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

IERS
Annual Report
2013

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IERS Annual Report 2013

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1 Foreword

The IERS took significant steps in 2013 in order to organize its efforts for the next decade. In May, the IERS held a Retreat over two days that concentrated on seven topics. By reviewing the seven topics and generating recommendations to address new areas of opportunity, the IERS is positioning itself to meet the needs of its users for year to come. For additional information, see Chapter 4.2 of this report or <http://www.iers.org/Retreat2013>.

Efforts to develop the new ITRF continued. With the decisions regarding the modeling and the timelines finalized, the official Call for Participation was released by the ITRS Centre. Work on reviewing the ITRF submissions continue and the new ITRF is expected to be released in 2015.

The ICRS Centre continued to participate in the organization of the upcoming ICRF-3. It is expected that the 2015 International Astronomical Union (IAU) General Assembly (GA) will pass resolutions regarding the strategy for ICRF-3 so that the 2018 IAU GA can adopt the final ICRF-3.

Following the IERS Workshop on Local Surveys and Co-locations in May, the leadership of the Working Group on Site Survey and Co-location was reorganized. Pierguido Sarti decided to step down as chair of the Working Group. His leadership for this often under-resourced area of study has provided improved ties between various geodetic observation techniques. His efforts are much appreciated and will be missed. Sten Bergstrand, the new chair of the Working Group, has stepped into the leadership role at an important time as the site ties will play a critical role in the development of the new ITRF.

Since the IERS was jointly established by the IAU and the International Union of Geodesy and Geophysics (IUGG), it is of interest that the IAU is reorganizing its commissions. The IERS stands ready to continue its long-standing relationship with the IAU and will engage the appropriate commissions once the reorganization has been adopted.

Several changes in personnel of the IERS Directing Board occurred during 2013. Jérôme Saunier replaced Bruno Garayt as the second IDS representative. Steven Fisher was named as the second IGS representative. Ralph Gaume replaced Jean Souchay as the ICRS Center representative and I replaced Gérard Petit as the Conventions representative as part of the regular rotation of responsibilities between the jointly shared centers.

Since 2001, Bernd Richter has been Director of the IERS Central Bureau. In 2013, Bernd resigned that position when he was selected for a new job with responsibilities outside of the Central Bureau. Daniela Thaller was subsequently chosen as the Director

of the Central Bureau. I want to thank Bernd for his many years of service to the IERS and wish Daniela well in her new position.

I want to take this opportunity to thank Chopo Ma for his eight-year tenure as Chair of the IERS Directing Board (2004–2012). During this time, the IERS achieved many significant milestones including adopting a new ITRF, new ICRF, and new Conventions. The IERS has benefited from his leadership and continues to build on his efforts.

Brian Luzum
Chair, IERS Directing Board, 2013

2 The IERS
2.1 Structure

From 2013 to 2014, 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 2013 and 2014.

Analysis Coordinator

Thomas Herring

Central Bureau

Director: Bernd Richter (1 January 2001 to 31 March 2013), Daniela Thaller (since 1 April 2013)

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

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, Jérôme Saunier
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

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

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: Pierguido Sarti (until 31 December 2013), Sten Bergstrand (since 1 January 2014)
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 2014*)

2.2 Directing Board

In 2013 to 2014, 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
Rapid Service/Prediction Centre	Brian J. Luzum
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	Bernd Richter (until 31 March 2013, Daniela Thaller (since 1 April 2013)
Technique Centers Representatives	
IGS	Steven Fisher, Tim Springer
ILRS	Jürgen Müller, Erricos C. Pavlis
IVS	Chopo Ma, Rüdiger Haas
IDS	Frank G. Lemoine, Jérôme Saunier
Union Representatives	
IAU	Aleksander Brzezinski
IAG / IUGG	Clark R. Wilson
GGOS	Bernd Richter

2.3 Associate Members

Andersen, Ole Baltazar
Appleby, Graham
Arias, Elisa Felicitas
Behrend, Dirk
Bergstrand, Sten
Biancale, Richard
Boucher, Claude
Bruyninx, Carine
Capitaine, Nicole
Carter, William E.
Chao, Benjamin F.
Chen, Jianli
Dawson, John
Fagard, Hervé
Feissel-Vernier, Martine
Fisher, Steven
Garayt, Bruno
Gaume, Ralph A.
Gendt, Gerd
Gross, Richard S.
Hugentobler, Urs
Johnston, Gary
Kolaczek, Barbara
McCarthy, Dennis D.
Moore, Angelyn W.
Neilan, Ruth E.
Noomen, Ron
Nothnagel, Axel
Pearlman, Michael R.
Petit, Gérard
Pugh, David
Ray, Jim
Reigber, Christoph
Rothacher, Markus
Salstein, David
Schuh, Harald
Schutz, Bob E.
Shelus, Peter J.
Seitz, Manuela
Souchay, Jean
Soudarin, Laurent
Veillet, Christian
Vondrák, Jan
Weber, Robert
Willis, Pascal
Yatskiv, Yaroslav S.
Yokoyama, Koichi
Zhu, Sheng Yuan

Ex officio Associate Members:
IAG Secretary General: Hermann Drewes
IAU General Secretary: Thierry Montmerle
IUGG General Secretary: Alik Ismail-Zadeh
President of IAG Commission 1: Tonie van Dam
President of IAG Subcommission 1.1: Tom Herring
President of IAG Subcommission 1.2: Claude Boucher
President of IAG Subcommission 1.4: Johannes Böhm
President of IAG Commission 3: Richard S. Gross
President of IAG Subcommission 3.1: Spiros Pagiatakis
President of IAG Subcommission 3.2: Markku Poutanen
President of IAG Subcommission 3.3: Maik Thomas
President of IAU Commission 8: Norbert Zacharias
President of IAU Commission 19: Cheng-Li Huang
President of IAU Commission 31: Mizuhiko Hosokawa
President of IAU Division A: Sergei A. Klioner

(*Status as of December 2014*)

3 Reports of IERS components
3.1 Directing Board

The IERS Directing Board (DB) met twice in the course of the year 2013. Summaries of these meetings are given below.

Meeting No. 56

May 25, 2013, Salle Jean Marcoux, 5, Rue Marie-Andrée Lagroua Weil-Halle, Paris, France

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 #55 were distributed together with the agenda of DB Meeting #56.

Reports from the Technique Centres

International DORIS Service (IDS)

Pascal Willis presented the current status of DORIS satellites and constellations:

- Several new Missions will be equipped with DORIS Receivers (e.g. SENTINEL 3A/3B, JASON-3).
- Currently 82% of the 57 ground stations are operating; four stations are out of service for over a year; new stations in Hokkaido and Chichijima, Japan and in Fr. West Indies and Nicaragua are planned soon.
- Further projects are under negotiation in South Korea, Wake Island (Marshall Islands, USA) and Tamanrasset, Algeria.

Ground antenna characterizations:

- Characterization of the phase center offset and variations (anechoic chamber campaign) of the DORIS Ground Antennas completed; results available in ANTEX files.

The SPOT-5 SAA effect on DORIS data has been investigated. The effect causes perturbed positions and velocities of South America stations. The data are deleted from the affected stations and a correction model, as with Jason-1, is applied.

Analysis:

- 7 DORIS ACs.
- All ACs are delivering SINEX files at least quarterly.
- ITRF2013 preparation: July start of data processing. Preliminary solutions and a combined solution are planned for September 2013. Complete solution for December 2013 and submission to IERS in February 2014. Some issues are still under discussion (e.g. gravity field, SAA effect, polar motion rates).

- EOP: new models applied causing an improvement of the polar motion (due to Jason-2 data).

Governing Board elections took place in December 2012 under the new Terms of Reference:

- IDS Chairman & Analysis Center Representative: Pascal Willis
- Data Center Representative: Carey Noll
- At Large member: Richard Biancale.

Next IDS meeting in October 15th and 16th in Washington, USA to compare ITRF2013 results of the ACs.

International Laser Ranging Service (ILRS)

Erricos Pavlis gave a report about the ILRS activities.

- New ILRS web site ready.
- New Russian stations in co-location with VLBI were approved in early 2013: Badary, Zelenchukskaya and Svetloe.
- New GGOS "Core" sites with SLR: San Juan, Argentina, Yebes, Spain, Ny Alesund, Norway, Metsahovi, Finland and Sejong, South Korea.
- LLR activities: ISSI workshop in spring 2012 (report should be finished soon); LLR part is under development on the new ILRS website; joint LLR paper in ILRS Journal of Geodesy special issue.
- AWG news: 8 ACs, new center of gravity model for LAGEOS and ETALON tested in a Pilot Project; slight improvements on station positions have been found.
- A re-analysis of observations from 1983 to present to test all modeling improvements has been performed and validated by all ACs (results in summer 2013).
- Publications: AR 2009–2010 has been printed and published; ILRS Special Issue in the Journal of Geodesy is planned.
- Past meetings:
  - ILRS Technical Workshop in Frascati, Italy in November 2012.
  - AWG Meeting in April 2013 in Vienna, Austria.
- Future meetings:
  - AWG Fall meeting 2013 in Potsdam, Germany before IAG Symposium.
  - 18th Int. Workshop on Laser Ranging in Fujiyoshida, Japan on November 11–15, 2013.
  - AWG meeting on Saturday, November 9, 2013.

International VLBI Service for Geodesy and Astrometry (IVS)

Rüdiger Haas presented the report on IVS activities.

IVS organization:

- IVS elections for Directing Board and representatives: new IVS Chair is Axel Nothnagel, new Analysis Coordinator is John Gipson and new IVS Technology Coordinator is Bill Petrachenko. New representatives have been elected as well as members at-large.

Past meetings:

- 1st International VLBI Technology Workshop in October 2012 in Haystack, USA.
- IVS/EGU Training School in Espoo, Finland in March 2013.
- 14th Analysis Workshop in March, 2013 in Espoo, Finland.
- 21th EVGA Meeting in Espoo, Finland in March 2013.
- 7th IVS TOW at Haystack, USA in May 2013.

Upcoming meetings:

- 8th IVS General Meeting in Shanghai, China on March 6–9, 2014.

Station issues:

- Tsukuba telescope will be down for 6 months; Wettzell maintenance in summer 2013. Replacements for Intensive sessions are foreseen for this period, but some sessions had to be cancelled.

Analysis:

- Too few different analysis packages; preparation for VLBI contribution for ITRF2013 has started.
- CONT14 campaign is scheduled for May 6–20, 2014 (15 days); 16 stations already plan to participate and broadband observations planned during the campaign.

VLBI2010:

- Technical development:
- First ever 24h VLBI2010 broadband session observed on May 21/22, 2013 on baseline (Goddard–Westford) with fringes found within the correlation.
- Projects:
  - VLBI2010 stations in Hobart, Yarragadee, Katherine and Warkworth (Australia and New Zealand) with four 12m telescopes; new telescopes at Goddard, USA, Westford, USA and Arecibo, USA.
  - Twin telescopes: Wettzell, Germany (“first light” expected by the end of 2013); new telescopes in Ny-Alesund, Norway (planned to be operational in 2018); two new telescopes

in Onsala, Sweden (planned to be operational in 2017); upgrade of station Metsähovi, Finland (planned to be operational in 2017).

- RAEGE-project (Spain and Portugal) with four 13.2m telescopes at Yebes, Azores and Canary Islands; Yebes12M "first light" expected at end of 2013.
- Plan for two telescopes in Kasan, Russia; new 13.2m telescopes in Badary, Zelenchukskaya and Svetloe, Russia.
- New telescopes in Ishioka, Japan, Korea and Kokee, USA.

ITRF2013 contribution: Z. Altamimi requests an IVS solution without loadingl corrections. The corrections will later be applied within the inter-technique combination. This issue will be discussed between Z. Altamimi and John Gipson.

Report on GGFC activities

Tonie van Dam reported on GGFC activities:

GGFC workshop in April, 2012 in Vienna, Austria: 10 recommendations have been formulated (combining the various products for atmospheric and hydrologic models). The program and presentations can be found at <www.iers.org>.

Call for proposals for new products in 2012: Several new products have been proposed and are being evaluated for latency and reliability until 2014.

Grids for atmospheric models to be used at the observation level for all the space techniques; tidal model S1/S2 in the conventions analyzed; model of R. Biancale to be tested, S1/S2 model from ECMWF. All models are available on GGFC web site.

The discussion came up if GGFC products are also GGOS products. It is not yet clear how a GGOS product is defined and how IERS products can be made more visible within GGOS and how the IERS and GGOS are interacting.

Decision: Investigate interaction with GGOS.

New Action Item:

#56.01 Identify the person within GGOS responsible for the GGOS portal. Begin discussion on the plans of the GGOS portal.

ITRS/ITRF

Zuheir Altamimi reported on the activities of the ITRS Center.

Report from ITRS Center

Past and current activities:

- Maintenance of the ITRF database and website: local survey reports online: the surveys are performed by NGS and by local organizations. Newly designed and improved ITRF web site.
- Analysis of solutions submitted to the joint call of ITRS/GGFC, with and without NT-ATML corrections.

- ITRF2013 to be ready in mid-2014, no NT models should be applied by the techniques – will be applied commonly within the ITRF generation. Techniques should submit their solutions in January/February 2014 at the latest.

The long-term plans of ITRF generation foresee an ITRF generation between 3 and 5 years (maximum).

Evaluation procedure and comparison for official ITRF of the three ITRF solutions (IGN, DGFI and JPL): The discussion came up if there is a need to set up an IERS evaluation group or to organize a discussion meeting between the three groups.

IERS Working Group on SINEX Format

Daniela Thaller reported briefly on the activities of the WG on Sinex format. No major modifications have been implemented since the last DB meeting. A report will be finished within the next weeks.

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

Richard Biancale reported on the COL activities.

Past meetings:

- Intermediate meeting took place in April 2013 in Vienna, Austria.
- 5th COL meeting in May 2013 in Munich, Germany, with participants from various institutions from Germany, Austria and France.

Currently nine groups with different software packages participate in the WG (two combination centers).

Activities: Homogenized processing of CONT08 and CONT11 campaigns solving for all parameters together; a long term combination is planned to be submitted in the ITRF2013 framework.

IERS Working Group on on Site Survey and Co-location

Pierguido Sarti reported on the current activities of the WG.

Workshop on site ties:

- 2nd workshop on site survey and co-location took place in May 2013 in Paris, France, with 46 registered participants.
- Three topics and several goals have been addressed during the workshop: Surveying, Techniques and CCs.
- A list of recommendations has been drafted, e.g. a local survey archive is planned.
- Presentations and recommendations will be put on the IERS web site.

Future developments:

- P. Sarti will retire as WG chair.
- Sten Bergstrand (Sweden) has already expressed his interest in serving as new WG chair. Candidates can express interest

until the end of June 2013. A vote by email of the DB will be set up if more than one candidate is interested. A letter of support from the candidate's institution is required. A brief resume of the candidate should be sent to the CB.

Z. Altamimi will circulate the list of recommendations and ask for feedback by June 15, 2013.

IERS Working Group on Site Coordinate Time Series Format

Tom Herring gave a presentation for Laurent Soudarin.

The WG is a joint WG of IERS and IAG. The goals are the definition of a common time series format and access of products via web interfaces.

Past meetings:

- 1st WG meeting in December 2012 in San Francisco.
- 2nd WG meeting in April 2013 in Vienna, Austria.

A representative from GGFC has yet to be nominated.

Decision: Investigate the possibility of compiling an IERS Technical Note on site survey workshop.

New Action Items:

#56.02: Ask participants if enough articles can be contributed to draft a TN.

#56.03: Circulate the list of recommendations and ask for feedback.

Earth orientation products

Report from Earth Orientation Centre

Daniel Gambis reported on IERS EOP products:

- Bulletin B and C04 series contain the same values – but with 30 days latency and shifted twice a week for C04 series. Even if both series are alike, Bulletin B is not obsolete, because there are a lot of users (statistics on website).
- The generation of C04 series is fully automated with daily quality checks and comparisons.
- EOPs are now available in XML format, also on the EOC web pages.

Report from Rapid Service/ Prediction Centre

Brian Luzum reported on the Rapid Service/Prediction Centre.

- All information are available on the web site (<http://www.usno.navy.mil/USNO/earth-orientation>).
- A second (backup) web site has been established.
- A new solution of ultra rapids is available 4 times per day.
- Changes: Future modification of short-term polar motion predictions (improvement ~20–25%).
- VLBA intensives to be incorporated in the solution.

Unification of product formats

Tom Herring reported on the unification of product formats.

Three main topics:

- EOP formats for different product levels: Current format problems: every product has a different format; some products have headers others do not; units are different between different formats; additional “observed” data are not in files.
- Leap second file format: file should be made more computer readable; change format to two parts of file (TAI-UTC handling until 1972)? Who will update and keep current files?
- Position time series format: a working group on position time series format has already been established in 2012 (see “IERS Working Group on Time Series Format”).

Summary from the IERS Retreat: need for unification while retaining existing formats. T. Herring proposed a small working group of ACs/PCs to decide on format. The question is still open who implements the final format. Probably the IERS CB can provide down converter to the old formats for the users.

Intended timeline: format specification is planned to be available until the end of 2013 (format basically similar to C04 format). First draft by T. Herring.

Leap seconds

Daniel Gambis reported on issues concerning the potential redefinition of UTC.

Universal Time UT1 is based on solar time and strictly proportional to the Earth Rotation Angle; Coordinated Universal Time UTC is an atomic time scale with leap seconds to maintain close to UT1.

Bulletins C and D are used to inform about leap seconds and have a large community of users (astronomy, computer centers, geodesy, radio stations, civil engineering, space research etc.). The discussion within ITU about leap seconds began in 2000. The decision to eliminate the leap second was postponed to ITU meeting 2015 (more studies are needed on potential impacts of the leap second suppression).

Surveys on leap seconds have been performed in 2002 and 2011 (90% of the users satisfied). It was discussed whether a new survey about leap seconds should be drafted. As the answer strongly depends on the way questions are posed, it was decided that designing an accurate survey was beyond the scope of the DB.

Next events:

- Colloquium on “Requirements for UTC and Civil Timekeeping on Earth” on May 29–31, 2013 in Charlottesville, USA.
- ITU/BIPM Workshop on “Future of the International Time Scale” in Geneva, Switzerland (background information meeting addressing the national delegates).

D. Gambis: Should the IERS DB take position about possible redefinition of UTC?

B. Luzum is invited to give a presentation on how the IERS distributes information, technical issues, etc. He will draft a presentation and send it out to the DB before the meeting. The summary of the presentation will be published on the IERS web site.

Report on GGOS

Detlef Angermann briefly reported on the latest GGOS activities:

- Last meeting in April 2013 in Vienna: GGOS Themes have been the focus of discussion; still no chair for Theme 2 (Geohazards).
- A new WG on simulations (PLATO) has been established (chair: Richard Gross). The goal is to study network distributions, etc. and their impact on ITRF realizations.

New chair of GIAC is Gary Johnston.

Status of ICRS/ICRF

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

The main activity is to establish the ICRF3 WG in order to prepare the next ICRF, which is expected to be finished by 2018.

IERS Conventions

Brian Luzum shortly summarized the activities on the IERS Conventions.

- Minor changes have been performed in the conventions and in some software.
- A study group was initiated by J. Ries in order to discuss the evolution of the conventional geocenter model.

Reports from IAG and IAU

Clark Wilson reported briefly on the activities of IAG and IAU.

IAG

Upcoming IAG meeting in September 2013 in Potsdam, Germany.

IAU

An IAU Commission 19 / IAG Commission 3 Joint Working Group on Theory of Earth Rotation has been established, chaired by Jose Fernandez (co-chair R. Gross) including three sub working groups to study nutation and consistency of models (achieving measurements activities).

United Nations Global Geospatial Information Management (UN-GGIM)

Z. Altamimi summarized the work within UN-GGIM.

The objectives of the UN-GGIM (United Nations Global Geospatial Information Management) are the promotion of global geospatial information to address key global challenges & to support improved decision-making.

As one critical issue a global geodetic reference system has been identified.

Meetings:

- UN-GGIM 2nd High Level Forum in Doha, Qatar in February 2013; Outcome: Doha declaration mentions “to improve a sustained operational global geodetic reference frame”.
- National representatives, in general the presidents of the national mapping authorities. ITRF recognition has to be brought in via IAG, which is member of UN-GGIM (not IERS).

A geodetic questionnaire of John Dawson was presented at the Doha meeting: 93 responses to the questionnaire. The objectives of the questionnaire are (amongst others):

- “Snap-shot” of the use of geodetic data and datum.
- Reliance on global infrastructure, products and services.
- Participation in the global geodetic community.

Concerning the key findings of the questionnaire’s answers, a UN mandate would help in the following issues (amongst others):

- Reduce government security concerns and encourage data sharing.
- To organize the geodetic community would be of great benefit.
- Convince the higher authorities of the importance of geodetic infrastructure.
- Facilitate improved intergovernmental coordination of geodetic activities and infrastructure development.
- Most of the international geodetic cooperation within the IAG services is currently based on the best efforts of national institutes and space agencies, universities and research laboratories, with potentially some risks in terms of sustainability.

IERS is not in the position to ask for a UN mandate, as the IERS is not approved by the UN. Only member states have the right so ask for a mandate.

Results of the IERS Retreat

Tom Herring presented a short summary of the IERS Retreat.

The retreat took place on May 23–24, 2013 in Paris, France, and covered the following sessions:

- Session 1: Towards “real-time” products
- Session 2: Rigorous combined products
- Session 3: Long-term stability and parameterization of the reference frame
- Session 5: EOP predictions improvements
- Session 6: Unification of product formats
- Sessions 4+7: New products and mechanisms for IERS evolution,

followed by a summary and recommendations block.

One point of discussion was the station position treatment for earthquakes: one proposal was to stop data time series evaluation two days before the earthquake and restart two days after the EQ (to exclude the day(s) of the EQ).

Session 7: Central Bureau's review of ToR:

- DB agreed to change the ToR in order to allow an external person to become DB chair. Process of nominations may be regulated by the DB (including self-nominations from within the DB).
- Role of IERS Associate Member: Proposal: match list of associate members with the correspondent list in order to have one list with corresponding members and to discard the term "associate members".

The presentations and the summary/recommendation document will be published on the IERS web site as soon as they are available. An announcement via IERS Message (or alternative way) will be discussed.

Decision: Publish presentations and summary document on IERS web site.

New Action Items:

#56.04 Send email to analysis coordinators about EQ station handling.

#56.05 Review the list of associate members, update the list and, if appropriate, match the associate members list with the list of the corresponding members.

#56.06 Publish presentations and summary document on IERS web site.

Annual Reports

Daniela Thaller gave an overview on the current status of the annual reports:

- AR 2011: The foreword and some contributions are still missing.
- AR 2010 is ready and in print.

Next DB Meeting

DB meeting #57 is planned to be held as a half day-meeting in the morning before the AGU 2013 on Sunday, December 8, 2013 in San Francisco.

Meeting No. 57

December 8, 2013, Hotel Westin, 50 Third 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 #56 were distributed together with the agenda of DB Meeting #57.

IERS Retreat 2013

Tom Herring gave a summary of the IERS Retreat in May 2013, followed by discussions on the main topics:

Real Time

- go via Analysis Coordinators of individual Technique Centers
- Tim Springer: IGS hourly series are available, these could be used as input.
- Zuheir Altamimi: Set priorities and deadlines, which should be evaluated by the IERS DB

Long-term stability of TRF/EOP

- Z. Altamimi: ITRS and EOP center should coordinate “daily” TRF+EOP combination
- T. Herring: long-term problems in IGS PM series
- Jake Griffiths: IGS PM problem is solved; final and rapid solution are generated differently
- COL: A real combination at the observation equation level is not fully done. T. Springer: Partly done at ESA for common satellites. T. Herring: Putting together at NEQ level could be more stable from a mathematical point of view.

Parameterization

- Z. Altamimi: The mean loading correction in ITRF2013 will be provided to the users.
- T. Herring: UNAVCO tested the monument stability. The results will be presented at AGU.

Models, Center-of-Mass

- T. Herring: The Convention Center should look into the pole tide modeling.

EOP prediction

- AAM/OAM should be used; Richard Gross generates the predictions.

Time series format

- T. Herring will provide a new format in January 2014.

Mechanism for IERS evolution

- Review and update Terms of Reference.

Status of ICRS/ICRF and IAU Working Group

Ralph Gaume reported on ICRF activities:

- A final Gaia catalog may replace the VLBI catalog as ICRF. The mission will be launched later this month.
- The ICRF-3 WG held a meeting during the Journées 2013 in Paris. The K-Band will be included (up to now only S- and X-Band are used).
- Status of VLBA: The VLBA is still at risk for closing. A USNO meeting with US-NSF will take place on December 18, 2013. IAU, IVS and IERS DB wrote a letter of support.

Report on GGFC activities

Tonie van Dam reported on GGFC activities:

- There is a proposal for hydrology products by a new group. Comparisons and validation will be done until the next DB meeting.
- Problem of "interaction" with GGOS. A discussion on this topic will be prepared for the next DB meeting in order to answer the main questions:
  - What is important for IERS?
  - What is the relationship to GGOS?

Report on GGOS

Bernd Richter reported on the GGOS Consortium meeting which took place one day before:

- The GGOS components are not well connected. They are all at the same level.
- The profile of a "Bureau of Analysis" and a "Bureau of New Products" is not clear yet. No final decision to realize these Bureaus has been taken yet.
- GGOS WGs will be related to Bureaus, supervised by the Coordinating Office. This implies more responsibility for the Coordinating Office.
- A new IERS representative to GGOS Consortium has to be appointed, Chopo Ma's term has ended. The DB suggested Tom Herring as new IERS representative to GGOS.

Report on ITU Workshop / Leap seconds

Brian Luzum presented a summary of "ITU/BIPM Workshop on the Future of the International Time Scale" which took place on September 19–20, 2013 in Geneva, Switzerland.

The aim of the workshop was to provide background information to the ITU members on the current time standards, time scales, and time dissemination systems. It also provided some insight into the possible future of Coordinated Universal Time (UTC). The goal was to provide the information necessary so that national radiocommunication authorities could determine their position in preparation for the upcoming World Radiocommunication Conference 2015 (WRC-15).

Details and a summary of the workshop can be found at <http://www.itu.int/ITU-R/index.asp?category=conferences&rlink=itu-bipm-workshop-13&lang=en>.

