

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

IERS Annual Report 2018

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IERS Annual Report 2018

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1 Foreword

In 2018, the IERS continued to ensure that the user community has the most up-to-date terrestrial reference frame by beginning preparations for the generation of the International Terrestrial Reference Frame 2020 (ITRF2020). Plans are now in place for this latest TRF with reprocessing beginning in 2020. To provide closure on the ITRF2014, an additional IERS Technical Note is scheduled to be published in 2019.

The International Astronomical Union (IAU) Division A Working Group on the Third Realization of the International Celestial Reference Frame (ICRF3) finalized their work which was subsequently adopted at the IAU General Assembly in Vienna, Austria in 2018. This effort benefitted from collaboration with the IERS ICRS Center. The IERS extends our thanks to all involved in creating this next generation of celestial reference frame, which will be beneficial to so many in the community.

To correct a known deficiency in the processing of the IERS Earth Orientation Center's (EOC's) 14 C04 series, a revision to the series was released on 16 April 2018. The new series was announced in IERS Message 354.

The IERS Conventions Center continued to make incremental changes to the published IERS Conventions to ensure that the document contains the latest models and constants. In 2018, changes to the Conventions include the adoption of a new secular pole and the elimination of the previous conventional mean pole. The changes necessitated revisions to Chapters 6, 7, and the Glossary. For the latest information on the IERS Conventions, please see the IERS Conventions web sites.

Preparations are underway for the upcoming 2019 Unified Analysis Workshop (UAW), which will be held in Paris. The UAW is a joint meeting co-sponsored by the International Association of Geodesy (IAG), the Global Geodetic Observing System (GGOS), and the IERS. It is expected that the UAW will generate recommendations that, when adopted by the geodetic community, will improve the consistency and the quality of the geodetic products that so many users have come to rely on.

The IERS Directing Board (DB) had several changes during the year. Jürgen Müller acted as the IERS representative to the IERS, temporarily replacing Ludwig Combrinck, until Jean-Marie Torre could be identified as the permanent replacement. Nick Stamatakis replaced Christian Bizouard on 1 January 2019 as the IERS Directing Board (DB) member from the IERS Convention Center as part of the rotating co-directorship. Robert Heinkelmann replaced Tom Herring as the IERS Analysis Coordinator on 1 January 2019. Tom's role as the Analysis Coordinator is arguably the most important role in the IERS for ensuring the quality and consistency of the IERS products. Tom always strived to

make the IERS products the best they could be and worked so that the IERS would not only meet current requirements, but be positioned to meet future requirements as well. We thank all of the representatives and we wish the best to both Ludwig and Tom in their future endeavors.

Brian Luzum
Chair, IERS Directing Board, 2018

2 The IERS

2.1 Structure

From 2018 to the beginning of 2020, 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 2018 and 1 January 2020. For reports of components see [Chapter 3](#).

Analysis Coordinator

Thomas Herring (until 31 Dec. 2018),
Robert Heinkelmann (since 1 Jan. 2019)

Central Bureau

Director: Daniela Thaller

Technique Centres

International GNSS Service (IGS)

IGS Representatives to the IERS Directing Board:

Rolf Dach, Chuck Meertens

IERS Representative to the IGS Governing Board:

Richard Gross

International Laser Ranging Service (ILRS)

ILRS Representatives to the IERS Directing Board:

Erricos C. Pavlis, Jürgen Müller (Apr. – Nov. 2018),

Jean-Marie Torre (since Dec. 2018)

IERS Representative to the ILRS Directing Board: Daniela Thaller

International VLBI Service for Geodesy and Astrometry (IVS)

IVS Representatives to the IERS Directing Board:

Rüdiger Haas, Guanli Wang (until Feb. 2019),

Sigrid Böhm (since 21 March 2019)

IERS Representative to the IVS Directing Board:

Rüdiger Haas

International DORIS Service (IDS)

IDS representatives to the IERS:

Jérôme Saunier, Hugues Capdeville

IERS Representative to the IDS Governing Board:

Brian Luzum

Product Centres

Earth Orientation Centre

Primary scientist and representative to the IERS Directing Board:

Christian Bizouard

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

Christine Hackman

Production director and lead project scientist: Nick Stamatakos**Conventions Centre***Primary scientists:* Nick Stamatakos, Christian Bizouard*Current representative to the IERS Directing Board:*

Christian Bizouard (until 31 Dec. 2018),

Nick Stamatakos (since 1 Jan. 2019)

ICRS Centre*Primary scientists:* Bryan Dorland, Jean Souchay*Current representative to the IERS Directing Board:*

Jean Souchay

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:*

Jean-Paul Boy

Co-Chair: 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:* Sten Bergstrand*Co-Chair:* John Dawson

Working Group on SINEX Format

Chair: Daniela Thaller

Working Group on Site Coordinate Time Series Format

Chair: Laurent Soudarin

(Status as of 1 January 2020)

2.2 Directing Board

From 2018 to the beginning of 2020, the IERS Directing Board had the following members (for addresses see [Appendix 2](#)):

Chair	Brian Luzum
Analysis Coordinator	Thomas Herring (until 31 Dec. 2018), Robert Heinkelmann (since 1 Jan. 2019)
<i>Product Centres Representatives</i>	
Earth Orientation Centre	Christian Bizouard
Rapid Service/Prediction Centre	Christine Hackman
Conventions Centre	Christian Bizouard (until 31 Dec. 2018), Nick Stamatakos (since 1 Jan. 2019)
ICRS Centre	Jean Souchay
ITRS Centre	Zuheir Altamimi
Global Geophysical Fluids Centre	Jean-Paul Boy
Central Bureau	Daniela Thaller
<i>Technique Centers Representatives</i>	
IGS	Rolf Dach, Chuck Meertens
ILRS	Erricos C. Pavlis, Jürgen Müller (from Apr. to Nov. 2018), Jean-Marie Torre (since Dec. 2018)
IVS	Rüdiger Haas, Guanli Wang (until Feb. 2019), Sigrid Böhm (since 21 March 2019)
IDS	Jérôme Saunier, Hugues Capdeville
<i>Union Representatives</i>	
IAU	Aleksander Brzezinski
IAG / IUGG	Axel Nothnagel (until 6 Dec. 2019), Thomas Herring (since 7 Dec. 2019)
GGOS	Richard S. Gross

2.3 Associate Members

Abbondanza, Claudio	Lestrade, Jean-François
Angermann, Detlef	Luceri, Vincenzo
Arias, Elisa Felicitas	Ma, Chopo
Behrend, Dirk	McCarthy, Dennis D.
Bergstrand, Sten	Métivier, Laurent
Bloßfeld, Mathis	Moore, Angelyn W.
Boucher, Claude	Moore, Michael
Bruyninx, Carine	Müller, Jürgen
Capitaine, Nicole	Noomen, Ron
Chanard, Kristel	Nothnagel, Axel
Chen, Jianli	Otsubo, Toshimichi
Chin, Mike	Pearlman, Michael R.
Collilieux, Xavier	Petit, Gérard
Combrinck, Ludwig	Ray, Jim
Craddock, Allison	Rebischung, Paul
Craymer, Michael	Reigber, Christoph
Dawson, John	Rothacher, Markus
Dorland, Bryan	Salstein, David
Fisher, Steven	Seitz, Manuela
Gambis, Daniel	Shelus, Peter J.
Garayt, Bruno	Soudarin, Laurent
Gaume, Ralph A.	Springer, Tim
Gipson, John	van Dam, Tonie
Heflin, Mike	Vondrák, Jan
Hugentobler, Urs	Wang, Guanli
Johnston, Gary	Weber, Robert
Lambert, Sébastien	Willis, Pascal
Lemoine, Frank	Wilson, Clark
Lemoine, Jean-Michel	Yatskiv, Yaroslav S.

Ex officio Associate Members:

IAG Secretary General: Poutanen, Markku
 IAU General Secretary: Lago, Maria Teresa V.T.
 IUGG General Secretary: Rudloff, Alexander
 President of IAG Commission 1: Kotsakis, Christopher
 Chair of IAG Subcommission 1.1: Hugentobler, Urs
 Chair of IAG Subcommission 1.2: Collilieux, Xavier
 Chair of IAG Subcommission 1.4: Malkin, Zinovy
 President of IAG Commission 3: Bogusz, Janusz
 Chair of IAG Subcommission 3.1: Braitenberg, Carla

Chair of IAG Subcommittee 3.3: Chen, Jianli
President of IAU Division A: Hestroffer, Daniel
President of IAU Commission A1: Souchay, Jean
President of IAU Commission A2: Seitz, Florian
President of IAU Commission A3: Hilton, James

(Status as of 1 January 2020)

3 Reports of IERS components

3.1 Directing Board

The IERS Directing Board (DB) met twice in the course of the year 2018. Summaries of these meetings are given below.

Meeting No. 66	April 08, 2018, Technical University of Vienna, Gusshausstr. 27, Vienna, Austria
Introduction and approval of agenda	Brian Luzum welcomed the guests and the members of the IERS Directing Board. The agenda was accepted. No additional comments were made.
Report within IERS	A standardized template for report contributions (e.g. Annual Report) is provided by the Central Bureau.
IERS Technical Notes on ITRF2014: Status and way forward	Technical Note 2: Input and evaluation by the Technique Centers • No contributions received by the CB until now • Services: - DGFI is working on two contributions: one on DTRF and one on evaluation – both are intended to be finished by end of May) - IVS: no contribution so far (A. Nothnagel will talk to John Gipson) - IDS: need more time (before summer) - IGS: reference frame chair and ACs showed no interest • The publication is foreseen for summer 2018. Technical Note 3: C04 series aligned to ITRF2014 • The publication is not yet ready. A Technical Note exists, but has to be improved. The Technical Note is expected to be ready in one month.
New Action Item	#66.01 Remind Technique Centers to contribute to Technical Note 2
Reports from the Technique Centers <i>IDS Report</i>	The report from IDS was given by Hugues Capdeville. • DORIS constellation status: - currently six DORIS missions in flight with DGXX(S) receiver, five future missions planned starting on April 2018 by the SENTINEL-3B mission; 46 co-locations out of 58 DORIS sites; nine beacons are currently out of order (reliable service of the network despite coverage gaps in Pacific and Russia)

- Analysis update:
Processing routine: 6 DORIS Analysis Centers provide SINEX solution; an IDS combined series is available online until the end of the third quarter of 2017. DPOD2014 v3: delivery is expected by June 2018 (observations from 1993.0 to 2018.0). Work in progress: implementation of DORIS RINEX data processing; DORIS scale issue (DORIS scale increase in 2012 can be removed); minimize the SAA effect on Jason-2 and Jason-3 USOs Next work: implementation and validation of the new standards/models recommended by IDS/IERS; DORIS orbit comparison campaign
- IDS reprocessing preparation for the next ITRF:
DORIS specific issues: systematic errors and others; adopt and evaluate the new standards/models recommended by IERS, IDS position for the next ITRF: doing the evaluation and elaboration of the combination will take between nine to twelve months → reprocessing could start in the second half of 2019 for an ITRF2020.
- IDS News:
Next IDS AWG meeting in Toulouse: 11–12 June
2018 IDS Retreat 13–14 June near Toulouse
Next IDS workshop in Ponta Delgada 24–29 September 2018
New Network display tool will be available soon.

IGS Report The report from IGS was presented by Rolf Dach.

- Analysis:
The database switched to RINEX 3: the ACs are working on the implementation of the new format. The discussion on output is still ongoing and is the upcoming task for the ACs for implementation. There will be no time for a reprocessing for the upcoming ITRF. T. Herring indicated that a radiation force model is needed. IGS will not be able to start a reprocessing before the end of 2019.
- Constellation:
New satellites QSat, Galileo: four satellites launched, four more will be launched in summer (24 satellites by the end of the year); Beidou: new signals (not defined in RINEX yet, ICD is not published yet)
- Format:
New Beidou 3 format, with two parallel identifiers for the same satellite (problem to be solved in RINEX); first Beidou 3 data should be available by the end of the year in network data (no receiver calibrations yet)

- **Personality:**
IGS Central Bureau changes: Steve Fisher quit, Allison Craddock was asked to fill the position – as Ruth Neillan retired – by the end of the year. Gary Johnston will step down from the Governing Board.
- **Next meeting:**
IGS workshop in Wuhan in the last week of October/first week of November (directly before ILRS workshop)

C. Hackman asked about the new secretary position and when Allison would become IGS Central Bureau Director. R. Dach said that this will be discussed in the afternoon within the IGS meeting.

- First papers on orbits of Beidou 3 satellites have been published in Chinese.
- UNAVCO established a new program: NCEO, supporting full GNSS, supports IGS coordinator role.

ILRS Report

The report from ILRS was given by Cincia Luceri.

- **ILRS network:**
still larger geographic gaps; about 13 (out of 38) stations are responsible for 76% of the observed passes on all satellites; new way to rate the stations in terms of observation quality and quantity
- **Missions and campaigns:**
Routinely tracked nearly 100 satellites in 2017
New satellites: Galileo, QZS, TechnoSat, S-Net and Geo-IK-2.
Future missions: additional Beidou/Compass, Galileo, etc., PN constellation (China), Sentinel-3B, GRACE-FO, HY-2c, SWOT, NISAR, COSMIC-2, IceSAT
- **Status and activities:**
Quality Control Board (QCB) addressing laser ranging data quality issues via monthly telecons; update to site log format complete; examining new strategies to “rate” station performance; new concept in retroreflector designs (e.g. LARES-2)
- **Analysis activities:**
preparations for reprocessing for upcoming ITRF are ongoing; currently the ILRS is working on a complete reanalysis from 1983; new operational approach to handle error sources in the current modeling standards will be discussed within the upcoming meeting.
A pilot project (PP) on station systematics is close to the operational phase (June 2018); next PP will deliver low-degree gravity

coefficients as a weekly product; Journal of Geodesy Special Issue on Laser Ranging (deadline is May 31, 2018)

- ITRFXX Plans:
implement linear mean pole model; develop and implement diurnal-subdiurnal tidal EOP models based on Desai-Sibois (2016) approach; adopt post EGM2008 static gravity field; highest-fidelity time-variable gravity (TVG) model; handling station Range Biases; use updated CoM offsets; handling of Time Biases.
A loading model will not be included in the reanalysis product for the next ITRF. As far as ILRS is concerned, the new model could be ITRF2019.
Metadata to implement instrument-monument thermal effect models: Z. Altamimi: collect data on the sites, but not necessarily for the next ITRF
- Recent and future meetings:
ILRS Technical Workshop was held in Riga on October 2017; the 21st International Workshop on Laser Ranging (IWLR) will be held on November 4–9, 2018 in Canberra, Australia.
The 22nd IWLR will be held in Kunming, PR China.

Z. Altamimi: impact of range bias on scale and also center of mass: total impact? C. Luceri: CoM correction 1:1 to range bias, range bias with CoM correction as we have now, if the model is changed, review range bias.

IVS Report The report from ILRS was presented by Rüdiger Haas.

- 50 years of geodetic VLBI (1968 to 2018); jubilee experiment VGOS session VT8095
- VGOS:
observing plan: several 24h experiments scheduled for 2018 using the VGOS antennas; in 2019 weekly and/or daily VGOS sessions
Plan forward: timeline for milestones (see presentation)
- Recent and upcoming VLBI activities:
correlation of CONT17 almost finished: three networks (2 legacy S/X, 1 VGOS)
Managing station clock offsets for correlation (e.g. ensure consistent UT1 values)
VEX2 roll-out: requires finishing specifications and parser
ICRF3 to be adopted at IAU General Assembly in August
GM2018 in Longyearbyen, Svalbard, Norway in June 2018
EVGA2019 in Gran Canaria in March 2019
- Letter from North Korea received, but not answered.

Z. Altamimi suggested for the improvements of sessions to repeat sessions with the most number of stations for the ITRF with more than 20 stations. A. Nothnagel pointed out that there are six sessions per year with close to 20 stations. Request on increasing these sessions. D. Thaller proposed that for the reprocessing for the upcoming ITRF a guidelines for sessions to be reprocessed would be helpful.

**Current activities at the ITRS
Combination Centers
*Report from ITRS Center***

The report from ITRS Center was given by Zuheir Altamimi.

- ISO standard on ITRS
Initiated originally by C. Boucher; a complete document finished, now available, and has been submitted to the ISO Project Team (PT) for comments and approval. Waiting for comments from the ISO PT.
- ITRS Technical Notes
Three past Technical Notes published by the IERS Center (TN37, TN38, and TN39); Technical Note on the evaluation of the three solutions (ITRF2014, DTRF2014, and JTRF2014): no contributions so far.
ITRS Center did substantial evaluation on the DTRF and JTRF strategy. Conclusion: persistent scale discrepancy of ~ 1.4 ppb between SLR and VLBI
- Periodic signals
Aim: evaluate and understand technique differences at co-location sites; concentrate on annual & semi-annual signals; combine them at co-location sites, provide them in a coherent Reference Frame (CM or CF/CN), and provide a coherent annual geocenter motion model compatible with ITRF2014
Estimated differences of the annual geocenter motion reach up to 4 mm depending on the approach and technique.

***Report from ITRS
Combination Centre at
DGFI-TUM***

The report was presented by Detlef Angermann.

- Comparison of ITRS realizations: ITRF2014, DTRF2014, JTRF2014
Precise Orbit Determination (POD) of SLR satellites (see Rudenko et al. 2018)
DGFI-TUM performed investigations on SLR and VLBI scale (publication under review)
- Consistent estimation of CRF, TRF and EOP
A consistent realization of CRF, TRF and EOP by combining VLBI, SLR and GNSS data (2005–2015) has been performed: see poster EGU2018–8843 and publication of Kwak et al. (2018)

- Contributions to ITRF error budget workshop in New Orleans
Presentation of M. Bloßfeld in New Orleans (Dec. 2017)
 - Current limitations of the ITRF:
 - * Limitations of input data
 - * Limitations of current ITRF solutions
 - * Other limiting factors (e.g., networks, co-locations, geophysical models)
 - Future ITRF concepts
 - * Estimation of Epoch Reference Frames (ERFs)
 - * Improved handling of non-linear station motions
 - * Refined geophysical modeling of non-tidal loading corrections
 - * Consistent estimation of CRF, TRF and EOPs
 - * Inclusion of new parameters (e.g. low degree Stokes coefficients)
- Contributions to discussion on roadmap for next ITRF
CfP for next ITRF:
 - ITRS Center consulted ITRS CCs and TCs concerning handling of technique systematic errors and needed model updates
 - Interaction between different components to prepare the CfP for next ITRF solution
 - Role of the IERS DB concerning the CfP?
- Test of ITRS CC solutions by TCs
 - Who defines test scenarios and criteria?
 - Who is responsible for the tests?
 - What are the consequences of the test outcome?
- ITRF validation (external)
 - External validation of ITRF (who, responsibilities, how, consequences,...)?
 - External validation after release of the ITRF?
- DGFI-TUM contributions to IERS TN “ITRF Comparisons”
2 DGFI-TUM contributions: DTRF2014 solution (Bloßfeld et al.) and DGFI-TUM comparisons of latest ITRS realizations (Angermann et al.)
- Latest DGFI-TUM publications on ITRF-related issues

T. Herring noted that survey ties do not match well in DTRF but better for ITRF.

**Report from ITRS
Combination Centre at JPL**

The report was given by Richard Gross.

Activities:

- Correlations in ground deformation (Chin et al.)
 - Account for regional correlations in ground deformation, caused by large-scale loading processes by including statistics of regional deformation in stochastic model of process. Extending software to allow a full process noise matrix, not just diagonal
- Joint TRF/EOP/CRF Determination (Soja et al.)
 - Kalman filter to determine CRF from VLBI-only data developed, variability of radio source positions modeled as random walk
- JTRF2014 Analysis (Abbondanza et al.)
 - Continuing to write article for IERS Technical Note; continuing to develop capability to update JTRF2014 monthly; time variable structure of VLBI-SLR scale difference

VLBI-SLR scale differences:

- Motivation
 - Analysis of the scale difference between VLBI and SLR within the framework of KALman filter for terrestrial REFerence Frame.
 - Dedicated study entirely focused on the combination of VLBI and SLR only Space-Geodetic inputs (X, EOPs) along with local ties at VLBI-SLR co-located sites.
 - As a result of the sequential nature of the algorithm, KALREF outputs a time series of the quasi-instantaneous Helmert scale parameters mapping VLBI's to SLR's scale.
 - We provide and discuss the time-variable structure of the quasi-instantaneous scale difference between the two observing systems.
- Key facts about the VLBI-to-SLR Scale Differences
 - Evidence of a persistently negative scale bias throughout the 6 configurations examined.
 - According to the sign convention, a negative VLBI-to-SLR scale difference indicates that the baselines between VLBI stations must be contracted in order to match SLR's.
 - This is equivalent to state that VLBI baselines are on average larger than SLR's.

- Biases and Drifts in the process noise-free configurations appear to be consistent with the results of Altamimi et al., who, on an equivalent data set, found an SLR-to-VLBI bias at 2010.0 of 1.02 ppb (6.5 mm) and a drift of 0.01 ppb/yr (0.06 mm/yr).

Roadmap for next ITRF generation

Z. Altamimi gave the following overview:

- Consultation on the roadmap for the next ITRF solution (2019 or 2020) was sent to the technique ACCs and GGFC (Jan. 2018).
- An inventory (list) was compiled including all effects and model updates to be considered.
- Feedback so far:
 - IVS:** General agreement, except: HF-EOP model to be recommended by the WG, Loading model (Atmospheric?) will be applied. Include the “removable” model corrections in SINEX. High priority to updating software to apply gravitational deformation.
 - ILRS:** Mostly agree on ITRS proposal. Different opinions on some topics, mainly the gravity field model(s). HF EOP: awaiting for a “consensus” model. ILRS will not include a loading model and no model for 3D thermal effects.
 - IDS:** Mostly agree on ITRS proposal. HF EOP: awaiting for a “consensus” model; waiting for IERS recommendation to apply or not a non-tidal loading model; no opinion on 3D thermal effects; a number of DORIS-specific effects will be addressed.
 - IGS:** response from Michael Moore: mostly agree on ITRS proposal. Adopt post EGM2008 model: Not all ACs are convinced this has a significant impact on GNSS; HF EOP: awaiting for a “consensus” model; most ACs not in favor of applying a loading model; 3D thermal effects: little impact on GNSS.
 - GGFC:** response from J.-P. Boy: GGFC is ready to provide the atmospheric, oceanic & hydrology loading in both CF & CM reference frame, and the corresponding geocenter time series.

Discussion of feedback to ITRF questionnaire and planning for ITRF2019/2020. Still open questions:

- IVS: only atmospheric loading model (removable model corrections?) → ITRF2020
- ILRS: will not include loading model → ITRF2019 or 2020
- IDS: → ITRF2020
- IGS: post EGM2008 model → ITRF2020

Summary and conclusion

- The data to be submitted need to be ready by Jan/Feb 2021. It takes about 6 months to generate a combined contributions from the Technique Centers.

Comments and discussion

- A. Nothnagel: NT-AL: how to describe the parameter: deltaX,Y,Z or dNEH in SINEX. This is a question for the SINEX WG.
- R. Dach: one additional parameter as scale of the model
- A. Nothnagel: thermal expansion of DORIS ground constructions; Source positions: unstable sources
- Z. Altamimi will circulate a call for participation by the end of the year.
- D. Angermann: the timeline of ITRF should be included in the CfP.

New Action Item #66.02 ITRF2020: circulate a call for participation.

IERS Conventions This report was given by N. Stamatakos.

Overview of IERS Conventions Centre (CC) Activities

- Chapters 6 and 7 were updated to be consistent with the overall direction of the UAW Conventional “mean” pole session summary and recommendations resolution held in July 2017.
- Next major revision to IERS Conventions estimated to be 2021 to 2022 time frame.
- Intention of IERS CC to publish electronic version of IERS Conventions 2021, and then, soon afterward, to publish a paper copy.
- It was announced at the last IERS DB meeting (December 2017): IERS CC has agreed upon a selection process for obtaining chapter experts, assistant experts, and editors to greatly assist IERS CC staff in updating the Conventions for version 2021. (More details to follow.)
- An email announcement – Call to Participate in the IERS Conventions – was sent via IERS Message No. 349 in early February 7, 2018. Additional emails sent to a few other parties who might be interested.

Rationale for Call to Participate in IERS Conventions

- IERS CC staff does not have all of the needed expertise or resources to create an IERS Conventions 2021/2022.

- Responsibilities and selection criteria for each role are:
 1. One Editor-in-Chief for each chapter
 2. One to three Chapter Experts for each chapter
 3. One Software Editor
- The details as well as the final selection criteria scoring can be found on <http://iers-conventions.obspm.fr/announcements/call-for-contributors.php> or <http://maia.usno.navy.mil/conventions/announcements/call-for-contributors.php>

Discussion

- Z. Altamimi asked the IERS CC to provide and update of the chapters that the TC need to have consistent models for the next ITRF20XX preparation.
- T. Herring noted that a reference should be given to which specific Convention Update one's referring.
- T. Herring proposed to provide implementations of conventional tests to evaluate the specific versions of the users.
- T. Herring noted that ocean tide models (current: FES2004) need better clarification of the data files.
- Z. Altamimi asked to update Chapter 4 to include the ITRF2014.

IERS CC activities

A volunteer participation should be kept and it should eliminate the necessity to provide a sponsoring letter from the institution, because this may cause the opposite intension and the institution itself is not willing to sign a paper. The letter could be included as an optional extra. The intentions are the following: 1) to know who is working on the Conventions, 2) to plan ahead, and 3) to create a sort of enforcement mechanism.

EOP Products *Report from Earth Orientation Centre*

Ch. Bizouard provided the following overview:

- Need for UT1 intensives 14 C04 (no systematic changes, but outliers because of missing UT1 intensive data).
- A flaw in UT1 values till January 2018 is visible.
- 14 C04 over the interval 1994–2017: The UT1 intensive sessions have not been taken into account, only IVS Combined values contributed. Anomalous residuals in SLR LAGEOS orbits disappear with the use of 08 C04 values (for which UT1 intensives contributed). Since January 2018 there are operational C04 accounts for UT1 intensives (IAA and BKG).

Necessity to correct prior values of the 14 C04 series since the start of “UT1 intensives” (1993), but C04 series are supposed to update only the last 30 days.

- Technical Note to appear soon

Decision

Omit the 30-days rule, add a version number and document changes in a readMe file. Indicate changes in the file header and the release date in the file name.

Older versions should be stored in subdirectories. If there are changes more than 30 days in the past, archive the current version and include the version information in the file header.

A. Nothnagel notes that it is not a C04 anymore and proposes one change to include all intensive sessions.

IERS CB: send out a message announcing the changes and the agreement.

IVS: ACs providing intensive SINEX files.

Report from IERS Rapid Service / Prediction Centre Update

This report was given by C. Hackman.

