRS Combination Centres

Deutsches Geodätisches Forschungsinstitut (DGFI)
Web site: http://www.dgfi.tum.de/en/international-services/itrs-combination-centre/

Institut Géographique National (IGN)
Wep site: http://itrf.ensg.ign.fr/

Jet Propulsion Laboratory (JPL)
Web page: http://www.iers.org/ITRSCC-JPL

Working Groups

Working Group on Site Survey and Co-location
Web site: http://www.iers.org/WGSiteSurvey

Working Group on Combination at the Observation Level
Web sites: http://hpiers.obspm.fr/combinaison/
http://www.iers.org/WGCOL

Working Group on SINEX Format
Web site: http://www.iers.org/WGSINEX

Working Group on Site Coordinate Time Series Format
Web page: http://www.iers.org/WGSCTSF

Appendix 5: Acronyms

The following acronyms and other abbreviations are used in this report. For more acronyms related to IERS see <http://www.iers.org/Acronyms>.

A&A	Astronomy & Astrophysics
AAM	Atmospheric Angular Momentum
AAS	American Astronautical Society
AC	Analysis Centre
AC	Analysis Coordinator
AGN	Active Galactic Nucleus [or Nuclei]
AGU	American Geophysical Union
AICAS	Astronomical Institute, Academy of Sciences of the Czech Republic
ALMA	Atacama Large Millimeter/submillimeter Array
AOD	atmospheric and oceanic dealiasing
AOV	Asia-Oceania VLBI Group for Geodesy and Astrometry
APSG	Asia-Pacific Space Geodynamics
AR	[IERS] Annual Report
AR	autoregressive
ASCII	American Standard Code for Information Interchange
ASI	Agenzia Spaziale Italiana
ASV	Astronomical Station Vidojevica
ATML	atmospheric loading
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
BVID	Bordeaux VLBI Image Database
CA	California, USA
CASLEO	Complejo Astronómico El Leoncito
CATREF	Combination and Analysis of Terrestrial Reference Frames
CB	Central Bureau
CB	Coordinating Board
CC	Combination Centre
CCD	Charge-Coupled Device
CDDIS	NASA Crustal Dynamics Data Information System
CDS	Centre de Données astronomiques de Strasbourg
CEOS	Committee on Earth Observation Satellites
CERGA	Centre d’Etudes et de Recherches Géodynamiques et Astronomiques
CfA	Harvard-Smithsonian Center for Astrophysics
CFHT	Canada-France-Hawaii Telescope
CLS	Collecte Localisation Satellites
CNES	Centre National d’Etude Spatiale
CODE	Centre for Orbit Determination in Europe
COL	combination at/on the observation level
CONT	continuous VLBI session/campaign
CPC	Climate Prediction Center
CRF	Celestial Reference Frame
CSR	Center for Space Research, University of Texas
CTIO	Cerro Tololo Inter-American Observatory
DB	Directing Board
DC	District of Columbia, USA
Dec, DEC	declination
deg	degree
DGFI	Deutsches Geodätisches Forschungsinstitut
DiFX	Distributed FX
DIS	IERS Data and Information System
DOI	Digital Object Identifier
DOMES	Directory Of MERIT Sites (originally; now of more general use)
DORIS	Doppler Orbit determination and Radiopositioning Integrated on Satellite
DSS	Digitized Sky Survey
DSS45	Deep Space Station 45
DTRF	ITRS realization by DGFI
DUT1	= UT1–UTC
EC	Executive Committee
ECCO	Estimating the Circulation and Climate of the Ocean

ECMWF	European Center for Medium Range Weather Forecasting
EGSG	Extra-Galactic Science with Gaia
EGU	European Geosciences Union
EMR	Energy, Mines and Resources Canada (replaced by NRCan)
EMRP	European Metrology Research Programme
ENVISAT	Environmental Satellite
EO	Earth orientation
EOC	Earth Orientation Centre
EOP	Earth Orientation Parameters
ERA	ECMWF Reanalysis Data
ERP	Earth Rotation Parameters
ESA	European Space Agency
ESO	European Southern Observatory
ESOC	European Space Operations Center, ESA
Eumetsat	European Organisation for the Exploitation of Meteorological Satellites
EVGA	European VLBI [Group] for Geodesy and Astrometry
e-VLBI	Electronic transfer VLBI
FAQ	Frequently Asked Question(s)
FedEx	Federal Express Corporation Inc.
FL	Floria, USA
FNMOC	[US Navy] Fleet Numerical Meteorology and Oceanography Center
FRA-UAS	Frankfurt University of Applied Sciences
FTP, ftp	File Transfer Protocol
GA	General Assembly
GA	Geoscience Australia
GAOUA	Main Astronomical Observatory of the Ukrainian Academy of Sciences
GB	Governing Board
GCRF	Gaia Celestial Reference Frame
GCRS	Gaia Celestial Reference System
GEO	Group on Earth Observations
GEST	Goddard Earth Science and Technology Center
GFZ	GeoForschungsZentrum Potsdam
GGAO	Goddard's Geophysical and Astronomical Observatory
GGFC	Global Geophysical Fluids Centre
GGOS	Global Geodetic Observing System
GGRF	Global Geodetic Reference Frame
GHz	gigahertz
GIAC	GGOS Inter-Agency Committee
GINS	Geodesy by Simultaneous Digital Integration [software]
GIOVE	Galileo In-Orbit Validation Element
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]
GLOUP	GLObal Undersea Pressure
GNSS	Global Navigation Satellite System
GOP	Geodetic Observatory Pecny
GPS	Global Positioning System
GPT	Global Pressure and Temperature
GRACE	Gravity Recovery and Climate Experiment
GRAIL	Gravity Recovery and Interior Laboratory
GRGS	Groupe de Recherches de Géodésie Spatiale
GSC	GSFC Analysis Center
GSFC	Goddard Space Flight Center
GSI	Geospatial Information Authority of Japan
HAM	Hydrological Angular Momentum
HartRAO	Hartebeesthoek Radio Astronomy Observatory
HEO	High Earth Orbiter
hr	hour, hours
HY	HaiYan / Haiyang [satellite]
IAA	Institute of Applied Astronomy, St. Petersburg
IAG	International Association of Geodesy
IAU	International Astronomical Union
IB	Inverted Barometer
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