The presentation of B. Luzum on the "Role of the IERS in the leap second" can be found at the workshop's web pages: <http://www.itu.int/dms_pub/itu-r/oth/0a/0e/R0A0E0000960016PDFE.pdf>

A summary of the presentation has been published on the IERS web site: <http://www.iers.org/biblio>

Reports from the Technique Centres

Frank Lemoine reported on IDS activities in 2012:

International DORIS Service (IDS)

5 future missions are planned and a new receiver capability of 7 channels has been constructed.

ITRF2013: 2 ACs have not yet delivered any input (IGN, INA). For the other ACs a delivery in time is expected.

An online plot tool is available for DORIS station coordinate time series and orbit residuals.

Meetings: IDS AWG will take place in March 2014 at CNES in Paris, France, and an IDS workshop on October 27–28, 2014 in Konstanz, Germany.

International GNSS Service (IGS)

Jake Griffiths reported on IGS activities:

An IGS workshop will be held in June 2014 in Pasadena, USA.

A meeting with the ACs is planned to be held on Thursday to discuss the Repro-2 for the ITRF2013.

The AC standards are not yet clear. It is also unclear whether the February deadline will be met.

Z. Altamimi suggested to use only those ACs which are ready.

Tim Springer reported that the IGS Real time service is active now. MGEX: GPS, GLO, Galileo, Beidou, QZSS; new RINEX 3 format with additional frequencies.

International Laser Ranging Service (ILRS)

Erricos Pavlis reported on ILRS activities:

The ILRS network is evolving with new stations in Russia, China and South Korea.

Past meetings:

- 18th Int. Laser Workshop in Fujiyoshida-shi, Japan, November 9–15, 2013
- First Fall 2013 AWG Meeting, GFZ Potsdam, Germany, Sunday, Sept. 1, 2013
- Second Fall 2013 AWG Meeting, Saturday, Nov. 9, 2013, in Fujiyoshida-shi, Japan

A site log viewer is accessible online.

ITRF2013 repro: 6 ACs will reprocess data between 1983 and 2013; BKG only data between 1993 and 2013. A submission is planned by March 15, 2014.

Future meetings:

- 19th Int. Workshop on Laser Ranging at Goddard, MD, (celebrating 50th anniversary of the first SLR experiment at GSFC) in late October 2014.
- Next AWG all-day meeting probably during the EGU week
- 20th Int. Workshop on Laser Ranging at GFZ Potsdam, Germany in 2015
- A Technical Workshop in Matera, Italy sometime in early 2015

International VLBI Service for Geodesy and Astrometry (IVS)

Chopo Ma reported on the latest IVS activities:

New IVS chair Axel Nothnagel, new IVS Analysis coordinator John Gipson and new IVS Technology coordinator Bill Petrachenko.

Past meetings:

- 7th Technical Operations Workshop at MIT Haystack Observatory, Westford, MA, USA, 6–9 May 2013
- 2nd International VLBI Technology Workshop, JejuIsland, South Korea, 10–12 October 2013

Upcoming meeting:

- 8th IVS General Meeting in Shanghai, China, 2–7 March 2014

The Intensive baselines will be replaced due to Wettzell and Tsukuba outage.

The CONT14 campaign will take place on May 6–20, 2014.

A new Calc/Solve version with standards from ITRS Conventions (2010) will be released. 10 AC contributions for ITRF2013 are expected.

ITRS/ITRF

Report from ITRS Center

Zuheir Altamimi presented the status:

- A new web site for ITRF is in preparation and will be ready in 2014.
- A paper by Xavier Collilieux about non-tidal loading campaign is in preparation.
- Planned schedule for ITRF2013: to be ready by summer 2014.
- New co-location sites have been built: e.g. Warkworth (GNSS/VLBI) in New Zealand; new ties at several sites since ITRF2008.

Contribution to UN-GGIM: Z. Altamimi represented IAG for ITRF matters. Objective: a global geodetic reference system.

Discussion on ITRF2013:

- All 3 solutions should be evaluated by the Technique Centers.
- Richard Gross will provide a checklist for the evaluation.

- E. Pavlis: The EOP series (“C04”) should be fitted to the new ITRF series; especially to fill the gaps between the VLBI sessions.

For future products GNSS-based LOD should be investigated for the densification.

Report from ITRS Combination Center at DGFI

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

The major activities are the accuracy assessment of the ITRS 2008 realization (agreement of datum parameters ~ 5mm for positions and 0.5 mm/yr for velocities between ITRF2008 and DTRF2008), the consistent estimation of CRF, TRF and EOPs and epoch reference frames.

D. Angermann proposed to validate the ITRF solutions by the IAG WG 1.2. (chaired by Xavier Collilieux).

Suggestion: Set up an ITRF2013 evaluation group. If the time is too short for the ITRF2013, than this has to be prepared for the next ITRF.

Report from ITRS Combination Center at JPL

Richard Gross displayed a list of papers which will be presented during the AGU on the work of the ITRS CC at JPL.

Decision: Include 1 month for evaluation by the Technique Centers to ITRF2013 schedule.

Reports from the Working Groups

IERS Working Group on Site Survey and Co-location

Daniela Thaller reported that there will a new WG chair, Sten Bergstrand, starting January 1, 2014.

IERS Working Group on SINEX Format

Daniela Thaller reported on some updates of the SINEX format which are under discussion.

IERS Annual Reports

Daniela Thaller reported on the status of the IERS annual reports: AR 2008-2009, 2010 and 2011 are in print. Only 4 contributions are still missing for the AR 2012.

Next IERS DB Meeting

The next DB meeting will take place on Sunday April 27, 2014 before the EGU.

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. 56, May 25, 2013, at University Paris-Diderot, Paris, France, and No. 57, December 8, 2013, at Westin Hotel, San Francisco, California, USA (see Section 3.1. for minutes of these meetings). It also co-organized together with IGN the IERS Retreat held on May 23–24, 2013, at University Paris-Diderot, Paris, France (see Section 4.2 for a report). Between the meetings the CB coordinated the work of the DB.

Members of the CB took part in the following meetings: European Geosciences Union General Assembly 2013, IERS Workshop on Local Surveys and Co-locations (see Section 4.1), IAG Scientific Assembly 2013, Journées 2013 “Systèmes de référence spatio-temporels”, ISO TC211 Meeting, 18th International Workshop on Laser Ranging, and AGU 2013 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 2013 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. A web page for the new ITRS Combination Centre at Jet Propulsion Laboratory was created.

IERS Technical Note No. 37 “Analysis and results of ITRF2008” was printed and distributed.

The CB finalized the IERS Annual Reports 2010 and 2011 and published them online in March and October 2013, respectively. 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, as well as a report about the Third GGOS Unified Analysis Workshop.

A report about the activities of the IERS during 2011 to 2013 was compiled for IAG in cooperation with members of the DB.

During the year 2013, 21 IERS Messages (Nos. 222–242) 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 2013 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 continued in cooperation with a software company. The improved system, which will be related to the Content Management System "Government Site Builder" used for the IERS web site, will allow easier maintenance and will give access for users to register as well as to check and update their data through the IERS web pages.

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 an ex officio member of the other working groups. Michael Lösler was active in the IERS Working Group on Site Survey and Co-location. 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 as 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 fulfill 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 2013 further developments of the IERS DIS concentrated on the new data management system. This system automatically retrieves all IERS products from different servers, checks them, extracts metadata, creates files in different formats (including XML), creates plots of Earth orientation series, and finally stores and displays the data files together with metadata and plots at the IERS web servers. This large software package, which was developed during 2012 by a software company in cooperation with the CB (see previous reports), started operation in May 2013, after an extended test phase had been finished successfully. Some software bugs were fixed throughout the year so that the system could run more stable. A separate new system for address management was developed (see above) and will be tested in 2014.

Staff in 2013

Dr. Bernd Richter, *Director (until 31 March 2013)*

Dr. Daniela Thaller, *Director (since 1 April 2013)*

Sabine Bachmann, *scientist*

Dr. Wolfgang R. Dick, *scientist*

Sonja Geist, *technician*

Carola Steinke, née Helbig, *secretary (on leave since March 2013)*

Michael Lösler, *technician (until 30 June 2013)*

Sandra Schneider-Leck, *technician*

Publications

Lösler, Michael; Haas, Rüdiger; Eschelbach, Cornelia (2013): Automated and continual determination of radio telescope reference points with sub-mm accuracy: results from a campaign at the Onsala Space Observatory. J. Geodesy, 87(8), 791–804, doi: 10.1007/s00190-013-0647-y.

Thaller, Daniela; Bachmann, Sabine (2014): The IERS Retreat: How to improve Earth Rotation products? In: Proceedings of the Journées 2013 “Systèmes de Référence Spatio-Temporels”, N. Capitaine (ed.), Observatoire de Paris, ISBN 978-2-901057-69-7, pp. 175–180.

Wolfgang R. Dick, Daniela Thaller

3.3 Analysis Coordinator

1. Introduction

In this report we outline the activities of the Analysis Coordinator during 2013. The main activities were running and summarizing the IERS Retreat held in May 2013 and planning the Unified Analysis Workshop to be held 2014 in conjunction with the IGS Workshop. The future of the leap second continues to be addressed with no clear resolution to either retain or do away with them.

2. Summary of 2013 IERS Retreat

The full details of the IERS Retreat are summarized later in this annual report (see Chapter 4.2). Here we briefly note the sessions and recommendations from the sessions.

Session 1: *Move towards "real-time" products*
The main recommendations were assessments of the accuracy and latency of real-time eVLBI and SLR EOP products and how these may be improved by being coupled to GNSS analyses. It was also recommended that the sensitivity of GNSS results to EOP prediction errors be determined.

Session 2: *Rigorous combined products*
The recommendations from this session focused on ICRF/ITRF consistency and the level to which this consistency is needed. Studies are also recommended to evaluate the impact of adding GPS gradient and atmospheric delays to the analysis of the VLBI intensives to how this processing effects biases and noise in the intensive UT1 estimates. Combinations at the observation level are expected to be submitted to ITRF2013 and these combinations can be used to determine the potential improvements afforded by combinations at the observation level. Differences between the IGS ultra rapid EOP estimates (generated with constrained site coordinates) and the final estimates (generated with minimal constraint approaches) are to be investigated by the IGS.

Session 3: *Long-term stability and parameterization of the reference frame*
A number of studies are recommended to look at extended position parameterizations (e.g. log post-seismic functions), how to best incorporate loading into the reference frame and the effects of GNSS antenna effects. The session also requested the development of methods to allow easy comparison of time series. The format definition study group report on this subject appears later in the report.

Session 4: *Next Generation of models and Center-of-Mass products*
Activities here would be carried out by the Global Geophysical Fluids Center in generating possible models for these products and assessing possible secular motions of the center of mass relative the center of figure. Secular motion of the pole and its impact on the pole-tide corrections are also be studied.

Session 5: *EOP prediction improvements*
The IERS product centers should look into formats and methods for delivering real-time EOP values. There should be continued studies of the impact of incorporating atmospheric and oceanic angular momentum results into the predictions. The benefits of ensemble averaging of current predictions will also be investigated.

Session 6: *Unification of product formats*
There is strong consensus that uniform EOP formats including web 2.0 (xml formats) should be developed. A machine-readable leap second format should be made available as soon as possible as well. The IAG position time-series-format working group should continue. A draft report appears in this annual report.

Session 7: *Mechanisms for IERS evolution*
Current Terms of Reference were reviewed and update to these will need to be addressed by the DB.

3. 4th Unified Analysis Workshop Preparation

This workshop will be held in Pasadena, June 27–28, 2014. Discussions within the community and the services have lead to the following issues to be addressed. These topics are not presented in any specific order.

(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 (CIO) level results. Update on current status and long-term impact of these approaches.

4. Discussions of the future of Leap Seconds

The future of the leap second and their future treatment still remains under discussion with no universal consensus forming.

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 2013 before the deadline of this publication. It is intended to give this report together with the report for 2014.

For IGS activities, see also the IGS web site at <www.igs.org> and the IGS Technical Report 2013 at <http://kb.igs.org/hc/en-us/articles/202459446-Technical-Report-2013>.

3.4.2 International Laser Ranging Service (ILRS)

Introduction

The International Laser Ranging Service (ILRS), established in 1998, is responsible for the coordination of SLR/LLR missions, technique development, network operations, data analysis and scientific interpretation. Here we summarize the status and developments in 2013.

Network

The network of SLR/LLR stations (Figure 1), under the aegis of the ILRS, has been subject to change over the years. From a technical perspective, the quality 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. NASA's next generation SLR system (NGSLR) was finally completed and delivered, demonstrating successful tracking of LEO to HEO targets at night and in daylight. The switching to high repetition rate systems at a number of sites has increased productivity and improved data quality. This evolution of the network led to the need for a revision of the definition of the way SLR normal

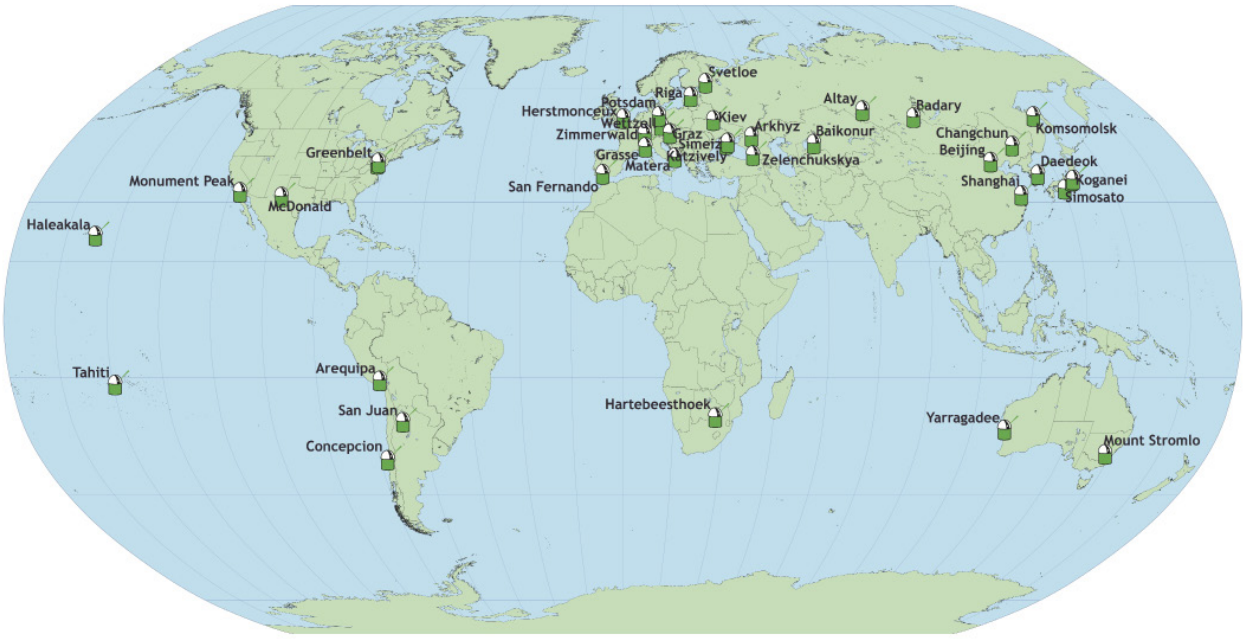

Fig. 1: The global network of SLR stations (status early 2014).

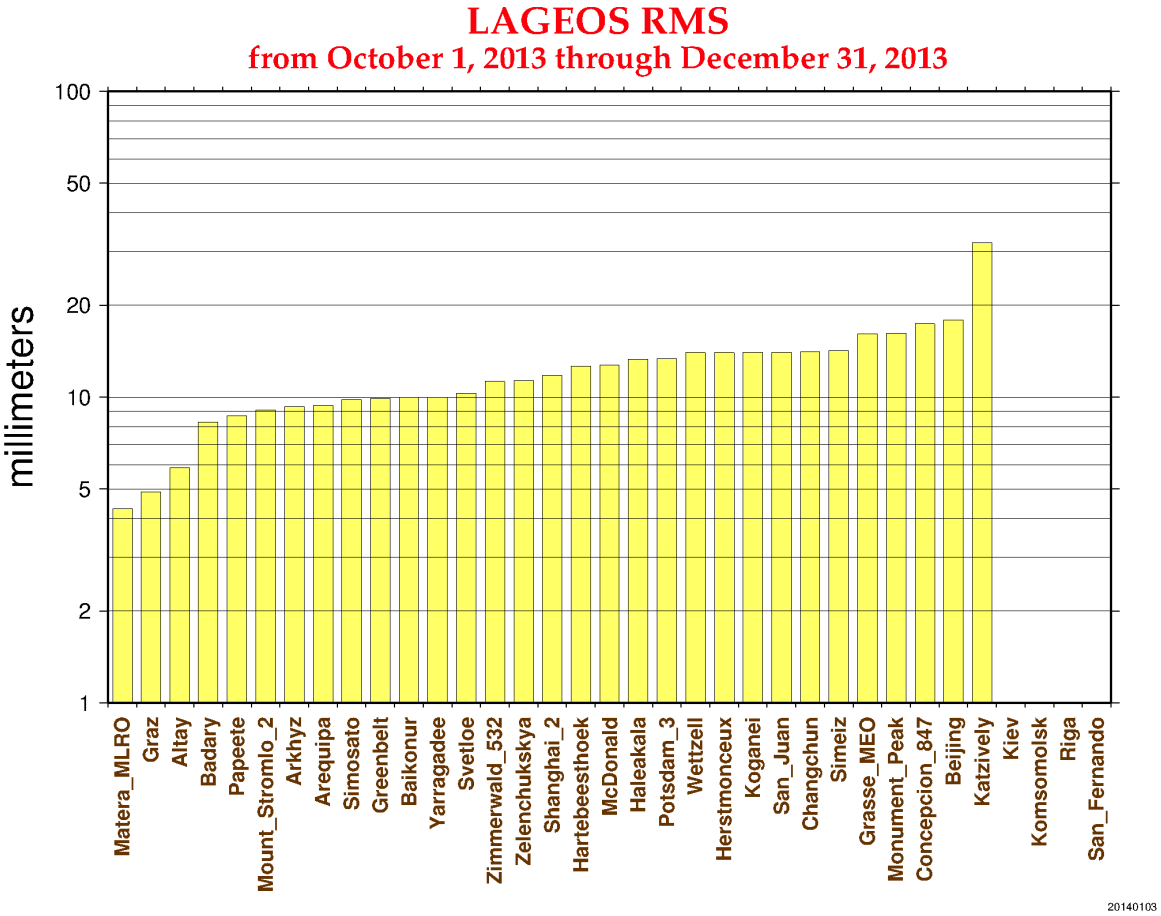

Fig. 2: Performance of the global network of SLR stations on LAGEOS (status end of 2013).

points (NP) are constructed. A task force worked on an improved NP definition that increases productivity. The new rule allows for collection of many more data on various targets when automated pass interleaving is exercised. This is achieved by limiting inactivity for high repetition rate systems that meet the NP precision requirement long before they exhaust the time interval that is assigned for the target being tracked. So far a limited number of stations have implemented the new approach. Russia has embarked on a program to deploy several new SLR sites around the world in addition to the expansion and upgrade of their network within the country. The first sites will be located in areas void of coverage up to this time, and they 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 2013 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 &

Table 1: ILRS Network Tracking Statistics for 2013.

		Number of Passes			
Site Name	**Station**	**Low**	**LAGEOS**	**High**	**Total**
Altay	1879	145	222	1,367	1,734
Apache Point	7045	0	0	151	151
Arequipa	7403	2,193	394	0	2,587
Arkhyz	1886	734	553	826	2,113
Badary	1890	904	258	101	1,263
Baikonur	1887	32	622	630	1,284
Beijing	7249	884	241	396	1,521
Changchun	7237	6,974	1,944	5,017	13,935
Concepcion	7405	936	413	76	1,425
Daejon	7359	357	179	195	731
Grasse	7845	1,080	703	1,376	3,159
Graz	7839	3,572	1,091	3,027	7,690
Greenbelt	7105	4,185	1,229	885	6,299
Haleakala	7119	1,380	576	0	1,956
Hartebeesthoek	7501	2,396	1,102	686	4,184
Herstmonceux	7840	2,547	1,028	1,874	5,449
Katzively	1893	1,274	345	41	1,660
Kiev	1824	1,061	336	81	1,478
Koganei	7308	194	154	189	537
Komsomolsk	1868	32	154	1,295	1,481
Kunming	7820	775	217	0	992
Matera	7941	3,494	1,951	1,898	7,343
McDonald	7080	871	492	224	1,587
Monument Peak	7110	3,707	1,084	973	5,764
Mount Stromlo	7825	6,244	1,532	1,136	8,912
Potsdam	7841	2,156	687	267	3,110
Riga	1884	356	10	0	366
San Fernando	7824	1,495	64	0	1,559
San Juan	7406	1,790	557	813	3,160
Shanghai	7821	1,625	556	1,363	3,544
Simeiz	1873	934	385	83	1,402
Simosato	7838	1,129	521	89	1,739
Svetloe	1888	206	118	25	349
Tahiti	7124	657	284	453	1,394
Wettzell	8834	3,683	1,126	3,204	8,013
Yarragadee	7090	13,769	3,577	7,173	24,519
Zelenchukskaya	1889	158	174	415	747
Zimmerwald	7810	4,542	1,669	3,595	9,806
Totals:	38	78,471	26,548	39,924	144,943

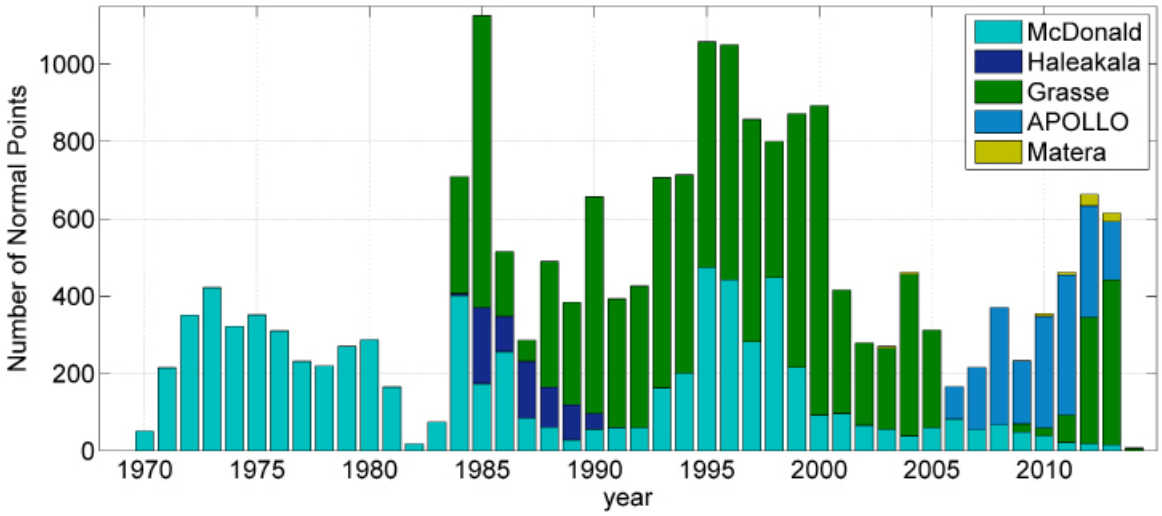

Fig. 3: Data yield of the global LLR network of stations (up to 2013). Note the increasingly significant contribution of Grasse's MeO system upon its return to operations.

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), very few are technically equipped to track retro-reflector arrays on the surface of the moon or spacecraft orbiting around the moon. In 2013, four active Lunar Laser Ranging (LLR) sites tracked the Moon: the McDonald Observatory in Texas, USA (generating 15 NP), the Observatoire de la Côte d' Azur, France (427 NP), the APOLLO site in New Mexico, USA (251 NP) and the Matera Laser Ranging station in Italy (22 NP). That means, almost 70% of the data have been collected at the French MeO site near Grasse and about one quarter of the data at the APOLLO site. Most of the data have been obtained by tracking the big Apollo 15 reflector (70%). Figure 3 shows the entire LLR data set 1970–2013, indicating the amount of data collected by each of the active LLR sites per year. It is more than 20,000 normal points in total. A steady increase of LLR NP in the last years is obvious. Additional data have been recovered through screening various archives and homogenizing the various data files maintained at individual institutions.

LLR data analysis is mainly carried out by four 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. A general objective is to achieve the mm level of accuracy for LLR data analysis, now still at the cm level. The four analysis centers cooperate to mutually improve the various codes. LLR remains one of the best tools to support lunar science and to test General Relativity in the solar

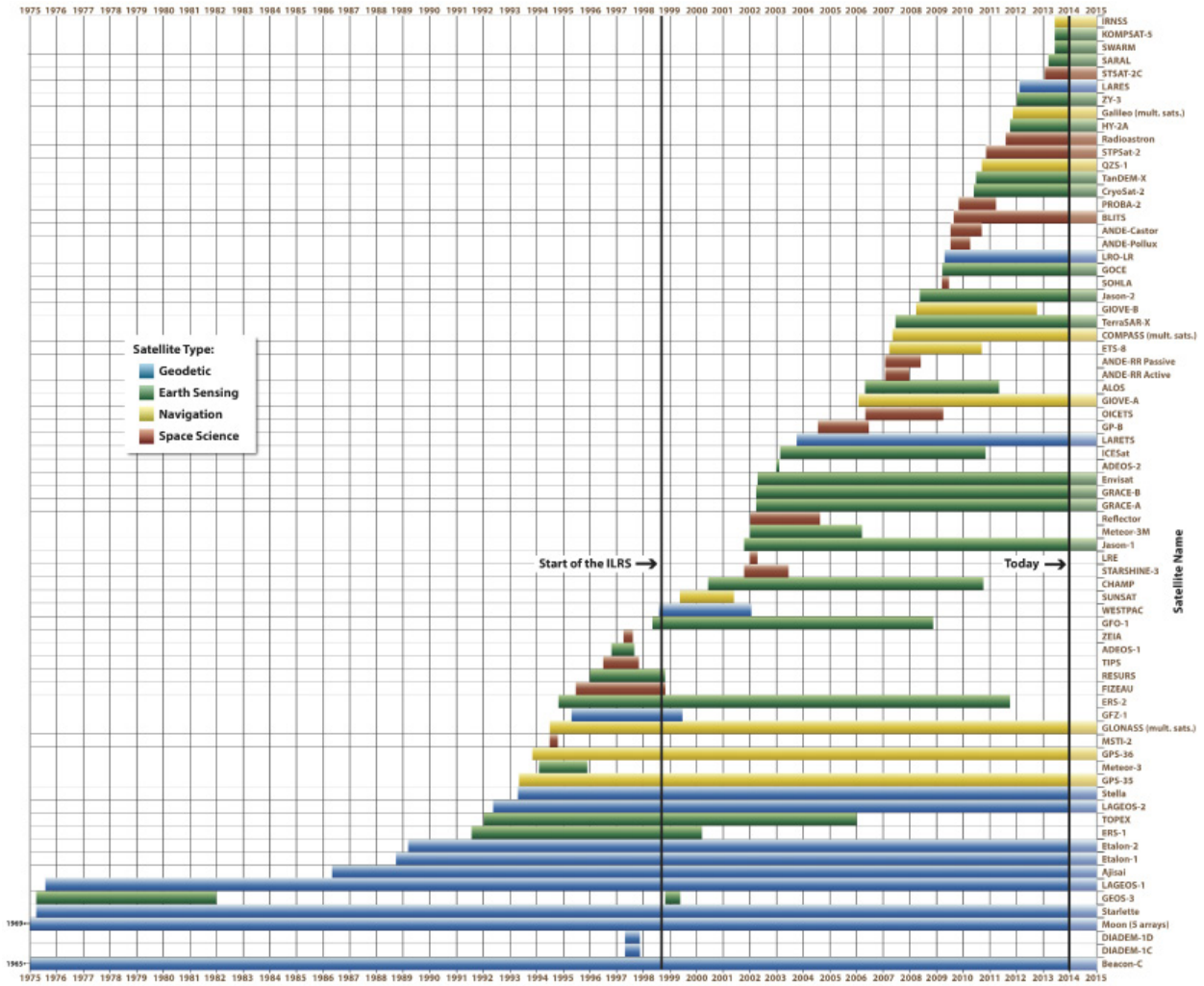

Fig. 4: The currently tracked SLR missions (status early 2014).

system, a fact presented at various conferences and in several papers of the LLR community. Recent activities also comprise comprehensive simulations to show the potential benefit of improved tracking from further observatories and/or to new reflectors.