IERS RS/PC product changes 29 Mar 2018:

- Products now aligned to 2014 C04 (was ITRF 2014)
- Implements IERS 2010 Conventions dX/dY CPO paradigm

Transitioning to new email system handling RS/PC, Bulletin A operations:

- Bulletin A delivery, bounce-backs
- User questions/issues/requests
- Will be from mail.mil domain
- Transition expected Fall 2018
- Will notify users via IERS Message, Bull. A, other means

Z. Altamimi proposed to generate an updated solutions for specific weeks (e.g. reprocessed IGS combination).

Decisions

C04 series: omit the 30-days rule, add a version number and document changes in a readMe file. Indicate changes in the file header and the release date in the file name.

New Action Item

#66.03 Send out a message announcing the changes on C04 series and the agreements.

**Working Group on “IERS
Product Distribution”**

T. Herring noted: ftp is getting a bad name and web services in http(s) are more convenient currently. A working group on how to make products available in future has to be established. The TCs should be part of the working group. N. Stamatakos and the IERS CB are also willing to participate in the WG.

**Working group to handle ITU
request “Future of the UTC
time scale”**

B. Luzum reported and discussed the following:

- He had no contact to the other WG members so far. One decision is that the organizations should involve Christian Bizouard, Christine Hackman, IDS, IVS, IGS, and ILRS.
- Organizations have to be able to answer the questions, which impact can be expected if the UTC definition changes (ITU request).
- The question arises, which of the two representatives will be the person to send the official response (in 2021, one year ahead of the official response in 2022).

**IAU Report: Preparations for
GA in Vienna, August 2018**

R. Gross reported:

- Two Sessions: (1) Reference Systems and Frames and (2) Gaia
- Centennial anniversary of IAU and IAU Commission A2 celebration on July 28, 2019
- Proposed IAU Symposium for October 7–11, 2019 in Belgium
- IAU Commission A2: 12 persons as organizing committee (president, vice-president, ex-officio members + regularly elected members)

**Status of ICRS/ICRF and
IAU Working Group**

B. Dorland presented the following report:

ICRF Status Update**ICRF3 Status**

- ICRF3 on schedule for approval at IAU in 2018
- Multi-wavelength reference frame
- Refereed ICRF3 paper to be submitted by 1 June 2018
- Heavy use of VLBA to support ICRF3 and follow on
- VLBA-St. Croix station knocked off-line by Hurricane Maria on 19 Sept 2017
- USNO beginning to work through imaging backlog for Radio Reference Frame Image Database

ICRF3 Technical Update

- S/X: Continued contributions from IVS scheduled observations (e.g., R1, R4, CRF)
- S/X: VLBA Cal Survey-II (VSC-II) to re-observe VCS sources published: sky distribution of the 2400 sources in the VCS-II campaign
- K-band: 825 sources from combined data sets; full sky coverage completed
- X/Ka data continues to be taken and processed (XKa (32 GHz): 678 sources)
- 100 μ as zonal declination errors being investigated for all bands: S/X, K, X/Ka
- Images available for S/X and K-bands

Gaia status

- ESA Gaia astrometry mission
- Data products:
Data Release 1 (DR1) – Sept 2016
DR2+ – April 2018
- Tying reference frames: Ongoing work to look at Gaia optical-to-ICRF radio reference frames; Precision $\sim 5\text{--}10$ μ as per rotation angle.
- Independent confirmation of VLBI and ICRF at the sub-mas level

USNO IERS ICRS Center-Related Work

- USNO is allocating 50% of the VLBA time to support reference frame and geodesy (e.g., ICRF3, CONT17)
- USNO is now processing backlog in VLBI imaging database this year (Radio Reference Frame Imaging Database – RRFID)
- Completing URAT-Southern Hemisphere bright star survey in June 2018 – fill in current Gaia bright star gap
- USNO, University of Hawaii collaborating on Northern Hemisphere K-band (IR) survey using UKIRT telescope
- USNO, Paris Observatory actively coordinating on ICRS Center issues

Summary and Future Work

- ICRF3 nearing completion

- On-track for 2018 IAU adoption
- Awaiting Gaia DR2 release
- Additional work being done

Overview on ICRF3

Background

- IAU Working Group formed in 2012 to generate ICRF3 for presentation at IAU 2018 General Assembly
- Excerpt from ICRF3 charter (see presentation)
- 2012–2015 focus on acquiring proper new VLBI data; 2015–2018 focus on building the frame

Data sets

- ICRF3 incorporates data up to 31/12/2017 in S/X (8 GHz), K (24 GHz), and X/Ka (32GHz) band

Overview of the work achieved

- Three rounds of ICRF3 prototype solutions produced; 9 solutions (using 6 different software) produced each time; alternate solutions varying the modeling/analysis configuration (assess the level of systematic errors)
- Comparisons between different solutions (also with Gaia DR1); final solutions to be produced shortly

Modeling/analysis configuration

- Adhere to IERS conventions: VMF1 mapping function for troposphere; GPS ionospheric maps from CCDis for K band data; orientation of celestial reference frame defined using no net rotation (NNR) constraints on the ICRF2 defining sources; orientation of terrestrial reference frame defined using NNR constraints on ITRF2014
- Parameters estimated: (local) clocks, troposphere, EOPs; (global) source positions, station positions and velocities

Variations in modeling/configuration

- Goal is to assess the level of systematic errors
- Various configurations varying cutoff elevation angle, troposphere modeling, station positions, special handling sources
- Impact of new (since ICRF2) southern-hemisphere stations in Australia and New Zealand

- ICRF2–ICRF3 transfer sources (alignment of the two frames) (Ongoing)
- Galactic aberration (not modeled, fixed to a priori value, estimated) (Ongoing)

Results (vs ICRF2)

- ICRF3 vs ICRF2 (3414 sources)
- ICRF3 vs Gaia DR1 (2191 sources)

Main features of ICRF3

- Incorporates 12 million VLBI observations (about twice as much compared to ICRF2); Includes an additional 30% of sources vs ICRF2; Much more uniform distribution of position errors than ICRF2; Multi- frequency frame (S/X, K and X/Ka band)

Remaining work to be done

- Finish tests regarding Galactic aberration and make a decision on whether to include it in the modeling
- Finalize the list of special handling sources and the list of ICRF2–ICRF3 transfer sources
- Produce the final ICRF3 solution, incorporating data up to 31/12/2017
- Estimate realistic errors (inflation factor and noise floor)
- Compare ICRF3 with the Gaia Data Release 2 (DR2) when available (25 April 2018)
- Select the list of ICRF3 defining sources

Communication and release plan

- Prepare a journal paper: the aim is to submit it in June and have it accepted before the IAU General Assembly
- ICRF3 to be presented at two upcoming conferences (IVS General Meeting and COSPAR 2018 Assembly)
- ICRF3 to be presented for adoption at IAU General Assembly 2018 (IAU resolution submitted on 15 February 2018)
- Press release to be made by the time of the IAU General Assembly
- ICRF3 to be released when paper accepted or by the time of IAU General Assembly.

The working group triennial report 2015–2018 is available.

Discussion on Adoption of ICRF3

A. Nothnagel: There was no involvement of the IVS in the whole ICRF3 process (and nor IERS involvement). Why IERS is asked for endorsement now?

Decision:

- Collect comments on the question of the endorsement, eventually electronic vote set up by the IERS CB (by the end of April or May, but before the IAU)
- IERS DB comments to be sent to the ICRF3 Working group
- Probably a follow-on WG will be established when the WG ends in August 2018

New Action Item #66.04 Collect comments on the question of the endorsement, eventually electronic vote.

GGOS report on EGV Panel

This presentation was given by D. Angermann.

Background on Essential Geodetic Variables (EGVs)

- It was agreed during GGOS Days 2017 that GGOS should work on the definition of EGVs.
- Example of EGVs: position of reference objects (e.g., ground stations, radio sources), EOPs, ground- and space-based gravity observations, ...)
- The EGVs could then serve as a basis for a gap analysis to identify requirements concerning observation requirements, networks and products.

Definition of EGVs

- A Panel on the definition of EGVs should be established within the Bureau of Products and Standards (BPS).
- BPS distributed a letter on the establishment of such a Panel on EGVs to the IAG Services and GGOS Science Panel members on Feb. 5th, 2018.
- The Panel should be re-named in “Committee on EGVs” and it should comprise the GGOS Science Panel members, the IAG Commissions, the Inter-Commission Committee on Theory, and the 4 GGOS Focus Areas, Representatives of the IAG Services, the GGOS Chair, Director GGOS BPS.

Meeting of GGOS BPS on Wednesday, April 11, 2018.

Discussion

The question came up on the IERS representative: as T. Herring is already nominated for IGS, the IERS is being asked to nominate two other representatives.

The IERS CB will send out an email to the DB asking for representatives for the Committee on EGVs.

New Action Item #66.05 Send out email to DB asking for representatives for the Committee on EGVs.

Reports from the Working Groups *IERS Working Group on Site Co-location*

R. Haas reported for S. Bergstrand.

- Conclusions: Systematic technique errors dominate error sources in discrepancies between ties and solution → differences between analytic solutions and local ties are thus primarily indicators of systematic errors of the techniques on the site (annual site surveys not necessary). See also IERS TN 39.
- Recommendations from the UAW: optimize a local network setup for a bundle adjustment based on instrument specification; development of an in situ GNSS antenna calibration method is a high priority.
- VLBI: gravitational deformation: measure as many VLBI antennas as possible to determine their gravitational deformation (A. Nothnagel will provide recommendations). Gravitational deformation of VLBI antennas needs to be taken into account when reducing VLBI observations.

SINEX format D. Thaller report: There has been no progress; one topic is loading deformations in SINEX and the question is how to handle long station names in IGS.

Time Series Format L. Soudarin reported: no progress in the last time, WG is on stand-by for the two last years, 75% of the work is done, requirements are defined, and two different format have been proposed. The next step is to share the formats within the WG and to evaluate them. L. Soudarin is looking for someone to take over the WG (within the WG).

Annual Reports D. Thaller reported that the printed versions have been sent out last week for the AR 2016. The call for the AR 2017 will be sent out after the DB meeting.

Next DB meeting (#67) The next DB meeting (half-day meeting) will take place on Saturday, December 8, 2018, before the AGU in Washington.

C. Hackman proposed to ask the DB members and invitees beforehand, whether they have some news to provide and to shorten the agenda appropriately.

New Action Item #66.06 Prepare IERS DB meeting No. 67

Miscellaneous IDS: new elections in September/October 2018.

Meeting No. 67 December 8, 2018, Hotel Washington Marriott at Metro Center, 775 12th Street NW, Washington, USA

Introduction and approval of agenda Brian Luzum welcomed the guests and the members of the IERS Directing Board. Agenda was accepted as is; no additional comments.

Changes in IERS Directing Board

New DB members:

- ILRS representative: Jean-Marie Torre
- Analysis Coordinator (starting with 1 January 2019): Robert Heinkelmann
- Representative of the Conventions Centre (starting with 1 January 2019): Nick Stamatakos

Other changes:

- IERS Representative to the World Data System: Christine Hackman
- IERS Representative to the IAU Comm. A2 OC: Daniela Thaller

Notes

The changes in the IERS DB have been announced – no concerns.

Z. Altamimi raised concern regarding IERS nominations to IAG EC – only 2 names; should we have 3? Time to submit names has probably passed.

Associate Members The list of Associate Members was reviewed, 4 corrections were proposed.

IERS Analysis Coordinator: Nomination and election No changes for election at this time; review ToR during interim and discuss in Vienna in April 2019.

**Current activities at the ITRS
Combination Centres
Report from ITRS
Combination Centre at JPL**

Richard Gross reported on the following activities:

- Correlations in ground deformation (Chin et al.)
Account for regional correlations in ground deformation caused by large-scale loading processes by including statistics of regional deformation in stochastic model of process. Extending software to allow a full process noise matrix, not just diagonal (Chin et al., GRACE/GRACE-FO STM, GFZ Potsdam, 09–11 October 2018).
- Joint TRF/EOP/CRF determination (Soja et al.)
SRIF filter to jointly determine TRF/CRF from SLR & VLBI data. Process noise applied to both station positions and radio source coordinates (Soja et al., Wednesday December 12, 13:40–18:00).
- JTRF2014 analysis (Abbondanza et al.)
Submitted article for IERS TN, Evaluation of JTRF2014 EOPs, Comparison to ITRF2014 & DTRF2014 EOPs, COMB2016, and geophysical models (Abbondanza et al., Thursday, 10:35–10:50).

**Report from ITRS
Combination Centre at
DGFI-TUM**

Mathis Bloßfeld presented this report.

IERS Technical Note on ITRF2014 – TN2

DGFI-TUM submitted in November two contributions to the IERS CB:

- DTRF2014: DGFI-TUM realization of the International Terrestrial Reference System (ITRS).
- Comparison of the latest ITRS realizations: ITRF2014, JTRF2014 and DTRF2014.
- Three additional contributions from different persons planned + two requested contributions.

ITRF roadmap

- Iteration of roadmap with Brian Luzum during the summer.

ITRF2020 Call for Participation

Important points for DGFI-TUM in the CfP are:

- ITRS CCs should be free to apply NT-L corrections officially provided by GGFC.
- GGFC models (NT-ATML, NT-OVNL, NT-CWCL) should be consistent to each other.
- IAG services should provide a preliminary list of discontinuities for the CCs.

LT issue

G. Johnson stated in his presentation that an improved alignment of measured local ties (LTs) to the current ITRF is necessary. Better transformations from the local horizontal system to the ITRF are required.

LTs with equal vector components (equal length) are not forwarded/reported to the ITRS Center! Is this really true? Identical measured LTs at different epochs will strongly improve the TRF stability!

Report from ITRS Center

The report was presented by Zuheir Altamimi.

ISO Standard on ITRS

Complete document is now at the stage of DIS (Draft International Standard), which will be submitted by January 2019. Final Standard publication is expected by April 2020.

Update of Chapter 4 of the IERS Convention

Terrestrial reference systems and frames to include ITRF2014 information (post-seismic deformation and transformation parameters to past ITRFs). First version circulated among members of ITRS Center for comments. Update in progress will be ready by January 2019.

Activities of UN-GGIM Subcommittee on Geodesy

Proposal under discussion: adoption of the International Terrestrial Reference System (ITRS) and its numerical realization, the International Terrestrial Reference Frame (ITRF) by the UN-GGIM Committee of Experts as the standard reference for geospatial and scientific positioning applications. France (Z. Altamimi) is chairing the Infrastructure WG.

IERS Technical Notes on ITRF

3 past Technical Notes published by the ITRS Center:

- TN37: Analysis and results of ITRF2008.
- TN38: Analysis and results of ITRF2014.
- TN39: IGN best practice for surveying instrument reference points at ITRF co-location sites.

TN40: IERS Technical Note on the evaluation of the three solutions: ITRF, DTRF and JTRF:

- Was hoping to be published by the end of the 2017.
- ITRS Center evaluation/contribution is also ready.
- Still waiting for input until a deadline: End of March 2019.

Specific investigations

Seasonal signals, geocenter motion: evaluate and understand technique differences at co-location sites to provide a coherent annual geocenter motion model compatible with ITRF2014.

Results:

- Large discrepancies of Up annual signals in CM-SLR caused by the co-motion constraints.

- Different estimates of annual geocenter motion for SLR using an uneven network, 8 stations or via multi-technique.

Investigate SLR to VLBI scale offset using new TEST solutions from VLBI (GSFC) and SLR (ASI).

Results:

- Scale offset of the ASI SLR Preliminary solution (with range biases applied following the new bias table) w.r.t. ITRF2014: 0.47ppb. Offset between ASI SLR Preliminary solution and the ILRS solution in ITRF2014: ~1.1 ppb.
 - GSFC VLBI Test solution: ATML does not capture all periodic displacements.

Roadmap for ITRF2020?

Call for Participation (first draft ready).

Error assessment by IERS Analysis Coordinator

The report was presented by Tom Herring.

Two aspects:

- Releasing products with realistic standard deviations associated with them: problematic due to correlated noise representation (current values in SINEX files e.g. not even close to realistic). For IVS and ILRS combined SINEX files, variance factors of 50 are needed to generate realistic short period noise estimates. We should be supplying the “best” estimates we can.
- Comparison of VLBI and SLR colocations again looking at scale differences:
 - Colocation sites for time series and scale comparison.
 - 25 VLBI/SLR sites within 10 km of each other. 17 pairs of these have VLBI and SLR velocities standard deviations < 1 mm/yr (3 of these are 1 VLBI with 2 SLR stations).
 - Only 6 pairs have survey ties between the VLBI and SLR sites in the ITRF2014 site-tie files.

Results:

Height differences

- Mean height difference excluding TIGO/CONZ is 3.9 mm which is equivalent to 0.6 ppb (about half the ITRF2014 value).
- TIGO/CONZ is outlier most likely due to complexity of earthquake processes.

Scale between SLR and VLBI

Values with $\sigma < 5$ mm. Mean $\sigma \sim 2.5$ mm:

- VLBI Mean 0.5 mm RMS 2.8 mm # 2603.
- SLR Mean -3.6 mm RMS 3.0 mm # 969.

There is a drift in the IGS scale for ITRF2014 which was not present for ITRF2008.

Where next?

- IERS services to provide realistic variances in their SINEX files?
- Generation and distribution of the “consensus” position time series and EOP estimates in simple ASCII files (for general community) and SINEX (for experts).
- Note the number of interesting phenomena that have been found in GPS time series to that non-expert users can access these results and do their own analyses (although not without some issues about how results are generated).

Roadmap for next ITRF generation (ITRF2020)

Presentation by IERS Chair

The current draft needs to be sent out. Only Zuheir Altamimi expressed an interest in receiving it.

Presentation by ITRS Centre

The report was presented by Zuheir Altamimi.

Recall of the Background/History

- Consultation was sent to the technique ACCs and GGFC on January 24, 2018.
- An inventory (list) of all effects and model updates to be considered by all and individual techniques in the reprocessing effort.
- Questions:
 - Review the list of effects and models.
 - Indicate the time needed for Software update.
 - Indicate the time needed to accomplish the reprocessing of the full history of observations?

Current status per Technique Center

- IVS
General agreement, except HF-EOP model to be recommended by the WG and Atmospheric Loading model (ATML) will be applied. The contribution of the ATML corrections to the right-hand side of the normal equation must be provided in the SINEX, i.e. $A^T P \cdot (oY_{ATML})$.

High priority to updating software to apply gravitational deformation.

No major obstacle for reprocessing time line.

- ILRS

Mostly agree on ITRS proposal. Different opinions on some topics, mainly the gravity field model(s). High-frequency EOP: awaiting for a “consensus” model. Will not include a loading model. No model for 3D thermal effects.

No major obstacle for reprocessing time line.

- IDS

Mostly agree on ITRS proposal. High-frequency EOP: awaiting for a “consensus” model. A number of DORIS-specific effects will be addressed.

Reprocessing time line: ITRF2020 is more realistic.

- IGS

Mostly agree on ITRS proposal. Adopt post EGM2008 model: not all ACs are convinced this has a significant impact on GNSS. High-frequency EOP: awaiting for a “consensus” model. Most ACs not in favor of applying a loading model.

Reprocessing time line: 15–17th April 2019 Dedicated AC workshop (after EGU) and start of reprocessing probably June 2019.

Call for Participation

- Draft circulated among IERS DB Thursday, December 06, 2018.
- List of suitable model updates in the annex of the CfP.
- Comments are welcome until January 10, 2019.
- Final CfP to be sent out by January 10, 2019.

ITRF2020 Inputs by TCs: specific model updates are strongly requested

- IVS: modeling the gravitational deformation for as many antennas as possible, possibly refine the thermal expansion modeling.
- ILRS: SLR range biases to be estimated/applied.
- IGS: up to date GNSS force models to be used.
- IDS: Improve analysis strategy, DORIS-specific model updates.

In preparation for ITRF2020, the ITRS Center will:

- Request specific solutions for testing purposes, e.g.
 - SLR range biases estimated.
 - New High-frequency EOP model applied.
 - Others TBD.

Schedule and time-line

January 10, 2019	Dissemination of the Call for Participation
February 10, 2021	Deadline for solution submissions by Technique Centers. Earlier submissions are welcome.
April 2021	First and early results to be shared and discussed with the TCs.
Until end of May, 2021	Inter-comparisons of the ITRF CCs solutions.
~June, 2021	Preliminary ITRF2020 solution available for evaluation by TCs.
Sep–Oct, 2021	Final ITRF2020 solution released by the ITRS Center.

ITRS CC DGFI-TUM

The report was presented by Mathis Bloßfeld

Important points for DGFI-TUM in the CfP:

- ITRS CCs should be free to apply NT-L corrections officially provided by GGFC.
- GGFC models (NT-ATML, NT-OVNL, NT-CWCL) should be consistent with each other.
- IAG services should provide a preliminary list of discontinuities for the CCs.

New Action Item

#67.01 Send out final Call for Participation for ITRF2020.

IERS Technical Notes related to ITRF2014

Zuheir Altamimi will send e-mail to CB and DGFI regarding deadline; should there be doi numbers associated with Technical Notes?

New Action Item

#67.02 Send out e-mail to CB and DGFI regarding deadline for TN on ITRF2014.

IERS Conventions

This report was given by N. Stamatakos.

Overview of Changes to IERS Conventions Chapters Since IERS DB meeting in Vienna, April 2018

- No major changes have been made since the last IERS DB meeting in Vienna, April 2018.

- A few changes to the Glossary Section are being implemented regarding definitions of Secular and Mean Pole.
- Those changes will be published soon.
- No major software changes have been implemented.

New Proposed Version Control of Text and Software

- “Conventions Updates” has been replaced by “Conventions Versions”: each version number lists what was changed, starting version was 1.0.0.
- When clicking on version number (e.g., v1.1.0), a tar ball is downloaded containing all the conventions Chapters and software related to that version.

Status of IERS Conventions Centre re-write staff tentative selections

- At previous IERS Directing Board (IERS DB) meeting, it was agreed by those participating in the IERS DB meeting that all selections for the IERS Conventions major revision staff should be reviewed by the IERS DB.
- E-mail was sent to all IERS DB members (twice) asking for their review. The list members of the IERS DB was found at <https://www.iers.org/DB>.
- Many members have given their approval/review; no members have had objections as of the writing of this presentation.
- Erricos Pavlis has suggested Sergei Kopeikin, PhD for providing assistance to Chapters 2 and 10.
 - Any additional suggestions by the IERS DB for positions that are vacant are most welcome.
- IERS CC will assume that the review is complete if no objections are raised by the end of the IERS DB meeting on Dec. 8, 2018 (agreement with the selections made and including Sergei Kopeikin to help with the re-write).

Changes in staff positions at the IERS CC

On January 1, 2019 Mr. Nick Stamatakos will become the Current representative to the IERS Directing Board (as agreed). It had been the tradition that the current representative switch between the French co-chair and the USNO co-chair once every 3 years (French co-chair started on 01 January 2016).

Sample of Questions Regarding IERS Conventions from Users

- Jim Williams on 23-SEPT-2018 asked about Section 9.1.2: Johannes Boehm answered on behalf of IERS CC.
- Kaifa Kuang had questions about the validity of FES2004 ocean tide model pertaining to the “Sn0” terms: Florent Lyard answered on behalf of the IERS CC.

EOP Products
Report from Earth Orientation
Centre

The report was presented by N. Stamatakos on behalf of C. Bizouard.

Main changes/novelties since April 2018

- IDS retreat held at Château de Mons (Caussens), 13–14 June leads us to update the “status” of DORIS pole coordinates series at Earth Orientation Center.
- The DORIS pole coordinates have been tremendously improved.
- On <http://iers.obspm.fr/eop-pc> IDS & INASAN operational solutions are provided for comparison and analysis.
- IDS Combined solution is now included in C04 combination.

Earth rotation news

1. The Chandler wobble amplitude decreased down to 40 mas with a tremendous phase change since 2012: situation is similar to the period 1925–1930.
2. The Earth rotation has strongly accelerated since 2016.

Status of 14 C04 Update April 2018

- Updates listed at: <http://hpiers.obspm.fr/iers/eop/eopc04/update/C04.txt>.
- Last update: April 16, 2018 according to the decision of IERS DB 66 (April 8, 2018 in Vienna): 14 C04 solution for UT1 has been modified by including the contribution of UT1 Intensives back to 1996 (see note of January 2018). Old version updated until 2018/04/16 is put in the sub-directory /eopc04.2017.
- Update essentially under-weighted R1 and R4 24-hour VLBI relative to intensives. A correction was applied to fix that issue in August 2018.

Report from Rapid Service /
Prediction Centre

C. Hackman presented the following report.

2017 Daily Product Accuracy

- 2017 (est/1-d pred): PM (μ as): 73/304; UT1 (μ s): 63/88
- 2014 best; 2016 had UT1 probs (UTGPS)

- 2017 changes: UTGPS de-weighted 29.03.2017; Aligned to ITRF2014
- 2017 outcomes: UT1 better than '16; PM worse than '16; Still chasing 2014
- 2017 factors: Compared to C04; aligned to ITRF; two $\sim 650 \mu as$ residuals included in PM-X, PM-Y

Optimization/modernization of combination/prediction algorithm

- Current algorithm has known problems.
- 2018: preliminary research on optimizing estimation scheme.
- Code-optimization effort is now a funded research program (Financial Years 2019–2023)
 - Examining normal-equation-based optimal estimation strategies (e.g., Kalman filter) for solving the combination solution.
 - May examine using some kind of VLBA/IVS solution (Mk-Wz) for coverage when Ishioka plans to go down.
 - Hiring of contract support underway; expected to begin early Calendar Year 2019.

IERS RS/PC product changes 29 Mar 2018

- Products now aligned to 2014 C04 (was ITRF 2014).
- Implements IERS 2010 Conventions dX/dY CPO paradigm.

Transitioning to new email system handling RS/PC, Bulletin A operations

- Bulletin A delivery, bounce-backs.
- User questions/issues/requests.
- Will be from mail.mil domain.
- Transition expected Fall 2018.
- Will notify users via IERS Message, Bulletin A, other means.

Working Group on “IERS Product Distribution”

Tom Herring presented the report.

- Working group still to be formed. WG should probably be made up of Analysis Coordinators of each service component and data centers.
- Highest priority: FTP access to products will almost certainly go away due to security issues with FTP. CDDIS has already stopped

for product uploads (curl replacement); Mac no longer includes FTP in OS distributions.

- HTTPS is likely replacement which would keep similar functionality as now (use curl or wget to access). Users will need to be informed and educated.
- Implementation of web services: similar to above but products delivery can more tailored to users requirements.
- WG should address both of these issues.
- Additional item: encourage IERS services to make more results available for ease of use by community. Specifically, position time series and even EOPs of some services (see for example, University of Nevada, JPL, UNAVCO, MIT for GPS position time series as ASCII files that users can analyze.) Less code needed than for SINEX files.

New Action Item #67.03 Notify users about then new e-mail system via IERS Message.

**Reports from Technique
Centers
IDS Report**

The report was presented by Hugues Capdeville.

DORIS Constellation Status

- Current Missions: Sentinel-3B and -3A, Jason-3 and -2, SARAL, HY-2A, Cryosat2.
- Future Missions: Sentinel-3C and -3D, HY-2C and -2D, Jason-CS1+CSB, SWOT (, MOBILE).