IfE	Institut für Erdmessung [Institute of Geodesy], University of Hannover
IGG, IGGB	Institute of Geodesy and Geoinformation of the University of Bonn
IGN	Institut National de l'Information Géographique et Forestière (formerly: Institut Géographique National)
IGR	IGS rapid [products / satellite orbits]
IGS	International GNSS Service
ILRS	International Laser Ranging Service
ILW	international laser workshop / International Workshop on Laser Ranging
IMCCE	Institut de Mécanique Céleste et de Calcul des Éphémérides
INA	= INASAN
INASAN	INstitut AStronomii Rossijskoj Akademii Nauk (Institute of Astronomy of the Russian Academy of Sciences)
INFN	Istituto Nazionale di Fisica Nucleare [National Institute for Nuclear Physics]
InSAR	Interferometric Synthetic Aperture Radar
INT	Intensive [VLBI session]
IPGP	Institut de Physique du Globe de Paris
IRAF	Image Reduction and Analysis Facility
IRIS	International Radio Interferometric Surveying
IRNSS	Indian Regional Navigation Satellite System
ISO	International Organization for Standardization
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
IUGG	International Union of Geodesy and Geophysics
IVOA	International Virtual Observatory Alliance
IVS	International VLBI Service for Geodesy and Astrometry
JADE	JApanese Dynamic Earth observation by VLBI
Jason-CS	Jason Continuity of Service [mission]
JCET	Joint Center for Earth Systems Technology, GSFC
JMA	Japan Meteorological Agency
JP	Japan
JPL	Jet Propulsion Laboratory
KALREF	Kalman filter for Reference frames
KASI	Korea Astronomy and Space Science Institute
LAB	Laboratoire d'Astrophysique de Bordeaux
LAREG	Laboratoire de Recherche en Geodesie
LARGE	Laser Ranging to GNSS s/c Experiment
LCA	LEGOS in cooperation with CLS
LDAS	Land Data Assimilation System
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LEO	Low Earth Orbit(er)
LFOA	Leopold-Figl-Observatorium für Astrophysik
LLR	Lunar Laser Ranging
LNA	Laboratório Nacional de Astrofísica
LOD	Length of Day
LQAC	Large Quasar Astrometric Catalogue
LRO	Lunar Reconnaissance Orbiter
LS	least-squares
LSDM	Land Surface Discharge Model
MA	Massachusetts, USA
MAO	= GAOUA
mas	milliarcsecond(s)
μas	microarcsecond(s)
MATLAB	matrix laboratory [programming language and environment]
MCC	Russian Mission Control Centre
MD	Maryland, USA
MeO	Métrologie Optique [Grasse SLR /LLR system]
MERIT	Monitoring Earth Rotation and Intercomparison of Techniques
MIT	Massachusetts Institute of Technology
MJD	Modified Julian Day
MOG2D	two-dimensional barotropic gravity wave ocean model
MPG	Max-Planck-Gesellschaft / Max Planck Society
MPIfR	Max-Planck-Institut für Radioastronomie / Max Planck Institute for Radio Astronomy