Missions

In 2013, a total of ~38 missions including the Moon (a total of over than 75 targets!) were being tracked by SLR/LLR (Figure 4). Of these, only about 1/3 are geodetic type targets (cannonball satellites), the rest are mainly Earth Observation missions and numerous navigation satellites, along with a small number of experimental space science missions. In 2013 the steady increase of tracking multiple GNSS targets continued for a third year in a row and given the inter-technique arrangements through the ILRS/GGOS LARGE Working Group (LAser Ranging to GNSS s/c Experiment), this trend is expected to persist and further increase in the coming years.

Table 2: ILRS Supported Missions Launched or Initiating Tracking in 2013.

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (sec)	Altitude (Km)	Inclination (deg)	First Data Date
SARAL	1300901	3201	39086	3	15	814	98.55	2013-Mar-04
STSAT-2C	1300301	3804	39068	3	15	300-1500	80	2013-Mar-29
GLONASS-131	1301901	9131	39155	9	300	19,140	65	2013-May-23
Swarm-C	1306703	8009	39453	1	5	530	88.95	2013-Nov-25
Swarm-A	1306702	8007	39452	1	5	460	88.35	2013-Nov-26
Swarm-B	1306701	8008	39451	1	5	460	88.35	2013-Nov-27
IRNSS-1A	1303401	3301	39199	9	300	42,164	29	2013-Sep-05
KOMPSAT-5	1304201	3803	39227	1	5	550	97.6	2013-Sep-09

Table 3: ILRS missions that de-orbited or ceased being tracked in 2013

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (sec)	Altitude (Km)	Inclination (deg)	Last Data Date
BLITS	904907	5558	35871	5	30	832	98.77	3/5/13
STPSat-2	1006201	1075	37222	3	15	650	72	10/18/13
GOCE	901301	499	34602	1	5	295	96.7	11/2/13

During 2013 several new missions were launched as shown in Table 2. SWARM is a demanding Earth Observation mission with targets orbiting within a few seconds apart, requiring special tracking procedures and a quick target interleaving approach.

Similarly, Table 3 shows the few missions that were removed from the list of active missions and the missions that were de-orbited or ceased requiring SLR tracking in 2013.

Despite the small decrease on active stations in 2013 and a significant increase in tracked targets, the ILRS network has increased its productivity tremendously to keep the data yield at a similar level as in the recent years (Figure 5). A major contributor in the recent years' data yield increase is the fact that several stations have started tracking all GLONASS satellites as of 2010.

Analysis and science

The Analysis Working Group (AWG) spent considerable effort in preparation for the complete data re-analysis in support of the development of ITRF2013. During the several AWG meetings in 2013, new models and processing approaches were developed, implemented tested and the participating ACs initiated the re-analysis process to meet the early 2014 delivery deadline to ITRS. Some of the new model improvements include better handling of systematic errors for the tracking systems, a detailed modeling

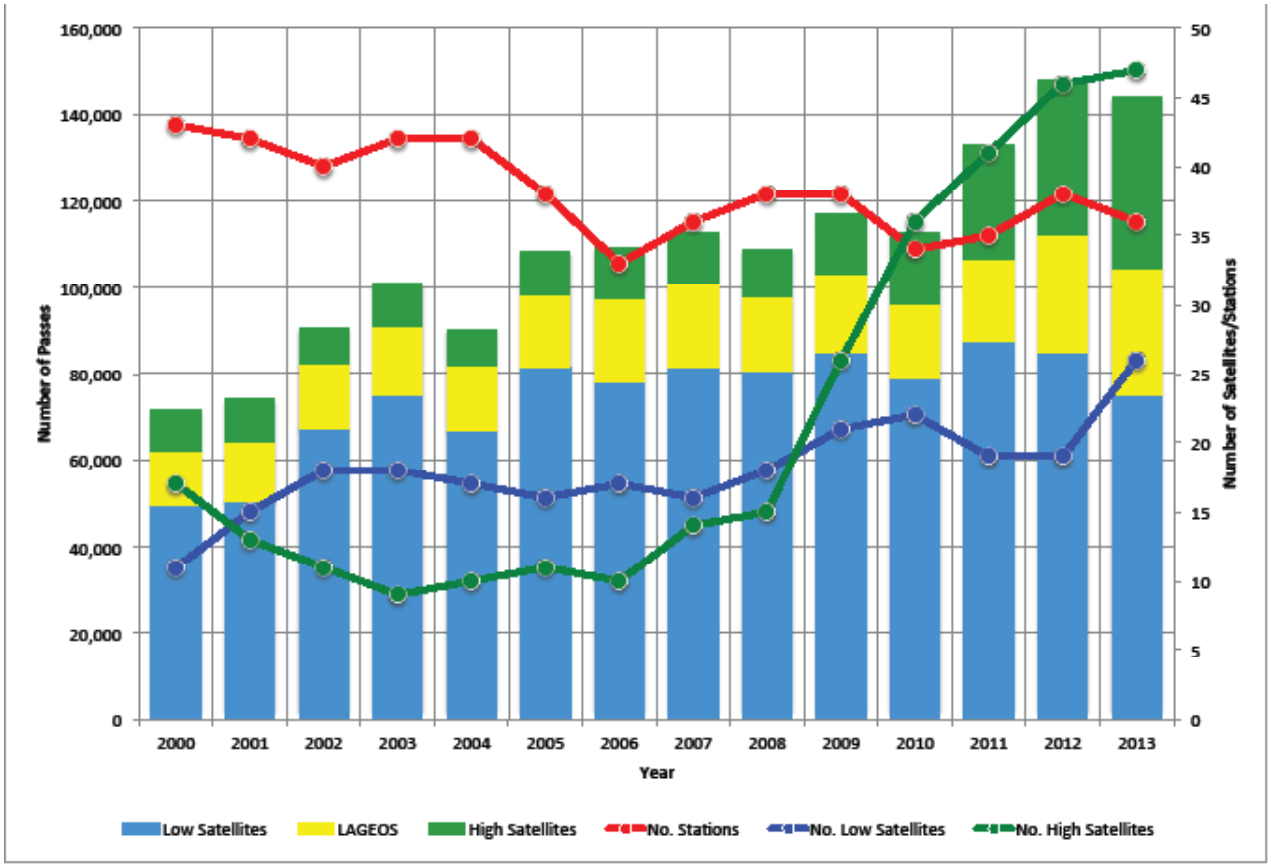

Fig. 5: ILRS network data yield over the past decade (status late 2013).

of time varying gravity to degree and order two, and a realistic modeling of the mean rotational pole used in the computation of the pole tide potential.

Several Pilot Projects (PP) will be completed after the ITRF2013 development process is completed.

Meetings

The ILRS held an international laser workshop in Fujiyoshida, Japan, November 11–15, with the title "Pursuing Ultimate Accuracy & Creating New Synergies", (ILW-18, <http://geo.science.hit-u.ac.jp/lw18>). The AWG held three meetings in 2013, one prior to the EGU General Assembly, on April 7 (<http://ilrs.gsfc.nasa.gov/docs/2013/Agenda_Spring2013_ILRS_AWGMeeting.pdf>, one prior to the IAG Scientific Assembly, in Potsdam, Germany, September 01 (http://ilrs.gsfc.nasa.gov/docs/2013/Draft_Agenda_Fall2013_ILRS_AWGMeeting.pdf), and one prior to the Fujiyoshida workshop, on November 9 (<http://ilrs.gsfc.nasa.gov/docs/2013/FINAL_Minutes_AWG_Fujiyoshida2013.pdf>). The ILRS Governing Board met once during 2013, during the Fujiyoshida workshop on November 14 (<http://ilrs.gsfc.nasa.gov/docs/2013/ILRSGB_minutes_20131114.pdf>).

Publications An extensive publications list of interest to ILRS can be found at the ILRS website:

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

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3.4.3 International VLBI Service (IVS)

IVS Organization and Activities

During 2013, 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:

- A VLBI Training School was held on March 2–5, 2013 in Espoo, Finland.
- The 14th IVS Analysis Workshop was held in Espoo, Finland on March 5, 2013.
- The 21st European VLBI for Geodesy and Astrometry (EVGA) Working Meeting was held in Espoo, Finland from March 6–8, 2013.
- The spring 2013 IVS Directing Board meeting (IVS DB #29) was held on March 8 at Metsähovi Observatory, Finland.
- The 7th IVS Technical Operations Workshop (TOW) was held at Haystack Observatory (USA), May 6–9, 2013.
- The fall 2013 IVS Directing Board meeting (IVS DB #30) was held on September 7, 2013, at GFZ Potsdam, Germany.
- The 2nd International VLBI Technology Workshop was held on October 10–12, 2013, in Seogwipo, Jeju Island, South Korea.
- In the summer of 2013 the IVS published the 2012 Annual Report. Furthermore, three IVS newsletters were published in April, August and December to keep the community informed about IVS activities.

At its 29th meeting at Metsähovi Observatory the IVS Directing Board elected Axel Nothnagel from the University of Bonn to be the chair of the IVS for the next four years, succeeding outgoing chair Harald Schuh. John Gipson replaced Axel Nothnagel as the IVS Analysis Coordinator.

Network Stations

The IVS network operated well for most of 2013. The average single station data loss (scheduled versus correlated) is estimated to have been at the 15% level for stations that participated in 25 or more sessions; this loss number is slightly higher than in the previous year primarily due to scheduled antenna maintenance. The most significant causes of loss identified were scheduled antenna maintenance (accounting for about 40% of the losses), followed by electronics rack problems (20%), miscellaneous problems (9%), receiver problems (8%), and radio frequency interference (6%).

A total of 188 geodetic/astrometric 24-hour sessions were observed during the year 2013. The number of observing sessions coordinated by IVS was about ~3.6 days per week, a slight increase over previous years mostly due to the addition of regional AUSTRAL sessions. The major observing programs during 2013 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). Kokee Park replaced Tsukuba in the Int2 Intensives from May through December during the repair of the antenna base at Tsukuba. Ny-Ålesund replaced Wettzell in the Int1 and Int2 Intensives from mid-July through the end of September while Wettzell was repaired and upgraded, except for Ny-Ålesund's maintenance period in the first two weeks of August during which Svetloe replaced Wettzell.

IVS-T2 Bi-monthly sessions coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn, Germany, with on average 18 stations per session. Seven of these sessions were observed to monitor the TRF with all IVS stations.

IVS-CRF The Celestial Reference Frame (CRF) sessions, coordinated by the U.S. Naval Observatory, provide astrometric observations that are required for improving the current CRF and in extending the CRF by observing 'new' sources. Sixteen sessions were observed for the maintenance of the ICRF in 2013.

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 2013.

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 2013 six OHIG sessions were observed.

APSG The Asia-Pacific Space Geodynamics (APSG) program operated two sessions in 2013.

AUSTRAL In 2013, 24 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 nine sessions during 2013. These sessions included the dedicated 32-m dish at Tsukuba and are designed to monitor the domestic network within the ITRF.

IVS-R&D Ten research and development sessions were observed in 2013. The goals of the 2013 R&D sessions included the testing of mixed-mode (legacy S/X and broadband) observing, the vetting of sources for the geodetic catalog of good point-like sources, the observation of link sources between *Gaia* and the ICRF2, and the testing of the observing mode for the Continuous VLBI Campaign 2014 (CONT14).

Correlators

The correlator at Haystack Observatory (USA), the correlator at the U.S. Naval Observatory in Washington (USA), the BKG/MPIfR correlator at the Max Planck Institute for Radioastronomy in Bonn (Germany) and the correlator at the Geographical Survey Institute (GSI) in Tsukuba, Japan continued their efficient processing of the data recorded for the IVS. The 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 still used the Mark IV hardware correlator and processed, e.g., the R4, Int1, and CRF sessions. The Haystack correlator processed RD 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 14th IVS Analysis Workshop was held in Helsinki, Finland on March 5, 2013. 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. One of the items that surfaced was the

apparent reversal of time-tags (time-tag of scan A later than the subsequent scan B) in some recent databases that were processed using the DiFX software correlator. This was ultimately traced to the way the DiFX software correlators were handling time-tags: the epoch assigned to all observations in a scan was halfway through the longest observation in the scan. In contrast, the Mark IV correlator used a time-tag which was halfway through the shortest observation in the scan. The DiFX software was modified to conform with the Mark IV hardware correlator convention and the affected databases were reprocessed resulting in slightly improved session fits.

The Combination Center at BKG/DGFI continued to perform the combination of session-based results from the individual 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.

Technology Development

Most of the activities in improving the VLBI technique was related to the VGOS (VLBI Global Observing System) system, which is the next generation VLBI system based on a broadband observation scheme. Work on developing the VGOS broadband system began in earnest in 2008 when the Eleven Feed was identified as a suitable candidate for use in the next generation VLBI system. As a result of work carried out in the subsequent years, the system is now in a useable state although not completely finalized. Several broadband test sessions were carried out on the ~600 km long baseline between Westford (Massachusetts) and Goddard (Maryland) in the U.S. with the first 24-hour geodetic session having been carried out in late May 2013. The new broadband system required nearly a complete reworking of the legacy S/X system including the frontend, backend, and even the connection between them. There has been significant progress over the past year in a number of areas.

Constituting one of the key technological innovations that makes the new VGOS broadband system possible, active development of the broadband feeds continued in 2013. The workhorse feeds for the Westford/GGAO broadband baseline are Quadridge Feed Horns (QRFH) developed at CalTech. These feeds perform at a high level, are cost effective, and are easy to integrate into cryogenic front ends. So far they are the only broadband feeds that have been successfully deployed in a working VGOS system. Work continued on the integration of the Eleven Feed developed at Chalmers University into a cryogenic front end; a broadband feed developed in Italy is being tested at Noto, and an innovative conical feed that naturally produces circular-polarized output is being proposed for the Spanish/Portuguese RAEGE antennas.

Digital-backend (DBE) development continues in China, Europe, Japan, Russia, and the United States. To help understand the similarities and differences between various DBEs, a document named the VLBI Receiver Back End Comparison, in which the features of all known DBEs are compared in a table, was produced. The document can be found on the IVS Web site. Of the DBEs compared, the ROACH-based DBE (RDBE) and DBBC2010 were the most applicable to the VGOS system.

The Mark 6 data recording system is now ready to enter operational service. It is an excellent fit for VGOS. It can accept data at the VGOS data rate of 16 Gbps, writing it directly into a 30 s RAM buffer and then moving it from the buffer to a (single) disk pack at a sustained rate just under 8 Gbps. With proper care in the development of a schedule it should be easy to ensure that the buffer is ready to be refilled by the time the VGOS antenna has slewed to the next source. This mode of operation opens the possibility of writing a complete 24-hour VGOS session onto a single 32-TByte disk pack that is very efficient for media shipment. The 2nd IVTW was hosted by the Korea Astronomy and Space Science Institute (KASI) at Seogwipo on Jeju Island, South Korea. The workshop focused on four topics: station status reports, e-VLBI/Science, wideband developments, and frequency standards. Attendees at this very well organized workshop were treated to a field trip to the nearby 21-m Tamna radio telescope which is an element in the Korean VLBI Network (KVN).

Training and Education

On March 2–5, 2013, just prior to the 21st EVGA Working Meeting, a geodetic VLBI school was held at Aalto University, Espoo, Finland. The school was sponsored by the IVS, the EGU, Onsala Observatory, the Finnish Geodetic Institute, Aalto University, and RadioNet. It was part of the activities of IVS Working Group 6, “Education and Training”, led by Rüdiger Haas. Lectures and exercises were prepared on a wide range of topics from radio telescopes, feed horns, and receivers to the terrestrial reference frame. It was an opportunity for young participants to get a broad introduction to the field and at the same time for technology experts to learn about analysis and vice versa. Since this was the first running of the school, an important result was the production of learning material on a broad range of topics related to geodetic VLBI. It was agreed that a school of this type should be held roughly every three years.

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3.4.4 International DORIS Service (IDS)

Overview

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

1 DORIS system

1.1 DORIS satellites

During this report period (2013), the number of DORIS satellites has decreased to five (see Table 1).

In June 2013, SPOT-4 was decommissioned after 15 years of a successful mission. It was launched in 1998 and featured the first DORIS real time on-board orbit determination (DIODE).

Jason-1 was passivated and decommissioned on 01 July 2013, terminating the mission after 11.5 years of operations.

SARAL-AltiKA Indian-French satellite (ISRO/CNES) was launched on February 25 2013 with a DORIS DGXX receiver onboard.

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

- SENTINEL3A (GMES/ESA) is planned for end 2015, then SENTINEL 3B 12 to 30 months later.
- Jason-3 (EUMETSAT/NOAA/CNES) is foreseen for March 2015.
- Jason CS (EUMETSAT/ESA/CNES) is expected from 2020.
- SWOT is foreseen for 2020.

Table 1: DORIS data available at IDS Data Centers. As of December 2013

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

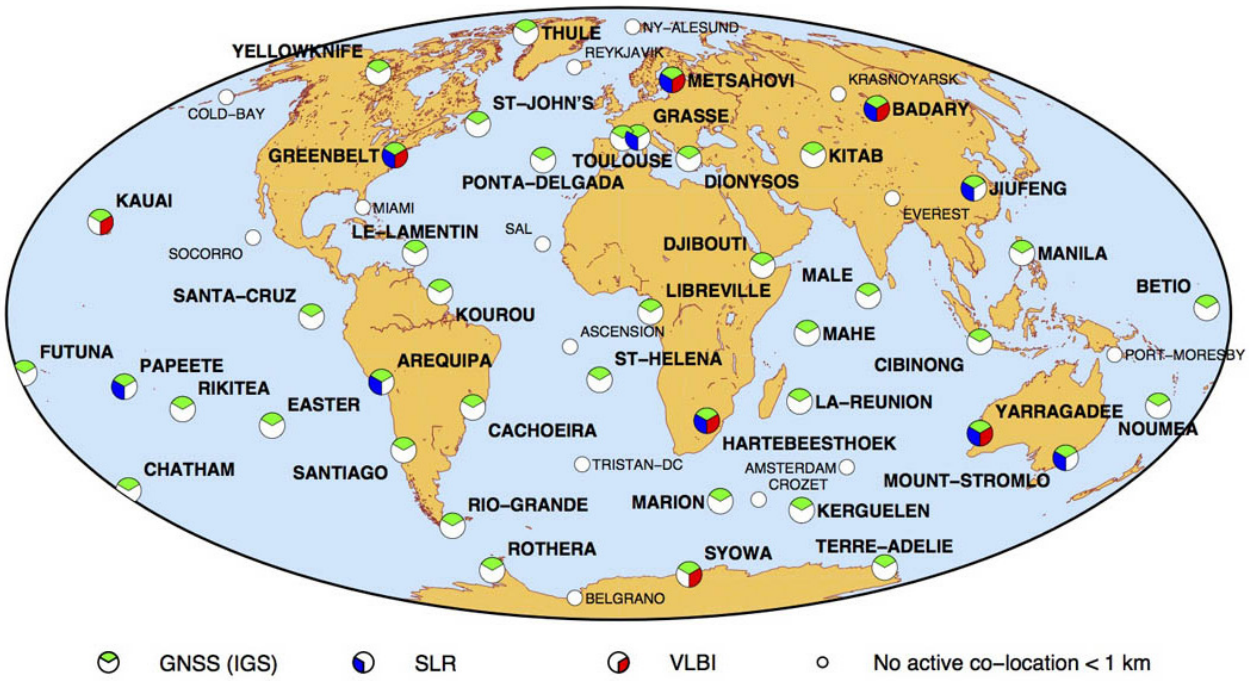


Fig. 1: The permanent DORIS network – 56 stations (as of Dec. 2013).

1.2 DORIS network

The DORIS network still provided a reliable service in 2013. The joint effort of CNES, IGN and all host agencies offered outstanding network availability with an annual mean of 88 % of operating stations. We were able to anticipate and respond in a timely way to the network events, and in parallel, we continue to carry out installation and renovation in order to keep up the network performance level.

The main events of the year are:

- new station at “Le Lamentin” in the French West Indies (Martinique) aiming at increasing the network density in this region and first DORIS station located on the Caribbean tectonic plate;
- renovation and local tie survey at St John’s, Yellowknife (Canada) and Grasse (France);
- with a view to installing a new station, Chatham Island (NZ), Nicaragua and Hokkaido Island (Japan) were also visited.

Grasse has been chosen as an experimental site. It is now equipped with geodetic control points in order to monitor the monument stability. The first observing campaign was carried out this summer.

Thanks to the REGINA network deployment (see IDS Activity Report 2011, Section 5), co-locations with IGS GNSS stations stepped up to forty and a lot of high precision local tie surveys were carried out by IGN during the last three years as an important contribution to ITRF2013.

Table 2: Composition of the IDS Governing Board (from January 2013)

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 IDS Central Bureau
Pascal Willis (chair)	IGN/IPGP	France	Analysis Center representative

2 IDS Governing Board

In December 2012, a new Governing Board was elected or appointed following the IDS Terms of Reference updated in 2011. The composition of the new Governing Board is given in Table 2.

3 IDS Central Bureau

3.1 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 2013 are reported hereafter.

- The presentations of the AWG meetings held in Toulouse in April 2013 and in Washington in October 2013 have been made available:
  <http://ids-doris.org/report/meeting-presentations/ids-awg-04-2013.html>
  <http://ids-doris.org/report/meeting-presentations/ids-awg-10-2013.html>
- The activity reports for 2012 were added (IDS Activity report, report for IERS) as well as the minutes of the IDS GB meetings held in 2013:
  <http://ids-doris.org/report/governing-board.html>
- The list of the peer-reviewed publications related to DORIS has been enriched with 7 new references of articles published in 2013:
  <http://ids-doris.org/report/publications/peer-reviewed-journals.html#2013>
- The pages Sitelogs have been upgraded.
  <http://ids-doris.org/network/sitelogs.html>
  - The previous codes of the stations have been added in the table of the main page. In addition, the URL links have been changed. The station's name is used instead of one of the station's codes.
  - Several updated versions of site logs have been provided by IGN, (among them the site logs for Le Lamentin and

Grasse), as well as more than 70 photos of station monumentations and host agency staffs. (see also <http://ids-doris.org/gallery.html>)

- The letter from the International Council for Science (ICSU) World Data System (WDS) accepting IDS as a Network Member has been put online: <http://ids-doris.org/documents/report/WorldDataSystem/WDS-NetworkMember_IDS_20131010.pdf>
- Links to brochures and videos about DORIS available on AVISO website have been added: <http://ids-doris.org/analysis-documents.html#general>

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

- "DORIS system definition" is a new document describing the DORIS missions, then the DORIS system in details, with its external and internal connections. It applies to the DORIS system from the DGXX generation: <ftp://ftp.ids-doris.org/pub/ids/DORIS_System_Definition.pdf>
- "Saral characteristics for DORIS calibration plan and POD processing" is a new document that describes the SARAL satellite characteristics: <ftp://ftp.ids-doris.org/pub/ids/satellites/Saral_CharacteristicsForDORISCalibrationPlanAndPODProcessing.pdf>
- A note about "station equipment and impact on the frequency" which reminds the possible changes of emitting frequency in case of equipment changes for the three kinds of DORIS beacons (Orbitography, Master, and Time beacons): <ftp://ftp.ids-doris.org/pub/ids/stations/AboutStationEquipmentAndFrequency.pdf>
- Version #4.5 of the document describing the modelling of DORIS 2GM instruments (cleaned of any reference to Cryosat-1): <ftp://ftp.ids-doris.org/pub/ids/satellites/DORIS_instrument_modelling_2GM.pdf>
- Version #5 of the document describing the DORIS satellite models implemented in CNES POE processing; it includes SARAL and updates on SPOT-5 solar panel offsets: <ftp://ftp.ids-doris.org/pub/ids/satellites/DORISSatelliteModels.pdf>
- Updated version of the DORIS internal tie file <ftp://ftp.ids-doris.org/pub/ids/stations/DORIS_int_ties.txt>
- The sitelogs were all gathered in: <ftp://ftp.ids-doris.org/pub/ids/stations/sitelogs/>

3.2 IDS Mail system

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

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

- Data from SARAL launched in February 2013 are now archived in the IDS Data Centers, in data format 2.1 and in RINEX version 3.0 (phase data), as it is the case for the DGXX receivers on Jason-2, Cryosat-2, and HY-2A.
- The Jason-1 satellite suffered a system failure in June 2013; the satellite was decommissioned shortly thereafter. The SPOT-4 satellite was de-orbited in June 2013. The number of operational satellites with a DORIS beacon is now at five.
- In the fall of 2012, the IDS Analysis Working Group requested a test data set where data from stations in the South Atlantic Anomaly (SSA) were reprocessed by applying corrective models. Data from 2011 in DORIS V2.2 format from the Jason-1 satellite (cycles 331 through 368) were submitted to the IDS data centers in late 2012; a set of SPOT-5 data (cycles 138 through 432, 2006 through 2013) were provided in 2013. These files were submitted to the IDS data centers and archived in dedicated directories.
- A solution (designated “ids”) produced by the IDS combination center from the individual IDS AC solutions started production in 2012.