Current DORIS tracking network

- 3 generations of beacons have been developed; third-generation beacon implemented everywhere since 2010 (improve measurements accuracy). Today, about 25% of the network has Starec C antennas.
- Planned network maintenance (2019): restarting at Santa-Cruz, Ecuador; reconnaissance in Iceland with the view to relocate the station; relocation at Easter Island, Chile; 4th generation beacon deployment from mid-2019.
- 4th generation beacon: up-to-date electronic components: to be operational up to 2033; deployment will start in mid-2019.
- New stations in Guam (MILAC, Mangilao) and San Juan (SJUC, Argentina). Relocated station Rothera, Antarctica and Ny-Ålesund, Svalbard. Restarted stations in Rio Grande, Argentina and Mahé, Seychelles. Station Badary, Russia shut down for indefinite period.

Analysis Update***Routine Processing***

- Six DORIS Analysis Centers (ESA, GOP, GSC, IGN, INA, GRG) routinely process data.
- The processing of the 3rd quarter of 2018 is underway by the IDS Combination Center.
- IDS Combination through the end of 2nd quarter 2018 is available:
https://cddis.gsfc.nasa.gov/pub/doris/products/sinex_series/idswd
https://doris.ensg.eu/pub/doris/products/sinex_series/idswd
- DPOD2014 v3 is available. (DORIS extension to ITRF2014 for Precise Orbit Determination). <https://cddis.gsfc.nasa.gov/pub/doris/products/dpod/> <https://doris.ensg.eu/pub/doris/products/dpod/>
 See also: Moreaux, G., Willis, P., Lemoine, F.G., Zelensky, N.P., Couhert, A., Ait Lakbir, H., Ferrage, P., 2018. “DPOD2014: a new DORIS extension of ITRF2014 for Precise Orbit Determination”, Adv. Space Res., 63(1), 118–138, doi:10.1016/j.asr.2018.08.043.

Work in progress

- Implement DORIS/RINEX data processing by all ACs.
- Introduce Jason-3 and Sentinel-3A in the IDS combined solution for All ACs.
- Verify that all ACs can reprocess 2012 data to eliminate scale anomaly.
- Mitigate the SAA effect on Jason-2 and Jason-3 USOs.

Continuing work

- Implement and validate the new standards/models recommended by the IDS/IERS.

How DORIS can Contribute to Future Realizations of the ITRF Origin

See also: Couhert, A., Mercier, F., Moyard, J., Biancale, R., 2018. “Systematic error mitigation in DORIS- derived geocenter motion”, J. Geophysical Research: Solid Earth, 123(11), 10,142–10,161, doi: 10.1029/2018JB015453.)

- “Cookbook” for obtaining independent DORIS-based geocenter time series: Sun-synchronous satellites should be disregarded ($\beta' \approx 365$ days) and vertical site displacement should be estimated.

IDS News

IDS Meetings in 2018:

- IDS AWG June 11–12, 2018, Toulouse, France.
- IDS Retreat June 13–14, 2018, Château de Mons, France.
- IDS Workshop September 24–29, 2018, Ponta Delgada, Portugal.

IDS Working Groups:

- WG “Near-real time data”, Chair: Denise Dettmering (DGFI/TUM). Delivery of NRT for use in Ionosphere models.
- IDS GB is evaluating formation of another WG on the Geocenter where non-IDS participation would be encouraged.

IDS Newsletter published ~2 times per year.

IDS Elections:

- Two positions to be renewed within the Governing Board for the term 2019–2022: Analysis Coordinator (1 candidate team) and Member-at-large (4 candidates). 2019: start of 4-yr term.

IGS Report Rolf Dach presented the report.

Recent IGS workshop in Wuhan:

- Location made it a challenging environment for splinter meetings.
- Returning to two-year IGS Workshop schedule.

Future workshop

- Boulder, CO, USA in 2020.

Recent activities

- Working on incorporating Galileo (calibration, etc.).
- GFZ will make multi-GNSS product generation.
- IGS elections: new vice-chair position.

ILRS Report Erricos Pavlis presented the report.

ILRS Status and Activities

- Governing Board Elections for the 18 elected members completed; Prof. Toshimichi Otsubo of Hitotsubashi University, Tokyo, Japan elected as the new GB Chair.
- Infrastructure: updated formats for Data (CRD) and Tracking Predictions (CPF), web-based station site log archive and maintenance; Harmonized data screening & QC between EDC and NASA OCs.

- Routine submission of all full-rate data to OCs and DCs from 32 out of the currently active stations (39).
- Stations asked to provide additional resolution in their epoch recording precision of their data (< 1 ns).
- Implementing new strategies to “rate” station performance underscoring value to the users and science products; list of satellites on ILRS tracking roster continues to grow (>100).
- ILRS sets tracking priorities to balance requests and maximize the utility of the network.
- Increased scrutiny in selecting new missions to track.
- Discussions with the IGS and the ICG on tracking GNSS s/c.
- Issues: Network gaps in Latin America, Africa, and Oceania, and mix of new and old technologies are the primary issues of concern now.

ILRS Network Status

- BKG AGGO in setup in La Plata Observatory (Argentina).
- New stations underway:
 - Russia: Ensenada (Mexico), Java (Indonesia), and Gran Canaria (Spain).
 - NASA/NASA affiliated: McDonald, Haleakala (USA), and Ny-Ålesund (Norway).
 - Others: Metsahovi (Finland), Mt. Abu and Ponmudi (India), and Yebes (Spain).
- Upgrades underway at some stations.
- First co-locations in Russian and NASA SLR laser systems established at Hartebeesthoek, South Africa; two Russian SLR at Mendeleevo.

ILRS Network Productivity (All targets)

- About 16 (out of 39) stations are responsible for ~80% of the observed passes on all satellites (wide divergence in station performance).

Mission News & Support

- Network routinely tracked 100+ satellites in 2018.
- New, approved missions in 2018: S-NET, Sentinel-3B, GRACE-FO, Tiangong-2, Beidou-3M, PAZ, ICESat- 2, Astrocast Precursor, GNSS.

- Future missions: Additional GNSS: BeiDou/Compass, Galileo, etc.; LightSail-2, COSMIC-2, HY-2C, SWOT, NISAR.

ILRS ASC – Analysis Activities

- Preparations for contributing to the development of ITRF2020.
- New operational approach in handling error sources was adopted at the last ASC meeting: estimation of systematic errors simultaneously with all other parameters (eliminate biases in station positions/velocities); correction of identified serious shortcomings in the current model for the target signature (“CoM correction” can affect the SLR-VLBI scale difference at the 0.25 ppb level); Adoption of new CoM model (early results to be presented at the 2019 EGU).
- SSEM PP resulted in significant change in the SLR scale (much closer to VLBI network scale now).
- SSEM Pilot Project on station systematics completed the next phase (awaiting final submission from DGFI (end of 2018) to complete the combination product).
- Result will be used as basis for the development of the ILRS product for ITRF2020 contribution.
- Time Biases estimation/handling added: Time biases now modelled based on T2L2 results; Additional time biases from T2L2 results for 2017 expected soon.
- RB & TB values & σ applied to each station included in SINEX file for next contribution to ITRF
- New QC products related to near real-time system evaluation (available online) and presented at the recent 21st IWLR in Canberra, Australia.
- Next PP will deliver low-degree gravity coefficients as a weekly product and introduce LARES as a 5th target for ITRF product support (by EGU 2019).

Special Issue of the Journal of Geodesy

- 10 articles accepted, 8 additional articles still under review.

Recent & Future Meetings Schedule

- 21st International Workshop on Laser Ranging (IWLR) November 4–9, 2018 in Canberra, Australia.
- ASC meeting on Sunday, Nov. 3, 2018.

- Technical Workshop in late 2019, candidate sites Stuttgart, Germany and Arequipa, Peru (no decision yet).
- 22nd International Workshop on Laser Ranging will be held in Kunming, PRC, in 2020 (date TBD).

IVS Report John Gipson presented the report.

CONT17

- 2 legacy and 1 VGOS network
- Data correlated and released
- Analysis ongoing
- Indications that legacy-1 with VLBA + IVS gave superior results

⇒ in 2019 RDV sessions with VLBA in parallel to R1

VGOS development

- In 2018: VT-sessions every 2nd week.
- Up to 7 station network.
- Data correlated at Haystack.
- VT-sessions will continue with this setup at least to April 2019.
- VGOS correlation cookbook pre-released.
- VGOS-correlation workshop in May 2019 at Haystack.

IVS DB elections

- Elections November 2018. New members:
 - Hayo Hase (BKG, La Plata)
 - James Anderson (GFZ Potsdam)
 - Chet Ruszczyk (MIT/Haystack)
 - Laura la Porta (Bonn correlator)

Office for Outreach and Communication (OOC)

- Call for Proposals: discussed at DB meeting in Longyearbyen in June 2018.
- Call distributed on July 9 with deadline for August 31.
- Successful proposal: MIT Haystack Observatory with Lead: Nancy W. Kotary.
- Implications: Extension of Directing Board. Change of IVS Terms of Reference to include the OOC.

- Tasks: attractive Web presence, outreach activities to other organizations, flyers and info material for colleagues, political decision makers and general public.

VLBI meetings

Past meetings:

- 10th IVS GM June 2018 in Longyearbyen, Svalbard, Norway.

Future meetings:

- 24th EVGA March 2019 in Las Palmas, Gran Canaria, Spain.
- TOW May 2019 in Haystack, USA.
- 11th IVS GM March 2020 in Annapolis, USA.

IAU Report Richard Gross presented the report.

Two resolutions – resolution B1 on ITRF and resolution B2 on ICRF – adopted at IAU General Assembly which took place on August 20–31, 2018 in Vienna, Austria.

IAU members voted to recommend renaming the Hubble law as the Hubble-Lemaître law. A new IAU representative to IERS needs to be named.

Commission 19/A2 centennial will be celebrated at Journées 2019 (07–09 October 2019) in Paris, France.

ICRS/ICRF report Brian Dorland presented the report.

ICRF3 Status

- ICRF3 released in 2018.
- Endorsed by IERS DB.
- Approved by IAU for adoption. Date of adoption: January 1, 2019.
- Key accomplishments:
 - Multi-wavelength (S/X, K, X/Ka).
 - Majority of sources much more accurate (factors of 3x+ improvement).
 - Approximately 30% more sources.
 - Available now via IERS ICRS Centre website.

Post-adoption plans

- Maintain ICRF3 with additional observations.
- Begin planning/discussion regarding integration of radio reference frame (ICRF3-based) with optical reference frame (Gaia-based).
- Comments

- Communication issues arose over the last six months between ICRF and possible “endorsing organizations” such as the IERS.
- These organizations might want to consider appointing official liaisons to the ICRF3 WG follow-on to represent the organization’s equities in the maintenance and development of the reference frame.

Possible IAU Symposium

- USNO and Paris Observatory (jointly, the IERS ICRS Centre) are planning on proposing a 2020 symposium to the IAU with the title: “Active Galactic Nuclei and the Celestial Reference Frame (AGNCRF)”.
- Motivation: Bring together AGN researchers with CRF researchers to communicate/coordinate/collaborate on AGN observations and research, benefitting both disciplines.
- Venue: Observatoire de Meudon (outside of Paris).
- Request: IERS DB/Chair endorsement (part of IAU proposal package).

An IERS representative to the next WG is needed; requesting letter of support for proposed IAU symposium.

GGOS report Richard Gross presented the report.

Personal changes

- Coordinating Office
 - Director of Coordinating Office Matthias Madzak resigned on October 31, 2018. Acting Director of Coordinating Office is Martin Sehnal.
 - Host of Coordinating Office is the Bundesamt für Eich- und Vermessungswesen (BEV), which is in process of finding permanent replacement.
- GGOS Focus Area on Sea Level
 - Lead of Focus Area Tilo Schöne resigned effective September 30, 2018.
 - Currently discussing options for continuation. Continue current focus, liaise with sea level community and redirect focus.

GGOS Affiliate

- National or regional organization that coordinates space-geodetic activities there.

- Established to increase participation in GGOS, particularly from under-represented areas like Africa, Asia, South and Central America.
- A component of GGOS with one representative each to Consortium and collectively two representatives to Coordinating Board.
- First GGOS Affiliate is the GGOS Working Group of Japan (established in 2013): provides a forum for multi-technique, space-geodetic discussions within Japan.
- Encourage others to become GGOS Affiliates.

Essential Geodetic Variables

- Observed variables are crucial to characterizing geodetic properties of Earth and key to sustainable geodetic observations (positions of reference objects (ground stations, radio sources), EOPs, Gravity measurements (ground-based, space-based))
- Assign requirements to each EGV like accuracy, spatial and temporal resolution, latency, stability, ...
- Derive requirements on EGV-dependent products (TRF, CRF, ...) and on infrastructure (observing systems)
- Can be used to update GGOS2020 book following a bottom-up approach to deriving requirements
- Established Committee within GGOS BPS to create list of EGVs, assign requirements to them, etc. The Committee includes representatives of IAG Services, Commissions, Intercommission Committees, GGOS Focus Areas.

DOIs for Geodetic Data

- Digital Object Identifiers (DOIs) for publications widely used by publishers and a unique identifier of publication. The DOI system is managed by International DOI Foundation (IDF).
- DOIs for data sets benefits users and benefits data providers.
- Registration agency manages DOI to URL mapping and develops registration server to share among data providers.
- Granularity of DOI assignment: one data set = one DOI, even if data set is updated. Example: IVS contribution to ITRF2014 (data set does not change). Example: IGS Final combined EOPs (data set changes, but not file name).
- Establish Working Group with representatives of the Services and data centers, and establish procedures for assigning DOIs to geodetic data sets.

Meetings

GGOS Days 2018 at GSI Headquarters from October 02 to 05, 2018 in Tsukuba, Japan.

Other Meetings:

- European Geosciences Union in Vienna, Austria; April 08–13, 2018.
- Japan Geoscience Union in Chiba, Japan; May 20–24, 2018.
- ISC WDS International Program Office – NICT in Koganei, Tokyo, Japan; October 01, 2018.
- American Geophysical Union in Washington, DC; December 10–14, 2018.

Future Meetings:

- European Geosciences Union in Vienna, Austria; April 07–12, 2019.
- International Union of Geodesy and Geophysics in Montreal, Canada; July 08–18, 2019.
- GGOS Days / SIRGAS in Rio de Janeiro, Brazil; November 11–14, 2019.
- American Geophysical Union in San Francisco, CA; December 09–13, 2019.

Unified Analysis Workshop 2019:

- Venue (tentative): GFZ Potsdam August 13–15, 2019.
- Program (tentative): Topics specific to each technique, e.g. systematic errors and biases in each technique, and Topics common to all techniques, e.g. Reference systems and frames (including preparation for ITRF2020), site surveys, co-location of techniques (including with gravity, unified height system), standards, conventions and formats, Digital Object Identifiers (DOIs) for geodetic data sets.
- Attendance by invitation, 5–6 representatives from each Service.

Annual Reports

B. Luzum reported: The last contribution to the Annual Report 2017 will be submitted by 9 December. All other 20 contributions have been submitted, edited and formatted; most of them are finally ready. The Annual Report 2017 will be published online not later than on 17 December.

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. 66, April 8, 2018, at Technical University of Vienna, Austria, and No. 67, December 8, 2018, at Hotel Washington Marriott, Washington, DC, USA (see Section 3.1 for minutes of these meetings). Between the meetings the CB coordinated the work of the DB.

Members of the CB took also part in the following meetings: European Geosciences Union General Assembly 2018 (including meetings of the GGOS Coordinating Board, the GGOS Bureau of Networks and Observations, and the GGOS Standing Committee PLATO), 10th IVS General Meeting, IAU XXX General Assembly, and 21st International Workshop on Laser Ranging.

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 2018 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. In an internal area, accessible for DB members and IERS Associate Members, all presentations given at IERS DB meetings since 2000 are available, and further documents were added.

The IERS Annual Report 2016 was printed and distributed. The CB edited the IERS Annual Report 2017 and published it online in December 2018. Along with the reports of the IERS components, provided by them, the annual reports contain general information on the IERS assembled by the CB. The CB compiled also summaries of DB meetings and its own report. The $\text{\LaTeX}$ template for Annual Reports was further improved.

A report of IERS for the period 2015–2018 was submitted to IAU Commission A2 in March 2018.

During the year 2017, 21 IERS Messages (Nos. 347–367) 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 2800 users in 2018 with

valid addresses who subscribed to IERS publications for e-mail and regular mail distribution.

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. Two public presentations on the leap second were given at Potsdam and Hamburg, Germany.

The Director of the CB, Daniela Thaller, chairs the IERS Working Group on SINEX Format and is ex officio member of the other IERS WGs. She also leads, together with Benjamin Männel of GFZ, the GGOS Standing Committee PLATO (Performance Simulations and Architectural Trade-Offs), which is also a Joint Working Group with IAG Sub-Commission 1.1. 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.

Time scales - Web Clock

Local Time: 20:34:21 . 963

Date: 2019-12-09 MJD: 58826

UT1-UTC: -0.17221 s Leap sec: 37 s

	h	m	s	ms
UTC:	19	34	21	963
UT1:	19	34	21	791
TAI:	19	34	58	963
TT:	19	35	31	147

- Data for UT1-UTC taken from Bulletin A -
 - Data for leap seconds taken from Bulletin C -
 - Local time taken from your computer system -
 Please note: The web clock only works if Javascript is activated in your browser.

Time scales for any date since 1972

UTC (HH:MM:SS): 12:00:00

Date (yyyy-mm-dd): 2018-01-01 or MJD

Date	2018-01-01 12:00:00
Leap seconds	37
MJD	58119
UT1-UTC	0.216341 s
UT1	2018-01-01 12:00:00.216
TAI	2018-01-01 12:00:37
TT	2018-01-01 12:01:09.184

- Data for UT1-UTC taken from Bulletin A -

Fig. 1: User interface of the Time scales tool, see also <https://www.iers.org/timescales>

IERS Data and Information System (DIS)

The IERS Data and Information System (IERS DIS) is continuously being adapted and extended by new components in order to fulfil the requirements for a modern data management and for the access to the data by the users. Besides routine work like maintenance of the data bases of users, products and web pages, in 2018 further developments of the IERS DIS concentrated on the new system for data management and the improvement of interactive tools and graphics. The new data management system was put into operation in spring 2018.

For security reasons, an https instead of the former http access was installed at the server iers.org. Security measures also changed links to IERS data at datacenter.iers.org and at ftp.iers.org.

Additional data privacy protection measures were implemented for the IERS web pages and for the IERS user management system.

Among the products, ICRF3 was added and the series EOP 08 C04 was moved to the “old series” directory, as it was officially stopped in April 2018 (cf. IERS Message No. 354).

Further improvements of the IERS DIS included an update on the IERS Time scales tool and the Time scales and leap second web service.

Staff in 2018

Dr. Daniela Thaller, *Director*

Dr. Wolfgang R. Dick, *scientist and Executive Secretary*

Sabine Bachmann, *scientist*

Sonja Geist, *technician*

Sandra Schneider-Leck, *technician*

Wolfgang R. Dick, Daniela Thaller, Sonja Geist

3.3 Analysis Coordinator

Introduction

This is my last annual report as IERS Analysis Coordinator and I am leaving this position in the capable hands of Robert Heinkelmann from GFZ Potsdam. In this final report, I will address issues of providing realistic error estimates for user of IERS products especially those products such as SINEX files where the full analysis of IERS products is possible. This issue is not just an IERS issue but rather the services that submit products to the IERS. The IERS is in a position to provide guidelines to the services as to the importance of providing realistic uncertainties and explanation of how these uncertainties should be interpreted. The other issue to be addressed is the distribution of IERS products in the modern era where protocols such the file transfer protocol (ftp) are being increasingly a computer security risk. Associated with this task is also the issue of generating and disseminating higher level products that a large user community can easily access and use for their own, often innovative, analyses.

Error assessment

We discuss two aspects of error assessment here. The first aspect is how to release products that have realistic standard deviations associated with them. The topic is problematic because of temporally correlated noise in the products. But current standard deviations and their associated covariance matrices in, for example, SINEX files are not even close to realistic. Again the assessment of the variances of results in products is an issues for the services not just the IERS. For IVS and ILRS combined SINEX files, variance factors of 50 are needed to generate realistic short period noise estimates i.e., the day-to-day or week-to-week scatter of position estimates derived from IVS and ILRS SINEX files is of order 7 times larger than the standard deviations of these position estimates given in the SINEX files. For users of IERS products, this difference is very confusing. Users questions would include confusion about the day-to-day scatter being real motions of the sites since they are so much larger than the standard deviations? If the standard deviations seem to have such large “errors”, how large are the errors in estimates themselves? The IERS products are most useful and would have widespread support, if outside users are encouraged to use the products. To encourage outside users to examine and use the IERS products, we should be supplying the “best” estimates of the uncertainties and how to interpret those uncertainties.

As an example of the issues associated with reported standard deviations and to look at an on-going issue with the ITRF, we examine results from VLBI and SLR collations where both systems are located at the same facility. The scale difference between VLBI and SLR will be the primary focus. These analyses are based on session (IVS) and

weekly (ILRS) SINEX files. The approach is to combine the VLBI and SLR separately and “predict” the other system coordinates using the survey tie information available for the ITRF ftp site.

In our comparisons, we compare both time series behavior and the scale estimates as assessed by the mean height differences at the collocated sites. There are 25 VLBI/SLR sites within 10 km of each other and 17 pairs of these have VLBI and SLR velocities with both standard deviations < 1 mm/yr. (Three of the pairs are one VLBI station with two SLR stations and so of the 17 there are only 14 distinct locations). Of these 17, there are (disappointingly) only 6 pairs that have survey ties between the VLBI and SLR reference points in the ITRF2014 site-tie files. Given the investment in these collocated sites, it seems short-sighted not to have survey ties to link the systems especially since we have only one third of the possible ties.

For the processing here, we used the ILRS SLRa ITRF2014 SINEX files (ends 2015.0) and the IVS on-going files in ITRF2014 systems (ended September 2018 for this report). We start the analyses in 1996 to be consistent with GPS and to avoid low quality early solutions.

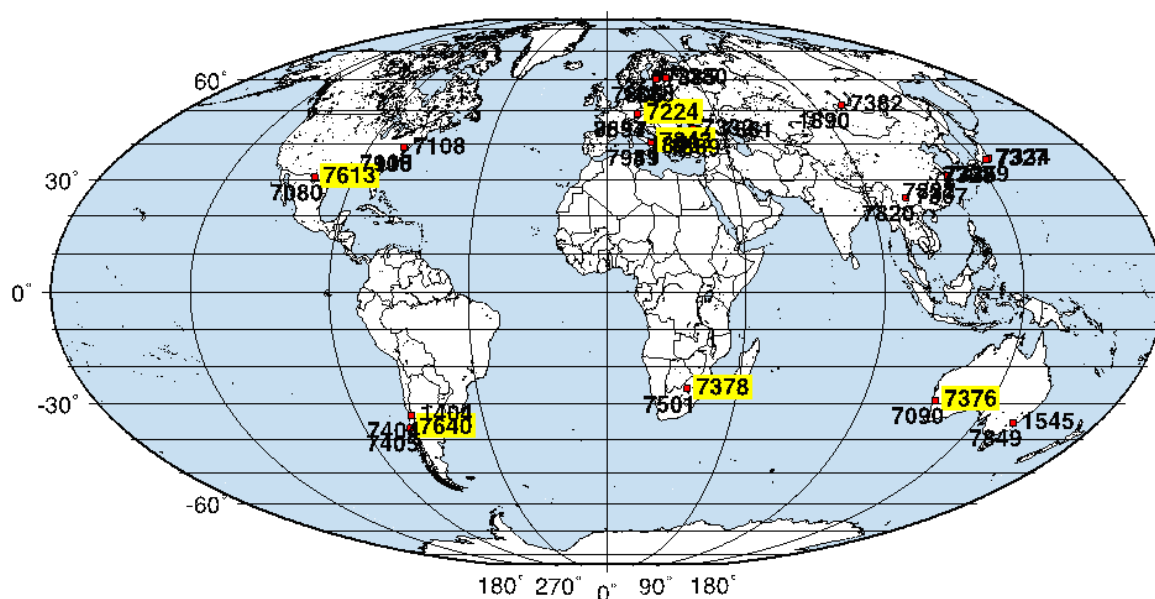


Fig. 1: Map of collocated VLBI and SLR sites. Yellow highlights are those sites with survey ties in the ITRF2014 SINEX tie files.

As an example of the time series results and the issues with standard deviations, we show results for Wettzell, Germany. The SLR site is 8834 and the VLBI site is 7224. The time series are generated in “smoothing” Kalman filter using the MIT GLOBK program. For VLBI and SLR separately, all SINEX files are combined in the Kalman filter with positions, velocities and time-series offsets estimated. Post-seismic

deformation models were applied apriori based on the ITRF 2014 values. The combined positions and velocities are aligned to ITRF2014 using only translations, rotations and their rates. No scale parameters are included and heights are heavily downweighed in the estimation of the transformation parameters. The time series are generated in the back/smoothing Kalman filter run with each day aligned with rotation and translation to the aligned results from the forward Kalman filter run. The process noise was large (1 m standard deviation for one day separations) and so the “smoothing” filter did not smooth the results.

Figures 2–5 show the time series residuals for Wettzell. We also show the plots for these residuals that are available on the ITRF2014 web site (http://itrf.ign.fr/ITRF_solutions/2014/ITRF2014.php). Unfortunately, only plots of these residuals are easily assessed. ASCII files with the residuals are available upon request and such restrictions on access to results reduces the number of users who would be willing to look more carefully and perform their own analyses of ITRF products.