ms	millisecond(s)
µs	microsecond(s)
MX	Mexico
N	number
NASA	U.S. National Aeronautics and Space Administration
Nat.	National, Nacional
NAVGEM	[U.S.] Navy Global Environmental Model
NCEP	U.S. National Centers for Environmental Prediction
NEQ	normal equation
NLS	National Land Survey [of Finland; Maanmittauslaitos]
NMA	Norwegian Mapping Authority
NMC	National Meteorological Center (replaced by NCEP)
NNR	No-net-rotation
NO	Norway
No.	Number
NOAA	U.S. National Oceanic and Atmospheric Administration
NOFS	[U.S.] Naval Observatory Flagstaff Station
NOT	Nordic Optical Telescope
NP	SLR normal point(s)
NRAO	[U.S.] National Radio Astronomy Observatory
NRCan	Natural Resources, Canada (formerly: EMR)
NSGF	NERC Space Geodesy Facility
NT-ATML	non-tidal atmospheric loading
NTP	Network Time Protocol
NTT	New Technology Telescope
NZ	New Zealand
OAM	Oceanic Angular Momentum
OB	Observatoire de Bordeaux
OBP	Ocean Bottom Pressure
Obs.	Observatory, Observatoire
OCARS	Optical Characteristics of Astrometric Radio Sources
OHIG	O'Higgins [station]
OHP	Observatoire de Haute Provence
OP, OPA	Observatoire de Paris
ORB	Observatoire Royal de Belgique
OSO	Onsala Space Observatory
PC	Product Centre
PCV	Phase-Center Variations
PG	Papua New Guinea
PI	Principal Investigator
PM	Polar Motion
POC	point of contact
POD	Precise [or Precision] Orbit Determination
POE	Precise Orbit Comparison
POLAC	Paris Observatory Lunar Analyses Center
PP	Pilot Project
ppb	parts per billion (10^{-9})
PSF	point spread function
PUL	Pulkovo Observatory
PZT	Photographic Zenith Tube [*or* Telescope]
QSO	Quasi-Stellar Object [*or* quasar]
RA	right ascension
RAEGE	Red Atlantica de Estaciones Geodinamicas y Espaciales
RAS	Russian Academy of Sciences
R&D	Research and Development
REFAG	[Symposium on] Reference Frames for Applications in Geosciences
RFI	radio frequency interference
RINEX	Receiver INdependent EXchange format
rms, RMS	Root Mean Square
RRFID	USNO Radio Reference Frame Image Database
RS/PC	IERS Rapid Service/Prediction Center
RT	radio telescope
RU	Russian Federation
SAA	South Atlantic Anomaly
SARAL	Satellite with ARGOS and ALTIKA
SB	Special Bureau
SBA	GGFC Special Bureau for the Atmosphere
SBCP	GGFC Special Bureau for the Combination Products
SBH	GGFC Special Bureau for Hydrology
SBO	GGFC Special Bureau for the Oceans
s/c	spacecraft
SDSS	Sloan Digital Sky Survey
sec	second(s) [of time]

SG	Study Group
SGP	Space Geodesy Project
SGSLR	Space Geodesy SLR system
SHAO	Shanghai Observatory
SINEX	Solution (Software/technique) INdependent EXchange Format
SIO	Scripps Institution of Oceanography
SLR	Satellite Laser Ranging
SNR	signal-to-noise ratio
SOD	CNES Service d’Orbitographie DORIS
SOKENDAI	Graduate University for Advanced Studies
SP	SP Technical Research Institute of Sweden [SP Sveriges Tekniska Forskningsinstitut; formerly Statens Provningsanstalt]
SpinSat	Special Purpose Inexpensive Satellite
SPOT	Satellite Pour l’Observation de la Terre
sq.deg	square degree
SSALTO	Segment Sol multi-mission d’ALTimétrie, d’Orbitographie et de localisation précise
STD	standard deviation
SWOT	Surface Water Ocean Topography [mission]
SYRTE	(Laboratoire) Systèmes de Référence Temps-Espace
TAI	Temps Atomique International (International Atomic Time)
TAROT	Télescopes à Action Rapide pour les Objets Transitoires
TC	Technique Centre
TCH	Three Corner Hat [technique]
TE	Temps des éphémérides / Ephemeris time
TN	[IERS] Technical Note
ToR	Terms of Reference
TPS	Tachymeter Positioning System / Total station Positioning System
TRF	Terrestrial Reference Frame
TT	Terrestrial Time
TU	Technical University
TUM	Technical University of Munich
TUW	Technische Universität Wien (Vienna University of Technology)
TWS	terrestrial water storage
U.	University
UAW	Unified Analysis Workshop
UCAC	USNO CCD Astrograph Catalog
UCL	University College London
UK, U.K.	United Kingdom
UKMO	U.K. Meteorological Office
UMBC	University of Maryland, Baltimore County
UN	United Nations
UNB	University of New Brunswick
UNAVCO	University Navstar Consortium
UN-GGIM	Global Geospatial Information Management Initiative of the UN
Uni, Univ.	University
URAT	USNO Robotic Astrometric Telescope
URL	Uniform Resource Locator
US, U.S.	United States
USGS	U.S. Geological Survey
USNO	United States Naval Observatory
USO	Ultra-Stable Oscillator
UT, UT0, UT1, UT2R	Universal Time
UTAAM	NOAA AAM analysis and forecast data
UTC	Coordinated Universal Time
UZ	Uzbekistan
VCS	VLBA Calibrator Survey
VEX	VLBI Experiment Documentation
VGOS	VLBI Global Observing System
VLBA	Very Long Baseline Array, NRAO
VLBI	Very Long Baseline Interferometry
VO	Virtual Observatory
VTRF	VLBI terrestrial reference frame
WDS	ICSU World Data System
WG	working group
WP	Work Package
WRMS	Weighted Root Mean Square
XML	eXtensible Markup Language
yr	year