Table 3: List of IDS Analysis Centers routinely participating in the analysis activities in 2013.

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

5 IDS Analysis Centers

Geoscience Australia has ceased its activities as an IDS Analysis Center in December 2012. The other six Analysis Centers continue to remain active, participating in the IDS activities, with a very important commitment in the Analysis Working Group (AWG) and the preparation of the DORIS contribution to ITRF2013.

6 IDS Combination

In addition to its operational activities of evaluation and combination of all the individual ACs weekly solutions, the IDS Combination Center has been involved in several studies related to the forthcoming DORIS contribution to ITRF2013. Conclusions of the two main studies are briefly developed hereafter. For more details on the IDS CC activities, we refer to the 2013 IDS annual activity report.

Based on the IDS Combination Center presentation done during AGU 2012 Fall meeting, ESA and GSC started 2013 by implementing beacon frequency variations. As depicted by Figure 2 and Figure 3, the updated series ESA 07 and GSC 18 have no longer scale jumps early 2002 while DORIS data format has changed. These corrections should improve the homogeneity of the combined scale.

With the delivery by CNES of both Starec and Alcatel DORIS antennas phase laws (PCVs), the two last quarters of 2013 were devoted to the evaluation by IDS CC of the impact of including these phase laws. Based on the evaluation of GOP, GSC and LCA tests series presented during the AWG in Washington (October 2013), and as expected, the major impact of the phase laws is on the scale (Figure 4). So far, some additional tests have to be performed in order to precisely understand the influence of these laws, notably to see any dependence with the time evolution of the network in terms of antennas type as well as any correlation with arrival of new DGXX missions. Nevertheless, due to the impact of the phase laws on the scale, all the IDS ACs agreed in Washington that those who will not use the phase law, will participate in the combination but not for the combined scale from DORIS.

Last but not least, in 2013, the IDS Combination Center joined both EGU and AGU fall meetings where it presented two oral

presentations respectively titled “Impact of beacon frequency changes on the DORIS contribution to ITRF2008” and “Status of DORIS contribution to ITRF2013”.

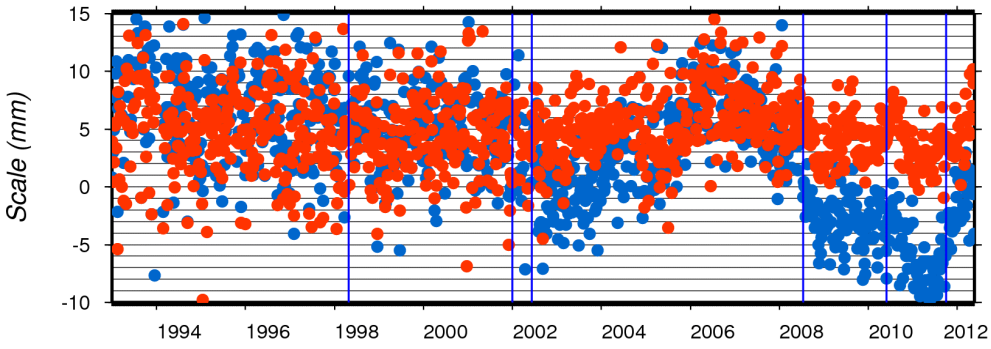


Fig. 2: Scale wrt ITRF2008 of ESA series 06 (blue) and 07 (red, 06 + beacon frequency variations).

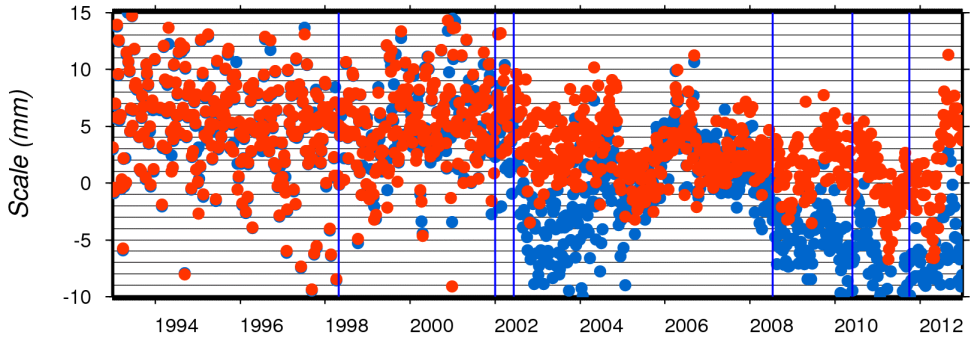


Fig. 3: Scale wrt ITRF2008 of GSC series 15 (blue) and 18 (red, 15 + beacon frequency variations).

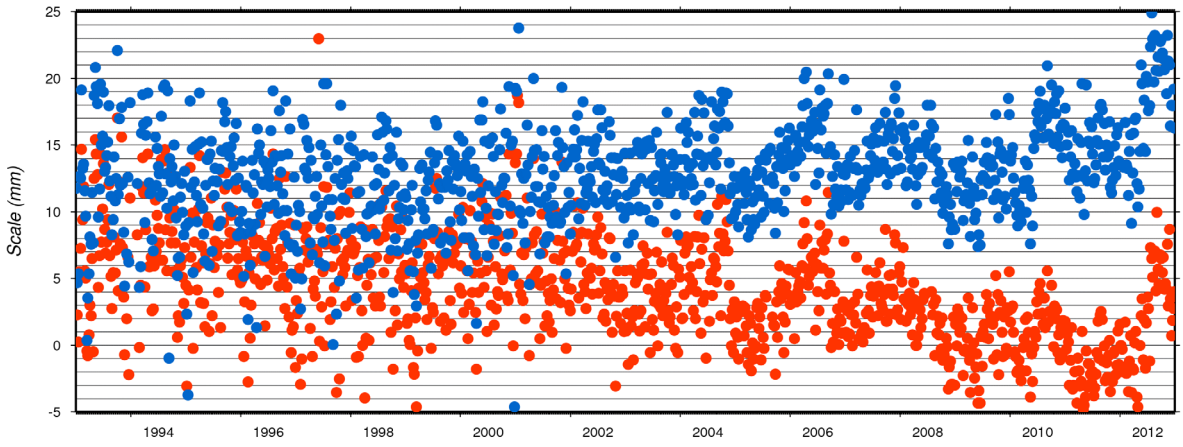


Fig. 4: Scale impact of DORIS antennas phase laws as observed by GSC (red=series 20 without phase laws, blue = series 21 == series 20 + phase laws).

7 Meetings

In 2013, the IDS organized two DORIS Analysis Working Group (AWG) meetings, first in Toulouse, France, on April 4 and 5, then in Greenbelt, Maryland, USA, on October 15 and 16.

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-04-2013.html>

<http://ids-doris.org/report/meeting-presentations/ids-awg-10-2013.html>

8 Publications

IDS published a 2012 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

In conclusion, the DORIS community had a productive year in 2013. The IDS has continued validation studies in preparation for ITRF2013 and started the processing of 20 years of DORIS data (1993-2013), involving the Analysis Centers and the Combination Center.

Despite the missions of Spot-4 and Jason-1 have stopped in 2013, the IDS gladly noted the successful launch of SARAL. This means that to ensure its mission, IDS can rely on a constellation of five DORIS receivers since July 2013: SPOT-5 with a 2nd generation DORIS receiver, and Jason-2, Cryosat-2, HY-2A and Saral equipped with the last generation of DGXX receiver. In addition, several new satellites equipped with DGXX instruments should be launched in the near future, starting with Jason-3 and Sentinel-3A in 2015.

Laurent Soudarin

3.5 Product Centres
3.5.1 Earth Orientation Centre

This section presents over the year 2013 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 2012–2013

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 2012–2013. 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 2012–2013. 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	330	15.7		165
EOP (BKG)	1–4d	145	11.2		91
EOP (GSFC)	1–4d	140	11.3		83
EOP (IAA)	1–4d	162	14.5		87
EOP (MAO)	1–4d	160	24.6		106
EOP (OPA)	1–4d	134	11.0		78
EOP (PUL)	1–4d	275	18.0		300
EOP (USNO)	1–4d	123	11.3		85
EOP (IVS) *	1–4d	105	6.7		37
VLBI – Intensive					
EOP (BKG) *	1–3 d		17.8		
EOP (GSFC) *	1–3 d		19.5		
EOP (IAA)	1–3 d		19.8		
EOP (PUL) *	1–3 d		21.0		
EOP (USNO) *	1–3 d		18.9		
SLR					
EOP (CGS)	1d	165		20.3	
EOP (IAA)	1d	270		20.6	
EOP (MCC)	1d	180		–	
EOP (PUL)	1d	110		16.6	
EOP (ILRS)*	1d	153		31.1	
GPS					
EOP (CODE)	1d	31		10.8	
EOP (EMR)	1d	49		21.9	
EOP (ESOC)	1d	80		12.2	
EOP (GFZ)	1d	40		10.3	
EOP (IAA)	1d	73		18.2	
EOP (JPL)	1d	45		18.7	
EOP (NOAA)	1d	73		8.9	
EOP (SIO)	1d	45		18.9	
EOP (IGR) *	1d	34		8.3	
EOP (IGS) *	1d	29		8.0	

Table 2: Mean and standard deviation in microarcsecond of the differences between various combined techniques solutions entering the combination and Bulletin B / C04 over 2012–2013.

EOP	IGS Comb – IERS 08C04		ILRS Comb – IERS 08C04		IVS Comb – IERS 08C04	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
X (μas)	–8	29	101	147	-8	115
Y (μas)	17	28	74	160	89	96
UT1 (μs)					0	6.7
LOD (μs)	0	8	2	31		
$D\psi \sin\varepsilon$ (μas)					0	68
$D\psi$ (μas)					–23	45

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 2012–2013.

EOP	Unit	Bull A – Bull B		Comb JPL – Bull B	
		Mean	Standard deviation	Mean	Standard deviation
X	μas	0	16	77	49
Y	μas	0	14	66	32
UT1	μs	2.0	13.3	–3.3	14.9

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>.

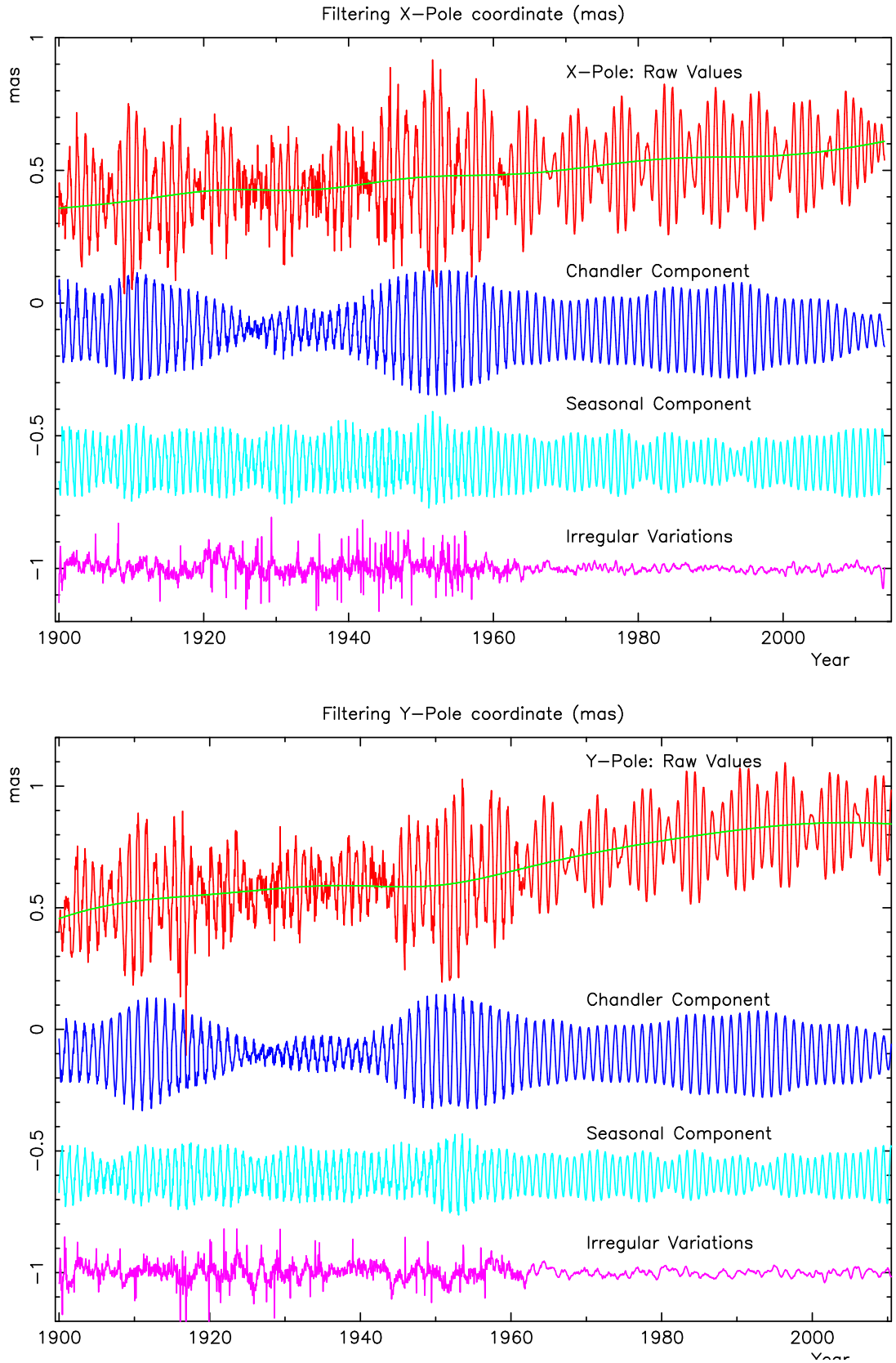
Long-term series: C 01 (1846–2013)

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.

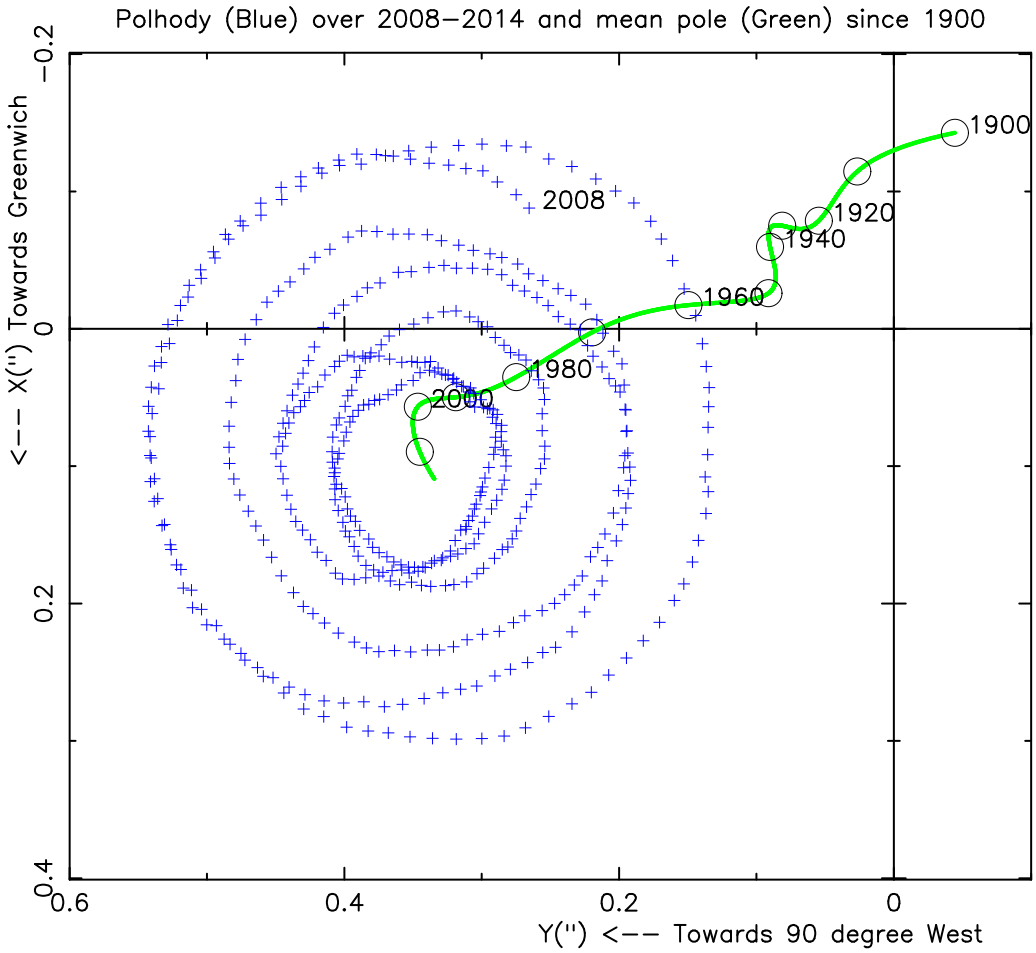


Fig. 2: Mean polar motion (1900–2013) and IERS C04 polhody over 2008–2014.

1962–2013: 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 1900–2013 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 2013 (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.

The mean pole is described by a third order polynomial (Conventions 2010). Its coefficients are published in Conventions 2010 (Petit and Luzum, 2010). The corresponding table is also available at the following address: <http://hpiers.obspm.fr/eop-pc/>.

After two years, it was interesting to match the extrapolated polynomial values and the updated mean pole time series. Table 4 and Figure 3 give the IERS mean pole components compared to the fitted polynomial and their differences which appear to remain roughly limited to a couple of mas over the extrapolated period 2010–2014.

Table 4: IERS mean pole components compared to the fitted polynomial and their differences which remain limited to a couple of mas over the extrapolated period.

Year	X-Pole (mas)			Y-Pole (mas)		
	IERS data	Polynomial	diff Xp	IERS data	Polynomial	diff Yp
2000	56.721	56.721	0.000	346.572	346.572	0.000
2001	58.657	58.632	0.025	347.918	347.963	-0.045
2002	60.915	60.890	0.025	348.962	349.027	-0.065
2003	63.495	63.478	0.017	349.693	349.757	-0.064
2004	66.390	66.380	0.010	350.097	350.150	-0.053
2005	69.590	69.582	0.008	350.162	350.202	-0.040
2006	73.078	73.067	0.011	349.877	349.907	-0.030
2007	76.838	76.820	0.018	349.234	349.261	-0.027
2008	80.849	80.824	0.025	348.228	348.260	-0.032
2009	85.090	85.065	0.025	346.855	346.899	-0.044
2010	89.545	89.526	0.019	345.117	345.174	-0.057
2011	94.201	94.192	0.009	343.014	343.080	-0.066
2012	99.048	99.047	0.001	340.548	340.612	-0.064
2013	104.083	104.076	0.007	337.719	337.766	-0.047
2014	109.304	109.262	0.042	334.527	334.537	-0.010
2015	0.000	137.725	0.000	0.000	349.460	0.000
2016	0.000	145.339	0.000	0.000	348.832	0.000
2017	0.000	152.953	0.000	0.000	348.203	0.000
2018	0.000	160.567	0.000	0.000	347.574	0.000
2019	0.000	168.181	0.000	0.000	346.946	0.000
2020	0.000	175.795	0.000	0.000	346.317	0.000

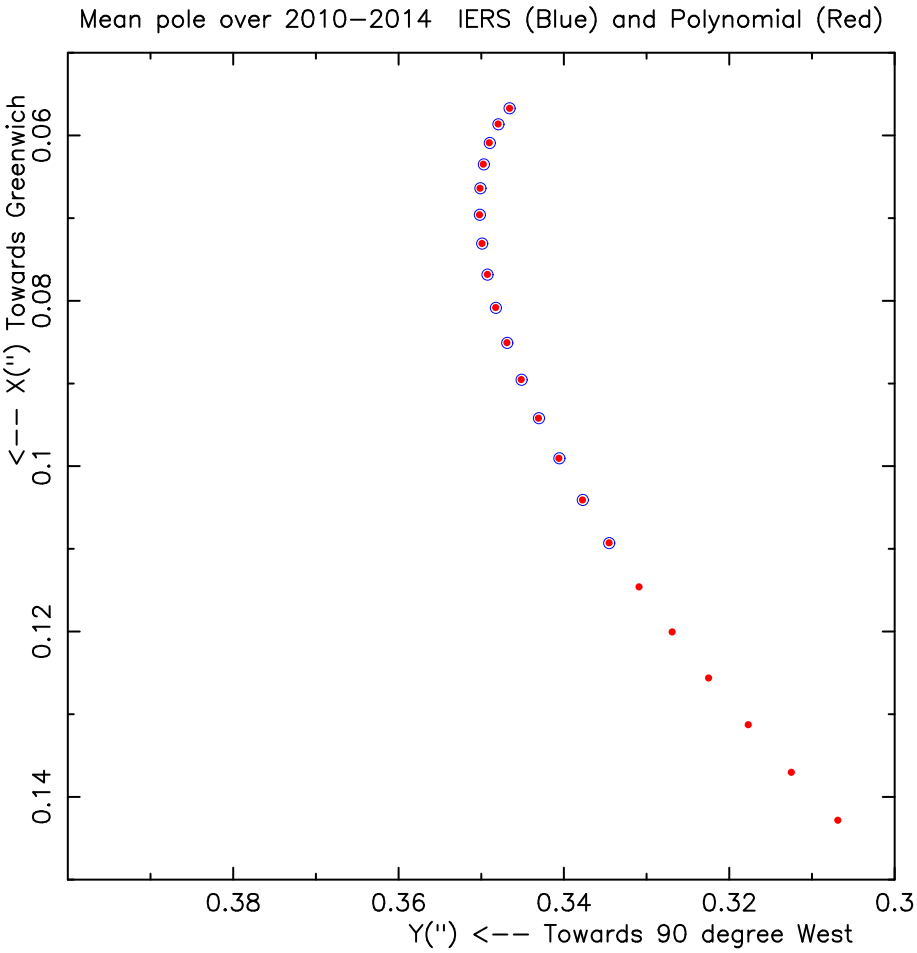


Fig. 3: Plot showing the good agreement between the data and the fitted polynomial. Their differences remain limited to a couple of mas over the extrapolated period 2010–2014.

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).

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.

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3.5.2 Rapid Service/Prediction Centre

Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Center (RS/PC) for the determination of the quick-look Earth orientation parameters (EOP) is based on a smoothing (weighted) cubic spline with adjustable smoothing fit to contributed observational data (McCarthy and Luzum, 1991a). Contributed data are corrected for possible systematic differences. Biases and rates with respect to the 08 C04 system of the IERS Earth Orientation Centre (EOC) at the Paris Observatory are determined using a robust linear estimator (Matlab function 'regstats'). The statistical weights used in the spline are proportional to the inverse square of the estimated accuracy of the individual techniques computed over the past several years. 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. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Estimated accuracies of data contributed to the IERS Rapid Service/Prediction Center for 2013 are given in Table 1. These

Table 1: Estimated accuracies of the contributors in 2013. Units are milliseconds of arc for x, y, $d\psi$, $d\varepsilon$, dX, and dY and milliseconds of time for UT1–UTC.

Contributor Information	Estimated Accuracy				
Name, Type	x	y	UT1	$\delta\psi$ (dX)	$\delta\varepsilon$ (dY)
ILRS SLR	0.30	0.35			
IAA SLR	0.23	0.20			
MCC SLR	0.19	0.20			
GSFC VLBI Intensives			0.020		
USNO VLBI Intensives			0.021		
GSI Intensives			0.012		
GSFC VLBI	0.13	0.15	0.005	0.65	0.29
IAA[1] VLBI	0.21	0.21	0.009	(0.14)	(0.22)
IVS[1] VLBI	0.11	0.16	0.004	(0.20)	(0.21)
USNO VLBI	0.29	0.37	0.008	0.37	0.11
IGS Final	0.01	0.00			
IGS Rapid	0.04	0.03			
IGS Ultra*	0.04	0.04	0.056*		
USNO GPS UT*			0.019*		

*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).

estimates are based on the residuals between the series and the combined RS/PC EOP solution for 2013. For polar motion (x and y) and the celestial pole offsets ($d\psi$, $d\varepsilon$, dX, and dY), all the contributors (which have associated statistics in Table 1) provide direct measurements of these quantities, respectively. For UT1, all the Very Long Baseline Interferometry (VLBI) contributors provide direct measurements of UT1; however, the International GNSS Service (IGS) ultra-rapid observations (IGS ultras) provide a length-of-day-type input, which is a derivative of UT1. 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, and the corresponding statistics shown for the IGS ultras are computed after the bias correction is applied.

Operationally, the smoothing (weighted) spline uses the following as inputs: the epoch of observation, the observed EOP value, and the weight of each individual data point. The software computes the spline coefficients for every data point, which are then used to interpolate the Earth orientation parameter time series so that x, y, UT1–UTC, $d\psi$, and $d\varepsilon$ values are computed at the midnight (00:00) UTC epoch for each day. While the celestial pole offset combination software can combine either $d\psi$ and $d\varepsilon$ or dX and dY, for historical reasons, it uses $d\psi$ and $d\varepsilon$. Therefore, the Institute of Applied Astronomy (IAA) and the International VLBI Service (IVS) VLBI dX and dY values are converted to $d\psi$ and $d\varepsilon$ 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 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 points whose errors, as reported by the contributors, are greater than three times their average reported precision. The other data excluded are those points that have a residual that is more than four times the associated *a priori* error estimate. Since all of the observations are reported with the effects of sub-daily variations removed, the input data are not corrected for these effects (see IERS Gazette No. 13, 30 January 1997).

Table 2 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. The running solution statistics, shown under the label

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Center combination solutions and the 08 C04 EOP solutions for 2013. 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	0.00	0.03
y	0.00	0.03
UT1-UTC	0.003	0.011
Bulletin A Weekly Solution (finals.data)[1]		
x	0.03	0.05
y	0.01	0.04
UT1-UTC	0.005	0.020
Bulletin A Daily Solution (finals.daily)		
x	0.02	0.05
y	0.01	0.04
UT1-UTC	0.002	0.037

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

"Bulletin A Rapid Solution", are the residuals of the combination solution versus the 08 C04 over the past 365-day period. 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 of the 7-day period, prior to the Bulletin solution epoch, of the 52 weekly Bulletin A solutions to the 08 C04 series. Each weekly Bulletin A solution is normally produced on Thursdays and contains EOP solutions for a prior 7-day period ending on the Thursday solution epoch. In generating the statistics, these periods are concatenated for the entire year, and then residuals and statistics versus the 08 C04 are computed.