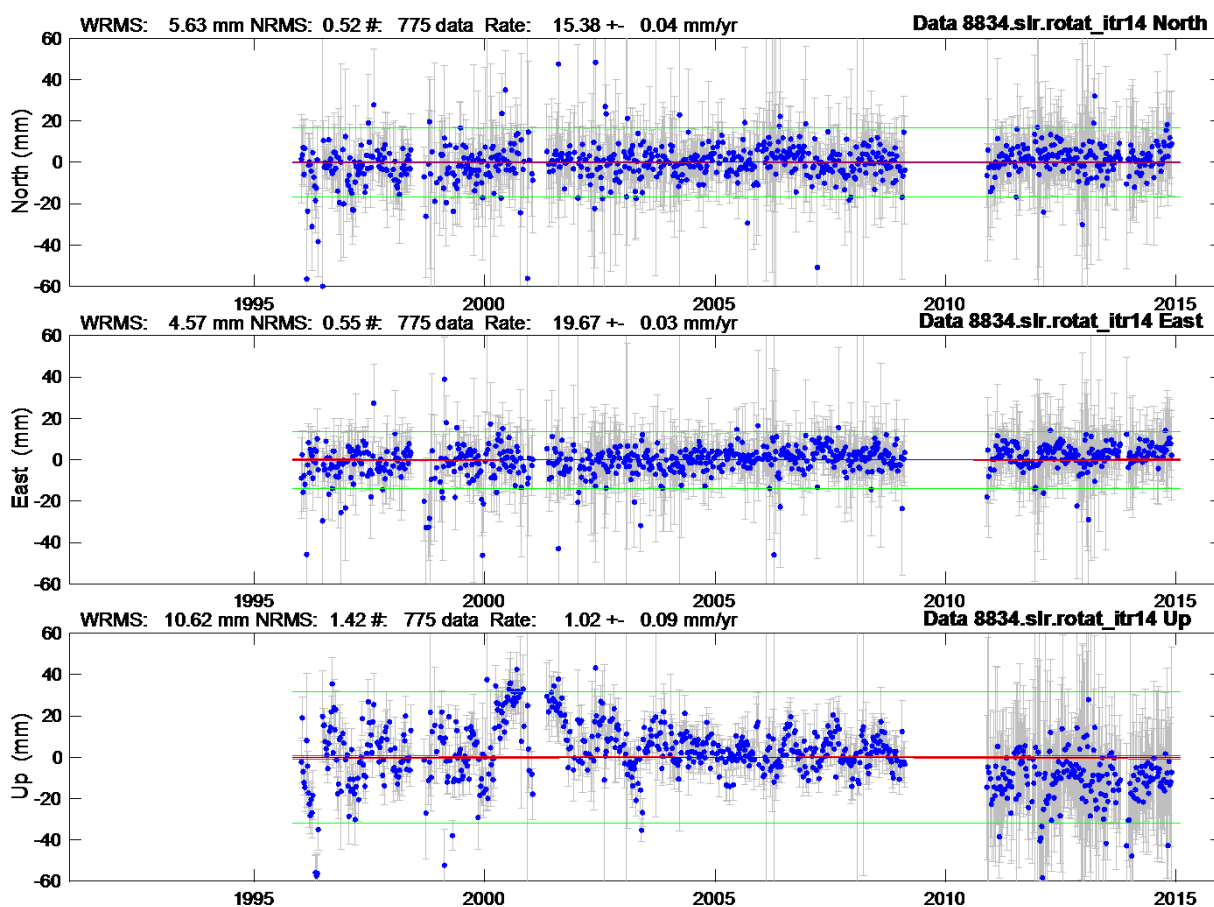


Fig. 2: SLR time series residuals from the Kalman filter back solution. A variance factor of 50 needed to be applied the ILRS SINEX files to generate error bars that matched the week-to-week scatter. SINEX files before 1996 were not included in the analysis.

The figures (2–4) illustrate that the error bars being displayed on IERS ITRF products and in the SINEX files are far smaller than they should be given the session-to-session and week-to-week scatter of the position residuals. The figures also show that our residuals are similar to those from the ITRF2014 analysis although this comparison can be easily made graphically because files with the residuals in machine readable form are only available upon request. This seems to be an unwarranted extra step for users who would like to examine the residuals more closely.

In this analysis we were also able to compare our height estimates of the VLBI and SLR sites with the site ties between them. The results are shown in Table 1 where the difference in height between our estimate for the VLBI and SLR stations and the ITRF2014 inferred values with the SINEX site ties applied. The difference between the SLR and VLBI values is our estimate of the scale difference between the systems based solely on the collocated sites with site ties. (The ITRF2014 scale difference estimate use many more sites because this estimate uses stations linked by GPS or DORIS sites.) The mean height difference between VLBI and SLR, excluding TIGO/CONZ, is 3.9 mm which is equivalent to 0.6 ppb. This difference is about half the ITRF2014 value but again is based solely on VLBI and SLR stations that are collocated. The TIGO/CONZ results are likely anomalous due to the complex post-seismic motions after the large earthquake near Concepcion on 27 February 2010.

Table 1: Average height differences between GLOBK analysis and ITRF2014 with survey ties applied. Most important here is the difference between VLBI and SLR.

Station	ΔU VLBI (mm)	ΔU SLR (mm)	VLBI-SLR (mm)
Wettzell	-11.9 ± 0.5	-13.0 ± 1.9	+1.1
Matera	-1.2 ± 0.6	-10.7 ± 0.8	+9.5
Yarragadee	8.0 ± 0.6	0.8 ± 0.7	+7.2
Hartebeesthoek	-2.9 ± 0.8	-3.2 ± 1.3	+0.3
McDonald, TX	-0.5 ± 0.8	-2.0 ± 0.9	+1.5
TIGO/CONZ	-11.5 ± 2.7	1.6 ± 2.1	-13.1

We are also able to estimate scale changes, again expressed as height changes, from the VLBI and SLR solutions and compare them to estimates from GPS. These results are shown in Figure 6. For VLBI, the mean is 0.5 mm with a root mean scatter (RMS) scatter of 2.8 mm

based on 2603 session values. For SLR the mean is -3.6 mm with RMS 3.0 mm for 969 weekly values. This difference between VLBI and SLR is very consistent with the values from the mean height differences although for these analyses all VLBI and SLR sites were used. The precision of the GPS results is very clear but the average value is based on matching the average scale from SLR and VLBI through the satellite antenna phase center location. There is a scale rate of 0.2 mm/yr which was not present in the ITRF2008 system.

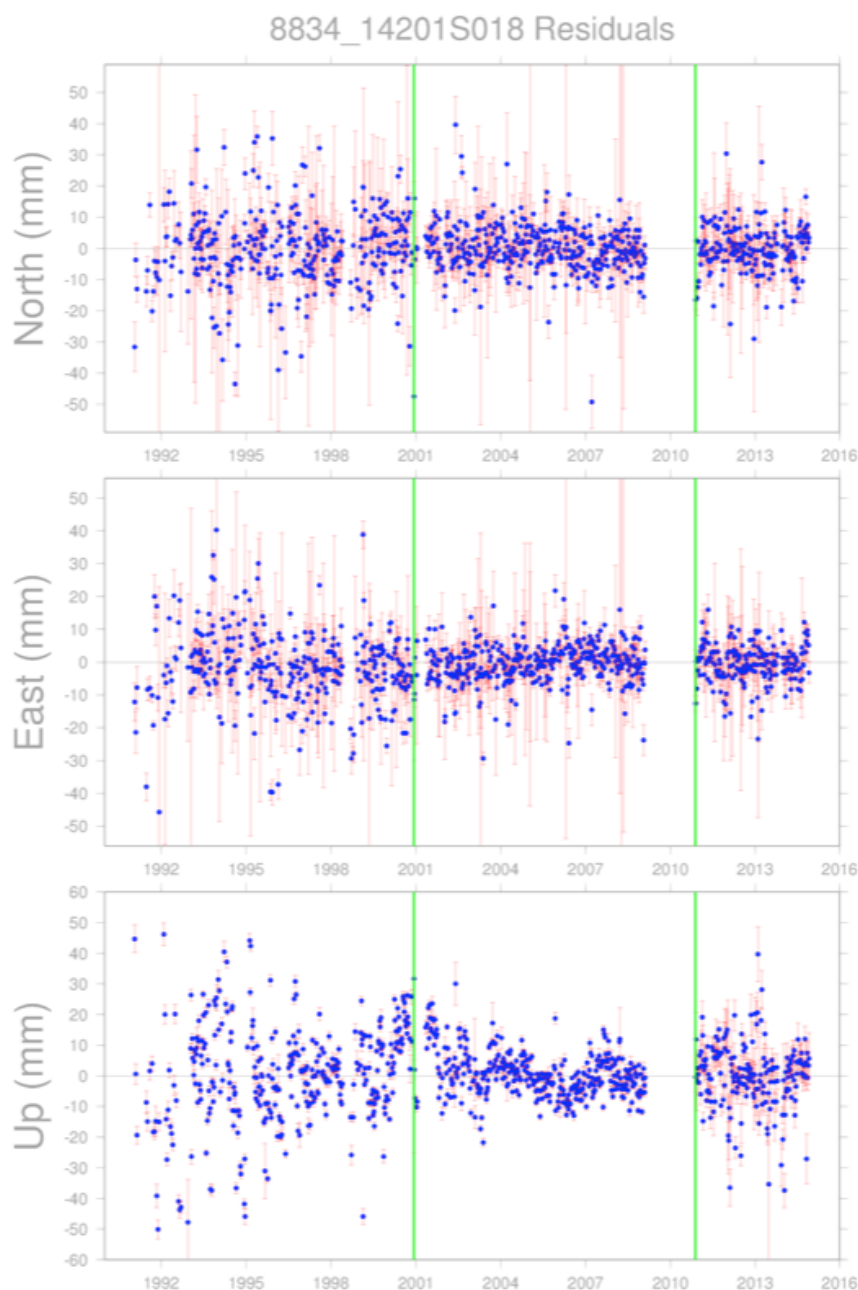


Fig. 3: The SLR equivalent type residual plot available from the ITRF2014 web site. Notice here that the error bars are not representative of the week-to-week scatter.

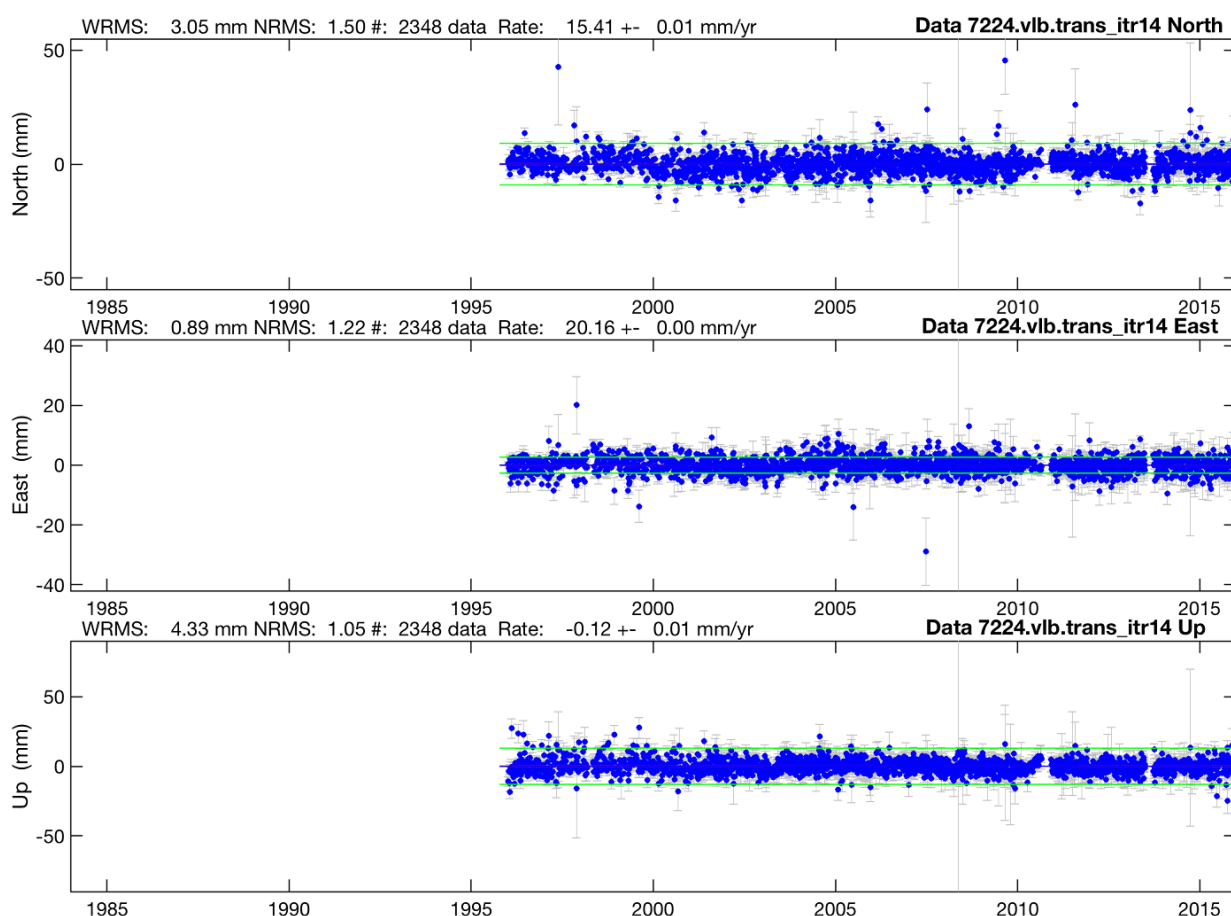


Fig. 4: VLBI time series residuals from the Kalman filter back solution. A variance factor of 50 (same as ILRS) needed to be applied the IVS SINEX files to generate error bars that matched the session-to-session (24hr) scatter. SINEX files before 1996 were not included in the analysis.

IERS product distribution

An action item for the next analysis coordinator could be to form a working group to make recommendations about the distribution of IERS products. As noted above, the distributed products from the IERS and the IERS services should provide realistic variances especially in their SINEX files. It also seems important there be generation and distribution of the “consensus” position time series and EOP estimates in simple ASCII files (for general community) and SINEX (for experts). There have been a number of interesting phenomena that have been found in GPS time series because non-expert users can access these results and do their own analyses. Examples include slow slip events and hydrological loading signals. Distribution of products to non-expert users can raise issues with mis-interpretations (e.g., understanding the impacts of estimating scale in reference frame realizations when hydrologic loading signals are being studied) but the experience from the IGS is that the benefits from a large community that has an interest in seeing the products continued outweigh the possible problems. For GPS position time series, there are multiple locations a user can go

and download results for stations they are interested in. For most of the IERS services, it is very difficult to find higher level products that users can analyze themselves.

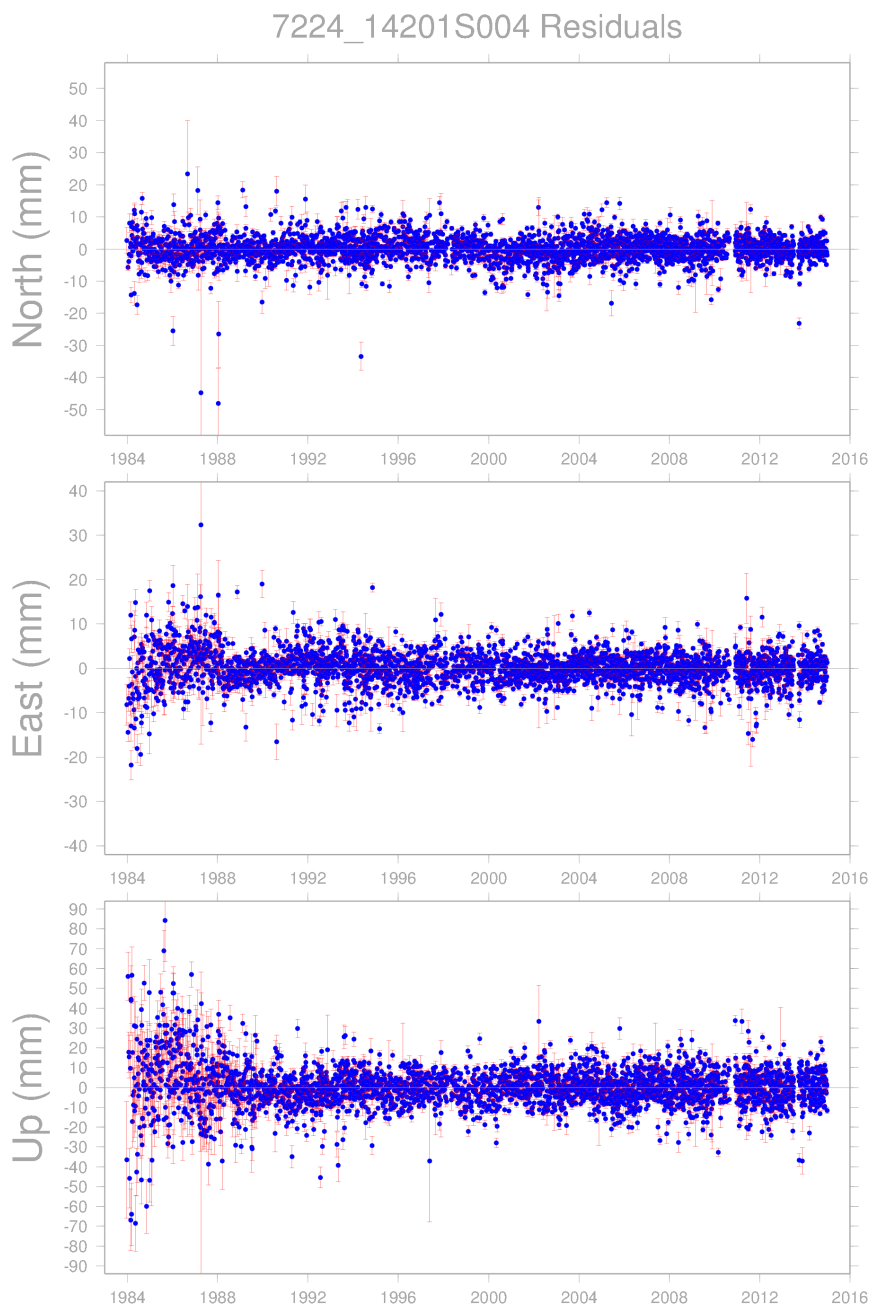


Fig. 5: The VLBI equivalent type residual plot for the VLBI sites available from the ITRF2014 web site. Notice here that the error bars are not representative of the session-to-session scatter.

The other product distribution issue that will need to be addressed is the file transfer protocol (ftp). The method of data access will almost certainly go away over the next few years due to the security risks associated with using it both to retrieve data and to host it. CDDIS has

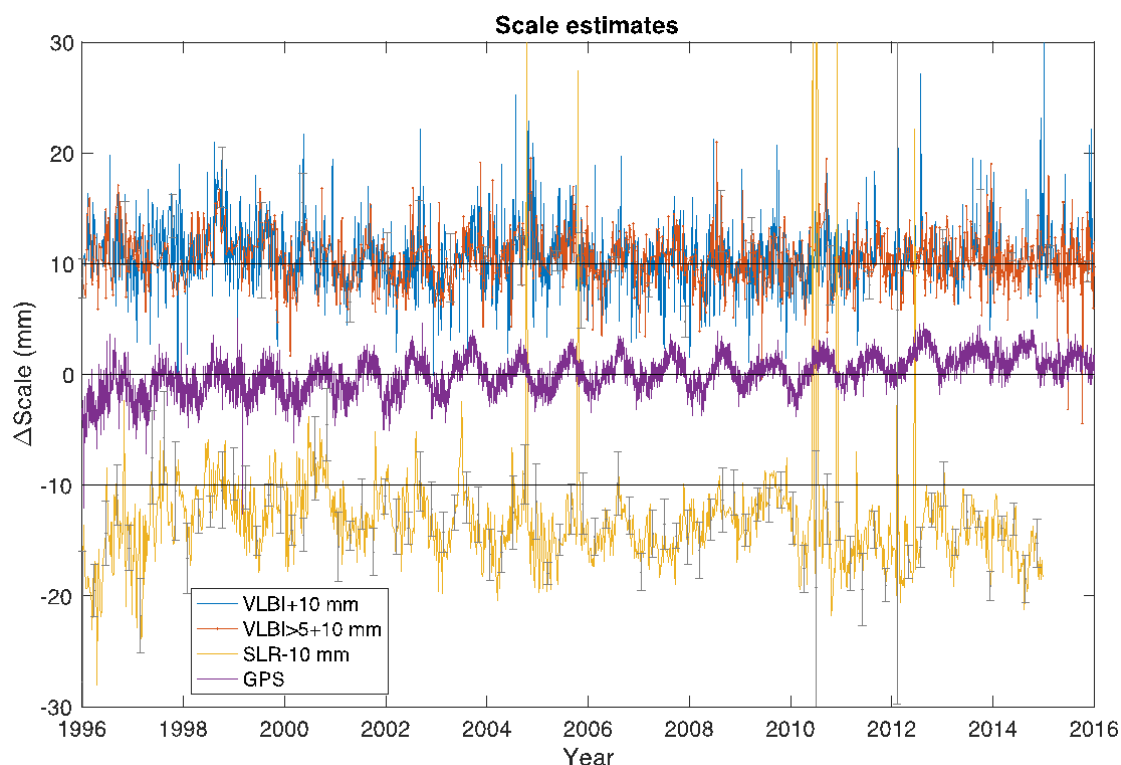


Fig. 6: Time series of scale estimates expressed as height differences from VLBI (blue, all results, dark brown values with standard deviations less than 5 mm) offset by +10 mm, GPS (purple) and SLR (light brown) offset by -10 mm.

already stopped using ftp for product uploads (curl replacement) and Apple operating systems (OS) no longer include FTP in new OS distributions. HTTPS is the likely replacement for ftp which would keep similar functionality as now (use curl or wget to access) but users will need to be informed and educated about changes in access methods. Implementation of web services is another approach and product delivery can more tailored to users requirements. Some IERS products are available through web services e.g., <https://www.iers.org/webservices>. Other groups such as UNAVCO provide interactive forms that allow users to create web service URL's which they can then modify to make more general calls (see e.g., <https://www.unavco.org/data/web-services/documentation/documentation.html#!/gps/getPositionByStationId>).

The Working Group should address both of these issues and strongly encourage the IERS services to make higher level products available so that a large community can assess and use them easily. The development of a large user community will ensure that there is strong support for continued generation of IERS products.

Thomas Herring

3.4 Technique Centres

3.4.1 International GNSS Service (IGS)

The International GNSS Service (IGS, where GNSS stands for Global Navigation Satellite System) was established in 1994 with a mission to provide the highest quality GNSS data and products for scientific use. The IGS provides a variety of products to the scientific community. Products of particular interest to the IERS include the Earth rotation parameters as well as global tracking station coordinates and velocities (typically obtained from a reprocessing effort), which serve as the GNSS technique contribution to the realization of the International Terrestrial Reference Frame (ITRF). In the generation of operational products, the IGS adopts the latest realization of the ITRF and IERS conventions, and thus provides its user community with direct access to these IERS products.

IGS activities and developments in 2018 that are of interest to IERS are summarized within this report. The information was compiled from the 2018 IGS Technical Report, which includes detailed report sections by the heads of all of the IGS Components and Working Groups. The Technical Report should be consulted for more detailed information regarding the IGS activities in 2018. It is available for download from the publications section of the IGS website www.IGS.org.

Routine Operational Activities

IGS network stations are maintained and operated globally by many institutions. This global network makes tracking data openly available at different latencies – from daily RINEX files to real-time streams – for public use. These data contain either the legacy GPS and GLONASS observations in RINEX 2 format, or the full set of potential signals/measurements for all available GNSS in RINEX 3 format. IGS tracking data, which is held by each of the five global Data Centers on permanently accessible servers, increased in volume over the last year by more than 4.2 Tb (30.5 million files). Many of these data are also redundantly provided through the IGS regional Data Centers.

The IGS Analysis Centers and Associate Analysis Centers utilize tracking data from between 70 to more than 350 stations to generate and control the quality of highest-precision products up to four times per day. Product Coordinators combine these contributions into official IGS products on an operational basis including a quality control procedure. Nearly 3.5 Gb IGS Final, Rapid, and Ultra-rapid product files (GPS and GLONASS) as well 28 Mb IGS real-time and 225 Mb for IGS MGEX products are made available weekly. Additionally, ionosphere (5 Mb per

day) and daily troposphere files (3.2 Mb per day) for more than 300 stations are produced.

The level of interest of users in IGS products is best exemplified by the download statistics, indicating typically over 1.7 billion files (170 Tb) downloads during the year (CDDIS statistics). The Central Bureau assumes responsibility for day-to-day management of the service, interaction with station operators, and answering of the order of 150–200 questions and requests from users per month. These activities are performed all year and day-by-day, with high redundancy and reliability, through the pooled resources of more than 200 institutions worldwide.

Network Status

The Central Bureau monitors a globally distributed network of 507 select GNSS tracking stations that operate according to the IGS guidelines. More than one third of them are providing an extended set of observations for the new GNSS constellations. Approximately 221 IGS stations provide real-time data streams to support the IGS real time activities.

Since GPS week 1934 (29 January 2016), the IGS has been using the IGS14 realization of the ITRF2014 reference frame. It contains the coordinates and velocities for 252 stations, where only a globally well distributed subset of 51 stations are used as so-called core sites for the datum definition when generating the IGS products. For 113 of them the coordinates are affected by the change of the related antenna phase center model. The geographical distribution of the stations is shown in Figure 1.

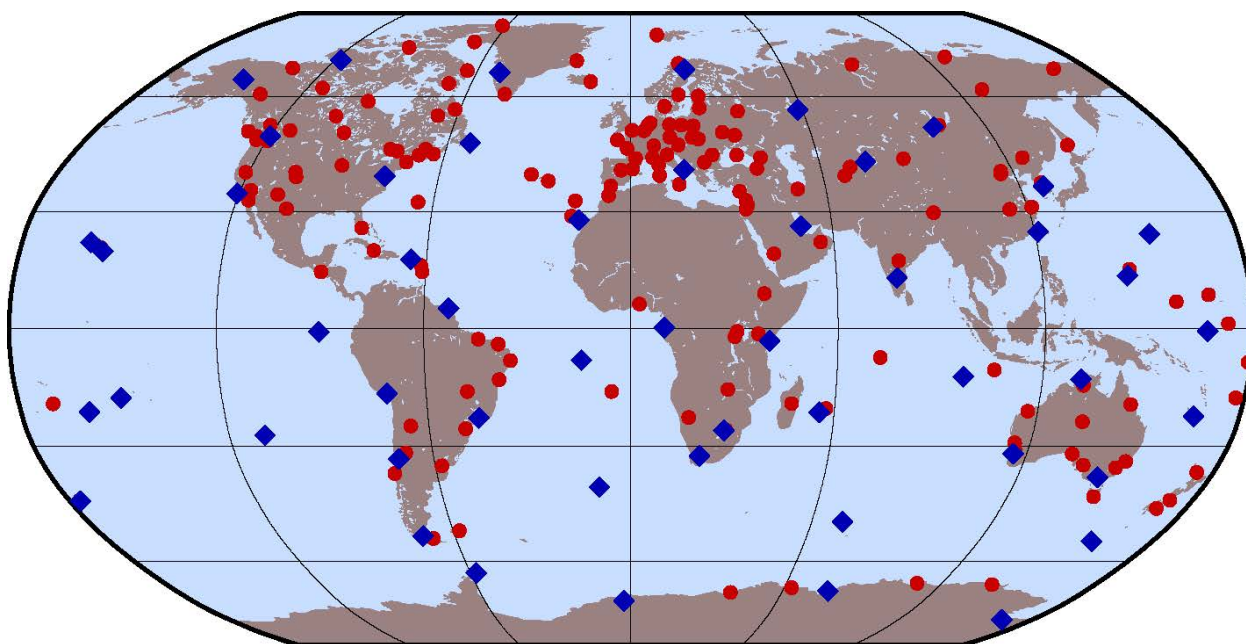


Fig. 1: Geographical distribution of the stations with given coordinates and velocities in IGS14 realization of the ITRF2014 reference frame. The blue diamonds indicate the location of the 51 core stations that are used for the datum definition when generating the IGS products.