The statistics for the daily solution, shown under the "Bulletin A Daily solution" heading in Table 2, are determined from a series of differences spanning one year where each element of the series is the difference for the day of the solution epoch. EOP accuracies for the Bulletin A rapid weekly combination solution for the day of the solution run and the daily solution at the time of solution epoch are similar and, therefore, not included in Table 2.

Figure 1 contains plots of the residuals between the daily rapid solution and the 08 C04, and the corresponding statistical results are listed in Table 2 under "Bulletin A Daily Solution (finals.daily)".

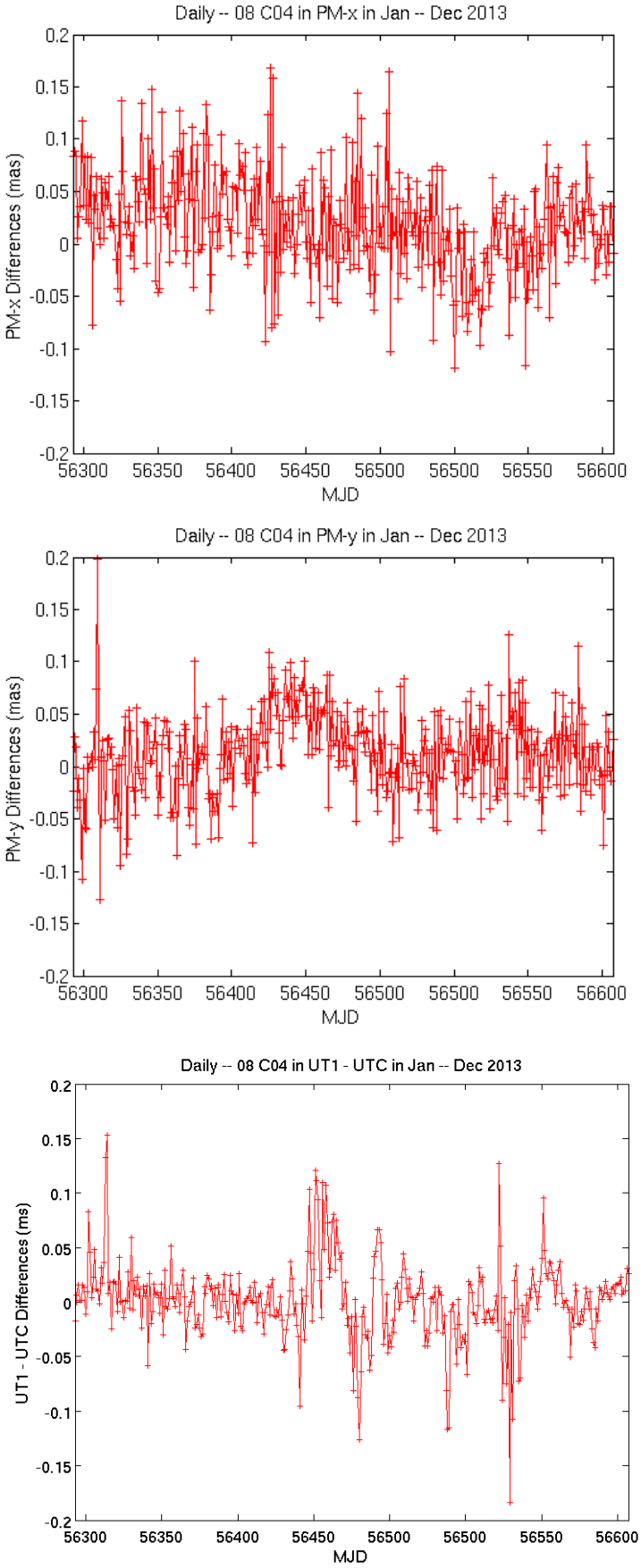

Fig. 1: Differences between the daily rapid solutions at each daily solution epoch for 2013 and the Earth orientation parameters available in the 08 C04 series produced in April 2014.

In 2013, the statistical results between the daily solution and the 08 C04 were similar to what resulted in 2012.

The mean and standard deviation for the UT1–UTC daily rapid residuals for 2013 were similar to the 2012 values (as reported in the IERS Annual Report for 2012). Until about mid-May 2013 (@ MJD 56425), the rms of the residuals was significantly lower than for the rest of the year, with an rms of 27 microseconds. Then, from around mid-May to the beginning of November, the level of the residuals increased significantly, with an rms of 46 microseconds. From November until the end of December 2013, the rms level decreased back to 24 microseconds.

The UT1–UTC residuals are largely influenced by the accuracy and timeliness of VLBI intensive inputs. Consequently, the large increase in rms from the mid-May to early-November period could be partly attributed to several factors: a) from the end of April through the end of 2013, the Tsukuba–Wettzell (TsWz) radio telescope baseline was not available due to problems with the Tsukuba antenna; and so Saturday and Sunday weekend, short 1-hr long VLBI observations, called intensives, were replaced with a single Saturday or Sunday Kokee–Wettzell (KkWz) baseline-based intensive – thus, effectively reducing the normal observations per week from 7 to 6; b) from the end of May through at least October, the Kokee antenna receiver X-band and S-Band system temperatures were higher than normal; and c) from mid-July to September 30, the Wettzell antenna was off-line for scheduled repairs, with Ny-Ålesund and then Svetloe substituting for Wettzell in the normal KkWz baseline (resulting in KkNy and KkSv baselines). The KkWz baseline is a well-established operational baseline; whereas the KkNy and KkSv baselines, while extremely useful as alternatives to KkWz, may not have been characterized for geodetic purposes to the same level as the KkWz baseline.

Figure 2 is a plot of the residuals from the daily rapid solution (labeled finals.daily in the legend) and the individual NASA Goddard produced KkWz, TsWz, KkNy, and KkSv baseline UT1–UTC residuals from Jan 1, 2013 through May 15, 2013. A correlation between the increased noise level of these NASA Goddard intensives, beginning around MJD 56427 (May 15, 2013), and the increased level of residuals in the daily rapid solution is apparent from the plot.

Prediction Techniques

In 2007, the algorithm for polar motion predictions was changed to incorporate the least-squares, autoregressive (LS+AR) method created by W. Kosek and improved by T. Johnson (personal communication, 2006). This method solves for a linear, annual, semiannual, 1/3 annual, 1/4 annual, and Chandler periods fit to the previous 400 days of observed values for x and y. This deterministic model is subtracted from the polar motion values to create

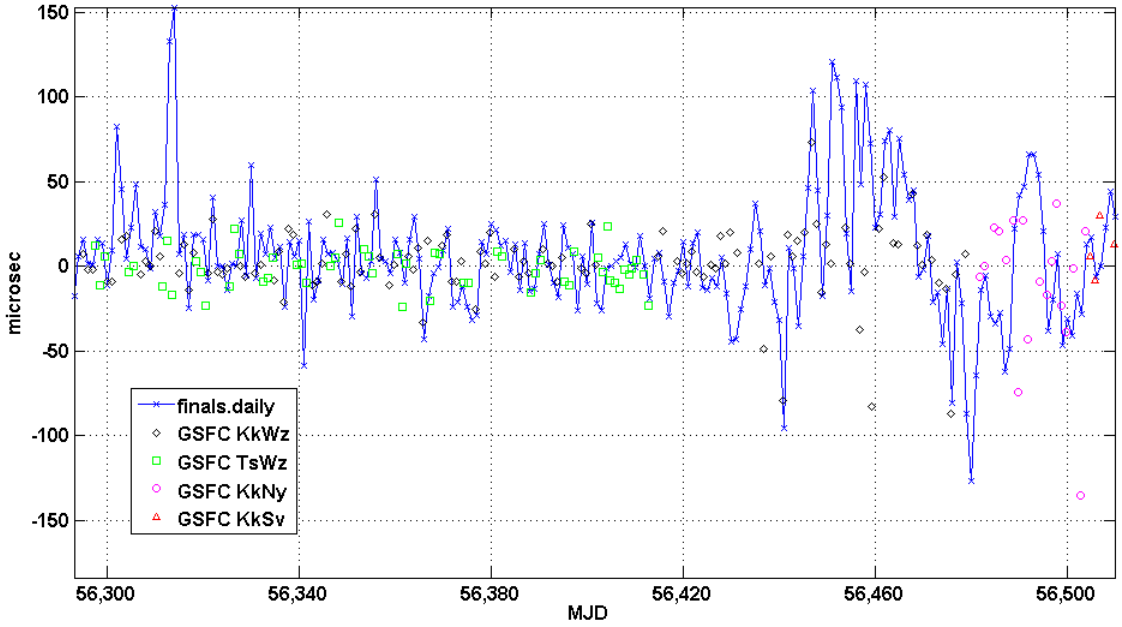

Fig. 2: The residuals of the daily rapid solution (labeled finals.daily in the legend) and the individual NASA Goddard produced KkWz, TsWz, KkNy, and KkSv baseline UT1–UTC residuals from Jan 1, 2013 through May 15, 2013.

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[1] (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 com-

[1] On July 25, 2013, the contribution of the US Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) to the AAM inputs was upgraded from the Navy Operational Global Atmospheric Prediction System (NOGAPS) to the Navy Global Environmental Model (NAVGEM).

bined smoothly with the longer-term UT1 predictions described below. For more information on the use of the UTAAM 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. Then, to determine a prediction of UT1–UTC n days into the future, $(UT2R–TAI)_n$, the smoothed time value from n days in the past, $<(UT2R–TAI)_{–n}>$ is subtracted from the most recent value, $(UT2R–TAI)_0$

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

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

Table 3a shows the root mean square of the differences between the 17:00 UTC solution predictions and the 08 C04 solution for 2013. Prediction errors were improved by roughly 7 to 9% when comparing 2013 to 2012 results. Figure 3 provides a plot of the 1-day prediction error as a function of polar motion value. There was also a roughly 8% improvement in the 1-day UT1–UTC predictions – despite the issues with the Kokee antenna, discussed several paragraphs above. The longer-term polar motion and UT1–UTC predictions also showed general improvement when comparing 2013 to 2012 results. The reasons for improvements in polar motion are being examined; however, preliminary indications point to improved IGS ultras. The improvement over the last few years in UT1–UTC short-term prediction is due to increased availability of rapid turnaround electronically transferred VLBI (e-VLBI) intensives.

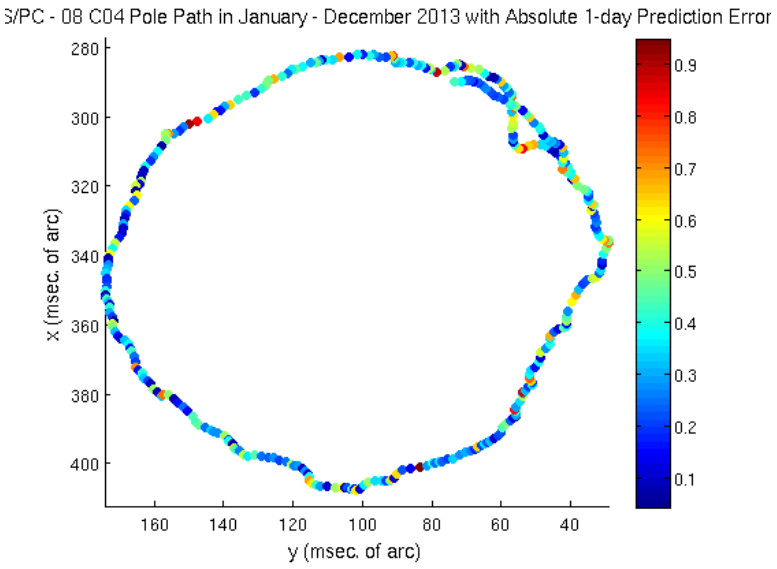

Fig. 3: Plot of the 1-day prediction error as a function of polar motion. The prediction error is in units of milliseconds of arc.

Table 3a: Root mean square of the differences between the EOP time series predictions produced by the daily solutions and the 08 C04 combination solutions for 2013. 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
1	.327	.228	.058
5	1.81	1.22	.214
10	3.46	1.94	.525
20	6.75	2.66	1.88
40	12.9	4.12	2.82
90	23.8	16.5	8.49

In previous annual reports, the prediction length was determined from 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 based on 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 are 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 solutions are collectively referred to as the Nxdaily solutions. The original solution at 17:00 UTC has been

Tables 3b, 3c, and 3d: Root mean square of the differences between the EOP time series predictions produced by the 4x daily solutions and the 08 C04 combination solutions for 2013. Note that the prediction length for the 1-day predictions is as shown in Figure 4.

Table 3b: RMS for the 21:10 UTC EOP solution for 2013.

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
1	.286	.195	.056
5	1.77	1.16	.215
10	3.45	1.89	.527
20	6.73	2.60	1.89
40	12.8	4.09	2.82
90	23.7	16.4	8.48

Table 3c: RMS for the 03:10 UTC EOP solution for 2013.

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
1	.230	.204	.052
5	1.73	1.27	.214
10	3.39	1.99	.528
20	6.75	2.69	1.89
40	12.8	3.76	2.82
90	23.7	15.9	8.48

Table 3d: RMS for the 09:10 UTC EOP solution for 2013.

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
1	.175	.151	.051
5	1.60	1.15	.211
10	3.30	1.92	.525
20	6.62	2.69	1.89
40	12.7	3.82	2.84
90	23.6	16.1	8.53

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 solutions 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 eVLBI 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, with a small amount of time between observation to EOP available solution, 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. However, VLBI intensives are not available as regularly as the IGS observations, and so the contributors shown for each solution are only an ideal case that occurs less than 100% of the time. 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 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 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.

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 2013. 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 solution will have more recent observations. The 2013 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 – 46% for PMx and 34% 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 12%.

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.

Each of the Nxdaily EOP solutions are updated daily at approximately 17:00 UTC, 21:10 UTC, 03:10 UTC, and 09:10 UTC, respectively. They are located in subdirectories of the following URLs:

<http://maia.usno.navy.mil/> or <http://toshi.nofs.navy.mil/>

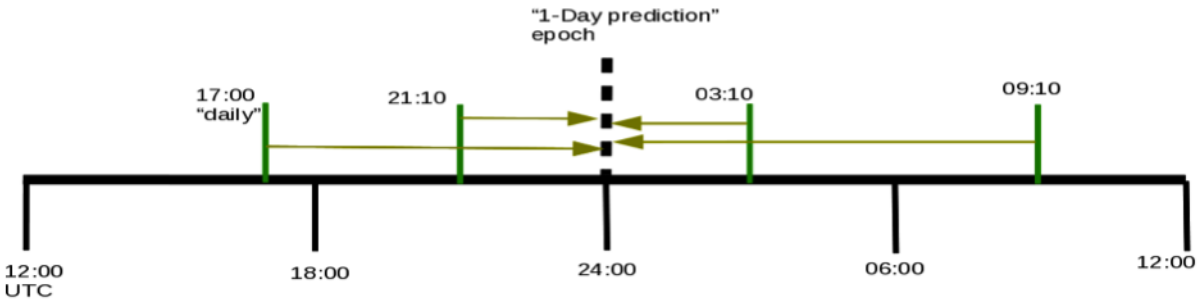

Fig. 4: Timeline of EOP 1-day prediction solutions in relation to the EOP "daily" solution produced at 17:00 UTC.

Time (UTC)	Sub-directory
17:00	ser7
21:10	eop2100utc
03:10	2xdaily
09:10	eop0900utc

For, example, the EOP USNO DC solution produced at 03:10 UTC is located at <http://maia.usno.navy.mil/2xdaily/finals.daily> or <.../finals2000A.daily>.

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 between the model and the last 20 days of celestial pole offset observations is computed. Correcting for this bias allows for a seamless transition between the observed and predicted celestial pole offsets. This bias is tapered so that as the prediction length is extended, the bias becomes progressively smaller. Since celestial pole offsets are based solely on VLBI data, if no new VLBI 24-hour session observations are available, a new rapid combination/prediction of these angles is not determined. Therefore, the predictions of celestial pole offsets start before the solution epoch and the length of the prediction into the future can and does vary in the daily solution files. The differences between the daily predictions and the 08 C04 for 2013 are given in Table 5.

Predictions of TT–UT1, up to 1 January 2024, 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).

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 2013.

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.12	.16	.30	.15
5	.13	.17	.32	.16
10	.14	.18	.35	.17
20	.17	.20	.42	.19
40	.23	.25	.58	.24

Table 5: Predicted values of TT–UT1, 2013–2024. 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)
2014 Jan 1	67.249	-0.015
2014 Apr 1	67.386	-0.005
2014 Jul 1	67.52	0.02
2014 Oct 1	67.66	0.05
2015 Jan 1	67.79	0.09
2015 Apr 1	67.9	0.1
2015 Jul 1	68.0	0.2
2015 Oct 1	68.2	0.3
2016 Jan 1	68.3	0.3
2016 Apr 1	68.4	0.4
2016 Jul 1	68.5	0.5
2016 Oct 1	68.6	0.6
2017 Jan 1	68.7	0.8
2017 Apr 1	68.9	0.9
2017 Jul 1	69.	1.
2017 Oct 1	69.	1.
2018 Jan 1	69.	1.
2018 Apr 1	69.	1.
2018 Jul 1	70.	1.
2018 Oct 1	70.	2.
2019 Jan 1	70.	2.
2019 Apr 1	70.	2.
2019 Jul 1	70.	2.
2019 Oct 1	70.	2.
2020 Jan 1	70.	2.
2020 Apr 1	70.	2.
2020 Jul 1	70.	3.
2020 Oct 1	71.	3.
2021 Jan 1	71.	3.
2021 Apr 1	71.	3.
2021 Jul 1	71.	3.
2021 Oct 1	71.	3.
2022 Jan 1	71.	4.
2022 Apr 1	71.	4.
2022 Jul 1	71.	4.
2022 Oct 1	72.	4.
2023 Jan 1	72.	4.
2023 Apr 1	72.	5.
2023 Jul 1	72.	5.
2023 Oct 1	72.	5.
2024 Jan 1	72.	5.

Center Activities in 2013

During 2013, several changes occurred in the generation of the RS/PC products: In July, the US Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) upgraded their AAM inputs to the EOP RS/PC solution from the Navy Operational Global Atmospheric Prediction System (NOGAPS) to NAVGEM; in August, a new global solution was received from the Institute of Applied Astronomy (IAA) 24-hr VLBI series; and in October, the UT1-like quantity generated from GPS inputs (UTGPS) based on the IGS rapids (UTGPS rapids) was replaced with one based on the 12-hour IGS Ultra-rapid observational inputs (UTGPS 12hr-ultras). The UTGPS 12hr-ultra has advantages over the UTGPS rapids. The 12hr-ultra solution is available at 15:00 UTC; whereas, the rapids solution is available at 17:00 UTC. If a problem occurs with the12hr-ultra solution the operator will have 2 hours to correct the problem before the 17:00 UTC EOP daily solution; however, there is very little time for the operator to correct a problem with the rapids solution before its use in the EOP solution at 17:00 UTC. Also, there was a small decrease in UT1–UTC error in using the 12-hour ultra solution rather than using the rapids solution. Additional UTGPS solutions based on the other ultras, namely the 0, 6, and 18-hr ultras are available; however, there are several implementation issues that need to be addressed before using these in an operational solution.

Also, several potential improvements to the EOP solution were investigated including using a) the Very Long Baseline Array (VLBA) inputs as a backup or additional UT1–UTC inputs, b) the IGS Ultra-rapid predictions for enhanced polar motion and LOD inputs to the EOP solution, and c) an improved polar motion solution using U.S. based Oceanic and Hydrological Angular Momentum (OAM and HAM) models.

The IERS RS/PC now provide the same operational EOP products, generated at USNO DC, at an offsite location at the Naval Observatory Flagstaff Station (NOFS); both are generated independently. The solutions at the USNO DC and NOFS are checked on a daily basis 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 product due to internet outage, power outage, etc.

The Earth Orientation transformation matrix calculator was maintained throughout the year. The calculator can now 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.

Availability of Rapid Service

The data available from the IERS Rapid Service / Prediction Center consist mainly of the data used to derive the IERS Bulletin A combination solution. Table 7 indicates which EOPs are provided by each contributor.

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

Contributor	PM-x	PM-y	UT1-UTC	LOD	$\delta\psi$	$\delta\varepsilon$	dX	dY
IAA VLBI								
GSFC VLBI								
USNO VLBI								
IVS VLBI								
GSFC Int.[1]								
USNO Int.								
GSI[2] Int.								
ILRS[3]								
IAA[4] SLR[5]								
MCC[6] SLR								
IGS								
USNO GPS								
NCEP AAM								
NAVGEM AAM								
IERS EOC								
IERS RS/PC[7]								

[1] The word “Int” an abbreviation for the word Intensive.
[2] Geospatial Information Authority of Japan.
[3] International Laser Ranging Service.
[4] Institute of Applied Astronomy of the Russian Academy of Sciences.
[5] Satellite Laser Ranging.
[6] Russian Mission Control Centre.
[7] Both combination and prediction values are available.

Other data sets are available that include: UT from NRCanada (EMR) GPS; UT0–UTC from University of Texas as Austin LLR, UT0–UTC from JPL LLR; UT0–UTC from CERGA LLR; UT0–UTC from JPL VLBI; latitude and UT0–UTC from Washington PZTs 1,3,7; latitude and UT0–UTC from Richmond PZTs 2,6; LOD from ILRS 1-day SLR; x, y, UT1–UTC from CSR LAGEOS 3-day SLR; x and y from CSR LAGEOS 5-day SLR; x and y from Delft 1-, 3- and 5-day SLR; and x, y, UT1–UTC, $d\psi$ and $d\varepsilon$ from IRIS VLBI.

The data described above are available from the Center in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current 365 days’ worth of predictions via electronic mail from

ser7@maia.usno.navy.mil or through
<http://www.usno.navy.mil/USNO/earth-orientation>.

Internet users can also direct an anonymous FTP to
<ftp://maia.usno.navy.mil/ser7> or
<ftp://toshi.nofs.navy.mil/ser7>.
where the IERS Bulletin A and more complete databases can be accessed including the daily solutions.

Center Staff

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

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

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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.

Over 2013, the work accomplished or in progress includes the following.

1. Technical content of the IERS Conventions

After the publication of the new reference edition, the IERS Conventions (2010), in electronic form (<http://tai.bipm.org/iers/conv2010/>) and as IERS Technical Note 36, work started on the updates to the Conventions (2010). The list below summarizes the changes in 2013. See <http://tai.bipm.org/iers/convupdt/convupdt.html> (or the site at <http://maia.usno.navy.mil/conv2010/convupdt.html>) for details.

- Corrected typos or other numerical errors or completed information in: Chapter 5 (Transformation between the International Terrestrial Reference System and Geocentric Celestial Reference System), Chapter 7 (Displacements of reference points), Chapter 9 (Models for atmospheric propagation delays), and the Appendices.
- Provided the yearly update of the free core nutation model.

2. Conventions software

The most significant updates to the Conventions software were:

- the update of GPT2 to make it consistent with the current version; and
- modifications to HARDISP and DEHANTTIDEINEL to correct for identified deficiencies.

3. Planned Changes

Discussions were initiated to update 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 have begun. 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>.

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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, has also greatly improved the sensitivity and quality of recent data. Further, enhan-

ced 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. Future 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 Center 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) 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. Additional VLBA observations to extend the ICRF to K-band and Q-band have been temporarily discontinued due to lack of available resources. These observations are part of a joint program between the National Aeronautics and Space Administration, the USNO, the National Radio Astronomy Observatory (NRAO) and Bordeaux Observatory. 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 Center personnel organized an effort to establish an IAU Working Group on ICRF-3. 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 2013 the ICRF-3 Working Group pursued new observations that will fill gaps and improve the most significant weaknesses of ICRF2 and pursued the establishment of reference frames derived from X/Ka band VLBI observations. It is anticipated that a progress report will be provided to the IAU General Assembly in 2015. The principal goal of the ICRF-3 WG is to complete ICRF-3 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, in specific magnitude ranges, 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

In 2013, new celestial reference frames were produced at different IVS analysis centers by the reanalysis of the full VLBI observational database and submitted to the IVS data center. The aus2013a catalog was produced at Geoscience Australia (Canberra), using the OCCAM geodetic VLBI analysis software package. Both catalogs bkg2013a and opa2013a were produced with the NASA Goddard Space Flight Center's package SOLVE: at one side at the Federal Agency for Cartography and Geodesy (BKG Leipzig) together with the Institute of Geodesy and Geoinformation of the University of Bonn (IGGB), and at the other side at the OPAR IVS analysis center of the Paris Observatory. Exhaustive technical descriptions of the solutions are available at the IVS data center.

We evaluate the consistency of the three catalogs with the ICRF2 by modelling the coordinate difference between the ICRF2 defining source coordinates in both the submitted catalog and the ICRF2. The coordinate difference was modelled by a 6-parameter transformation as used at the IERS in previous comparisons (see, IERS Annual Report 1995, p. II-32). The results are reported in the Table hereafter. The 6 parameters were estimated on the coordinate difference of the defining sources present in the catalogs. The slopes in right ascension and declination (usually noted $D\alpha$ and $D\delta$, respectively) have been omitted in the Table since they

Table 1: Characteristics and transformation parameters relevant to the three catalogs submitted to the IVS in 2013. Columns 4–5 correspond to the rms differences to ICRF2 after alignment.

	No. Sources		Rms		Transformation parameters			
	All	Defining	α cos δ µas	δ µas	A_1 µas	A_2 µas	A_3 µas	B_δ µas
aus2013a	2949	291	64	59	-22	3	3	-13
±					5	5	5	5
bkg2013a	3294	287	44	55	-3	12	-3	13
±					5	5	4	4
opa2013a	3580	295	45	54	-5	12	-9	5
±					5	5	4	4

do not exceed 0.6 mas per degree with formal error of 0.2 mas per degree. Table 1 represents the residual (i.e., after alignment onto the ICRS) differences between each catalog and the ICRF2.

VLBA RDV observations and analysis

Observations of International Celestial Reference Frame (ICRF) sources at radio frequencies of 2.3 GHz and 8.4 GHz using the Very Long Baseline Array (VLBA), together with up to 10 geodetic antennas, continued in 2013. These VLBA RDV observations constitute a joint program between the U.S. Naval Observatory (USNO), Goddard Space Flight Center (GSFC) and the National Radio Astronomy Observatory (NRAO) for maintenance of the celestial and terrestrial reference frames. During the calendar year 2013, a total of six VLBA RDV experiments were observed.