Analysis and Core Product Generation

The IGS core products have continued to be routinely combined and delivered to users in a timely manner through 2018. To ensure continued production of high-quality IGS products, the Analysis Center Coordinator (ACC) performed high-level oversight and quality control of Analysis Center (AC) products, combination performance, and maintenance of the ACC website with updated plots acc.igs.org. The ACC also coordinates the ACs to assimilate changes made by them and to ensure that the best analysis models and procedures are used, along with coordination among the other relevant IGS Components, preparation of component reports, and so forth.

Despite a few minor delivery delays caused by power or network outages of the combination server, all of the IGS core products met availability targets (Table 1). The product reliability and quality of the IGS Ultra-rapid and Rapid products has remained similar to previous years. To improve the reliability of the GLONASS Ultra-rapid product, more AC contributions are needed. Details regarding the effects of these factors on the IGS products are described in the Analysis Center Coordinator Section of the IGS Technical Report.

Installing the combination software on two Amazon cloud computers has proven itself in daily use, in particular because two institutions (GA and MIT) are coordinating this activity.

Real-time Service

The IGS Real-Time Service (IGS-RTS) was launched in April 2013. Real-time GNSS observation data from a global observation network is provided via the IGS-RTS observation casters. Eight Real-Time Analysis Centers (RT-AC) and three RT Combination Centers (RT-CC) contribute to the service. The IGS-RTS provides real-time orbit and clock corrections for GPS. Four RT-ACs include GLONASS as well. In addition, experimental orbit and clock corrections are available for GLONASS, BeiDou and Galileo as well as code and phase biases and ionospheric corrections. Three RT-CCs combine orbit and clock corrections to three separate, combined product streams: two GPS-only product streams and one stream containing GPS+GLONASS corrections. At present, the positioning performance using Precise Point Positioning (PPP) is at the level of 10 cm and will be improved as more correction data become available. All IGS-RTS observation and product data streams are based on open RTCM standards. The service is focused on supporting geophysical applications, such as natural hazards monitoring in the framework of GGOS, but it will also support a large variety of applications in positioning, navigation, time transfer, system monitoring, and others.

More information and an updated status of the service can be found on the RTS website at rts.igs.org.

Multi-GNSS Extension

The Multi-GNSS Experiment (MGEX) is considered a key project that will enhance IGS capabilities to support the emerging satellite navigation systems. It has proceeded with high priority since its launch in February 2012. At the Governing Board meeting in February 2016 it was raised to the status of a Pilot Project. In order to keep the well established acronym it was renamed to *Multi-GNSS Extension (MGEX)*.

It was decided at the IGS 2014 workshop in Pasadena, California, USA, that the related dataflow of RINEX 3 files with an extended set of observations be integrated into the legacy dataflow. This activity was coordinated by the Infrastructure Committee and did involve all relevant components of the IGS (station manager, data and analysis centers, and several working groups). Currently about 60% of the IGS stations deliver their data in RINEX 3 format using the new longer station IDs, as foreseen in the RINEX 3 format description.

The focus of MGEX is now on the data processing. Several ACs provide solutions for the new satellite systems with different latency, completeness, and using different strategies. More information on the current status can be found on the website www.igs.org/mgex. This site also contains selected comparisons demonstrating the current performance of the different contributions.

Formats and Standards

The joint IGS/RTCM RINEX Working Group is responsible for maintenance of the RINEX format. The latest adapted version is RINEX 3.04. While tracking data from GNSS-capable equipment shall be solely available in RINEX 3 after a target date to be specified, tracking data from legacy receivers will continue to be available in RINEX 2 for the foreseeable future.

The IGS Infrastructure Committee has established a transition plan to the general usage of RINEX 3 format within the IGS. In the current phase the new and longer station IDs are incorporated into the various product file formats. Additional potential changes in the file formats (mainly driven by the needs of the MGEX Pilot Project) are currently under discussion.

Table 1: IGS core products and availability targets. Availability is defined as the percentage of time that accuracy, latency and continuity of service meet target specification.

		Sampl. Interv.	Accuracy	Latency	Submission	Target Avail.
GPS Satellite Ephemerides / Satellite & Station Clocks						
Broadcast (for comparison)	Orbits Sat. clocks	1 s	≈100 cm ≈5 ns RMS ≈2.5 ns SDev	real time	continuous	99.99%
Ultra-Rapid (predicted half)	Orbits Sat. clocks	15 min	≈5 cm ≈3 ns RMS ≈1.5 ns SDev	predicted	4x daily at 03, 09, 15, & 21 UTC	95%
Ultra-Rapid (observed half)	Orbits Sat. clocks	15 min	≈3 cm ≈150 ps RMS ≈50 ps SDev	3–9 hours	4x daily at 03, 09, 15, & 21 UTC	95%
Rapid	Orbits Sat. & sta. clocks	15 min 5 min	≈2.5 cm ≈75 ps RMS ≈25 ps SDev	17–41 hours	daily at 17 UTC	95%
Final	Orbits Sat. & sta. clocks	15 min 5 min	≈2.5 cm ≈75 ps RMS ≈25 ps SDev	12–18 days	weekly every Thursday	99%
Real-time	Orbits Sat. clocks	5–60 s 5 s	≈5 cm ≈300 ps RMS ≈120 ps SDev	25 seconds	continuous	95%
GLONASS Satellite Ephemerides						
Ultra-Rapid (predicted half)	Orbits	15 min	≈10 cm	predicted	4x daily at 03, 09, 15, & 21 UTC	95%
Ultra-Rapid (observed half)	Orbits	15 min	≈5 cm	3–9 hours	4x daily at 03, 09, 15, & 21 UTC	95%
Final	Orbits	15 min	≈3 cm	12–18 days	weekly, every Thursday	99%
Geocentric Coordinates of IGS Tracking Stations						
Positions of real-time sta.	horizontal vertical	daily	≈3 mm ≈6 mm	1–2 hours	daily	99%
Final positions	horizontal vertical	daily	≈3 mm ≈6 mm	11–17 days	weekly every Wednesday	99%
Final velocities	horizontal vertical	daily	≈2 mm/yr ≈3 mm/yr	11–17 days	weekly every Wednesday	99%

Earth rotation						
Ultra-Rapid (predicted half)	PM PM rates LoD	daily	$\approx 200 \mu\text{s}$ $\approx 300 \mu\text{s/day}$ $\approx 50 \mu\text{s}$	predicted	4x daily at 03, 09, 15, & 21 UTC	95%
Ultra-Rapid (observed half)	PM PM rates LoD	daily	$\approx 50 \mu\text{s}$ $\approx 250 \mu\text{s/day}$ $\approx 10 \mu\text{s}$	3–9 hours	4x daily at 03, 09, 15, & 21 UTC	95%
Rapid	PM PM rates LoD	daily	$\approx 40 \mu\text{s}$ $\approx 200 \mu\text{s/day}$ $\approx 10 \mu\text{s}$	17–41 hours	daily at 17 UTC	95%
Final	PM PM rates LoD	daily	$\approx 30 \mu\text{s}$ $\approx 100 \mu\text{s/day}$ $\approx 10 \mu\text{s}$	12–18 days	weekly every Thursday	99%
Atmospheric parameters						
Final tropospheric zenith path delay with N, E gradients		5 min	$\approx 4 \text{ mm (ZPD)}$	< 4 weeks	daily	99%
Final ionospheric TEC grid 5 deg (lon) $\times$ 2.5 deg (lat)		hourly	$\approx 2\text{--}8 \text{ TECU}$	$\approx 11 \text{ days}$	weekly	99%

Governance

The year 2018 signaled a changing of the guard within the IGS Central Bureau, with the long-standing Director of the Central Bureau, Ruth Neilan, moving on to other endeavors after serving the IGS community since its inception, and before. The contribution Ruth has made to science and society through the IGS cannot be underestimated, and the IGS Governing Board wish her well for the future.

Allison Craddock was appointed by NASA JPL to take on the role of Director of the IGS CB in early 2018, and confirmed by the Governing Board at its meeting in April 2018. Mayra Oyola was appointed in February 2019 to fill the role of Deputy Director and Executive Secretary of the Governing Board.

The Governing Board conducted a 6-month-long formal review of the Central Bureau in 2018. A dedicated review panel, consisting of Ignacio Romero, Tom Herring, and Chris Rizos, engaged with Craddock and the JPL Central Bureau Task Manager, Michael “Mick” Connally, via email and telecons over the past six months. A Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis exercise was conducted (in consultation with the 2017 Terms of Reference), which laid the foundation for dialogue between the review panel members and CB, and served to identify areas of concern. Resulting from this dialogue,

avenues of potential improvement were identified, providing guidance and direction for the Central Bureau in its future work.

Additionally, Felix Perosanz of CNES was appointed to serve as the first Vice Chair of the IGS Governing Board. The Vice Chair position has been created as an acknowledgment of the increasing outreach role of the Governing Board, and the increasing diversity of participation in the IGS. The Vice Chair, working closely with the Chair and Executive committee, will assist with the representation of the IGS at the many forums where IGS participation is of value.

Organizationally, the Terms of Reference were updated in early 2019 to be in alignment with a forward-looking and sustainable organizational vision. This includes the addition of appendix “procedures” documents, which outline such things as Associate Member Engagement, and Governing Board Elections processes, with more to come. The IGS continues to function as a service of the International Association of Geodesy (IAG), and a contributor to the Global Geodetic Observing System (GGOS). Accordingly, a number of the GB members continue to participate in IAG and GGOS governance, bureaus, commissions and working groups, ensuring the IGS retains its strong level of relevance and impact, and therefore sustainability. Importantly, GB members also participate in the United Nations Global Geospatial Information Management (UN GGIM) efforts on Geodesy, which aims to enhance the sustainability of the global geodetic reference frame through intergovernmental advocacy for geodesy. GB members also routinely invited to present and provide valuable input at the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board, providing input and recommendations to the United States government.

The IGS Governing Board met four times in 2018:

- 8 Apr. 2018 Governing Board Business Meeting, held prior to the 2018 European Geosciences Union meeting Vienna, Austria
- 28 Oct. 2018 50th Governing Board Meeting (1 of 2 sessions), held immediately before the 2018 IGS Workshop Wuhan, China
- 2 Nov. 2018 50th Governing Board Meeting (2 of 2 sessions), held immediately after the 2018 IGS Workshop Wuhan, China
- 8 Dec. 2018 51st Governing Board Meeting, held prior to the 2018 American Geophysical Union meeting Washington, District of Columbia, United States

The IGS Executive Committee – consisting of Gary Johnston, Rolf Dach, Charles Meertens, Chris Rizos, and Allison Craddock, with regu-

lar participation by other Governing Board and Central Bureau members as required – met several times via teleconference.

Strategic Planning

The current IGS Strategic Plan covers the period 2017–2020.

IGS Workshop 2018

The latest IGS Workshop, with the theme of “Multi-GNSS through Global Collaboration” took place 29 October to 2 November, 2018. The workshop was hosted locally by Wuhan University at the East Lake Conference Center in Wuhan, China, and was the first IGS Workshop to be held on the Asian continent. Over 300 individuals participated in the sessions.

This workshop brought together researchers from all over the world, with a very strong contingent from China, to discuss the current work program of the IGS and plans for the future. The geographical location of the workshop also made it appropriate to strongly consider the role of Beidou in the multi-GNSS future that the IGS is embracing.

The workshop featured two keynote presentations:

- “Introduction to BeiDou-3 Navigation Satellite System” presented by Yuanxi Yang of the State Key Laboratory of Geo-Information Engineering, based in Xi’an, China.
- “BeiDou Augmentation and its Future” presented by Liu Jingnan, an Academician of the Chinese Academy of Engineering, based at Wuhan University in Wuhan, China.

The theme of the 2018 workshop – “Multi-GNSS through Global Collaboration” – was echoed through ten plenary sessions, posters, and working group splinter meetings. Underpinning much of this Multi-GNSS momentum was the IGS MGEX White Paper, titled “Satellite and Operations Information for Generation of Precise GNSS Orbit and Clock Products”. The paper discusses the parameters needed to ensure the highest possible performance of IGS products for all constellations and motivates the need for provision of satellite and operations information by the GNSS providers. All information requested by the IGS is considered to be sufficiently abstract such as to neither interfere with the GNSS providers’ safety and security interests nor with intellectual property rights. <http://bit.ly/MGEXwhitepaper>

New IGS Working Group on PPP Ambiguity Resolution Established

It was noted that while current IGS products are high quality, they are not fully compatible with PPP-AR and lack multi-GNSS support. In response to this, a new IGS working group that will focus on PPP with ambiguity resolution (PPP-AR) was established at the Wuhan Workshop. It is Chaired by Simon Banville from NRCan in Canada.

RINEX 3.04 Update The RINEX GNSS data format is a standard that is jointly managed by the IGS RINEX Working Group and the IGS Governing Board, together with the Radio Technical Commission for Maritime Services (RTCM) Special Committee (SC) 104 on Differential Global Navigation Satellite Systems (DGNSS). This relationship was formed between IGS and RTCM to ensure that RINEX would continue to be freely available.

The release of RINEX 3.04 was officially approved by the IGS Governing Board at the IGS Workshop in Wuhan. It was also recently approved by the RTCM SC-104. Key changes in this version include adjusting for new signals.

Laser Ranging to GNSS At the request of the International Laser Ranging Service (a sister service within the International Association of Geodesy) the IGS issued two official recommendations. One encouraged the extension of SLR stations supporting high-altitude tracking, specifically in the Asia-Pacific region, and the transition to kHz laser systems enabling shorter normal point duration. The other addressed the increasing load on ILRS stations caused by the increasing number of GNSS satellites equipped with laser retroreflectors by recommending that observatories give priority to dedicated campaigns for tracking of selected GNSS satellites at the expense of a reduced background tracking activity while using remaining tracking resources to select and track the remaining GNSS satellites in a randomized manner – the latter of which to be defined at the discretion of the observatory.

Real Time GNSS Service (RTS) Currently, IGS combined products are limited to clocks and orbits for GPS, with GPS+GLONASS products still classed as experimental. Some multi-GNSS analysis center solutions are available, notably CNES (France) and GFZ (Germany), with the CNES stream currently disseminating (unmonitored and uncomparing) biases. ESA ESOC also plans to generate a multi-GNSS solution, but this is not yet at a stage where it can be disseminated.

IGS real-time orbit products are based on the ultra-rapid predictions. Thus, all information that helps to improve the IGS orbit products are needed, and of this, access to complete and accurate satellite metadata (information pertaining specifically to the physical properties of GNSS satellites) remains an issue.

It was recommended at the 2018 IGS Workshop that the IGS Real-Time Service should prepare for the transition to a true multi-GNSS service. In order to accomplish this, a number of prerequisites need to be fulfilled, such as the availability of predicted orbits for all constellations, the availability of processing, combination and validation capabilities as well as the selection of a suitable transfer format.

The next IGS Workshop will be held from 10 to 14 August, 2020, in Boulder, Colorado, USA. It will be jointly hosted by UNAVCO and UCAR.

Outreach

The IGS is represented on the GGOS Coordinating Board. It also plays a leadership role in the International Committee on GNSS (ICG), in particular by co-chairing Working Group D on Reference Frames, Timing and Applications. The trial project of ICG Monitoring and Assessment Task Force (IGMA) has been established, co-organized by IGS and ICG. The IGS is also well represented in the International Earth Rotation and Reference Systems Service (IERS) and in IAG Sub-Commission 1.2 on Global Reference Frames, in the RTCM SC104, and others.

Official IGS Citation Updated

In response to ever-growing applications for precise GNSS data as a public utility, the work of the IGS and its constituent elements continues to increase in relevance, especially as applications that essentially rely on IGS data and products expand both within and outside of the sciences.

As it enters its second quarter-century, the IGS is evolving into a truly multi-GNSS service. For 25 years, IGS data and products have been made openly available to all users for use without restriction, and continue to be offered free of cost or obligation. In turn, users are encouraged to participate within the IGS, or otherwise contribute to its advancement and to include a reference to the IGS in their citations.

The IGS Governing Board recently updated the official citation for acknowledging IGS data, products, and other resources in scholarly publications. The new official citation is the IGS chapter in the 2017 Springer Handbook of Global Navigation Satellite Systems.

The IGS Central Bureau gratefully acknowledges the contributions of IGS Governing Board and Associate members in the drafting of this article, as well as to Geoscience Australia for financially supporting the authorship. Special thanks to the article's authors, Governing Board Chairman Gary Johnston, as well as to Anna Riddell and Grant Hausler.

Johnston, G., Riddell, A., Hausler, G. (2017). The International GNSS Service. In Teunissen, Peter J.G., & Montenbruck, O. (Eds.), Springer Handbook of Global Navigation Satellite Systems (1st ed., pp. 967–982). Cham, Switzerland: Springer International Publishing, DOI: 10.1007/978-3-319-42928-1

The book is currently available for purchase and download on the Springer website: <https://www.springer.com/us/book/9783319429267>. A special pre-print version of this document may be found on the IGS Knowledge Base.

The IGS Library function has also transitioned to a Google Scholar-based platform. Please view <https://scholar.google.com/scholar?q=International+GNSS+Service> or <http://bit.ly/IGSlibrary> to learn more.

Rolf Dach

3.4.2 International Laser Ranging Service (ILRS)

Introduction The International Laser Ranging Service (ILRS), established in 1998, is responsible for the coordination of Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) missions, technique development, network operations, data analysis and scientific interpretation. Here we summarize the status and developments in 2018.

Network The network of SLR/LLR stations (Figure 1), under the aegis of the ILRS, has been subject to change over the years. In 2018 the network remained very much in its past years form. The only significant change was the introduction of a new system (laser) at the old Kunming site in PR of China. From a technical perspective though, the quality and quantity of the observations has improved drastically during the past few years. 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 on average at the 10 mm level, with the best one dozen stations doing significantly better. Nearly all stations deliver normal points (NPs) 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. During 2018 the ILRS Central Bureau (CB) continued its efforts to encourage all stations to submit for archival their Full Rate (FR) data in addition to their NPs. These data are extremely important in characterizing correctly the response of each system with respect to each target array and calculate the precise correction that connects the ranges to the center of gravity of the target spacecraft, commonly known as the “center-of-mass” correction. Examination of the tracking over the past year indicates that the tracking targets increased by $\sim 20\%$ while the collected pass segments increased by about 13%, with no change in the number of tracking sites (Table 1 and Figure 8). NASA is moving forward with the deployment of the first next generation Space Geodesy SLR systems (SGSLRs) at McDonald Obs., Texas, to be followed by the one at Mt. Haleakala, Hawaii, and the development of a third system for the Norwegian Mapping Agency, to be deployed at their new core site of Ny-Ålesund, Svalbard. Russia’s expansion and upgrade of their network continues, with the announcement of future deployment of a new system in co-location with the current one at Irkutsk and Mendeleevo in the coming year. All sites will be co-located with GNSS systems primarily intended to tie the GLONASS monitoring network with that of the ILRS SLR.

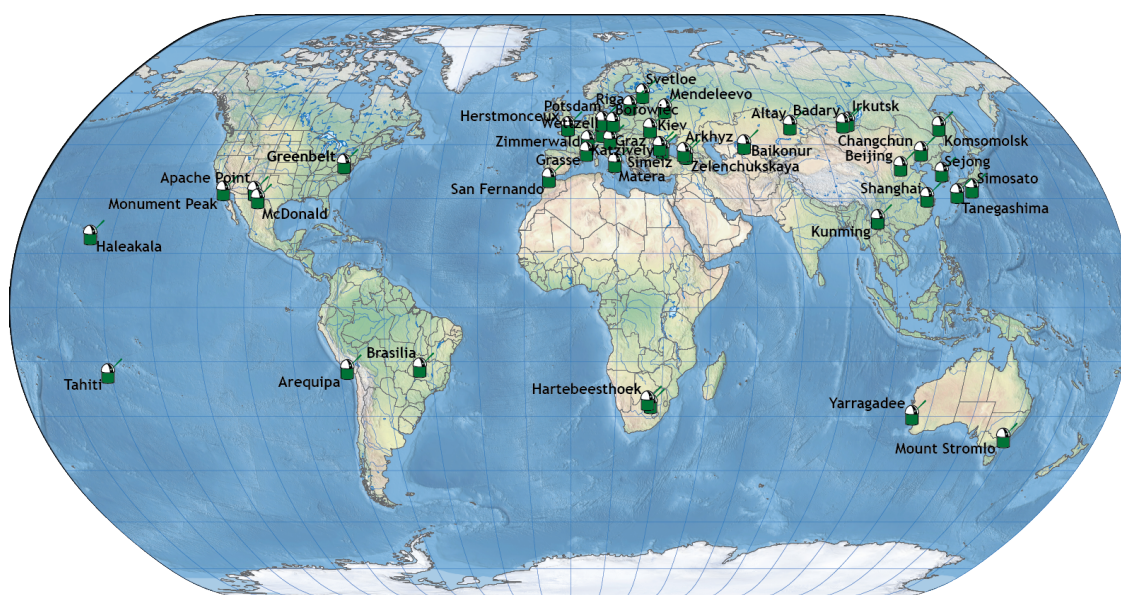


Fig. 1: The global network of SLR stations (status late 2018).

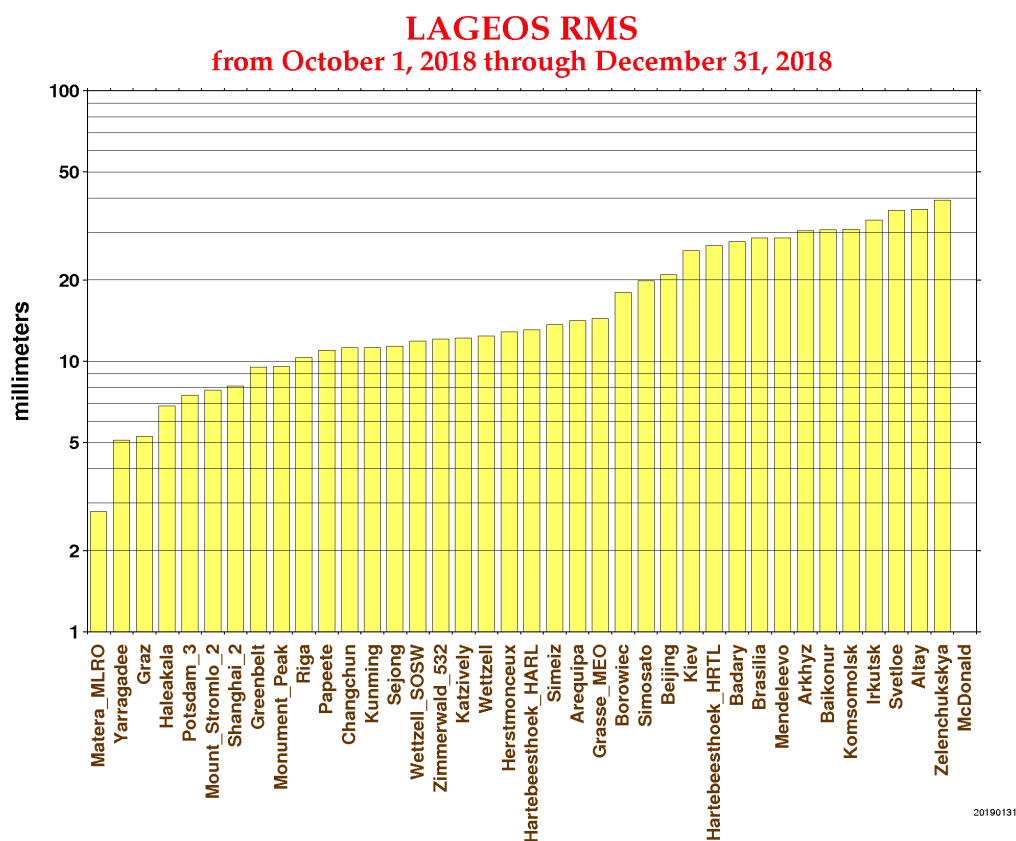


Fig. 2: Performance of the global network of SLR stations on LAGEOS (last quarter of 2018).

Table 1: *ILRS Network Tracking Statistics for 2018*

SITE NAME	Station	NUMBER OF PASS SEGMENTS			
		LEO	MEO	HEO	Total
ALTAY	1879	74	319	2,012	2,405
AREQUIPA	7403	3,521	233	0	3,754
ARKHYZ	1886	441	247	697	1,385
BADARY	1890	1,235	331	203	1,769
BAIKONUR	1887	3	336	1,118	1,457
BEIJING	7249	1,902	481	1,449	3,832
BOROWIEC	7811	966	314	70	1,350
BRASILIA	7407	325	358	790	1,473
CHANGCHUN	7237	9,488	1,434	5,255	16,177
GRASSE	7845	45	236	864	1,145
GRAZ	7839	3,734	817	2,488	7,039
GREENBELT	7105	6,552	1,392	1,106	9,050
HALEAKALA	7119	1,643	478	0	2,121
HARTEBEESTHOEK	7501	3,729	1,174	1,814	6,717
HARTEBEESTHOEK	7503	1,096	315	453	1,864
HERSTMONCEUX	7840	5,841	1,393	4,643	11,877
IRKUTSK	1891	1,393	478	842	2,713
KATZIVELY	1893	1,928	318	9	2,255
KIEV	1824	571	87	0	658
KOMSOMOLSK	1868	39	248	1,917	2,204
KUNMING	7819	2,635	594	3,049	6,278
MATERA	7941	4,320	1,955	3,336	9,611
MCDONALD	7080	137	29	2	168
MENDELEEVO	1874	107	113	295	515
MONUMENT PEAK	7110	7,340	938	852	9,130
MOUNT STROMLO	7825	6,702	1,747	2,479	10,928
POTSDAM	7841	4,783	1,094	1,149	7,026
RIGA	1884	1,047	175	35	1,257
SEJONG	7394	397	122	9	528
SHANGHAI	7821	2,742	818	3,073	6,633
SIMEIZ	1873	2,182	467	397	3,046
SIMOSATO	7838	1,150	436	19	1,605
SVETLOE	1888	681	184	109	974
TAHITI	7124	1,246	263	590	2,099
WETTZELL	7827	2,522	832	3,444	6,798
WETTZELL	8834	4,812	1,159	4,012	9,983
YARRAGADEE	7090	26,270	5,500	13,053	44,823
ZELENCHUKSKAYA	1889	825	209	364	1,398
ZIMMERWALD	7810	8,046	1,860	4,594	14,500
GRAND TOTALS:	39 stations	122,470	29,484	66,591	218,545

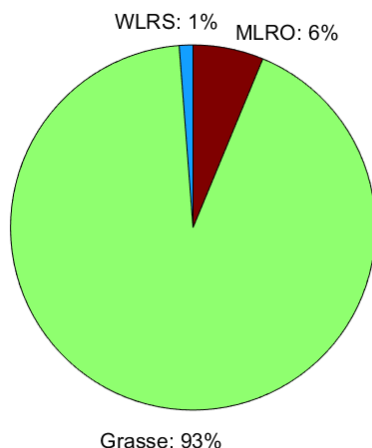


Fig. 3: Observatory statistics in 2018 (except for APOLLO, not available yet).

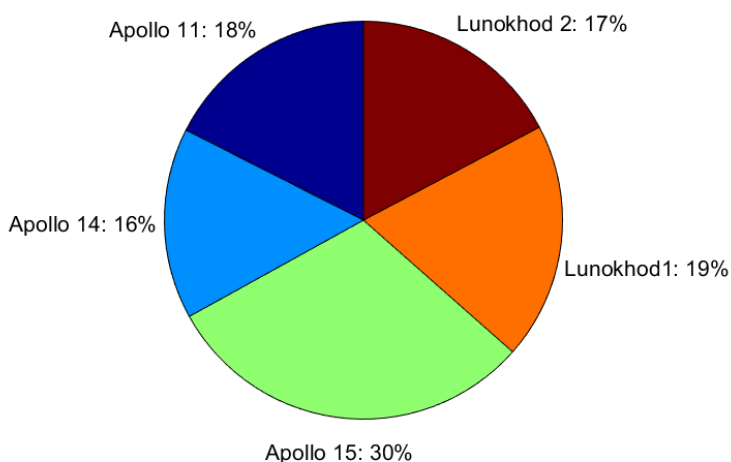


Fig. 4: Retro-reflector statistics by reflector in 2018.

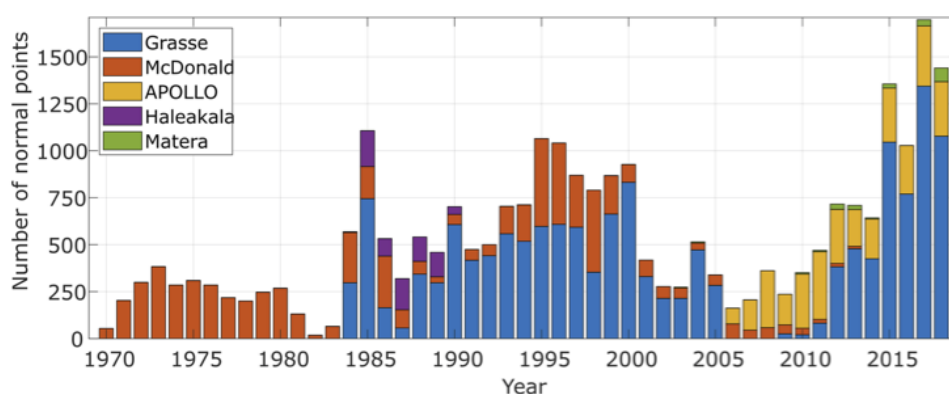


Fig. 5: Data yield of the global LLR network of stations (up to end of 2018). Note the increased contribution of Grasse's MeO system upon its return to operations in 2011, the steady yield of APOLLO, the small increase at Matera, and the absence of McDonald Obs. the last five years.

Statistics of the SLR data collected as pass segments during the calendar year 2018 are summarized in Table 1. For each of the contributing stations the tracked passes are broken down in three categories of target orbits: Low Earth Orbiters (LEO), LAGEOS 1 & 2 and LARES (MEO), and the High Earth Orbiters (HEO), GPS, GLONASS, Etalon 1 & 2, GIOVE-A/B, Galileo, BeiDou, IRNSS, QZSS and the moon.

Some of the SLR stations are technically equipped to track retro-reflector arrays placed on the surface of the moon. Currently there are only three Lunar Laser Ranging (LLR) capable stations within the ILRS network of about 40 SLR stations. These are the MeO system of the Observatoire de la Côte d'Azur at Grasse, France, the Matera Laser Ranging Observatory (MLRO) station in Matera, Italy and the non-SLR station

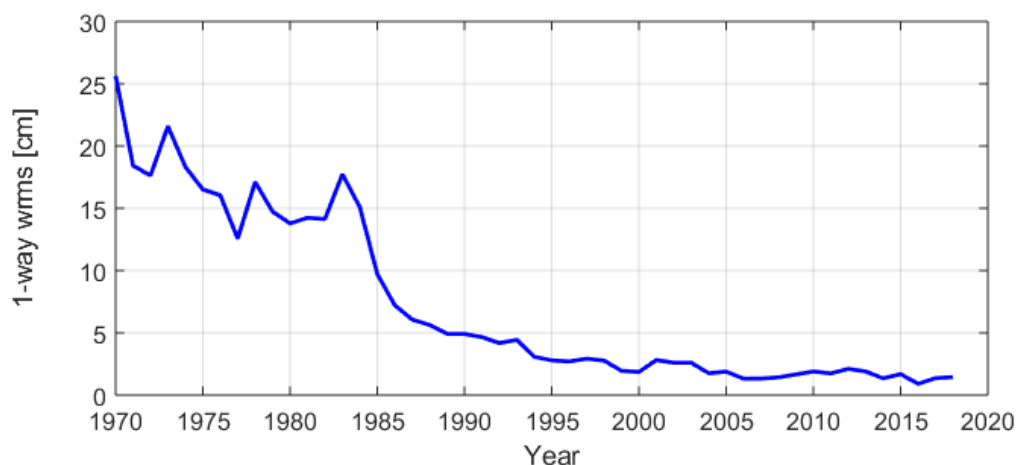


Fig. 6: LLR residuals, annual WRMS 1970 to 2018.

Apache Point Observatory Lunar Laser-ranging Operation (APOLLO) in New Mexico, USA. Additionally, stations Kunming in China (http://english.ynao.cas.cn/research/rp/201801/t20180123_189509.html) and Wettzell (WLRS) in Germany, successfully detected lunar returns since the beginning of 2018. Stations in Russia (Altay), China and South Africa plan to join the LLR network over the next few years.

Although data have been taken on the Apollo 11, 14, and 15, and the Lunokhod 1 and 2 reflectors, the bulk of the data has been from the largest reflector array, Apollo 15. In the next few years, a new generation of reflectors, more accurate and more efficient, are expected to be deployed on the Lunar surface. LLR data analysis is carried out by a few major LLR analysis centers: Jet Propulsion Laboratory (JPL), Pasadena, USA; Center for Astrophysics (CfA), Cambridge, USA; Paris Observatory Lunar Analysis Center (POLAC), Paris, France; Institute of Geodesy (IfE), University of Hannover, Germany. In the last few years, the National Institute for Nuclear Physics (INFN), Frascati, Italy, and the Graduate University for Advanced Studies (SOKENDAI), Tokyo, Japan, have also increased their analysis activities. The six LLR analysis centers focus on different research topics (such as relativity, lunar interior, etc.). Some interest towards this end has also been shown by the Hartebeesthoek Radio Astronomy Observatory (South Africa) where an ex-Observatoire de la Côte d'Azur 1-m aperture telescope is being prepared for LLR use. In addition, various research projects have been successfully run combining LLR, GRAIL, and LRO data.

During the last few years, the strong increase in the annual LLR normal point rate was mainly due to the effort at the French station in Grasse (Courde et al., 2017). The total data archive is still dominated by the Apollo 15 reflector, but its impact was reduced and for the period

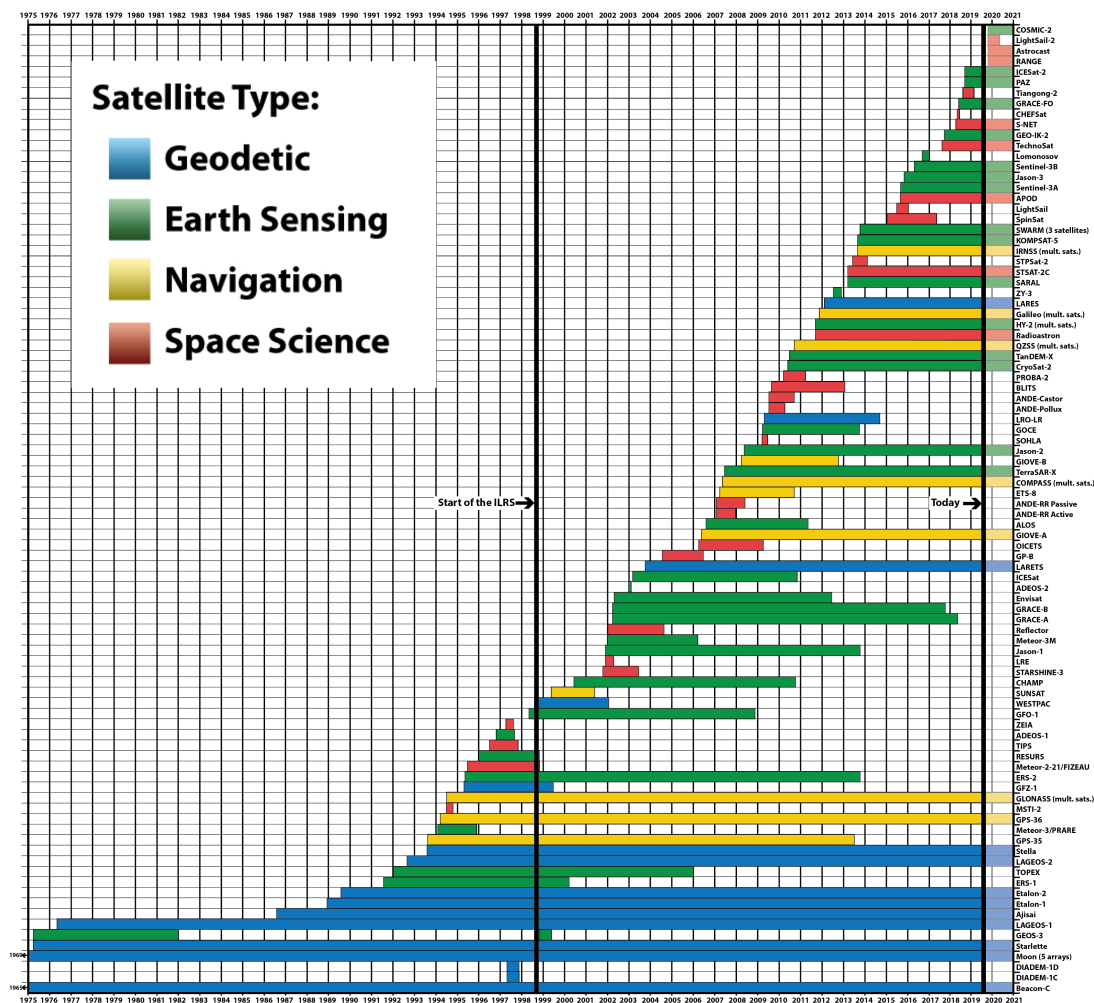


Fig. 7: The currently tracked SLR missions (status as of early 2019).

between 2016 and 2018 (Fig. 4) the contribution from the smaller reflectors has increased with the Apollo 15 share down to 30%. It should be noted however, that the data count from the APOLLO site is known approximately, since the exact number of normal points after 2016 have not been distributed to date and could only be guesstimated in the Figures 3–5.

LLR is an important tool to support lunar science, to study the Earth-Lunar dynamics and to test General Relativity in the solar system. Current improvements in the estimation of relativistic parameters include, e.g., tests of the equivalence principle, possible time variability of the gravitational constant and Lorentz symmetry (Hofmann and Müller, 2018). LLR based EOP results contribute to combined EOP solutions. With the larger LLR data set over time the lunar tidal acceleration has been more accurately determined (Williams and Boggs, 2016) as well as station coordinates and velocities. Through the study of lunar tides, physical librations and the lunar orbit, LLR has been an important tool in improving our understanding of the physical properties and the interior

of the moon. Discrepancies between LLR and GRAIL derived results (Pavlov et al., 2016) of elasticity parameters (Love numbers) and the degree-3 gravitational field which leads us to recognize that there is still very interesting and challenging science to address, especially in the modelling of dissipation and properties of the lunar interior.

Missions

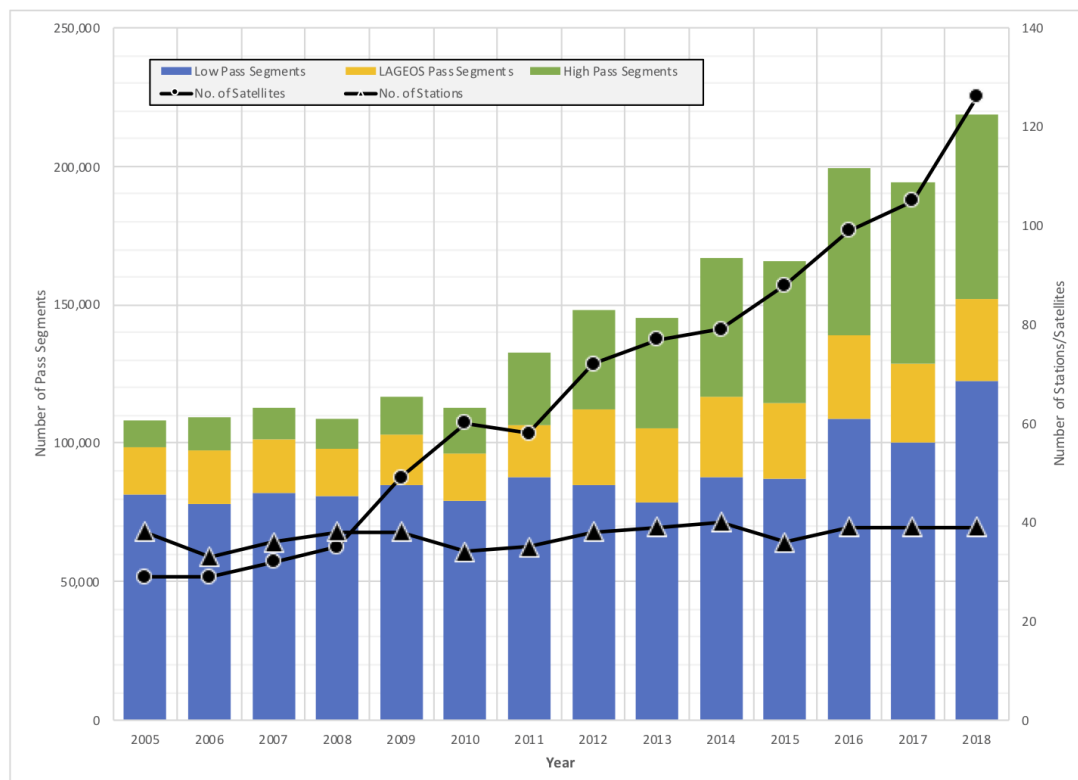
In 2018, a total of ~120 targets, including those on the moon, were being tracked by SLR/LLR (Figure 7). This indicates a ~20% increase in targets since 2017. Of these, only about 1/3 are geodetic targets (cannonball satellites), about one half are navigation satellites (GNSS) and the rest are Earth Observation missions, including a small number of experimental space science missions. In 2018 the steady increase of tracking multiple GNSS targets continued for a seventh year in a row. The three tracking campaigns initiated in 2017 for the three QZS spacecraft were completed by February and two dedicated tracking campaigns organized through the ILRS/GGOS LARGE Working Group (LAser Ranging to GNSS s/c Experiment), resulted in a substantial increase in data yield from such missions. The launch of the GRACE Follow-On mission resulted in the initiation of a tracking campaign in late 2018, which will be finalized in 2019:

- *August 25, 2017–February 28, 2018 – [QZS-2](#) tracking campaign*
- *November 01, 2017–February 28, 2018 – [QZS-3](#) tracking campaign*
- *December 01, 2017–February 28, 2018 – [QZS-4](#) tracking campaign*
- February 15–May 15 – First [LARGE](#) campaign of 2018
- August 01–October 31 – Second [LARGE](#) campaign of 2018
- December 15, 2018–January 15, 2019 – [GRACE-FO](#) tracking campaign

The seventeen new missions that were launched during 2018 are shown in Table 2. Seven spacecraft were part of GNSS Constellations, six were remote sensing and Earth observation missions and four comprised a small experimental constellation of CubeSats. Despite the significant increase in the number of targets in 2018, the ILRS network has increased its productivity to keep pace with this increased demand for support, and kept the data yield rate positive, as in the past years (Figure 8).

Table 2: *ILRS Supported Missions Launched or Initiating Tracking in 2018*

Satellite Name	Satellite ID	SIC Code	Satellite Catalog Number	NP Indicator	Bin Size (s)	Altitude (km)	Inclination (Å°)	First Date Tracked
GLONASS-139	1808601	9139	43687	9	300	19,140	65	2018-Nov-03
HY-2B	1808101	2208	43655	5	30	971	99.35	2018-Nov-01
ICESat-2	1807001	6873	43613	1	5	496	92	2018-Nov-02
Galileo-220	1806004	7220	43567	9	300	23,220	56 ± 2 deg	2018-Oct-17
Galileo-219	1806003	7219	43566	9	300	23,220	56 ± 2 deg	2018-Oct-17
GRACE-FO-2	1804702	124	43477	1	5	500	89	2018-May-23
GRACE-FO-1	1804701	123	43476	1	5	500	89	2018-May-23
Sentinel-3B	1803901	8011	43437	3	15	814.5	98.65	2018-May-03
IRNSS-1I	1803501	3309	43286	9	300	35,786	5	2018-May-09
BeiDou-3M10	1802902	2020	43246	9	300	21,500	55	2018-Aug-03
BeiDou-3M9	1802901	2019	43245	9	300	21,500	55	2018-Aug-04
PAZ	1802001	2501	43215	1	5	514	97.44	2018-Feb-22
BeiDou-3M3	1801802	2015	43208	9	300	21,500	55	2018-Aug-10
SNET-1	1801410	6204	43189	1	5	600	97.6 - 97.9 deg	2018-Apr-27
SNET-4	1801409	6207	43188	1	5	600	97.6 - 97.9 deg	2018-Apr-12
SNET-3	1801408	6206	43187	1	5	600	97.6 - 97.9 deg	2018-Apr-20
SNET-2	1801407	6205	43186	1	5	600	97.6 - 97.9 deg	2018-Apr-21

Fig. 8: *ILRS network data yield by target type since 2005 and up to the end of 2018.*

Analysis and science

The effort to identify, mitigate and monitor systematic errors in the ILRS data has continued-on since several years with new initiatives and results. The Pilot Project to develop a strategy for a combined product that delivers estimates of station systematics on a regular basis led to the development of an operational tool. A re-analysis of the main ILRS targets LAGEOS and LAGEOS-2 was completed and in 2018 it included the two Etalons, since it became obvious that these targets were not modeled sufficiently accurately. The re-analysis revealed serious shortcomings of the “target signature” model (aka “center of mass” – CoM correction), so a new model was developed, leading to significant changes over the previous model. A second reanalysis followed the first, this time using the corrected CoM model, delivering preliminary results for the expected changes in the ITRF scale realized by the SLR technique. These preliminary results are very promising because they indicate that the new SLR-implied scale is significantly closer to that implied by VLBI, bringing the gap down by more than 1 ppb! When the re-analysis is completed the new approach will transition to a fully operational product that will become available in 2019, once a trial period with the participation of all ILRS ACs is successfully completed. The weekly scale estimates from a preliminary combination were compared to the original results using the old approach (no simultaneous bias estimation) over 1993 to 2018 period to get an estimate of what is to be expected for the ITRF2020 re-analysis (Figure 9).

The next phase of the project is the development of this product as a service to the network, so that stations can be notified when an abnormal estimate is obtained. The process requires careful implementation to limit false alarms and for that we first needed to develop a long history of the systematics for each station separately. This task will be completed in 2018, and the operational service will be in test mode during early 2019.

Meetings

In 2018 the ILRS held the 21st International Workshop on Laser Ranging, in Canberra, Australia, November 04–08, followed by a 1-day Workshop on Space Debris. The theme for the main workshop was: “Laser Ranging for Sustainable Millimeter Geoscience” and the topics that were addressed:

- SLR Contribution to Global Geodetic Observing System – A 2020 Perspective
- Improvements in the SLR Product Quality and Precise Orbit Determination
- Satellite Missions and Techniques for Geodetic Applications
- Characteristics of Retroreflector Arrays

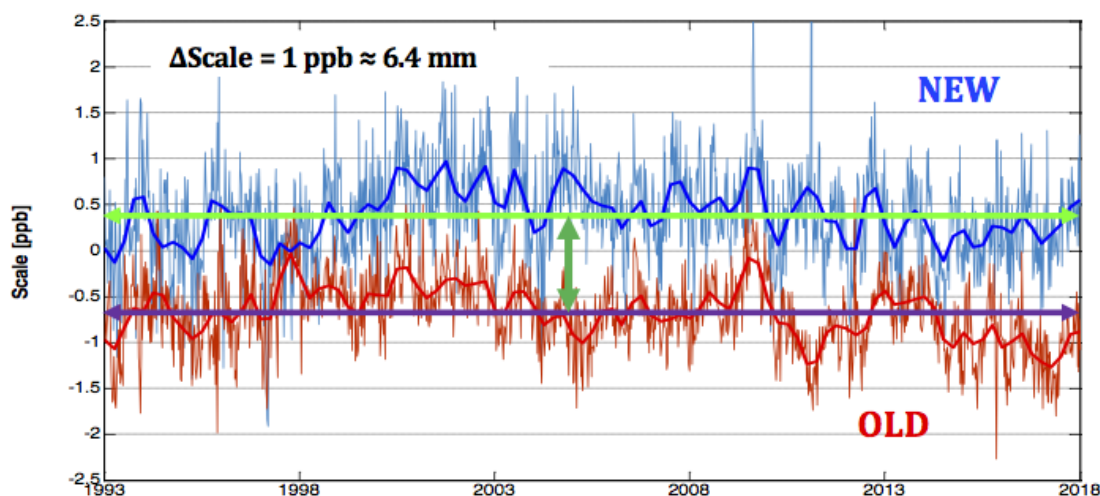


Fig. 9: Preliminary results from the SSEM Pilot Project: comparison of the SLR scale realized in the standard weekly series (OLD) and the newly adopted approach (NEW). The horizontal lines are roughly at the average values of the two series over the period 1993–2018 (~1305 weeks), to provide a figure of merit for the expected scale change in the ITRF2020 development.

- Sources of Systematic Errors
- Network Operations and Site Upgrades
- Developments in SLR Techniques and Technologies
- Developments in Software and Automation
- Lunar Laser Ranging and Deep Space Missions

The workshop was very well attended with over 150 participants from many countries, nearly 80 oral presentations and 60 poster presentations. An additional 25 oral and 15 poster presentations were presented during the Workshop on Space Debris. The ASC held two meetings in 2018, one during the EGU General Assembly, on April 12, and one prior to the Canberra Workshop, on November 1. The ILRS Governing Board met once in 2018, prior and at the conclusion of the Canberra workshop on November 4 and 8. In 2019 the ILRS will hold a Technical Workshop on Laser Ranging that will take place in Stuttgart, Germany, October 21–25. For more information please see:

<https://ilrsworkshop2019.besl-eventservice.de>

The topic of the 2019 Technical Workshop is: “Laser ranging: To improve economy, performance, and adoption for new applications”.

Publications

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

<https://ilrs.cddis.eosdis.nasa.gov/about/reports/biblio/bibliography.2018.html>

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3.4.3 International VLBI Service for Geodesy and Astrometry (IVS)

IVS Organization and Activities

During 2018, 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:

- Several IVS Analysis Centers (ACs) in cooperation with the International Astronomical Union (IAU) Working Group on the third realization of the International Celestial Reference Frame (ICRF3) prepared CRF solutions as input to ICRF3. The new frame was adopted at the IAU General Assembly in Vienna, Austria on August 30, 2018 under Resolution B2. ICRF3 contains positions of more than 4500 extragalactic radio sources at three frequencies and became the Fundamental Astrometric Reference Frame on 01 January 2019.
- The IVS continued an observing program to determine the alignment of the next radio frame (ICRF3) with the future *Gaia* optical frame by observing ICRF–*Gaia* transfer sources.
- Following a call for proposals in July 2018, the Board approved the creation of an IVS Office for Outreach and Communications (OOC) at the MIT Haystack Observatory (lead: Nancy Kotary) at the end of 2018. The OOC will promote awareness and understanding of geodesy's unique and vital role in science and society to the larger scientific community, decision makers, and the general public.
- The Ny-Ålesund Twin Telescopes were inaugurated on June 6, 2018 as part of the Tenth IVS General Meeting, which was held in Longyearbyen, Svalbard, Norway. The meeting attracted 100 participants from around the world.
- The IVS published three IVS Newsletters in April, August and December, keeping the community informed about IVS activities.

Table 1: *IVS meetings in 2018. The AOV is a regional subgroup of the IVS organizing institutions that are active in geodetic and astrometric VLBI in Asia-Oceania.*

Event	Location	Date
10th IVS General Meeting	Longyearbyen, Norway	June 3–7, 2018
19th IVS Analysis Workshop	Longyearbyen, Norway	June 8, 2018
39th IVS Directing Board meeting	Longyearbyen, Norway	June 9, 2018
3rd General Meeting of the AOV	Canberra, Australia	November 9–10, 2018
7th Int'l VLBI Technology Workshop	Krabi, Thailand	November 12–15, 2018

Network Stations and observing sessions

A total of 190 geodetic/astrometric 24-hour sessions were observed during the year 2018 using the legacy S/X system. That translates to about ~3.6 observing days per week that were coordinated by the IVS to determine operational products including EOP. Further, there were 366 1-hour Intensive sessions observed for the determination of UT1–UTC. Lastly, twenty-four 24-hour VGOS sessions were observed to establish the processing chain of the new VLBI system. The major observing programs during 2018 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 Ishioka (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 Ishioka (Japan). For the Int3, Wettzell was employing their 20-m legacy antenna and repeatedly also the 13-m VGOS antenna (70% of the Int3s).

IVS-T2 Bi-monthly sessions coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn, Germany, with 14–16 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 Hartebeesthoek Radio Astronomy Observatory, provide astrometric observations that are required for improving the current CRF and for extending the CRF by observing ‘new’ sources. Twelve sessions were observed for the maintenance of the CRF in 2018.

VLBA The Very Long Baseline Array (VLBA), operated by the Long Baseline Observatory (LBO), allocated six observing days for astrometry/geodesy. These sessions included the 10 VLBA stations plus up to four 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 ses-

sions in 2018.

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 2018 six OHIG sessions were observed.

APSG The Asia-Pacific Space Geodynamics (APSG) program operated two sessions in 2018.

AUSTRAL In 2018, 23 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.

AOV The Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) had 12 sessions during 2018.

IVS-R&D Ten research and development sessions were observed in 2018. The main goal of the 2018 R&D sessions was the observation of link sources between *Gaia* and the ICRF2.

Correlators The correlator at Haystack Observatory (USA), the correlator at the U.S. Naval Observatory in Washington (USA), the BKG/MPIfR correlator at the Max Planck Institute for Radio Astronomy in Bonn (Germany), the correlator at the Shanghai Astronomical Observatory (China), and the correlator at the Geospatial Information Authority of Japan (GSI) in Tsukuba efficiently processed the data recorded for the IVS. The majority of the 24-hour sessions were processed by the Bonn and Washington correlators. Both correlators used the DiFX software correlator; while the Bonn correlator processed the R1, EURO, T2, Int3, and OHIG sessions, the Washington correlator was responsible for the R4, Int1, and CRF deep south sessions. The Shanghai correlator analyzed CRF, APSG, and AOV sessions. The Haystack correlator processed R&D sessions and some T2 sessions. The Int2 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).