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 Very Long Baseline Array (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 4033 Very Long Baseline Array (VLBA) images of 1170 sources mostly at radio frequencies of 2.3 GHz and 8.4 GHz, but includes images for some sources at 24 GHz and 43 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 the future connection between the ICRS and the GCRS (Gaia Celestial Reference System). During the reporting period (2013) ICRS Center personnel continued to make progress with several astrometric star catalogs the extragalactic link to ICRF sources, and in preparation for the Gaia astrometric space mission.

Study of the Quasars forming the ICRF with the Gaia mission

The current version of the ICRF (Fey, Gordon, and Jacobs, 2009) is formed by the unique, time independent positions of 3414 extragalactic objects. Such unique positions were extracted from the analysis of 30 years of VLBI observations – to about 6.5 million individual measurements – aiming at compact and stable sources. The above numbers expressively state the care that must be em-

ployed to select compact and stable objects among the intrinsically unstable and morphologically complex population of quasars and AGNs. The radio wavelength aspects, and the construction of the ICRF, are comprehensively presented in the IERS Technical Note 35. On the optical wavelengths the situation was comparatively simpler when faced through ground observations, back to the times in which the acronym quasi-stellar-object (QSO) was coined. In what concerned astrometry, and the optical representation of the ICRS, either the object aimed at was a QSO, or an unusable extended galaxy or just an empty field to the detection limit. The physics characteristics of the object would not matter to improve the optical astrometric precision.

This situation changes when the optical positions reach sub-milliarcsecond to micro-arcsecond precision, like for instance on the ongoing Gaia mission, or with very small scale measurements. Isophotes or unmodeled light from the host galaxy disturb the centroid determination. Variability introduces quasi-periodic terms on the astrometric error budget and centroid wandering. Instabilities of a large scale dust wrap, if not in the boundaries of the accretion disk, would change the photocenter balance. So would episodes of luminous enhancement along the jets. In practice all these phenomena are bound to appear in changeable combinations. A number of investigations begun in 2013 address these issues, mostly in connection with the Gaia mission.

Optical counterparts of the ICRF

The “Rio survey” published the positions of 300 optical counterparts of ICRF2 sources, between declinations -90° and +30°, referred to the second version of the United States Naval Observatory CCD Astrograph Catalog (UCAC2). The positions were compared with 10 other selected optical astrometric surveys and studied the link between the Hipparcos Catalogue Reference Frame (HCRF) and the International Celestial Reference Frame, Second Realization (ICRF2). The main goal was to investigate the possible causes for the observed non-coincidence between the optical and VLBI positions. The correlation between position disagreement and the source morphology was investigated on basis of the structure indexes defined in the radio (Fey and Charlot, 1997) and in the optical (Souchay et al., 2012) domain. It was also investigated how the position offset could originate from the perturbation of the optical point spread function (PSF) of the source’s core, for instance by a second source of flux. An analytical relation describes the resulting centroid shift, as a function of the atmospheric seeing, the brightness ratio and the relative distance between the two contributing flux sources. Two scenarios, modeled by this relation, can be discussed: an extinction window in the dust torus nearby the core, and a Galactic star near the line of sight.

Optical monitoring of extragalactic radio sources for the link between ICRF and the future Gaia celestial reference frame

First observation of AGN's has been obtained in 2010 with the 1.2m telescope of the "Observatoire de Haute Provence" (OHP). Since then a lot of telescopes have been involved in the monitoring of AGN's both for morphology and for photometry purposes. Fig. 1 gives an overview of the telescopes spread all over the world that contribute to this effort of observation in the goal to bring information to astrophysicists and astrometrists. The observations currently go on for both aspects of the program, morphology and photometry. The first results about photometry have been published in A&A (Taris et al., 2013). The "Telescopi Joan Oró" (TJO) has been used from July 2013 to observe a new list of 47 targets (Petrov, 2011; Bourda et al., 2011). Fifty hours have been allocated by the Time Allocation Committee of this telescope to begin our program that will be pursued in 2014. Together with this telescope, the twin TAROT telescopes continue their observations and have obtained some long term series with very good time sampling (Fig. 2). Statistical analysis of these series will be performed to determine periodic signatures due to astrophysical processes, and will be compared to time series obtained at other wavelength (radio…). Two other 60cm telescopes have provided photometric data in 2013, one at Rozhen Observatory (Bulgaria)

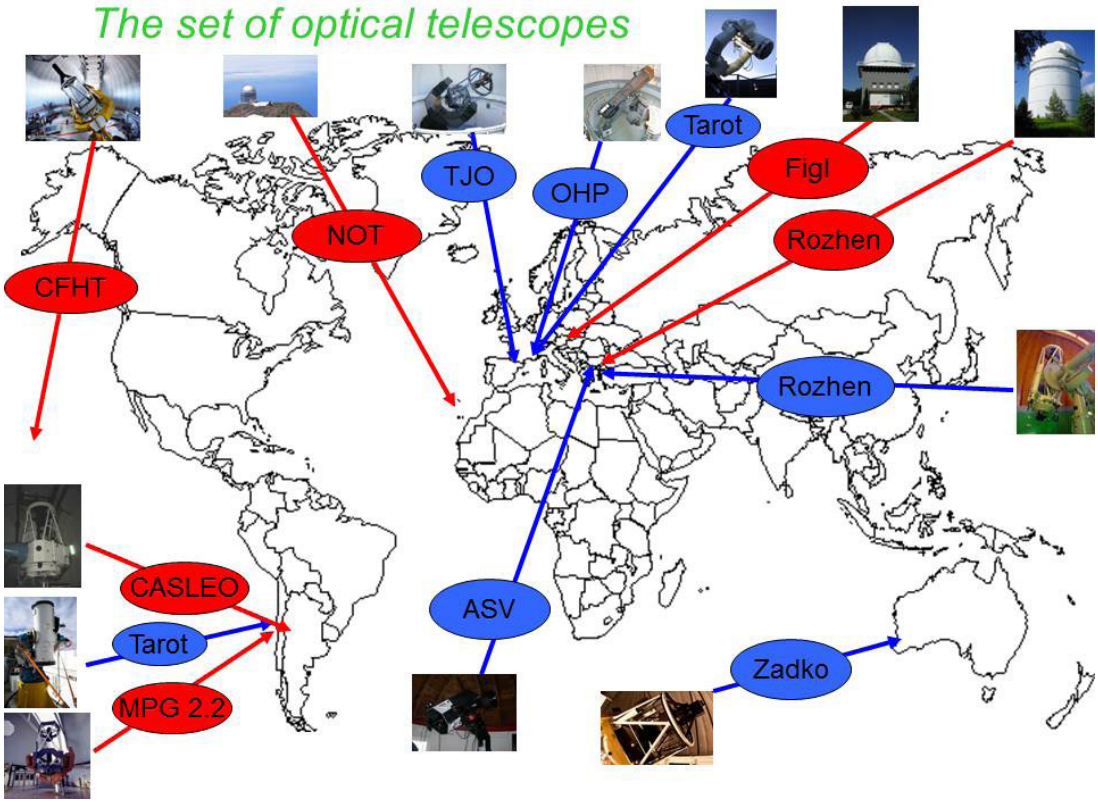

Fig. 1: The set of optical telescopes providing images for the astro-photometry program. In red the telescopes that have provided images for morphology and in blue for photometry.

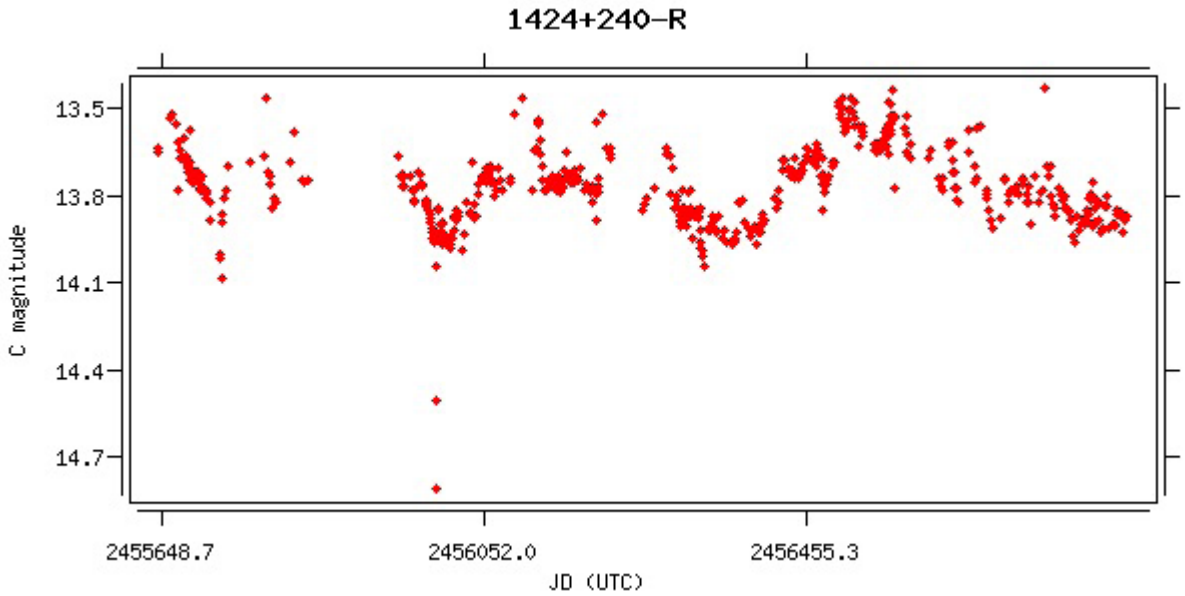

Fig. 2: QSO1424+240 in R filter. 465 measurements obtained with the TAROT telescope in Observatoire de la Côte d'Azur.

and the other at the Astronomical Station Vidojevica (Serbia). These two telescopes are used in the frame of an international collaboration with the Astronomical Observatory of Belgrade (AOB) that formerly begins in 2013.

In the frame of this collaboration, the 2m Rozhen telescope is also in use for the morphology aspect of our program. It has begun to provide images that are currently analysed with the Galfit and Iraf software. Together with this telescope two other ones have provided images for the morphology studies. The 1.52m telescope from Leopold-Figl-Observatorium für Astrophysik (LFOA, Universität Wien) in the frame of the AOB collaboration, and the 2.5m Nordic Optical Telescope (Observatorio del Roque de los Muchachos, La Palma, Canarias, Spain) in the frame of another collaboration with Observatorio Nacional – MCT (Brazil).

In 2013, the space probe Gaia has been launched from Kourou. The CU9 (Catalogue access) of the Data Processing and Analysis Consortium (DPAC) is in charge, among others, to check the consistency of correlations between several parameters and more particularly between astrometry and photometry (Work Package 945). Our group plan to be part of this WP and some discussions and meetings are in progress in the frame of the DPAC. Another WP is in charge of variability (WP946) where we will be invested.

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. On the optical window long term campaigns follow the sources variability (see more on this topic elsewhere in this report). The program here described obtain optical images to high SNR, using the B and R Johnston 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. During 2013, northern observations were conducted at the 2.5m Nordic Optical Telescope at Roque de los Muchachos, and southern observations were conducted at the 2.15m CASLEO telescope in the Argentinian Andes. The observations will continue through the following year, also through a successful time bid at the 1.60m LNA telescope, in Brazil.

The Gaia Initial QSO Catalog

The latest, updated, and fully corrected version of the Gaia Initial QSO Catalog (GIQC) was produced by the CU3 GWP-S-335-13000. It 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 MDB version currently contains nearly 1 million more quasars than in the IGSL and should preferably be used to match Gaia own observations.

Spectroscopic observations of ICRF sources

We continued in 2013 the program of optical spectroscopic observations of reference ICRF radio sources. The targets were selected from the International VLBI Service (IVS) candidate ICRF catalogue. New redshifts were obtained with four optical telescopes: the 3.58m ESO New Telescope Technology (NTT) Visitor program (092.A-0139(A)), the two 8.2m Gemini telescopes (Chile, program

GN-2012B-Q-127 and Hawaii, program GS-2013A-Q-99), and 2.5m Nordic Optical Telescope (NOT) at La Palma (Spain).

We obtained spectra of about 140 compact radio-sources, and measured redshifts of 113 emission-line objects, together with a set of BL Lac objects and faint several targets with low signal-to-noise ratio. These identifications contribute to the precise radio-optical frame tie to be undertaken by Gaia mission, launched in December 2013. A few cases of close alignment (1"–2") of the reference radio sources and foreground galactic stars were reported. In particular, the radio source IVSB 0758-737 (alias PKS 0757-737) obscured by a galactic star is relatively strong and could be monitored for indication of possible lensing effects.

Link between HCRS and extragalactic frame

Regarding the radio-optical reference frame link the final catalog of over 600 optical counterpart positions of over 400 ICRF sources on the Hipparcos system was published (Zacharias & Zacharias, 2013). With a mean optical position error of 25 mas per coordinate this is the most precise investigation of its kind to date. The associated journal paper (Zacharias & Zacharias, 2014) postulates a detrimental, astrophysical, random noise (DARN) effect on the order of 10 mas per coordinate and source, likely caused by optical structure of the host galaxies which is unresolved on the arc second scale. Part of the larger than expected radio-optical position differences can be explained by optical reference star catalog issues. However, too many sources are found to be "outliers" in the observed radio-optical position offsets of ICRF sources, correlated with redshift, leading to the DARN hypothesis supported by other, similar investigations. If confirmed, this effect will have a large impact on the Gaia to VLBI position link accuracy of a future celestial reference frame. Gaia's absolute proper motions and parallaxes should not be affected.

UCAC 4

The final USNO CCD Astrograph Catalog (UCAC4) journal paper was published (Zacharias et al., 2013). Over 60,000 astrometric and photometric observations of known double stars were extracted from UCAC4 data and 4755 new common proper motion pairs identified (Hartkopf et al., 2013).

URAT

The USNO Robotic Astrometric Telescope (URAT) continued its all-sky survey from the Naval Observatory Flagstaff Station (NOFS). By end of 2013 a total of 41,261 exposures were taken with the 4-shooter camera, each covering 28 square deg of sky. The quality control pipeline was completed and analysis of calibration data revealed astrometric performance as expected over the entire 3rd to 18th magnitude range covered by URAT. For latest information see <http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/urat>.

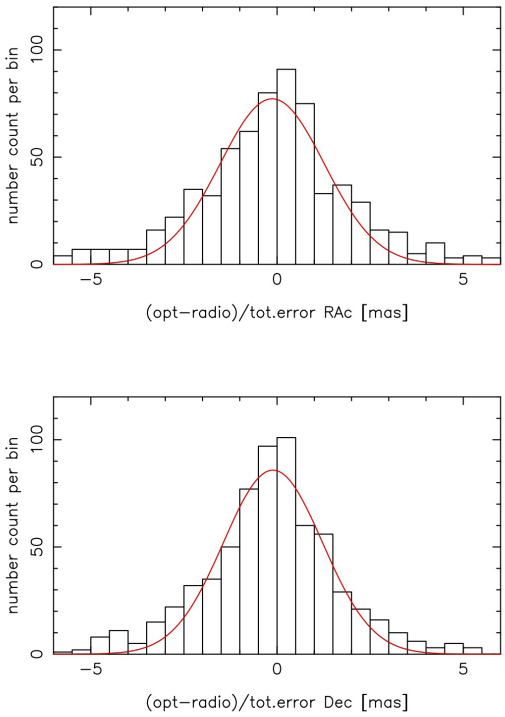

Fig 3: Histogram of the scaled (optical-radio)/ error position differences per coordinate of ICRF sources from the USNO RORF program based on CTIO 0.9m data and contemporary astrograph reference stars tied to Hipparcos via Tycho-2.The plot line represents the best fit normal distribution. A large number of "outliers" is seen. Taken from Zacharias & Zacharias, 2014, AJ 147, 95, Figure 7.

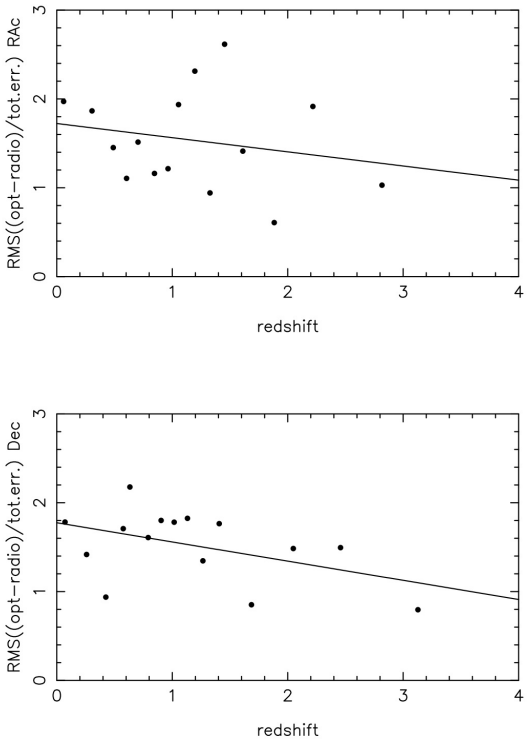

Fig 4: Optical-radio position differences divided by total formal error of individual sources (RMS over 16 offsets per dot) as a function of redshift, RA component on top, Dec at bottom, using USNO RORF program data. A correlation is seen which can not be explained by reference star catalog errors. Taken from Zacharias & Zacharias, 2014, AJ 147, 95, Figure 13.

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Oleg Titov, Norbert Zacharias

3.5.5 ITRS Centre

This report summarizes the activities of the IERS ITRS Centre during the year 2013.

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 website interface (see below).

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 online; 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 2015.

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 Website and 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.

IERS Workshop on Local Surveys and Co-locations

The ITRS Product Centre has organized the IERS workshop on local surveys and co-locations in Paris in May 21–22, 2013, at the University of Paris-Diderot. The full programme, presentations and recommendations are available at the Workshop website: <http://iersworkshop2013.ign.fr/>. See also Section 4.1 in this report.

Other activities

- Participation in most meetings of the analysis working groups of the Technique Centres (in 2013: IDS, IGS, ILRS).
- Convening and organizing EGU and AGU sessions.
- Participation in the 8th meeting of the International Committee on GNSS held in Dubai, 9 – 14 November 2013.

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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 (Collilieux 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.

The results have not yet been compiled. These will be reported on in the 2014 annual report.

As always, proposals for new GGFC provisional products are being solicited. The procedure for certifying the products requires an analysis of the latency and reliability over a two-year period. In 2014, the original two-year validation will be complete and the provisional products will be upgraded to GGFC Operational Products.

These and all other GGFC Operational and Provisional products can be found through the GGFC website: <http://geophy.uni.lu/>

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).

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3.6 ITRS Combination Centres

3.6.1 Deutsches Geodätisches Forschungsinstitut (DGFI)

In 2013, the focus of the work of the ITRS Combination Centre at DGFI was on the computation of a new common realization of the ITRS and ICRS and on the computation of epoch reference frames.

Simultaneous computation of CRF and TRF

In the annual reports of the years 2011 and 2012 the motivation for a common realization of ITRS and ICRS was given. The first solution set up, performed in the last years, included only 18 of the 24 VCS sessions. Now, a new solution was computed, including observation data of VLBI, GNSS and SLR from the individual beginning of the techniques until the end of 2010. In case of VLBI, most of the X/S sessions (4341) observed in this time span and all 24 VCS sessions are included now so that the CRF solution is more complete and comparable to ICRF-2. The computation is based on the combination of time series of constraint free normal equation systems provided by three Analysis Centres of the international technique services. Table 1 gives an overview about the input data.

Table 1: Input data for a simultaneous and consistent realization of ITRS and ICRS.

	Institution	Time span	Sessions	Number of obs.
VLBI	IGG Bonn	1980-2010	4341 (all 24 VCS) only sessions with at least 3 stations are used	7,900,328
GNSS	TUM	1994-2010	6208 (daily SINEX)	3,530,603,612
SLR	DGFI	1983-2010	1272 (weekly SINEX)	3,080,959

The combination of constraint free normal equation systems means that the original technique observations are adjusted and the input normal equations do not contain any constraint related to the geodetic datum. The orientation of the combined solution is determined by no-net-rotation conditions applied for the station network and the source positions w.r.t. respective a priori frames. The parameters determined explicitly are given in Tab. 2. Altogether, 57,032 parameters are estimated.

Parameters common to all techniques are the station coordinates and the EOP. Even, if the satellite techniques cannot provide UT1–UTC and nutation parameters in an absolute sense, these parameters are set up in the satellite normal equations in a piecewise linear representation. This means, that the satellite-only normal equations can only be solved by fixing at least one UT1–UTC

Table2: Explicit parameters of the common realization of ITRS and ICRS.

						Indirect parameters	
	station coord.	source coord.	pole	nuta-tion	UT1-UTC	origin	scale
VLBI	x	x	x	x	x		x
GPS	x		x	rate	LOD		
SLR	x		x		LOD	x	x

offset or one offset per nutation component to the a priori value or zero, respectively. However, in the combination the absolute information is provided by VLBI and constraints are not necessary.

A first solution was computed by combining VLBI and GNSS as some problems did arise with the early SLR EOP. The combination has an impact in particular on the EOP and thus indirectly also on the CRF. The combined EOP series are continuous during the satellite era and benefit w.r.t. their standard deviations and scatter. Figure 1 shows the decrease of the standard deviation of the x-component of the terrestrial pole compared to the VLBI-only solution. In particular during the early years, the standard deviations decrease even if the first GNSS data are available in 1994. This means that the whole solution benefits w.r.t. stability. A detailed analysis of the change of correlations has still to be done. The marked standard deviations related to VCS sessions do not show a special characteristic.

Figure 2 shows the results for UT1–UTC. As GNSS provides daily information on LOD only the combined series is continuous but shows a higher scatter than the VLBI-only series. Zooming into the time series of standard deviations (Fig. 3) shows that they increase for the GNSS only epochs and reach maximum values

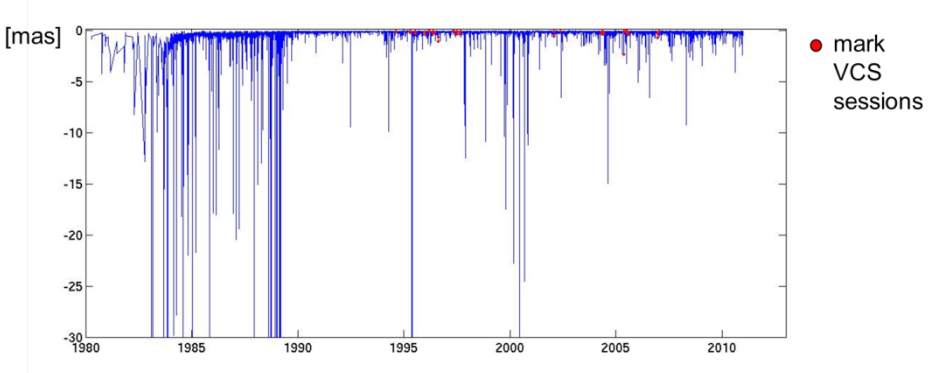

Fig. 1: Change of standard deviation of x-component of the terrestrial pole of combined solution w.r.t. VLBI-only solution.

at the epochs with the largest distance to a VLBI epoch. This behaviour underlines the appearance of a larger scatter.

Due to the decreasing of EOP standard deviations also the standard deviations of the sources decrease. Positions changes are mainly visible for VCS sources and sources observed in RDV sessions. Detailed investigations of the CRF results are still under work.

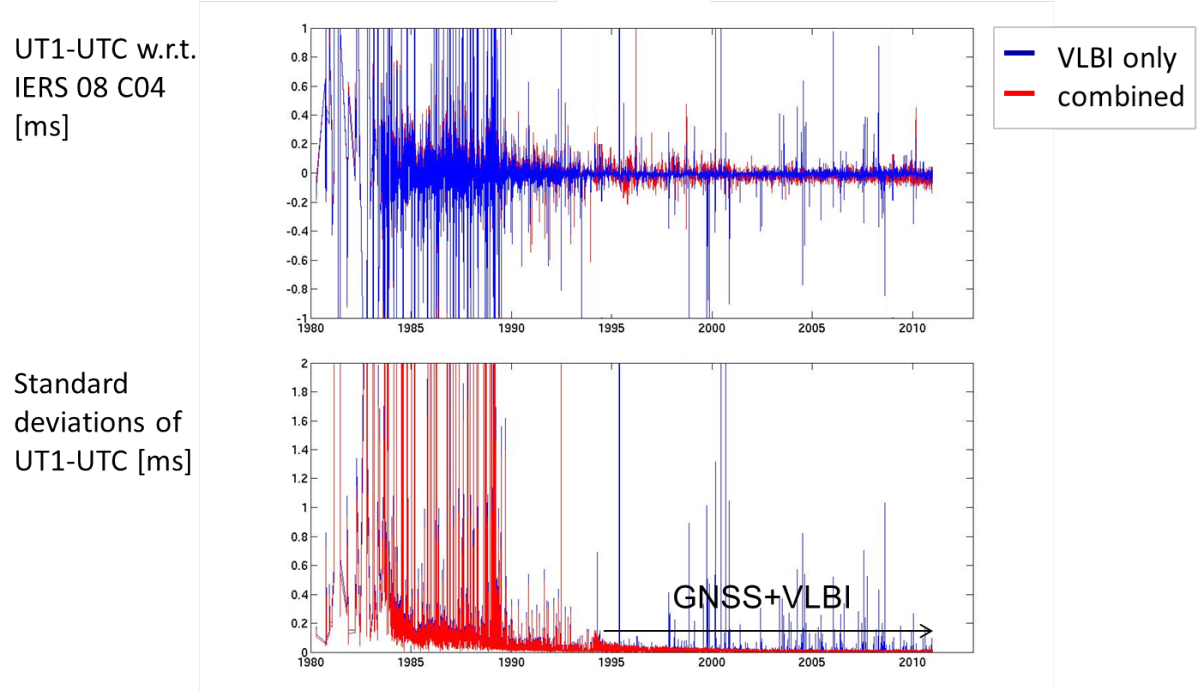

Fig. 2: UT1–UTC time series w.r.t. IERS 08 C04 (upper panel) and the related standard deviations (lower panel).