Data Analysis

The IVS began the transition from the legacy MK3 database format to the new vgosDB format in 2017. The original deadline of 30 September 2017 was postponed because a few analysis packages were not able to support the new format. The transition was essentially complete by 31 May 2018.

IVS Working Group 8 on Galactic Aberration successfully completed its charter to investigate the effects of galactic aberration and to make a recommendation to the IVS. Galactic aberration is due to the rotation of the solar system about the galactic center and leads to an apparent change in source position over time. The magnitude and direction of the effect depends on the source coordinates with respect to galactic center, and it is a dipole pattern. The VLBI determined constant is $5.8 \mu\text{as/yr}$, which is relatively close to estimates of $4.8\text{--}5.4 \mu\text{as/yr}$ that can be derived from independent galactic astronomy measurements of proper motions and parallaxes of galactic masers. Although this effect is small, it is non-negligible given the 40-year timespan of VLBI measurements. The coordinates for ICRF3 include the effect of galactic aberration.

The CONT17 data (28 November to 12 December 2017) was correlated and made available to the IVS community. CONT17 involved two independent legacy S/X networks of 14 stations, and an independent 6-station VGOS network. This allows independent checks of the precision and consistency of VLBI measurements of EOP. Preparations are under way for a special issue devoted to CONT17 in *Journal of Geodesy*.

Several IVS Analysis Centers participated in the work of the IERS Working Group on Diurnal and Semi-diurnal EOP variation. Ten different models (including the current IERS model) of HF-EOP were used in VLBI analysis and different measures of goodness, such as baseline length repeatability or session fit, were evaluated. Some of the models were derived using altimetry-based models of ocean heights and currents, while others were purely empirical.

Technology Development

The main focus of the IVS technology development was placed on the build-out of the next-generation VLBI system (VLBI Global Observing System, VGOS) network and achieving operational readiness with the various installations of the signal chain realizations. Over the next several years a number of new VGOS stations will come online. Operational readiness for the existing VGOS stations was worked on in a series of test sessions of initially 1-, 2-, and 6-hour lengths in 2015/16 and then extended to 24-hour sessions from the second half of 2016 onward. These tests uncovered a number of smaller and larger issues of high-level, low-level, and transient nature that were successively ironed out or identified and actively being worked on. Since 01 January 2019 the currently available six-station VGOS network was operating in a stable

way, so that the session results could be made available on the IVS Data Center for general use. Aside from increasing the VGOS network size in the next couple of years, the focus of the VGOS effort will be on the data transport and correlation parts of the processing chain. Here the use of cloud services and distributed correlation to deal with the large amount of data are aspects that will be investigated.

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3.4.4 International DORIS Service (IDS)

Overview The International DORIS Service was established in 2003 with the primary mission to provide a service to support geodetic and geophysical research activities through DORIS data and derived products. The current report summarizes the different activities held in 2018 by the IDS components. More detailed information can be found in the IDS Annual Report available for download from the IDS website at <https://ids-doris.org/ids/reports-mails/governing-board.html#activity>.

DORIS system

DORIS satellites During this report period (2018), the number of DORIS satellites has increased to seven (see Table 1).

Table 1: *DORIS data available at IDS Data Centers. As of December 2018*

Satellite	Start	End	Mission
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	11-DEC-15	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
Jason-3	17-JUN-16	-	Altimetry
SENTINEL-3A	16-FEB-16	-	Altimetry
SENTINEL-3B	25-APR-18	-	Altimetry

In 2018, a new DORIS instrument came to join its fellows. It operates onboard Sentinel-3B, launched in April 2018. With Jason-2, Cryosat-2, HY-2A, Saral, Jason-3, and Sentinel-3A, there are now seven active DORIS instruments, all the same DGXX generation.

Many future missions currently under preparation should guarantee a constellation of DORIS contributor satellites up to 2030 and beyond:

- HY2-C and HY-2D (CNSA/NSOAS), two Chinese missions flying DORIS, are planned for 2019 (or early 2020) and 2020, respectively.
- Jason-CS will ensure continuity from Jason-3 with a first launch in 2020 (Jason-CSA/ Sentinel-6A) and 2025 (Jason-CSB / Sentinel-6B). The Jason-CS / Sentinel satellites are part of the Copernicus program and are the result of international cooperation between ESA, Eumetsat, the European Union, NOAA, CNES and NASA/JPL.
- Sentinel-3C and -3D (ESA/Copernicus) are under development and expected for 2023 and 2025.
- SWOT (Surface Water Ocean Topography), a joint project involving NASA, CNES, the Canadian Space Agency and the UK Space Agency, is planned for 2021.

Network With 57 stations (including 4 master beacons and 1 time beacon) that are spatially well distributed over the Earth's land surface, the DORIS permanent network fully meets the orbit determination requirements for satellite altimetry. Two additional DORIS stations are dedicated to IDS for other scientific applications: Wettzell (Germany) and Mangilao (Guam Island, USA).

Notwithstanding the extensive outage of 2 stations (Santa-Cruz and Betio) and the shutdown of the 2 Russian stations (Badary and Krasnoyarsk) for regulation issues, the DORIS network provided a reliable service in 2018 with an annual mean of 88% of active sites thanks to the resourcefulness and the combined efforts of CNES, IGN and all agencies hosting the stations: 6 failed beacons and 2 failed antennas were replaced, including Mahé restarted in November after 3-yr outage.

There have been many developments and maintenance operations for the ground network in 2018. Early in the year, we moved the station at Rothera about 100 m away because of site refurbishment. In April, a new DORIS site has been set up in Guam Island, at Mangilao, close to the IGS station "GUUG" and the tide-gauge of Pago Bay (PSMSL 2130). This station will provide a significant contribution to the coverage of the western North Pacific Ocean over the Micronesia and the Mariana Trench. Then, two main events occurred in Argentina in the

last semester: the restarting at Rio Grande after 2-yr outage and the station installation at San Juan. These two stations were both eagerly expected to fill the coverage gap in this area. Finally, in October, the station in Svalbard was relocated about 3 km away to be part of the new geodetic observatory Ny-Ålesund II.

Regarding the network equipment, we continued the gradual replacement of Starec ground antennae B type with C type for which standard uncertainty of the 2GHz phase center in the vertical direction was reduced to 1 mm from 5 mm to improve measurements accuracy. 25% of the network is equipped with such antennae (Starec type C). The 4th DORIS beacon generation is now in its final stage of development. Following the testing of the prototype in 2018, the manufacturer will proceed with the construction of the production models with the first delivery planned in the spring of 2019. Using a signal amplifier at the foot of the antenna, a longer distance between beacon and antenna (up to 50 m vs. 15 m before) will make it easier to find suitable environment for the coming antennae installations and give the opportunity to relocate existing antennas to get better visibility.

Co-location with other space geodetic techniques and with tide gauges remains a major objective for the DORIS network. In 2018, we increased the number of co-located DORIS sites with GNSS at Mangilao and Ny-Alesund II, with SLR at San Juan, with VLBI at Ny-Alesund II (Figure 1).

All tie vectors between DORIS and the other techniques are compiled in a maintained file available on the IDS data centers: ftp://ftp.ids-doris.org/pub/ids/stations/DORIS_ext_ties.txt

In 2018, the following sites were visited:

- Re-location in Rothera (Antarctica)
- New site at Guam Island (USA)
- Reconnaissance in Changchun (China)
- Visit at Ponta-Delgada (Azores, Portugal)
- New site at San Juan (Argentina)
- Re-location in Ny-Ålesund (Svalbard, Norway)
- Restarting at Mahé (Seychelles)

In 2019, the overall objectives are:

- Start of the deployment of the 4th generation beacon
- Equipment replacement and local tie survey at St-John's (Canada)
- Reconnaissance in Iceland
- Restarting at Santa-Cruz (Galapagos, Ecuador)

- Restarting at Badary and Krasnoyarsk (Russia)
- New site in Changchun (China)
- Re-location at Easter Island (Chile)

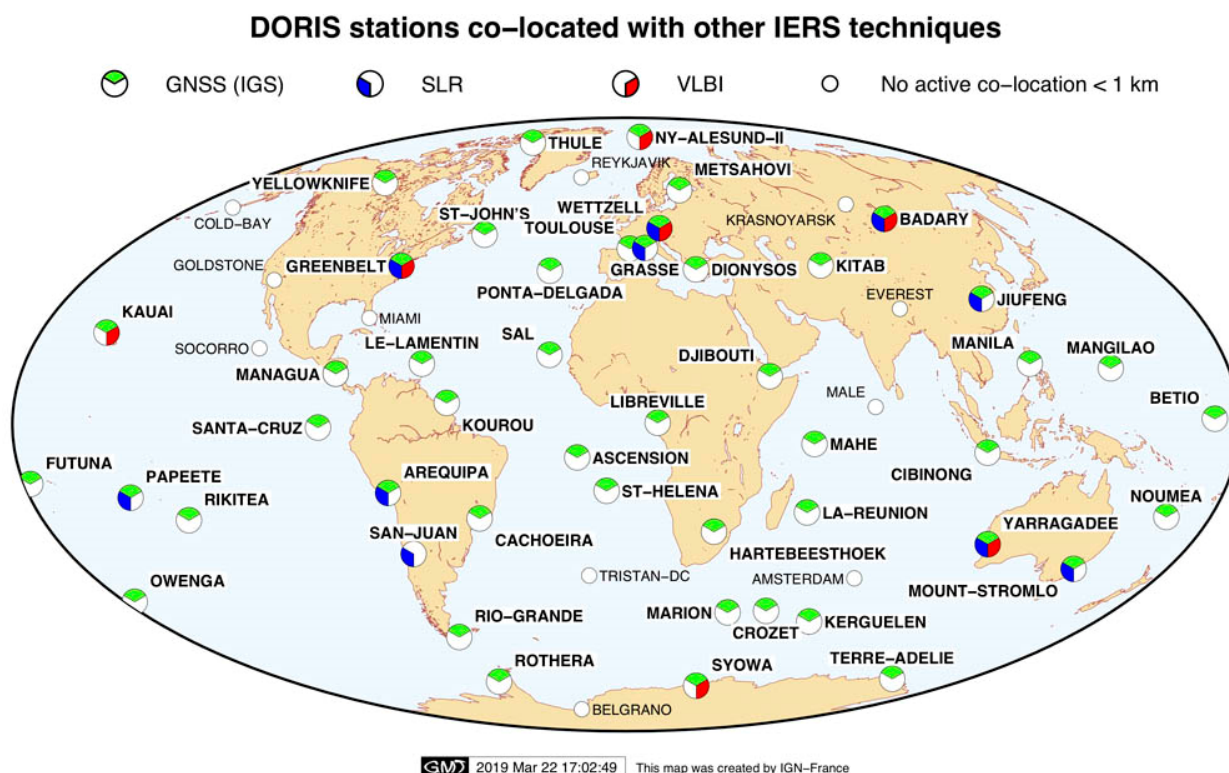


Fig. 1: The permanent DORIS network – 57 stations – and co-location with other IERS techniques (as of March 2019).

IDS organization and activities

Governing Board

In fall 2018, IDS organized elections to renew two posts expiring at the end of 2018. The holders of these posts are: Hugues Capdeville (CLS)/Jean-Michel Lemoine (CNES) as Analysis Coordinator, and Marek Ziebart as one of the Members at Large.

After the elections, the new members elected by the IDS Associates are:

- Hugues Capdeville & Petr Štěpánek as the new tandem for the Analysis Coordination,
- Claudio Abbondanza as a Member-at-Large.

They took up their duties within the Governing Board (GB) on January 1st, 2019 to serve for the period 2019–2022.

A new IAG representative (previously Petr Štěpánek who resigned for the Analysis Coordination) will be designed by IAG Executive Committee in July 2019.

The current list of members can be seen at the web page <https://ids-doris.org/ids/organization/governing-board.html>.

Meetings In 2018, IDS organized a meeting of the Analysis Working Group on June 11 at CNES in Toulouse (France), and a Workshop in Ponta Delgada (Azores Archipelago), Portugal, from 24 to 26 September, as part of the 25 Years of Progress in Radar Altimetry Symposium with the Ocean Surface Topography Science Team (OSTST) 2018.

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

<https://ids-doris.org/ids/reports-mails/meeting-presentations/ids-awg-06-2018.html>

<https://ids-doris.org/ids/reports-mails/meeting-presentations/ids-workshop-2018.html>

In 2019, IDS organizes two meetings of the Analysis Working Group, first in Munich (Germany), on Thursday April 4 (hosted by DGFI-TUM), then in Paris, end of September.

IDS retreat After 15 years of activity, the IDS organized its first retreat on June 13 and 14 at Château de Mons, near the small town of Caussens, in Gascony, in the Southwest of France (country of the Musketeers and Armagnac). In addition to the members of the IDS Governing Board, eleven people including outside members of IDS such as Christian Bizouard (Observatoire de Paris), Klaus Börger (University of Bonn), Pierre Exertier (OCA), Oliver Montenbruck (DLR), Paul Poli (SHOM) were asked to work on the strengths, weaknesses, opportunities and threats of the IDS. To support the general discussions dealing with how to grow or to increase the visibility of the IDS, five subjects of special interest (possible evolution of the DORIS technology, Precise Orbit Determination, interest in ionospheric-tropospheric derived products, DORIS geocenter and pole estimations, IDS scientific goals and organization) were addressed. From the minutes of all the discussions, the IDS Governing Board will write a preliminary version of the IDS strategic plan. The next step will be consultation with the DORIS system stakeholders. Then, the first IDS strategic plan including both medium and long-term actions will be made available.

User Service Data information service

The Central Bureau works with the SSALTO multi-mission ground segment and the Data Centers to coordinate the data and products archiving and the dissemination of the related information. In 2018, this activity focused on:

- the delivery of Sentinel-3B's DORIS data (first data on IDS DCs in DORIS-RINEX format only with DIODE time tagging on May 1st, 2018)
- the delivery of the CNES orbits in POE-F standards (file naming, store folders, description files)
See [ftp CDDIS or IGN]
pub/doris/products/orbits/ssa/README_SP3.txt

The Central Bureau also interfaced with the Combination Center for making available the DORIS SINEX master file that contains for each DORIS station geographic positions, station IDs, type and eccentricity of the antennas. See <ftp://ftp.ids-doris.org/pub/ids/stations/ids.snx>.

Web and ftp sites

Address: <https://ids-doris.org>

The main updates of the website, as well as the list of the new documents and files put on the ftp site, can be found in the 2018 IDS Activity Report (<https://ids-doris.org/ids/reports-mails/governing-board.html#activity>).

DOR-O-T, the IDS Webservice

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

Several new features were added to the IDS web service in 2018. The main ones have been brought to the network viewer (<https://apps.ids-doris.org/apps/map.html>). In addition to the DORIS network and the IGS co-located stations, it is now possible to display the boundaries of the tectonic plates (Bird, 2003), the large Earthquakes (magnitude greater or equal to 6) within a 500 km radius of the DORIS stations (source USGS), as well as the horizontal and vertical velocity vectors of the DPOD2014 solution. A new plottool for position residuals was created to plot the position residuals (North, East, Up) of the cumulative solution derived from the routine analysis of the IDS Combination Center (<https://apps.ids-doris.org/apps/dpodtool.html>).

Newsletter

IDS Newsletter #5 was published in September 2018. It contains the following articles:

- DORIS stations in polar regions, an ongoing challenge for continuous operation (J. Saunier, IGN)
- Focus on Rothera on the Antarctic Peninsula (J. Saunier, IGN)
- Rothera: the host agency in short (D.G. Vaughan, BAS)
- DORIS on Sentinel-3B: and now seven! (CNES)
- Jason-2, ten years after (CNES)

- IDS meetings: a time to remove the nose from the grindstone (G. Moreaux, L. Soudarin, CLS)

The issues are distributed via email and are also available at <https://ids-doris.org/ids/reports-mails/newsletter.html>.

Data Centers Two data centers currently support the archiving and distribution of data and products for the IDS:

- Crustal Dynamics Data Information System (CDDIS), funded by NASA and located in Greenbelt, Maryland, USA (<ftp://cddis.nasa.gov>)
- l'Institut National de l'Information Géographique et Forestière (IGN) in Marne la Vallée, France (<ftp://doris.ign.fr>) and (<ftp://doris.ensg.eu>)

In 2017, CDDIS developed all new software to automate the ingest of data submitted by SSALTO and in 2018 add product ingest as well. This new software is a significant improvement over the previous process and performs a full range of quality-checks and metadata extraction. The software uses these new checks and metadata to generate a summary file for each data file. All incoming DORIS data have its metadata extracted and stored in a local database. These metadata, which includes satellite, time span, station, and number of observations per pass, and are utilized to generate data holding reports on a daily basis.

Analysis Centers and Coordination

The activities of all the DORIS analysts of the past year 2018 have been dominated by taking into account the last DORIS satellites Jason-3, Sentinel-3A and Sentinel-3B which DORIS data are only available in RINEX format, defining the best strategy to mitigate the impact of the sensitivity to the South Atlantic Anomaly (SAA) effect of DORIS Ultra Stable Oscillator (USO) and starting the preparation of the next ITRF contribution. An International DORIS Service Analysis Working Group (IDS-AWG) meeting was hosted in CNES on June 11, 2018 in conjunction with Copernicus POD Quality Working Group. The IDS workshop 2018 was held from 24 to 26 September 2018 in Ponta Delgada (Azores Archipelago, Portugal), as part of the 25 Years of Progress in Radar Altimetry Symposium with the Ocean Surface Topography Science Team (OSTST) 2018.

All the IDS Analysis Centers (AC) continue the standard routinely processing by taking into account the last DORIS data available. The IDS includes six ACs and three “associate analysis centers” who use seven different software packages. We also note which analysis centers on a routine basis perform POD analyses of DORIS satellites using

other geodetic techniques (c.f. Satellite Laser Ranging (SLR), or GNSS). The multi-technique analyses are useful since they can provide an independent assessment of DORIS system performance and allow us to validate more easily model changes and the implementation of attitude laws for the different spacecraft.

The behavior of the various DORIS on-board oscillators in the vicinity of the high radiation area “South Atlantic Anomal” (SAA) has been studied. It has been shown by different ACs (and associated) that all DORIS receivers are frequency-sensitive to the crossing of the SAA, though at very different levels. For Jason-1 and SPOT-5 satellites, a corrective model has been developed and used for the realization of the ITRF2014. However, Jason-2 is also impacted, not at the same level as Jason-1 but strong enough to worsen the multi-satellite solution provided for ITRF2014 for the SAA stations. The last DORIS satellites are also impacted by the SAA effect, in particular Jason-3. Currently we have several possibilities to mitigate the SAA effect. For Spot-5 and Jason-1, ACs can use the DORIS2.2 data corrected by the models available at CDDIS and IGN Data Centers. For Jason-2 and Jason-3, ACs can adjust at least a Bias+drift by pass for SAA stations in their POD processing. We can also use the strategy to add single satellite solution affected by the SAA in the multi-satellite solution.

The space-geodetic observation of geocenter motion is still in its infancy. Independent solutions have systematic differences as large as the signal level. The ITRF origin is only sensed by SLR observations of the LAGEOS-1 and 2 satellites. There are other techniques than SLR (DORIS, GPS-LEO satellites). DORIS can play a role because the tracking network is stable and well-distributed (reduces network effects). The collinearity of TZ with residual SRP modeling errors can be mitigated well for Jason-like satellites since their 118-day draconitic period is not close to one solar year. So, the Jason-2/3 satellites are appealing for geodetic DORIS-based geocenter motion determination. The upcoming launches of future DORIS satellites HY-2C (inclination of 66°), Jason-CS/Sentinel-6 (66°), and SWOT (inclination of 78°), should also permit the same type of geocenter solutions. IDS GB is evaluating formation of Working Group on the Geocenter where non-IDS participation would be encouraged.

The analyses associated with ITRF2014 as well as subsequent work have demonstrated that the DORIS products contain signals at distinct tidal, TOPEX/Jason-draconitic, semi-annual, and annual periods. These signals point to potential problems in force and measurement modeling, potentially associated with the tidal EOP modelling and with the modeling of non-conservative forces on some satellites. ACs have to improve SRP modelling to reduce draconitics, in particular for Topex/Jasons

satellites by using solar angle panels, by estimating SRP coefficient, by improving the macromodels, ...

The Jason-3, Sentinel-3A and Sentinel-3B satellites have to be added in the DORIS processing chain of IDS ACs. ACs have to complete their DORIS/RINEX data processing implementation in order to take into account the data from these new satellites.

IDS ACs have to adopt and evaluate the new standards/models recommended by IERS for the next ITRF. ACs have to implement in particular the new linear mean pole model and adopt a Time-Variable Gravity (TVG) model compatible. The next IDS Analysis Working Group will be held in Munich (Germany) hosted by DGFI, on April 4, 2019.

Combination Center

In 2018, in addition to the routine evaluation and combination of the IDS AC solutions, the IDS Combination Center delivered to the IDS Data Centers its third version of the DPOD2014 (DORIS extension of the ITRF2014 for Precise Orbit Determination) based on the third version of the DORIS cumulative position and velocity solutions. All the details on the realization and validation processes of the DPOD2014 are described in Moreaux et al., 2019 (that paper is in open access until the end of 2019). In preparation to the realization of the IDS contribution to the next ITRF (ITRF2020), the IDS CC started to review the whole combination strategy with the objective of improving the station positioning and EOP performances, mainly over the time period 1993.0–2002.3.

Publications

IDS published the 2017 activity report that was broadly distributed to all DORIS participants and relevant services (see <https://ids-doris.org/ids/reports-mails/governing-board.html#activity>).

All DORIS related articles published in international peer-reviewed journals are available on the IDS Web site <https://ids-doris.org/ids/reports-mails/doris-bibliography/peer-reviewed-journals.html>.

Conclusions

2018 has been highlighted by the organization of the first retreat of the IDS, first step for the definition of a strategic plan for the next years.

The IDS Combination Center delivered its third version of the DPOD2014 (DORIS extension of the ITRF2014 for Precise Orbit Determination).

The activities of all the DORIS analysts of the past year 2018 have been dominated by taking into account the last DORIS satellites Jason-3, Sentinel-3A and Sentinel-3B which DORIS data are only available in RINEX format, defining the best strategy to mitigate the impact of the sensitivity to the SAA effect of DORIS Ultra Stable Oscillator (USO) and starting the preparation of the next ITRF contribution.

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3.5 Product Centres

3.5.1 Earth Orientation Centre

This section presents the activities and main results of the Earth Orientation Centre, located at Paris Observatory, over the year 2018.

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 Rotation Parameters (ERPs): Pole coordinates (x,y), Difference UT1–UTC, Length of Day variation (LOD) and Celestial pole offsets (dX, dY) are available to a broad community of users in various domains such as astronomy, geodesy, geophysics, space sciences and time. ERPs 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 the previous year and the Bulletin B / C04 given at one-day intervals, which is published monthly with a 30 day delay (Gambis, 2004; Bizouard and Gambis, 2009; Gambis and Luzum, 2011, Bizouard et al, 2018).

C04 series

According to the decision of IERS DB 66 (April 8, 2018 in Vienna), the 14 C04 solution for UT1 has been modified by including the contribution of UT1 intensive back to 1996 (see note of January 2018). The old version, updated until 2018/04/16, has been put in the sub-directory /eopc04.2017.

Whereas they are delivered officially on Tuesday and Friday, C04 series are updated every day. As far as possible, the values are checked several times in the week, even during the week-end with the active participation of Jean-Yves Richard. To this aim we set up a graphic comparison with other EOP series: http://hpiers.obspm.fr/eop-pc/WEBFTP14/accueil_C04.html.

Web site upgrade

The interactive WEB page allowing to compare polar motion and length of day with their geophysical excitation has been updated, and in addition to atmospheric NCEP and oceanic ECCO angular momentum function, now it includes the hydro-atmospheric series derived by GFZ in according to the output of the coupled ECMWF (atmospheric), MIP-MOM (ocean) and LSDM (land water): <http://hpiers.obspm.fr/eop-pc/index.php?index=excitactive&lang=en>.

Statistics Statistics of 14 C04 for the year 2018 are provided in Table 1 (standard deviations of C04 – intra-techniques solutions), Table 2 (mean and standard deviations of C04 – intra-technique combined solutions) and 3 (mean and standard deviations of C04 – multi-technique combined solutions).

Table 1: *Intra-techniques solutions: averaged time sampling and standard deviation with respect to the combined solutions Bulletin B / C04 over the year 2018. Solutions contributing to Bulletin B / C04 are flagged by stars (*).*

Individual solutions	Estimated uncertainties				
	Time sampling	Terrestrial Pole	UT1	LOD	Celestial Pole
		μas	μs		μas
VLBI - 24h					
EOP(AUS)	~16 d	265	28.1		144
EOP(BKG)	~3 d	133	25.8		78
EOP(GSFC)	~2 d	124	26.2		81
EOP(IAA)	~3 d	159	25.8		78
EOP(OPA)	~3 d	87	28.0		77
EOP(USNO)	~3 d	43	27.7		58
EOP(IVS) *	~3 d	89	27.7		39
VLBI - Intensive					
EOP(BKG) *	~1 d		38.2		
EOP(GSFC) *	~1 d		36.6		
EOP(IAA) *	~1 d		39.3		
EOP(PUL)	~1 d		37.8		
EOP(USNO) *	~1 d		37.2		
SLR					
EOP(MCC)	~1 d	104		187	
EOP(IAA)	~1 d	192		29	
EOP(ASI)	~1 d	206		42	
EOP(ILRS) *	~1 d	144		19	

GPS					
EOP(CODE)	~1 d	41		10	
EOP(JPL)	~1 d	36		13	
EOP(GFZ)	~1 d	39		10	
EOP(ESOC)	~1 d	34		9	
EOP(NOAA)	~3 d	50		9	
EOP(SIO)	~1 d	58		22	
EOP(EMR)	~1 d	47		12	
EOP(IAA)	~1 d	78		21	
EOP(GRGS)	~1 d	31		11	
EOP(ASI)	~1 d	50		42	
EOP(MIT)	~1 d	55		11	
EOP(IGR) *	~1 d	35		9	
EOP(IGS) *	~1 d	30		9	

Table 2: Mean and standard deviation (STD) in microarcsecond of the differences between intra-techniques combined solutions entering the combination and Bulletin B / C04 over 2018.

EOP	IGS Comb – IERS 14C04		ILRS Comb – IERS 14C04		IVS Comb – IERS 14C04	
	Mean	Stand deviation	Mean	Standard deviation	Mean	Standard deviation
$X(\mu as)$	59	36	49	129	77	98
$Y(\mu as)$	-23	23	74	158	-59	79
$UT1(\mu s)$					21.2	27.7
$LOD(\mu s)$	0	9	-2	19		
$dX(\mu as)$					-24	48
$dY(\mu as)$					-1	29

Table 3: Mean and standard deviation for Pole coordinates (x,y) and UT1 of the differences between combined solutions derived by both the Rapid Service/Prediction Center at USNO, the JPL and Bulletin B / C04 over 2018.