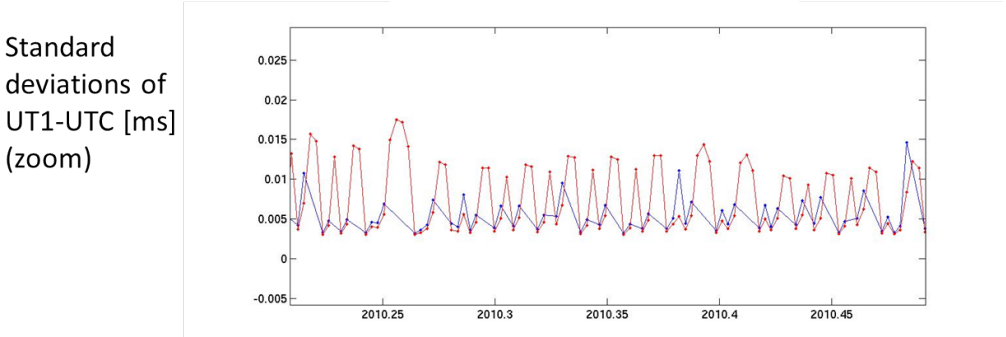

Fig. 3: UT1–UTC standard deviation time series (zoomed). Legend as in Fig. 2.

Epoch reference frames (ERFs)

Conventional global terrestrial reference system realizations take only linear variations of crust-fixed station positions into account. Non-linear station motions are handled by conventional models (e.g., Earth tides). In this kind of realizations, the instantaneous station position can only be computed if, besides other effects, the common translations (often named geocenter motion in the geodetic literature) and non-tidal atmospheric and hydrologic loading effects are modeled. Nowadays, a conventional model for the geocenter motion is still missing and also for loading not one unique conventional model is defined and applied. Furthermore, the individual station motions due to local environmental (geophysical or anthropogenic) effects are neglected, which are very hard to model.

One possibility to approximate the instantaneous station position more accurately is the frequent (e.g., weekly) estimation of station positions from an epoch-wise combination of different geodetic space techniques. These reference frames are named Epoch Reference Frames (ERFs). DGFI computed a time series of ERFs based on a homogeneous reprocessing of GNSS, VLBI and SLR using common a priori models and common parameterizations. The geodetic datum of the ERFs is realized consistently to the conventional approach: the origin is realized by SLR, the scale is realized as a weighted mean scale of SLR and VLBI and the orientation is aligned to a previous reference frame by a No-Net-Rotation (NNR) condition using a selected subnet of well-determined GNSS stations. Due to a varying global station network (especially in the case of SLR and VLBI), the datum of the weekly reference frames varies from week to week. Due to the sparse station distribution, only a subset of the available local ties can be applied. Therefore, the accuracy of the transfer of the datum information (e.g., SLR origin to GPS) is limited. Furthermore, the poor network geometries cause correlations between common station translations and rotations. Therefore, the neglected translational variations (mainly with an annual period) propagate partly into the orientation. Through the NNR condition, these variations are forced into the complementary parameters of the network orientation, the terrestrial pole coordinates. The effects of the non-linear station motions on the terrestrial pole coordinates is investigated in detail by Bloßfeld et al. (2014).

In order to stabilize the geodetic datum of the ERFs, DGFI investigated the impact of the length of the sampling interval on the datum stability and its tradeoff w.r.t. the ERF ability to monitor short-term non-linear station motions. In total, three different test time series of ERFs with a combination interval of 7-days, 14-days and 28-days have been computed and compared to a conventional reference frame based on identical input data. Figure 4 shows the translation time series in x-direction (upper plot) and the corres-

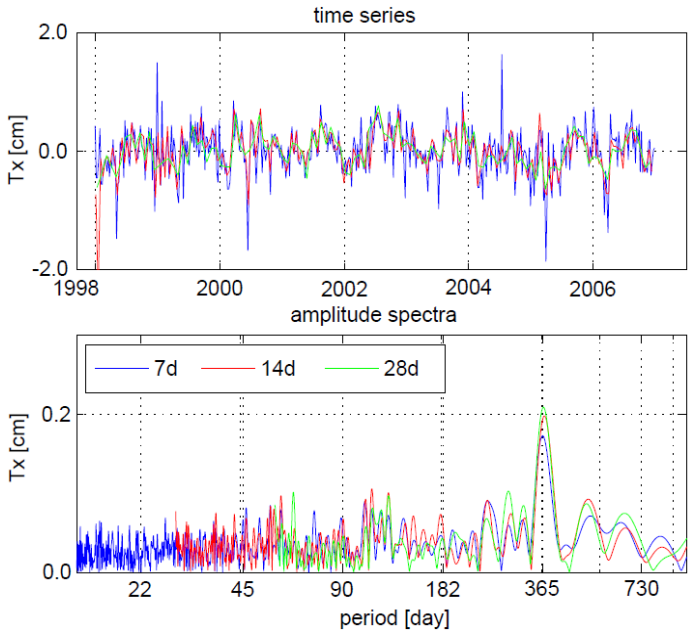

Fig. 4: Time series and spectra of x-translations of weekly (blue), 2-weekly (red) and 4-weekly (green) combined ERFs w.r.t. a conventional reference frame based on identical input data.

ponding spectra (lower plot). The scatter of the x-translations is reduced when the combination interval is enlarged. The significantly determined amplitude of the annual variation nearly remains the same for all three test time series. The obtained values for the annual amplitudes and the scatter (RMS) of the time series are summarized in Bloßfeld et al. (2015).

Besides the datum stability, also the ERF ability to monitor short-term non-linear station motions is investigated. If the sampling interval is enlarged, the ERFs are not able to monitor these variations any more. Figure 5 shows exemplarily a snapshot of the Russian GPS station Yakutsk, where the antenna is deflected due to snow coverage (local effect). Compared to the daily GPS-only time series (green), only the 7-day ERF time series (blue) is able to monitor this deflection with appropriate amplitude. The 14-day and 28-day ERFs show a smaller deflection compared to the GPS-only solution.

More details on the investigation of epoch reference frames and possible applications can be found in Bloßfeld et al. (2014) and Bloßfeld et al. (2015). The results show that a high datum stability and the absolute accuracy of the estimated parameters have to be balanced or the computation of different ERF series for different applications have to be considered.

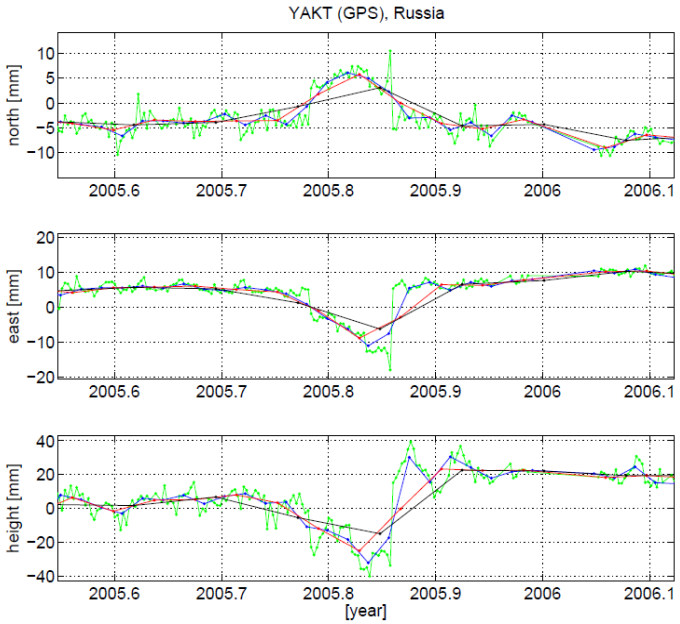

Fig. 5: Daily individual GPS-only (green) time series of the station Yakutsk (Russia). In addition, the weekly (blue), 2-weekly (red) and 4-weekly (black) individual time series of the combined ERFs are shown.

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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 2013. These research activities are mainly related to the preparation for the ITRF2013.

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 ITRF2013

Specific new developments were achieved in preparation of the ITRF2013: 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 will be submitted to the ITRF2013.

Other developments are also in progress, 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.

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3.6.3 Jet Propulsion Laboratory (JPL)

The activities during 2013 of the ITRS Combination Centre at JPL are summarized here. They consisted mainly in continuing to develop a Kalman filter for realizing terrestrial reference frames and in using the Three-Corner Hat technique to estimate the uncertainties in the observed positions of co-located space-geodetic stations.

KALREF

JPL is developing an approach based on using a Kalman filter to realize terrestrial reference frames (TRFs) from time series of observed VLBI, SLR, GNSS, and DORIS station positions and associated Earth orientation parameters (EOPs) and site ties. This KALman filter for REFerence frames (KALREF) has been used to produce a number of ITRF2005-like and ITRF2008-like reference frames using updated ITRF2005 and ITRF2008 SINEX files. Comparisons show that these frames agree with ITRF2005 and ITRF2008 at the sub-millimeter and sub-millimeter per year level.

Kalman filters are commonly used for estimating parameters of some system when a stochastic model of the system is available and when the data contain noise. For the purpose of determining a terrestrial reference frame, the system consists of the time-dependent positions and velocities of geodetic observing stations along with their full covariance matrices. The data consist of time series of observed VLBI, SLR, GNSS, and DORIS station positions along with the data measurement covariance matrices, EOPs and site ties.

KALREF includes options for constraining the stations to move linearly or to move linearly and annually. Through the use of stochastic models for the process noise, the station positions can be constrained to exactly follow this linear or linear and annual motion (by setting the process noise to zero), to exactly recover the observed station positions (by setting the process noise to a large value), or to follow a smoothed path (by setting the process noise to some intermediate value).

KALREF has been used to determine four different ITRF2008-like reference frames using three different stochastic models for the process noise: no process noise with linear motion constraint, no process noise with linear plus annual motion constraint, process noise variances based on surface geophysical fluid loading models, and large values of the process noise to exactly recover the observed station positions. Figure 1 shows the comparison of the linear frame and the linear part of the linear and annual frame to ITRF2008. As can be seen, JPL's frames agree quite well with ITRF2008, with differences in translation (T) and rotation (R) being at most 0.7 mm. The difference in scale (D) is larger because the KALREF scale is a weighted average of the SLR and VLBI scales

Transformation Parameters from Secular Combination (ITRF2008) to Weekly Combination (KALREF) Using ITRF2008 Input Data

All Data with No Annual Components

Tx (mm)	Ty (mm)	Tz (mm)	D (mm)	Rx (mm)	Ry (mm)	Rz (mm)
0.1 ± 0.2	-0.3 ± 0.2	0.7 ± 0.2	2.6 ± 0.6	0.2 ± 0.1	0.5 ± 0.1	-0.1 ± 0.1
Vx (mm/yr)	Vy (mm/yr)	Vz (mm/yr)	$\dot{D}$(mm/yr)	$\dot{R}_x$(mm/yr)	$\dot{R}_y$(mm/yr)	$\dot{R}_z$(mm/yr)
0.02 ± 0.03	-0.1 ± 0.03	0.1 ± 0.04	0.08 ± 0.1	0.0 ± 0.02	0.2 ± 0.01	-0.2 ± 0.02

All Data with Annual Components

Tx (mm)	Ty (mm)	Tz (mm)	D (mm)	Rx (mm)	Ry (mm)	Rz (mm)
-0.1 ± 0.2	-0.2 ± 0.2	0.3 ± 0.2	2.8 ± 0.6	0.2 ± 0.1	0.5 ± 0.1	0.0 ± 0.1
Vx (mm/yr)	Vy (mm/yr)	Vz (mm/yr)	$\dot{D}$ (mm/yr)	$\dot{R}_x$(mm/yr)	$\dot{R}_y$(mm/yr)	$\dot{R}_z$ (mm/yr)
0.01 ± 0.03	-0.04 ± 0.03	0.1 ± 0.04	0.07 ± 0.1	0.0 ± 0.02	0.2 ± 0.01	-0.2 ± 0.02

Fig. 1: Comparison to ITRF2008 of JPL's ITRF2008-like frames wherein the stations are constrained to move linearly (top) or to move linearly and annually (bottom).

whereas the ITRF2008 scale is a simple average of the SLR and VLBI scales. Differences in translation rate, rotation rate and scale rate are all quite small, being at most 0.2 mm/yr.

Station Position Uncertainties

The formal uncertainties of station position estimates are oftentimes overly optimistic and do not reflect the true uncertainties of the estimates. The formal uncertainties must therefore be adjusted to obtain more realistic values for the uncertainties. There are many ways of doing this including the analysis of post-fit residuals. At JPL we have explored the possibility of using the Three-Corner Hat technique to estimate the uncertainties of observations of station positions for space-geodetic stations that are co-located with each other.

The Three-Corner Hat technique allows the uncertainty of measurements to be estimated when at least three independent measurements of the same signal are available. If each measurement is modeled as the sum of a common signal and a remaining "noise" term, then forming pair-wise differences of the measurements eliminates the common signal, leaving pair-wise differences of the "noise" terms. Forming a covariance matrix of the differenced "noise" series results in an underdetermined set

of equations for the variances and covariances of the “noise”. Assuming the “noise” terms are uncorrelated with each other reduces the set of unknowns to just the variances, which can be exactly solved if three measurements are available. If more than three independent measurements are available, then the set of equations are overdetermined and can be solved by least-squares.

The Three-Corner Hat technique has been applied to measurements of the positions of GNSS, SLR, VLBI, and DORIS stations that are co-located with each other at the same site. Since the stations are co-located, they should exhibit the same geophysical motion. Pair-wise differences of the station position measurements will eliminate this common geophysical motion, leaving pair-wise differences of the uncommon, or “noise”, terms. This approach was applied to the stations at 16 co-located sites that were used when determining ITRF2008. It was found that GPS, although affected by time-correlated errors, is the most precise of the space-geodetic techniques, with median north, east, and height uncertainties of 1.1, 1.2, and 2.8 mm, respectively. The median uncertainties of the VLBI north, east, and height components were found to be 2.2, 2.0, and 6.2 mm, respectively. And the (SLR, DORIS) median north, east, and height uncertainties were found to be (8.5, 9.2), (7.6, 11.7), and (9.0, 10.6) mm, respectively.

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Richard S. Gross

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

The activity of the working group underwent a very significant moment during the Spring of 2013, when a two days workshop was organized in May in Paris (France), with a full endorsement of the IERS. The 2013 Paris workshop followed the first IERS Workshop on local tie surveying, tie vectors and co-location sites organized in October 2003 in Matera (Italy). This latter represented a very significant moment for the geodetic community and propitiated the identification of the state of the art in the procedures adopted so far and the issues to be addressed in the near future, thus tracing the path of those further initiative that have followed ever since and that are resumed by the documents, reports and presentations that have been uploaded on the IERS Working Group site (<http://www.iers.org/WGSiteSurvey>).

In Paris, during the workshop, P. Sarti announced his intention to resign from the chairmanship of the working group and asked the IERS Directing Board to gather new expression of interests for the role and to identify a new appropriate chairman.

Working Group meetings in 2013

The Paris workshop represented the main meeting for 2013 and no further meetings were actually organized during the same year. A Section dedicated to the Workshop can be found in the remainder of this Annual Report.

Working group activities

During 2013, a few working group members published peer reviewed papers regarding their investigations on topics related to the working group activities.

Kallio and Pouttanen (2013) compared and discussed the estimates of a GPS-VLBI tie vector that were obtained with three different methods (static and kinematic GPS and total station observations) at the Metsähovi observatory. The search for an accurate, flexible and time saving approach in tie vector surveying is an important issue, especially for those sites having heavy observing schedules and that require frequent re-observation of the tie vector itself. The authors also discuss the necessity to identify an effective procedure to transform the tie vector observed with total stations into the global terrestrial reference frame. They mention a few suitable methods capable of realizing an alignment of the vector from the topocentric frame to the global frame. This latter aspect represents a key issue in the provision of tie vectors for the combination of space geodetic solutions and, given the impact that wrong alignments may have on the final ITRF solution, it requires further, specific investigation.

Lösler et al. (2013) focused their attention on the survey of the reference point of the VLBI antenna in Onsala. They illustrated the potential of an indirect automated method and compared several experimental set ups. They limited their investigation to a single space geodetic reference point and focused on the repeatability of the results obtained in a topocentric frame.

Sarti et al. (2013) discussed the local stability at Medicina site and the repeatability of the GPS-VLBI tie vector, exploiting all the different local surveys carried out at the site since 2001. The different surveys were homogeneously reprocessed paying careful attention to the realization of the topocentric frame at the different epochs. Medicina sites confirms as being critical due to the unfavourable geological settings and the magnitude of the local movements that can be detected on the local ground control network pillars as well as on the tie vector itself. At site where such ample instabilities are detected, it is strictly necessary to regularly repeat the local survey and produce up to date estimates of the tie vector.

Change of WG chairmanship

P. Sarti, in view of a chairmanship that started in January 2009 and that would have soon approached a five-year duration, announced his intention to resign as chairman. He favoured a valuable and effective rotation of the WG chairmanship to bring in new ideas and energies under a beneficial turnover perspective and pure cooperative spirit.

The announcement was made during the Splinter meeting that immediately followed the Paris workshop (<http://iersworkshop2013.ign.fr/?page=program>), to ensure prompt information to a wide audience of experts and possibly solicit expression of interests for the position to be later collected and evaluated by the IERS Directing Board.

The resignation was officially presented at the IERS Directing Board held in Paris on May 25th, 2013. The IERS Directing Board decided to issue a call for interest for the chairmanship and collect the expressions of interest with the CV of the applicants at the Central Bureau for later evaluation.

The final decision on the new chairmanship was taken in September 2013. Dr. Sten Bergstrand, from the SP Technical Research Institute of Sweden, E-mail: Sten.Bergstrand@sp.se, took over the chairmanship role effectively by January 1st, 2014.

The working group web page and the documents therein reflect such alternation (<http://www.iers.org/WGSiteSurvey>).

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Acknowledgments

P. Sarti would like to thank the WG members who actively contributed to the discussions at the different meetings and by e-mails, Dr. Z. Altamimi, Dr. J. Ray and Dr. C. Abbondanza for the active feedback that had incessantly provided during his chairmanship, Dr. W. Dick of the IERS Central Bureau for his professional and prompt feedback and the IERS Directing Board members.

Pierguido Sarti

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.

We report thereafter about two meetings which were organized in 2013 and the organization of the French team GRGS to contribute to the next realization of the ITRF (ITRF2013).

5th COL Working Group Meeting held on May 3 at DGFI, Munich

The objective of the meeting was to review the work done by the various analysis and combination centers since the last WG meeting and this concerning the analysis of data over the test periods coinciding with CONT08 and CONT11 intensive VLBI campaigns. Standards defined in the previous meeting have been as far as possible adopted by the ACs. Activity reports of the different ACs (GRGS, DGFI, GFZ, ASI, TUW, and AIUB) followed by those of the Combination Centers (DGFI and GRGS) were first presented.

Presentations (in pdf) from ACs and CCs are available in the COL forum and at the IERS ftp and web sites:

<http://grgs.obspm.fr/forum/>
<ftp://hpiers.obspm.fr/iers/eop/grgs/Meetings/Munich_May_2013/>
<http://www.iers.org/WGCOL>

Discussions which took place thereafter were mainly dealing with

- EOP parameterization (3h offsets and drifts at epochs 0h, 3h, 6h, …)
- SINEX file compatibility
- Weighting of the various techniques in the combination
- Results comparison strategy

COL Working Group Meeting held on October 2 at Paris Observatory, France

This meeting was mainly attended by GRGS members and concerned particularly its contribution to the ITRF2013 project. The next realization of ITRF, ITRF2013 will be provided in the course of the year 2014 or in the early 2015. The Call for Participation focused mainly on results obtained by the Technical Centers associated with geodetic techniques (IVS, ILRS, IDS, and IGS). Results deriving from combinations of techniques at the observational level are not supposed to be taken into account in the combination of ITRF2013; they only will be compared to the ITRF2013 realization

in a second step. GRGS is participating in this project. 12 years of combined weekly normal equations will be provided. An action list was written and distributed to each group processing the various technique observations (LLR/SLR, VLBI, GPS and DORIS). The following technical items were discussed during the meeting:

- 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 2013 (this will not be achieved for all technical)
- List of stations DOME
- 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 ITRF2013

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 2 shows the different techniques delivered by the GRGS Analysis Centers and their contribution to this campaign. Table 3 shows the parameters to be considered for this comparison campaign and their a priori values

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 inconsis-

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

tencies 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

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

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

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

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

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 Equation 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 2014.

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3.7.3 Working Group on SINEX Format

The IERS Working Group (WG) on SINEX Format was established in early 2011, with a kick-off meeting during EGU General Assembly 2011 in Vienna and a follow-on meeting during EGU General Assembly 2012 also in Vienna. The agenda and the minutes of the WG meetings are available on the website together with the Charter of the Working Group <http://www.iers.org/WGSINEX>.

WG Members

The list of WG members was changed only slightly during 2013: Bernd Richter handed over the Lead of the IERS Central Bureau to Daniela Thaller. And Axel Nothnagel handed over the IVS Analysis Coordination to John Gipson (NASA Goddard Space Flight Center).

- Chair: Daniela Thaller
- IERS Analysis Coordinator (ex officio): Tom Herring
- IERS Central Bureau (ex officio): Daniela Thaller (replacing Bernd Richter)
- IDS Analysis Coordination: Laurent Soudarin
- IDS Combination: Guilhem Moreaux
- IGS Analysis Center Coordination: Jake Griffiths
- IGS Reference Frame Working Group: Paul Rebischung
- ILRS Analysis Coordination: Erricos Pavlis
- ILRS Combination: Cecilia Sciaretta
- IVS Analysis Coordination: John Gipson (replacing Axel Nothnagel)
- IVS Combination: Sabine Bachmann
- ITRS Center and ITRS Combination Center at IGN: Zuheir Altamimi
- ITRS Combination Center at DGFI: Manuela Seitz
- IERS Co-location Working Group: Pierguido Sarti
- IERS Conventions Center: Gérard Petit
- GGOS Bureau for Standards and Conventions: Peter Steigenberger

Revision of SINEX Format

The block for documenting any discontinuities at site positions, e.g. after Earth quakes or equipment changes, is still under discussion and development. IGN (Institut Géographique National) is working on the definition of such a block. The work is embedded in the generation of the new ITRF2013 which is thought to provide a much better handling of non-linear station motions and station position discontinuities.

In the framework of the IERS Retreat held in Paris on May 23–24, 2013 some aspects related to the SINEX format came on the table:

- Discontinuities in station position time series: a proposal how to handle this information in the SINEX format will be provided by IGN (see above);
- Non-linear station motions: The parameterization of non-linear station motions is not independent of the question how to handle and parameterize station discontinuities. Therefore, both requests will be handled together, and a proposal will be provided by IGN, too (see above);
- Loading corrections: The ongoing discussion whether loading due to mass variations within the geophysical fluids (i.e., atmosphere, oceans and hydrology) should be taken into account directly on the observation level or at the parameter level brought up the request that the loading corrections have to be provided along with the solution itself. Therefore, an extension of the SINEX format with a block containing the loading correction for each station is needed. The mean corrections have to be stored with the valid time interval for each individual station. A distinction should be made between the contributors atmosphere, oceans and hydrology. Additionally, it is worth to distinguish between the tidal and non-tidal part. BKG is working on the definition of a SINEX block for loading corrections.

Additional requests for modifications in the SINEX format came from the IVS:

- The parameterization of Earth Orientation Parameters (EOPs) is not unambiguously defined in SINEX, i.e., constant offsets and a piece-wise linear polygon parameterization are not distinguishable. The discussion on this topic is lasting already quite some time (see previous IERS Annual Report 2012). A final decision was not yet taken.
- As the IVS is now providing source positions within the SINEX files, additional information related to the radio source estimates are needed: time interval and mean (or median) epoch for observations to each radio source, i.e., a block similar to the SOLUTION/EPOCHS block that is used for the ground stations.
- A statistics on number of observations (or sessions) contributing for each radio source position is suggested by the IVS. This kind of information is desired as a quality measure for the estimated source positions. A specific format of such a block (OBSERVATION/STATISTICS) was not yet provided, and the open point in the discussion is whether the block could / should be generalized for other parameters.

Daniela Thaller (on behalf of all WG members)

3.7.4 Working Group on Site Coordinate Time Series Format

The Working Group is now 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).

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>.

Laurent Soudarin

4 IERS Workshop and Retreat

4.1 Workshop on Local Surveys and Co-locations

The Workshop was organized by the IERS with a strong support of the ITRS Centre of the Institut National de l'Information Géographique et Forestière (IGN) at the Laboratoire de Recherche en Géodésie (LAREG) headquarter located at the University Paris-Diderot (<http://iersworkshop2013.ign.fr>). It took place on May 21–22, 2013, right before the IERS Retreat and the IERS DB meeting that took place in the following days.

The workshop was organized in three main thematic sessions, eventually divided in 6 working slots on i) Site survey and computation (two slots), ii) Tie vector surveying, guidelines and specifications, iii) Space geodesy instrumentations and their systematic biases, iv) Technique systematic errors and v) Combination of space geodesy solutions and local ties.

A total of 46 participants (<http://iersworkshop2013.ign.fr/?page=participants>) contributed to the excellent scientific presentations and discussions that took place during the workshop. A total of 25 talks were scheduled over the two days workshop (<http://iersworkshop2013.ign.fr/?page=program>) and their abstracts can be downloaded at the workshop web page, following the proper link available at the workshop's programme page.

The workshop represented an excellent opportunity for space geodesy specialists, surveyors, engineers and students to discuss the main topics still unsolved in local tie surveying, tie vector estimation and the combination of space geodetic solutions. The discussion was further enhanced by a splinter meeting organized at the end of the scientific sessions of the workshop. The meeting represented an opportunity to debate the details of the local site surveying approaches, data reduction and analysis, tie vector estimation, data storage and exchange options. Tie vector ancillary data such as local values of the deflection of the vertical, geoidal undulations, ancillary and episodic local GPS surveys and others were also taken into consideration and their saving options discussed with the purpose of identifying a suitable set of metadata that can form a real, permanent, open access repository with standardized format and entries.

During the discussion, many surveyors agreed on the complications introduced by site-dependent features (e.g. radomes over space geodetic instruments, intervisibility and separation of space geodetic instruments, geological settings, local ground control network peculiarities) that often demand *ad hoc* solutions to be adopted locally and prevent the identification of standardized methods and guidelines having a general validity. The identification of standards and guidelines further complicates when terrestrial

observations are concerned (e.g. triangulation, trilateration, levelling) since terrestrial surveying approaches also strongly depend on the expertise and habits of the surveying crews.

Finally, the discussion clearly highlighted that a stronger cooperation between surveyors and space geodesy experts and data analysts is required. Consequently, the working group should incessantly pursue this action keeping in mind that scientists involved in the compound process of terrestrial system realization should be aware and understand each of the different step required: tie vector surveying and estimation, space geodetic data analysis and combination of solutions. It should be made extremely clear that coarse and careless procedure in one of the different steps may affect the final frame accuracy.

Pierguido Sarti

4.1 IERS Retreat

Dates: Thursday/Friday, May 23–24, 2013
Location: University Paris-Diderot, 35 Rue Hélène Brion, Paris, France

Session 1: Move towards "real-time" products

Move towards "real-time" products (products that support low latency (1-sec) applications of geodetic data; eVLBI incorporation). The theme to be addressed here is the need for low latency high accuracy EOP for the real-time GNSS applications, e.g., in Geoscience, being developed. A current trend in these applications is the use of precise point positioning methods. As opposed to differential positioning, the PPP methods need to define the terrestrial reference frame through the orbits and clocks of the GNSS satellites. Currently this is a challenging task in the GNSS community and this session will examine how to best deploy IERS resources to achieve these aims.
Organizers: Harald Schuh and Jens Wickert

Discussion items:
Initial part of the sessions and the presentations focused on the evolution of systems eVLBI, GNSS real-time and the potential interaction between these two systems. IVS performance improvements are expected in terms of geodetic parameters estimated as the VLBI2010 systems are deployed. With these new systems there is the potential for multi-station 1-hr solutions of EOPs in near real-time. Currently the ILRS has a two-day latency for EOP estimates but 95% of data are available within one hour and the possibility of developing a near real-time SLR EOP product could be investigated. The discussion also suggested that there is the potential for significant improvements to near real-time UT1 determination by combining IGS ultra-rapid polar motion values and VLBI intensives. Berne and BKG have plans to investigate the gains from a GNSS/VLBI coupled analyses.

It was also decided that there should be an assessment of the IGS requirements for real-time EOP to allow real-time precise-point-positioning (PPP) with millimeter accuracy. The IGS real-time service could potentially return accurate EOP in real-time and the IGS should be asked to look at this possibility. This new product type will require a data format that allows for real-time dissemination.

For the daily VLBI intensive sessions, there are concerns about poor EOP estimates due to the short duration (1h) and different baselines involved affecting the EOP predictions made by the IERS Rapid Service/Prediction Center.

Recommendations and studies:

(1) Assess accuracy and latency of near real-time eVLBI and SLR EOP products.
(2) Carry out studies into the potential improvements in EOP products through coupled VLBI/GNSS analyses.
(3) Assess the sensitivity of real-time GNSS results to EOP prediction errors.
(4) Start investigating a possible data format and dissemination method for real-time EOP products.

Session 2: Rigorous combined products

Rigorous combined products (e.g., services are generating EOP and terrestrial RF simultaneously; IERS is simply averaging EOP values). This topic is considered critical to the future of the IERS and will occupy two sessions because of its great impact potentially on the service. Of importance here is the consideration of inclusion of both the terrestrial (ITRF) and celestial reference frames (ICRF). The discussion here will focus on how to assess the need for rigorous combination, how best to achieve such combinations, and how to determine whether we need to proceed with such techniques. This session will be divided into two basic discussions. One will deal with the long-term product generation, the combined ICRF and ITRF product, and the other discussion will focus on the day-to-day generation of IERS products. The implementation of a rigorous combination approach also has major impact on the services contributing to the IERS and the path forward will need to establish the impact on the services as well. It will also need to be established how we blend pre-spaced geodesy measurements with the conventional astronomical ones. This session was allotted two time slots.
Organizers: Zuheir Altamimi, Manuela Seitz and Richard Biancale

Discussion items:

ICRF consistency issues (adherence to IAG/IAU resolutions):
The issue was raised whether the ICRF is consistent with the ITRF and EOPs. One question that needs to be addressed is: are radio sources needed in operational generation of ITRF. The consensus of the discussion was that the ICRF is decoupled enough from the ITRF that radio sources do not need to be included but this question should be more fully addressed. ICRF working group should clarify issues associated with consistency implementation and quantify level of consistency needed. Additional studies evaluate impact of using polar motion from IGS instead of IVS when the ICRF is determined. The impact on estimates and sigma should be quantified. Groups that can do these studies are encouraged to do this.

Rigorous combination for day-to-day EOP determination:
Rapid service: Consensus was that the rapid EOP estimates are generated with such slow latency (4-times per day, 10 minute run times) that not enough time (with current systems) would be available for a rigorous SINEX-based approach to be used in their generation. For the non-rapid EOP estimates, the Earth Orientation Center should evaluate the impact of rigorous combination. An initial study would compare C04 and ITRF recovered EOP during the over lap period.

Alignment of EOP series:
The discussion showed that there was a need for better analysis and reporting of biases between techniques to see how large they are currently with all techniques using ITRF2008. The VLBI Intensives could have more consistent biases because a single baseline is used as opposed to 24-hr VLBI sessions, which use different stations on different days (impact on biases is likely to be from non-linear station motions). The most appropriate source for polar motion values for analysis of the intensives (e.g., fixed to Bulletin-A) should be determined. There should be a study to evaluate the impact of adding GPS gradient and atmospheric delays to the analysis of the VLBI intensives to how this processing effects biases and noise in the intensive UT1 estimates. There are differences between IGS ultras and finals EOP and these differences cause problems with blend in the rapid products. The magnitude and origin of these differences between final and ultra EOP estimates should be looked at IGS.

Combination at observation level (COL):
Progress has been slow in the implementation of combinations at the observation level (COL). The sense was that progress will continue to be slow. A clear summary of the impact of observation level combinations (mainly common tropospheric parameters, orbits for altimeter satellites) would be useful. There was a suggestion that ITRF2013 submission of COL solutions should be compared to regular ITRF solutions to allow an assessment of the potential of COL improvements over current combination methods.

Recommendations and Studies:

(1) The ICRF working group to clarify consistency implementation and quantify level of consistency needed.
(2) Earth Orientation Center should evaluate the impact of rigorous combination of EOP estimated using a SINEX/ITRF based approach. An initial study could be carried out comparing C04 with the ITRF2008 EOP estimates during the overlap interval.

(3) There should be a study to evaluate the impact of adding GPS gradient and atmospheric delays to the analysis of the VLBI intensives to how this processing effects biases and noise in the intensive UT1 estimates.
(4) The magnitude and origin of the differences between final and ultra EOP estimates should be looked at IGS.
(5) ITRF2013 submission of COL solutions should be compared to the regular ITRF solutions so that an assessment of the potential of COL improvements to the combined results.

Session 3: Long-term stability and parameterization of the reference frame

This session will address how to parameterize the ITRF. With the GGOS aims of defining an ITRF accurate to 1 mm and 0.1 mm per year, serious consideration has to be given to precisely how to define such a system when there are unknown non-secular components to the motions of all of the ITRF sites. The session will outline the steps that need to be taken in understanding how to incorporate such phenomena as earthquake co-seismic and post-seismic deformations, anthropogenic and natural loading phenomena, and other deviations from secular motion. Also to be addressed is how to approach the appropriate parameterization of variations in the ICRF. Consideration of source structure variation and source evolution needs to be addressed. The impact on the services will need to be assessed.
Organizers: Xavier Collilieux and Daniela Thaller

ITRF parameterization:
There was consensus that there needed to be consistency between the different technique analyses in the parameterization of the ITRF especially in terms of breaks due to earthquakes even if it is not clear for some techniques that they are able to directly detect these effects (e.g. jumps due to earthquakes and anthropogenic effects). As a treatment for non-linear site motions (other than simple offsets), it was decided that these sites would not be included in the ITRF solution but that they would be retained in the time series analysis. The ITRF reference sites would be limited to sites with largely linear motion and a few as possible offsets in the time series. The parameterization need to be consistent between techniques and the users must understand the nature of these parameterizations. New parameterizations for SINEX (e.g. log post-seismic functions) will be needed and these should be developed in consultation with the SINEX WG. Mean loading corrections, atmospheric and hydrologic, should be added to the SINEX file and the method through which this is done needs to be defined (SINEX WG). The IERS GGFC should compare existing loading models to assess the level of difference between the different centers.

There needs to be a discontinuities analysis to assess which equipment generates the best geodetic result. These studies would focus mainly on GNSS and DORIS sites (less so for the later which are better controlled). The IERS should request the IGS examine antenna effects and assess the level of systematic phase residuals at GNSS site.

There was consensus that methods should be developed to allow easy access position residuals from the individual centers contributing to the ITRF combinations. The technique center (TC) and analysis centers (ACs) should examine this from each of the techniques. Ideally overlaying results from different techniques and different analysis centers within the same technique should be easily done by uses.

Recommendations and Studies:

(1) New parameterizations for SINEX (e.g. log post-seismic functions) will be needed these should be developed in consultation with the SINEX WG.
(2) Methods of incorporating mean loading models should be studied by the SINEX WG.
(3) The IERS GGFC should compare existing loading models to assess the level of difference between the different centers and report back the community on the outcome of these studies.
(4) The IERS should request the IGS examine antenna effects and assess the level of systematic phase residuals at GNSS site.
(5) Developed methods to allow easy comparison of time series from different analysis centers and techniques contributing to the ITRF.

Session 4: Next Generation of models and Center-of-Mass products

How to establish need (improvements needed in diurnal/semi-diurnal EOP, tidal loading)? This session will address the types of model updates that should be included in the IERS conventions, and how to determine the need for these updates. The inclusion of new IERS products such as a center of mass product will also be discussed. Models and new products should also consider the celestial component of the reference systems as well.
Organizers: Tonie van Dam and Richard Gross

Studies should be carried out to determine at your center motion model that can be used to relate the center of figure the center of mass. It was not clear that such a model can be generated but such models are being developed on at the moment. The GGFC should review current status of these models. LEO orbits are effected by these motions. The IERS Conventions Center is

currently developing this class of model. Much of the discussion focused on the need for careful bookkeeping so that processes are not accounted for twice. These analyses apply loading corrections and center of mass variations are both considered.

The current models used for polar motion and UT1 diurnal and semidiurnal variations still need improvement (ocean current contribution). There was discussion on how to best combine oceanographic models with geodetic measurements of these diurnal and semi diurnal variations. There was concern of potential aliasing effects, particularly arising from GNSS estimates of these variations.

Further analysis is also needed of long period and/or secular motion of the Z-component of center of mass than has been observed. The interpretation of cause of the secular motion is not clear currently (curvature over 20-years in similar to annual amplitude).

The model for long period motion of the mean pole for use in the pole tide correction needs updating for recent mean pole deviation. The historical motion is based on observed polar motion but the prediction into the future is always a simple linear trend. As data Is collected the models need to be updated. A method for systematically doing these updates should be developed. The mean pole motion issue is also related to C21/S21 changes with time that also need to be incorporated into orbit determination.

Recommendations and Studies:

(1) The GGFC in coordination with the convention center should review current status of models of the relative motion between the center of mass and center of figure.
(2) Develop methods for improved diurnal and semidiurnal models of EOP variations with particular attention paid after blending oceanographic and geodetic measurements while minimizing potential aliasing effects.
(3) Assess quantitatively the secular motion of the center of mass of the Earth relative to center of figure and investigate possible origins of such motion.
(4) Establish methodologies for treating the secular motion uphold and its consequence to the pole tide correction.

Session 5: EOP prediction improvements

This session will address the need for EOP prediction accuracy and how best to achieve these accuracies and determine the timescales over which predictions need to be made. The uses of these prediction products will also need to be determined and their requirements established.

Organizers: Brian Luzum and Christian Bizouard

Many issues were raised in this session concerning how to best deliver real-time EOP estimates and predicted values. There needs

to be developed a real-time transfer data protocol that can be used in the future. The current flat ASCII file formats will not work. There should also be greater emphasis on machine readability of the files.

There was a general sense but for improved predictions they should be reduced latency to the last data point and this last data point should have the highest accuracy possible. Some improvement in EOP prediction would be possible improved AAM and OAM update schedules i.e., updates with 6 hour versus 24 hour latency. The GGFC will be asked to look into these rapid updates.

Studies should be carried out to examine the being in prediction accuracy by using ensemble averages of different prediction algorithms that already exist. Initial studies into such averages suggest that the ensemble would perform better dent the individual series.

One aspect of long-term predictions is there potential application to estimating when leap seconds will be needed. The possible impacts of not correctly predicting when a leap second will occur should also be investigated.

Recommendations and Studies:

(1) Develop formats that would be appropriate for real-time delivery of EOP values.
(2) In collaboration the DG FC, investigate the improvement expected in prediction values by using more frequent AAM and OAM updates.
(3) Study the benefits of ensemble averaging of current prediction.

Session 6: Unification of product formats

This session will cover two broad areas. One will be the unification of the IERS product formats to allow easy comparison and combination. The other area will be establishing modern standards for product formats such as the metadata content and how to express that. The target products here are the EOP products that are used by wider IERS community.
Organizers: Thomas Herring and Laurent Soudarin

Benefits of common formats and data types to be included were discussed. For the IERS there are several data products that could benefit from common formats. Primary among these are position time-series and EOP estimates.

For EOP series: Polar motion rate estimates (LOD is already present) are not in every analysis. When rates are included, correlation between epoch value and rate should be included and this would allow effective mean epoch of pole determination to be determined. The distribution of data within the interval of the EOP determinations is an issue DORIS and SLR and this knowing the effective epoch of the determination would allow more

accurate comparison of results. VLBI and GNSS data tend to be more uniformly collected during the interval over which EOPs are determined but even for these techniques, correlation estimates would be useful.

Date style and resolution: Currently dates are given on day boundary and this will need to change for higher temporal resolution EOP and time systems (UTC vs GPST).

The contents of the EOP files for different systems (e.g., rapid, Bulletin B and C04 and between the different geodetic techniques are the same. Not all EOPs are available for all systems and this makes comparison more difficult. Use of a common format and content for input series and combined EOP would allow easy comparison of the input series from different techniques with the final combined products. Consideration should be given to evolving the formats to web 2.0 standards to allow web service access and analysis of data.

The leap second file should be made available in a machine-readable form. Paris Observatory has such files but these can not be found on the Leap second page of the Paris Observatory web site <http://hpiers.obspm.fr/eop-pc/index.php?index=leapsecond&lang=en>.

There was discussion of a common position time series format but the IERS and IAG already have a working group developing this format and investigating methods for web access to these files (including graphical presentations).

Recommendations and Studies:

(1) The IERS AC along with the ACC for each of the techniques contributing to the IERS should determine a mutually acceptable common format for EOPs. This format would be in addition to existing formats that users are familiar with.
(2) Work should start on developing web 2.0 based standards for EOPs (XML format)
(3) A machine-readable leap second format should be made available as soon as possible.
(4) The IERS working group on developing a position time series format should continue its activities.

Session 7: Mechanisms for IERS evolution

The aim of this session is to provide a mechanism for evolving the IERS as time goes on and needs change. During the last retreat, over a decade ago, new components of the IERS were established. Since then these components have stayed in place and there is no formal mechanism for changing the components of the IERS. This session will look at how best to establish such procedures so that the IERS can evolve more quickly between retreats.
Organizers: Bernd Richter and Chopo Ma

Recommendations and Studies:

(1) Current terms of reference were reviewed and update to these will need to be addressed by the DB.

Tom Herring

Appendix 1: IERS Terms of Reference

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

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

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

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

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

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

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

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

The IERS accomplishes its mission through the following components:

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

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

TECHNIQUE CENTERS (TC)

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

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

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

PRODUCT CENTERS (PC)

PCs are responsible for the products of the IERS.
Such centers are the following:

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

ITRS COMBINATION CENTER(S)

ITRS Combination Center(s) are responsible to provide ITRF products by combining ITRF inputs from the TCs and others. Such products are provided to the ITRS Center.

RESEARCH CENTER(S)

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

IERS ANALYSIS COORDINATOR (AC)

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

The AC is elected by the DB for a term of four years with the possibility of re-election for one additional term. The responsibility of the AC is to monitor the TC and PC activities to ensure that the IERS objectives are carried out. This is accomplished through direct contact with the independent TC Analysis Coordinators and PC chairs or equivalent. Specific expectations include quality

control, performance evaluation, and continued development of appropriate analysis methods and standards. The AC interacts fully with the Central Bureau, the Product Centers and the Combination Research Center(s).

CENTRAL BUREAU (CB)

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

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

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

DIRECTING BOARD (DB)

The Directing Board consists of the following members:

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

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

- One representative from each Product Center.
- Representative of the Central Bureau.
- IERS Analysis Coordinator.
- Representatives of IAU, IAG/IUGG and GGOS.

The Chairperson is one of the members of the DB elected by the Board for a term of four years with the possibility of re-election for one additional term. The Chairperson does not vote, except

in case of a tie. He/she is the official representative of IERS to external organizations.

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

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

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

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

WORKING GROUPS

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

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

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

- Draft charter clearly specifying:
  - Proposed goals (two pages at maximum),
  - Proposed structure of the group or project,
  - Working plan including schedule / deadlines including the anticipated end of work,
- Candidate for a chairperson to be appointed by the DB (optional),

- Initial list of members,
- Proposed plans for an operational phase (if applicable),
- Draft IERS message to inform the IERS community.

IERS ASSOCIATE MEMBERS

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

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

IERS CORRESPONDENTS

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

October 10, 2010

Appendix 2: Contact addresses of the IERS Directing Board

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

Central IERS web site

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

Products

For a complete list of all IERS products see <www.iers.org/products>.

Earth orientation data

Rapid data and predictions
Web access:
http://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:
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Special Bureau for Hydrology
Web site: http://www.csr.utexas.edu/research/ggfc/
Special Bureau for the Atmosphere
Web site: http://www.aer.com/scienceResearch/diag/sb.html
Special Bureau for Combination
Web site: http://geophy.uni.lu/

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	International Laser Ranging Service (ILRS) Web site: http://ilrs.gsfc.nasa.gov/
	International VLBI Service (IVS) Web site: http://ivscc.gsfc.nasa.gov/
	International DORIS Service (IDS) Web site: http://ids-doris.org/
ITRS Combination Centres	**Deutsches Geodätisches Forschungsinstitut (DGFI)** Web site: http://www.dgfi.badw.de/index.php?id=122
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	Jet Propulsion Laboratory (JPL) Web page: http://www.iers.org/ITRSCC-JPL
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	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
ACC	[IGS] Analysis Center Coordinator
AGN	Active Galactic Nucleus [or Nuclei]
AGU	American Geophysical Union
AICAS	Astronomical Institute, Academy of Sciences of the Czech Republic
AIUB	Astronomical Institute, University of Bern
ANTEX	Antenna Exchange [format]
AOB	Astronomical Observatory of Belgrade
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)
AVISO	Archiving, Validation and Interpretation of Satellites Oceanographic data
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
Caltech	California Institute of Technology
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
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
CRF	Celestial Reference Frame
CSR	Center for Space Research, University of Texas
CTIO	Cerro Tololo Inter-American Observatory
CV	Curriculum Vitae
DARN	detrimental, astrophysical, random noise
DB	Directing Board
DBE	digital backend
DC	District of Columbia
Dec	declination
deg	degree
DGFI	Deutsches Geodätisches Forschungsinstitut
DiFX	Distributed FX
DIODE	DORIS real time on-board orbit determination
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
DPAC	Data Processing and Analysis Consortium
DPOD	DORIS terrestrial reference frame for precise orbit determination

DTRF	ITRS realization by DGFI
DUT1	= UT1–UTC
ECMWF	European Center for Medium Range Weather Forecasting
EGU	European Geosciences Union
EMR	Energy, Mines and Resources Canada (replaced by NRCan)
ENVISAT	Environmental Satellite
EO	Earth orientation
EOC	Earth Orientation Centre
EOP	Earth Orientation Parameters
EQ	earthquake
ERF	epoch reference frame
ESA	European Space Agency
ESOC	European Space Operations Center, ESA
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EVGA	European VLBI [Group] for Geodesy and Astrometry
eVLBI, e-VLBI	Electronic transfer VLBI
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FNMOC	[US Navy] Fleet Numerical Meteorology and Oceanography Center
FTP, ftp	File Transfer Protocol
GA	General Assembly
GAOUA	Main Astronomical Observatory of the Ukrainian Academy of Sciences
GB	Governing Board
Gbps	Gigabit(s) per second
GCRF	Gaia Celestial Reference Frame
GCRS	Gaia Celestial Reference System
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
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
GLO	= GLONASS
GLONASS	GLObal'naya NAvigatisionnay Sputnikovaya Sistema [Global Orbiting Navigation Satellite System, Russia]
GMES	Global Monitoring of Environment and Security
GNSS	Global Navigation Satellite System
GOP	Geodetic Observatory Pecny
GPS	Global Positioning System
GPST	GPS Time
GRACE, GRGS	Groupe de Recherches de Géodésie Spatiale
GSC	GSFC Analysis Center
GSFC	Goddard Space Flight Center
GS	Gemini South [telescope]
GSI	Geographical Survey Institute
HAM	Hydrological Angular Momentum
HCRF	Hipparcos Catalog Reference Frame
HEO	High Earth Orbiter
hr	hour, hours
IAA	Institute of Applied Astronomy, St. Petersburg
IAG	International Association of Geodesy
IAU	International Astronomical Union
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

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)
INT	Intensive [VLBI session]
IPGP	Institut de Physique du Globe de Paris
IRIS	International Radio Interferometric Surveying
ISO	International Organization for Standardization
ISRO	Indian Space Research Organisation
ISSI	International Space Science Institute
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
ITU	International Telecommunication Union
IUGG	International Union of Geodesy and Geophysics
IVOA	International Virtual Observatory Alliance
IVS	International VLBI Service for Geodesy and Astrometry
IVTW	International VLBI Technology Workshop
JADE	JApanese Dynamic Earth observation by VLBI
JPL	Jet Propulsion Laboratory
KALREF	Kalman filter for Reference frames
KASI	Korea Astronomy and Space Science Institute
KVN	Korean VLBI Network
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
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
LS	least-squares
MAO	= GAOUA
mas	milliarcsecond(s)
μas	microarcsecond(s)
MCC	Russian Mission Control Centre
MCT	Ministério da Ciência e Tecnologia, Brasília
MeO	Métrologie Optique [Grasse SLR /LLR system]
MERIT	Monitoring Earth Rotation and Inter-comparison of Techniques
MGEX	Multi-GNSS Global Experiment
MIT	Massachusetts Institute of Technology
MJD	Modified Julian Day
MLRO	Matera Laser Ranging Observatory
MPIfR	Max-Planck-Institut für Radioastronomie / Max Planck Institute for Radio Astronomy
ms	millisecond(s)
μs	microsecond(s)
NASA	U.S. National Aeronautics and Space Administration
Nat.	National, Nacional
NAVGEM	[U.S.] Navy Global Environmental Model
NCEP	U.S. National Centers for Environmental Prediction
NEQ	normal equation
NGS	U.S. National Geodetic Survey
NGSLR	[NASA's] Next Generation SLR
NNR	No-net-rotation
NOAA	U.S. National Oceanic and Atmospheric Administration
NOFS	[U.S.] Naval Observatory Flagstaff Station
NOGAPS	[U.S.] Navy Operational Global Atmospheric Prediction System
NOT	Nordic Optical Telescope
NP	SLR normal point(s)
NRAO	[U.S.] National Radio Astronomy Observatory
NRCan	Natural Resources, Canada (formerly: EMR)
ns	nanosecond(s)

NSF	US National Science Foundation
NT	non-tidal
NT-ATML	non-tidal atmospheric loading
NTP	Network Time Protocol
NTT	New Technology Telescope
OAM	Oceanic Angular Momentum
OB	Observatoire de Bordeaux
Obs.	Observatory, Observatoire
OHIG	O'Higgins [station]
OHP	Observatoire de Haute Provence
OP, OPA	Observatoire de Paris
OPAR	Paris Observatory IVS Analysis Center
ORB	Observatoire Royal de Belgique
PC	Product Centre
PCV	Phase-Center Variations
PKS	Parkes Radio Sources
PLATO	Performance Simulations & Architectural Trade-Offs
PM	Polar Motion
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})
PPP	Precise Point Positioning
PSF	point spread function
PUL	Pulkovo Observatory
PZT	Photographic Zenith Tube [*or* Telescope]
QRFH	Quadridge Feed Horn
QSO	Quasi-Stellar Object [*or* quasar]
QZSS	Quasi-Zenith Satellite System
RA	right ascension
RAEGE	Red Atlantica de Estaciones Geodinamicas y Espaciales
RAM	Random-Access Memory
R&D	Research and Development
RDBE	ROACH Digital Backend
RDV	Research and Development (sessions) with the VLBA
REGINA	Regional glacial isostatic adjustment and CryoSat elevation rate corrections in Antarctica
RF	Reference Frame
RFI	radio frequency interference
RINEX	Receiver INdependent EXchange format
rms, RMS	Root Mean Square
ROACH	Reconfigurable Open Architecture for Computing Hardware
RORF	Radio Optical Reference Frame
RRFID	USNO Radio Reference Frame Image Database
RS/PC	IERS Rapid Service/Prediction Center
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
sec	second(s) [of time]
SGP	Space Geodesy Project
SINEX	Solution (Software/technique) INdependent EXchange Format
SIO	Scripps Institution of Oceanography
SLR	Satellite Laser Ranging
SNR	signal-to-noise ratio
sq.deg	square degree
SSA	South Atlantic Anomaly
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	technical committee
TC	Technique Centre
TE	Temps des éphémérides / Ephemeris time
TJO	Telescopi Joan Oró
TN	[IERS] Technical Note
ToR	Terms of Reference
TOW	Technical Operations Workshop
TRF	Terrestrial Reference Frame

TT	Terrestrial Time
TU	Technical University
TUM	Technical University of Munich
TUW	Technische Universität Wien (Vienna University of Technology)
U.	University
UCAC	USNO CCD Astrograph Catalog
UK	United Kingdom
UMBC	University of Maryland, Baltimore County
UN	United Nations
UNAVCO	University Navstar Consortium
UN-GGIM	Global Geospatial Information Management Initiative of the UN
URAT	USNO Robotic Astrometric Telescope
URL	Uniform Resource Locator
U.S.	United States
USNO	United States Naval Observatory
UT, UT0, UT1	Universal Time
UTAAM	NOAA AAM analysis and forecast data
UTC	Coordinated Universal Time
UTGPS	UT-like quantity using GPS
VCS	VLBA Calibrator Survey
VGOS	VLBI Global Observing System
VLBA	Very Long Baseline Array, NRAO
VLBI	Very Long Baseline Interferometry
VO	Virtual Observatory
WDS	ICSU World Data System
WG	working group
WP	Work Package
WRC	World Radiocommunication Conference
WRMS	Weighted Root Mean Square
w.r.t	with respect to
XML	eXtensible Markup Language
yr	year