EOP	Unit	Bul A – Bul B		Comb JPL – Bul B	
		Mean	Stand deviation	Mean	Standard deviation
X	μas	56	50	27	63
Y	μas	-20	37	4	38
UT1	μs	12.5	44.5	10.8	35.7

Earth Orientation Center staff

Christian Bizouard, Astronomer, head
 Olivier Becker, Engineer, operational work and automation
 Teddy Carlucci, Engineer, system
 Jean Yves Richard, Engineer, EOP consistency with ITRF
 Pascale Baudoin, Secretary
 Sébastien Lambert, Assistant-Astronomer, Consultant, representative of the IERS EOC

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Christian Bizouard

3.5.2 Rapid Service/Prediction Centre

Introduction

This section provides a discussion and summary of the Earth orientation parameter (EOP) results produced by the IERS Rapid Service/Prediction Center (RS/PC) for the calendar year 2018. The accuracies of both the inputs used and the subsequent EOP combination and prediction results produced by the IERS RS/PC are provided. The combination and prediction comprise the Bulletin A results and are published in several human and machine readable formats. In addition, a plot of the polar motion path for the year, a summary of the expected times during each day at which inputs are provided to the IERS RS/PC solution, a low precision table of predictions of TT-UT1, and a comprehensive list of the inputs to the IERS RS/PC combination and prediction process are provided. This section also contains an overview of the combination processing techniques, the prediction processing techniques, the center activities that include developmental work to improve EOP results, and the web and FTP locations available to users for obtaining results. Lastly, detailed analyses and discussions regarding results may not, in general, be discussed in this section, but may be presented at upcoming conferences and meetings.

Combination Processing Techniques and Results

In combining the contributed observational data to generate the quick-look EOP results, the IERS RS/PC employs a smoothing cubic spline that weights each of the input data series based on its reported observational errors, which is referred to as a “weighted smoothing cubic spline” (WSCS) (McCarthy and Luzum, 1991a). Observational data contributions are corrected for possible systematic differences in the form of offsets and rates computed with respect to the C04 series of the IERS Earth Orientation Centre (EOC) at the Paris Observatory; to this end, a robust linear estimator is employed which ameliorates the effect of outliers on the computed offsets and rates. The statistical weights used in the spline are proportional to the inverse square of the estimated accuracy of the individual techniques computed over the past several years. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Weights for each contributor in the algorithm may be either a priori values estimated by determining the standard deviation of a long history of residuals or values based on the internal precision reported by contributors. The estimated accuracies for each of the IERS RS/PC contributors to the EOP combination solutions for 2018 are provided in Table 1. The estimates are based on the residuals between the contributor series and the IERS RS/PC (USNO) EOP solution (contained in the file `finals.data`) for all the epochs in 2018.

On 29 March 2018, the RS/PC EOP series for UT1–UTC, Polar Motion, and Celestial Pole Offsets (CPOs) was transitioned to be consistent with the newly computed and corrected 14 C04 EOP series. Two adjustments were made to implement this transition; 1) a small offset and slope (systematic corrections) were applied to the entire RS/PC EOP time series going back to 1972 to diminish any long-term drift between the two series and 2) the combination was re-solved going back approximately one year from 29 March 2018, with each input contributor having a revised systematic correction applied. Just before the transition, revised systematic corrections applied to each series had previously been computed based on the residuals of the observational inputs versus the 14 C04 series. (Note that a complete list of the input contributors to the combination software are listed in Table 7a.)

Some of the EOPs are measured directly while others are a hybrid of direct measurements and related quantities. For polar motion (x and y) and the CPOs, all the contributors provide direct measurements of these quantities. As mentioned in the previous report for 2017, starting in March 2018, all the CPO contributor inputs have been in terms of dX and dY , and are consistent with the IERS Conventions 2010 and IAU 2006 precession and 2000A nutation models. For UT1–UTC, some contributors provide direct measurements and others provide estimates based on the derivative of UT1.

All of the Very Long Baseline Interferometry (VLBI) contributors provide direct measurements of UT1; the International GNSS Service (IGS) ultra-rapid observations (IGS ultras) provide a length-of-day (LOD) type input, which is a derivative of UT1; and the USNO GPS UT provides a UT1-like estimate based on GPS orbit modeling. The VLBI-based results have been used to correct for the LOD bias in the IGS ultras and to minimize drifts in UT estimates in both the IGS ultras and USNO GPS UT (“UTGPS”). The corresponding statistics shown for the IGS ultras and UTGPS are computed after the bias corrections are applied. Although the Atmospheric Angular Momentum (AAM) inputs may be added to the EOP combination in the future, currently the AAM inputs do not contribute to the EOP combination solution, but provide inputs to the EOP UT1–UTC predictions out to seven days into the future; therefore, there is no mention of AAM results in Table 1. The combination refers to solutions of past EOP results; whereas, predictions refer to the current and future EOP look-ahead solutions, which are discussed later in the chapter.

Each day at approximately 17:00 UTC, input data spanning one year into the past are provided to the WSCS software to update EOP solutions. The data consists of the following: the epoch of observation, the observed EOP value, and the corresponding weight. The software computes the spline coefficients for every unique input data point, which

are then used to interpolate the Earth orientation parameter time series so that x , y , UT1–UTC, dX , and dY values are computed for the midnight (00:00) UTC epoch for each day.

Table 1: *Estimated accuracies of the contributions to the IERS RS/PC combination results for 2018 with respect to the IERS RS/PC EOP series. Units are milliseconds of arc (mas) for x , y , dX , and dY and milliseconds of time for UT1–UTC. (All acronyms used in this table are defined in the Acronyms section – Appendix 5 – of this IERS Annual Report 2018.)*

Contributor	Estimated accuracy				
	x	y	UT1–UTC	dX	dY
ILRS SLR	0.22	0.22	–	–	–
IAA SLR	0.19	0.23	–	–	–
MCC SLR	0.13	0.18	–	–	–
GSFC VLBI Intensive	–	–	0.018	–	–
USNO VLBI Intensives	–	–	0.018	–	–
GSI Intensives	–	–	0.016	–	–
GSFC ⁺ VLBI	0.06	0.08	0.003	0.07	0.05
IAA ⁺ VLBI	0.20	0.25	0.008	0.06	0.07
IVS ⁺ VLBI	0.08	0.09	0.004	0.06	0.06
USNO ⁺ VLBI	0.08	0.07	0.004	0.05	0.07
IGS Final	0.02	0.01	–	–	–
IGS Rapid	0.03	0.03	–	–	–
IGS Ultra [*]	0.05	0.04	0.034 [*]	–	–
USNO GPS UT [*]	–	–	0.050 [*]	–	–

⁺ GSFC, USNO, IAA, and IVS VLBI nutation values are in terms of dX/dY using IAU 2000A Nutation Theory (see Petit and Luzum, 2010).

^{*} All satellite techniques provide information on the rate of change of Universal Time contaminated by effects due to un-modeled orbit node motion. VLBI-based results have been used to correct for LOD biases and to minimize drifts in UT estimates.

Additionally, LOD and estimated error results are published along with the EOP combination results. The LOD results 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 (after leap second discontinuities are removed) 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 are those EOP inputs that have contributor reported errors (sometimes called formal errors) greater than three times their average reported precision. The other data excluded are those inputs that have a residual that is more than four times the associated a priori error estimate. Also, note that since all of the observations are reported to the IERS RS/PC with the effects of sub-daily variations already removed, the input data do not need to be corrected for these effects (see IERS Gazette No. 13, 30 January 1997).

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Center combination solutions and the 14 C04 EOP solutions for 2018. 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	0.07	0.06
y	-0.02	0.04
UT1–UTC	-0.015	0.052
Bulletin A Weekly Solution (finals.data)¹		
x	0.05	0.08
y	-0.02	0.06
UT1–UTC	0.009	0.060
Bulletin A Daily Solution (finals.daily)		
x	0.02	0.07
y	-0.00	0.04
UT1–UTC	0.000	0.074

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

Comparing statistics provided in Table 1 versus the same table in the IERS RS/PC section of the IERS Annual Report 2017¹, one can see some noteworthy differences. The ILRS SLR estimated accuracy for 2018 was 0.22 versus 0.14 for Polar Motion X and 0.22 versus 0.17 for Polar Motion Y; the GSFC, IVS, and USNO VLBI Polar Motion X and Y accuracies all improved by at least 20%. CPOs in Table 1 above are

¹The IERS Annual Report (AR) 2017 and previous ARs are found at <https://www.iers.org/AnnualReports>

reported only as dX and dY ; whereas previous annual reports reported these quantities as either $d\psi$ and $d\epsilon$ or dX and dY depending on the contributor CPO system being used or reported by the contributor.

When comparing the integrated IGS Ultra LODs (IIUL) RMS residual value provided in Table 1 to that shown in Table 1 in the AR 2017, one can see a substantial decrease (0.034 for 2018 vs 0.051 milliseconds (msec) for 2017). The RMS provided is computed using the first IIUL residual for that solution if any IIULs were used in the combination for that day. The exact causes for the change are being considered; however, reasons for the change could be affected by the manner in which the following were computed: a) the RMS statistics and b) the IIUL constants of integration for each day. A discussion of the computation of the RMS statistics and IIUL constants of integration for each day were provided in the IERS RS/PC section of the IERS AR 2017 and the reader is referred to that detailed discussion. The causes of any noteworthy differences between the values reported in Table 1 above to those reported in the IERS 2017 AR may be discussed in more detail at an upcoming conference to be held in 2019 or later.

Table 2 shows the accuracies of Rapid Service/Prediction Center's combination solution for the running, weekly, and daily products compared to the 14 C04 series maintained by the IERS EOC for 2018; the latter series uses somewhat different data inputs and a different combination algorithm, which makes it suitable for comparison. Nominally, each Thursday, the IERS RS/PC produces a weekly EOP solution in two general file formats – “finals.data” and the “ser7.dat” files. The finals.data solution contains EOP data in a tabular, machine-readable form, for each day from 1992 to one year into the future from the Thursday updated solution date. At the same time, the results are published in the ser7.dat file, which is more in a human readable format. Formats for each can be found at <http://maia.usno.navy.mil/ser7/readme.finals> and [ser7/readme.bulla](http://maia.usno.navy.mil/ser7/readme.bulla). In addition, each day, the IERS RS/PC computes and publishes an EOP solution in the file “finals.daily”. This file has the same format as the finals.data file; however, it only contains the current day, three prior months, and three future months of EOP results.

Figure 1 contains plots of the 2018 residuals between the daily rapid and the 14 C04 solutions, and the corresponding statistical results are listed in Table 2 under “Bulletin A Daily Solution (finals.daily).” These daily rapid solutions are considered the last combination or 0-day prediction results. The statistics for the Daily Solution are the differences between the EOP solution, updated daily and at each corresponding daily epoch for 2018, versus the respective 14 C04 series solution for that epoch when it becomes available. (An example of the method used to compute the Bulletin A Daily solution (finals.daily) statistics

is provided in the RS/PC section of the IERS Annual Report 2015 on pages 82 and 83.)

The absolute value of the mean of UT1-UTC decreased to 0.000 in 2018 compared to -0.027 milliseconds for 2017; however, the STD increased to 0.074 in 2018 compared to 0.058 milliseconds for 2017. However, if one were to compare the USNO finals.daily UT1-UTC results versus the JPL EOP SPACE series², one would obtain a mean of 0.000 and STD of 0.0524 milliseconds. As may be shown in more detail in a conference or meeting later in 2019, there was possibly an overweighting of the IVS VLBI intensives observations compared to the IVS 24-hour series within the C04 series from early May to early August 2018. This overweighting caused the comparison of the RS/PC finals.daily results to the C04 reference series to have larger residuals than it should have if the C04 did not have this issue.

The running solution statistics, shown under the label “Bulletin A Rapid Solution (finals.data),” are the residuals of the combination solution, contained in finals.data, versus the 14 C04 series over the 365-day period covering 2018. The finals.data file used in computing these statistics was computed on January 14, 2019 (and also archived). Nominally, the last observational input data for the year (in this case, 2018) is processed and provided to the IERS RS/PC by January 14 of the following year (in this case, 2019); the last observational data to become available are usually the 24-hour VLBI input series. Thus, the running solution includes the effects of any late-submitted, but highly accurate data.

As seen in Table 2 under the label “Bulletin A Rapid Solution (finals.data)”, there were noteworthy differences in the comparison of the polar motion X mean and UT1-UTC STD between the 2018 and corresponding 2017 results. The polar motion X mean differences were 0.07 and 0.01 milliarcseconds, respectively; reasons for the differences are not yet known, but may be investigated. The increase in UT1-UTC STD from 2017 to 2018 was 0.018 to 0.052 milliseconds. The cause of the UT1-UTC STD difference is most likely an issue with the C04 as mentioned a few paragraphs above; it should be noted that the STD compared to the JPL EOP SPACE series was only 0.023 milliseconds.

The “Bulletin A Weekly Solution” results shown in Table 2 are the statistics of the residuals obtained from the Bulletin A combination values, contained in the ser7.dat format, for 2018 versus the 14 C04 series. These combination values for 2018 are the concatenation of all 52 Bulletin A, 7-day EOP combination results. For each Bulletin A, there is a set of 7-day EOP combination results listed prior to the solution epoch. (For example, the Bulletin A solution computed on January 11,

²https://keof.jpl.nasa.gov/predictions/latest_midnight.eop

Prediction Techniques and Results

2018 has EOP combination results from 5 through 11 January, 2018.)

In 2007, the algorithm for polar motion predictions was changed to incorporate the least-squares, autoregressive (LS+AR) method created by W. Kosek and improved by T. Johnson (personal communication, 2006). This method solves for a linear, annual, semiannual, 1/3 annual, 1/4 annual, and Chandler periods fit to the previous 400 days of observed values for x and y . This deterministic model is subtracted from the polar motion values to create residuals that are more stochastic in nature. The AR algorithm is then used to predict the stochastic process while a deterministic model consisting of the linear, annual, semiannual, and Chandler terms is used to predict the deterministic process. The polar motion prediction is the addition of the deterministic and stochastic predictions. The additional unused terms in the deterministic solution help to absorb errors in the deterministic model caused by the variable amplitude and phase of the deterministic components (T. Johnson, personal communication, 2006). For more information on the implementation of the LS+AR model, see Stamatakos *et al.* (2008). A deficiency with the current implementation of this algorithm occasionally may cause poor quality short-term polar motion predictions. It is anticipated that within a few years, an evaluation effort recently funded by USNO will yield improved prediction algorithms.

The UT1–UTC prediction makes use of a UT1-like data product derived from a combination of the operational National Centers for Environmental Prediction (NCEP) and U.S. Navy's Global Environmental Model (NAVGEM) Atmospheric Angular Momentum (AAM) analysis and forecast data (UTAAM). AAM-based predictions are used to determine the UT1 predictions out to a prediction length of 7.5 days (Johnson *et al.*, 2005). For longer predictions, the LOD excitations are combined smoothly with the longer-term UT1 predictions described below. For more information on the use of the 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, resulting in a quantity called $UT2S - TAI$. ($UT2S$ is a smoothed version of $UT1$, removing periodic seasonal and long period variations due to tides, including the long-period tides up to 18.6 years.) Then, to create the prediction of $(UT2S - TAI)_N$ N days into the future, the smoothed time value from N days in the past, $(UT2S - TAI)_{-N}$, is subtracted from 2-times the most recent value, $2(UT2S - TAI)_0$ to yield:

$$(UT2S - TAI)_N = 2(UT2S - TAI)_0 - (UT2S - TAI)_{-N}.$$

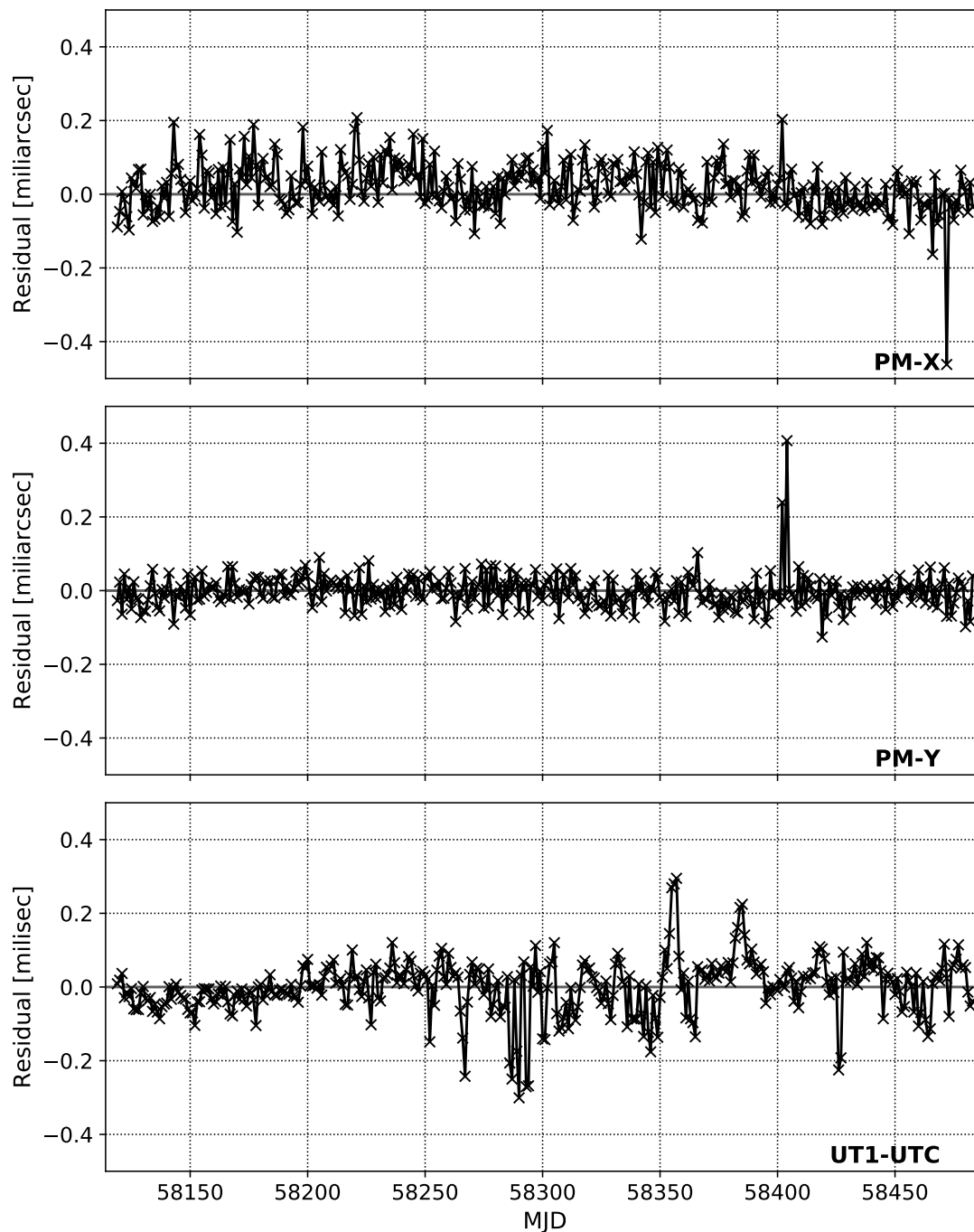


Fig. 1: Differences for 2018 between the daily updated EOP solution at the day of the solution update and the 14 C04 series combination solution. (The day of the solution is also known as the last combination or 0-day prediction epoch.) Earth Orientation Parameters shown are: a) Polar Motion X; b) Polar Motion Y; and c) UT1-UTC.

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 UTGPS, 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 UTGPS estimates to constrain the UT1 rate of change for the most recent observation.

Errors of the prediction estimates are derived from analyses of the past differences between observations and the published predictions. Formulas published in Bulletin A can be used to extend the Bulletin A tabular data, but predictions derived from these formulas are significantly less accurate than the tabular predictions and are not recommended for operational use.

For several representative prediction days, the RMS of the residuals between USNO produced polar motion and UT1–UTC predictions and the 14 C04 series combination values for 2018 are shown in Tables 3a through 3d. Prediction day “ N ” is defined as “ N ” days into the future from the current day for which the EOP solution was updated. For example, prediction day 10 for the EOP solution that was updated on MJD 58392 (October 1, 2018) is MJD 58402 (October 11, 2018). Table 3a provides the RMS prediction errors for EOP solutions updated at 17:00 UTC; Tables 3b, 3c, and 3d provide RMS prediction errors for solutions updated at 21:10, 03:10, and 09:10 UTC, respectively.

As Table 3a shows, for most prediction days (although certainly not all) there were small improvements in the polar motion and UT1–UTC predictions compared to the same table in the AR 2017; one notable degradation is in the 0 day UT1–UTC prediction which went from 0.063 to 0.074 milliseconds. However, as was previously mentioned in the report, it should be noted that the C04 series had some known issues for UT1–UTC in 2018, thus affecting the residuals since the C04 is the baseline of the comparison. More detailed explanations of the comparisons may be provided at upcoming conferences.

In annual reports up through 2013, the prediction length (as shown in Tables 3a) was determined from the epoch of the last known VLBI or IGS observation, and not based on the date of the solution epoch. It has been determined that many EOP users base their inputs on the prediction from the date of the solution epoch, and also using this new paradigm simplifies the comparison of results among the 17:00 UTC EOP solution and the 21:10, 03:10 and 09:10 UTC solutions (which

are discussed below). In general, the results are very similar since on most days an observation is made either on the solution day or the day before. The statistics based upon the older paradigm could be made available upon request from usn.ncr.navobsydc.mbx.eopcp@mail.mil.

Table 3a: *RMS of the differences between the EOP time series predictions produced by the 17:00 UTC daily EOP solutions and the 14 C04 combination solutions for 2018. Note that the prediction length starts counting from the day after the date of the solution epoch.*

Days in future	PMx (mas)	PMy (mas)	UT1–UTC (ms)
0	0.07	0.04	0.074
1	0.31	0.23	0.087
5	1.75	1.32	0.198
10	3.29	2.29	0.537
20	5.89	3.80	2.347
40	10.24	5.78	5.118
90	17.25	9.28	9.748

Table 3b: *RMS of the differences between the EOP time series predictions produced by the 21:10 UTC daily EOP solutions and the 14 C04 combination solutions for 2018.*

Days in future	PMx (mas)	PMy (mas)	UT1–UTC (ms)
0	0.07	0.04	0.072
1	0.29	0.21	0.084
5	1.72	1.31	0.196
10	3.26	2.29	0.540
20	5.78	3.89	2.348
40	10.25	5.85	5.148
90	17.30	9.26	9.798

Table 3c: *RMS of the differences between the EOP time series predictions produced by the 03:10 UTC daily EOP solutions and the 14 C04 combination solutions for 2018.*

Days in future	PMx (mas)	PMy (mas)	UT1–UTC (ms)
0	0.07	0.04	0.072
1	0.29	0.28	0.083
5	1.86	1.60	0.196
10	3.25	2.62	0.537
20	5.62	4.27	2.349
40	10.03	6.33	5.158
90	17.36	9.26	9.815

Table 3d: *RMS of the differences between the EOP time series predictions produced by the 09:10 UTC daily EOP solutions and the 14 C04 combination solutions for 2018.*

Days in future	PMx (mas)	PMy (mas)	UT1–UTC (ms)
0	0.07	0.04	0.072
1	0.27	0.21	0.083
5	1.69	1.34	0.195
10	3.19	2.36	0.535
20	5.64	3.97	2.344
40	10.02	6.09	5.133
90	17.15	9.21	9.783

In addition to the 17:00 UTC EOP solution, three additional EOP solutions are computed each day – new solutions are computed at 21:10, 03:10, and 09:10 UTC. These four solutions are collectively referred to as the Nxdaily solutions. At these solution times, the EOP results

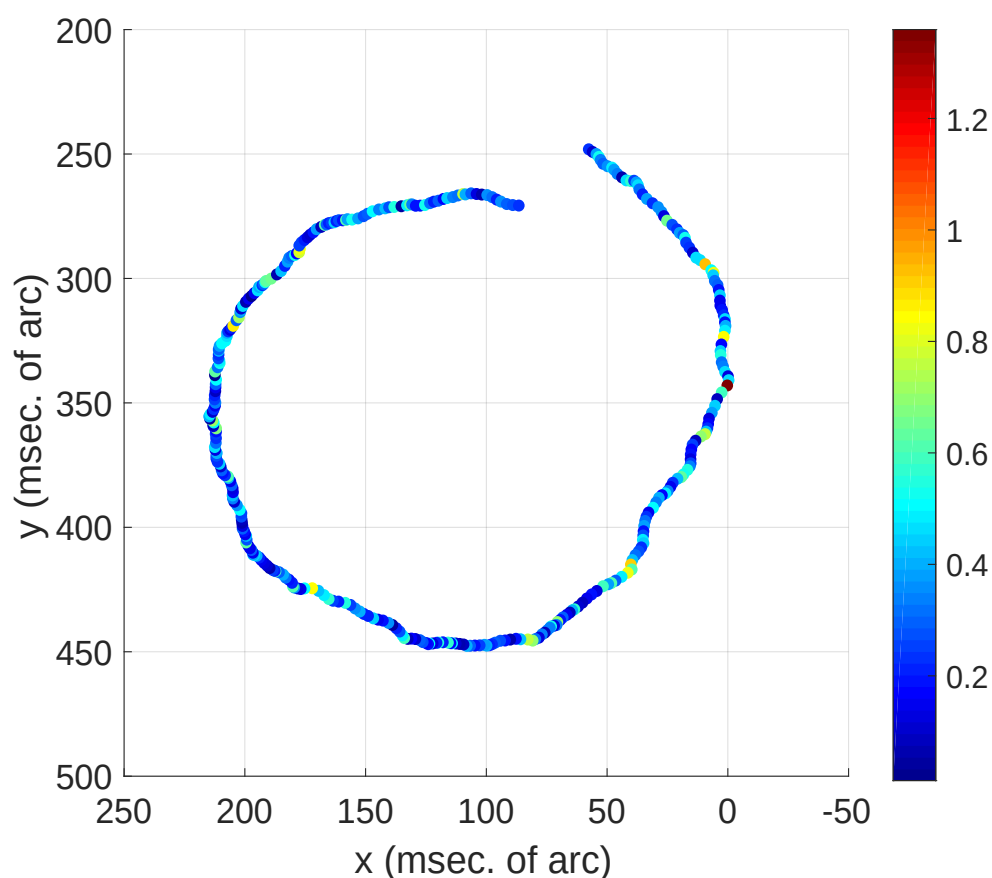


Fig. 2: Plot of the polar motion path for 2018 with corresponding 1-day prediction residual values. The residuals are the RMS of the combined polar motion x and y residual values and are in units of milliseconds of arc (msec of arc) and correspond to the color-coded vertical bar at the right ranging from less than 0.1 (dark blue) to greater than 2.2 (dark red) msec of arc.

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

At each N_{xdaily} UTC solution time listed in Tables 4a and 4b, major contributors, whose latencies between observations to availability for the EOP solution are under a few days, are listed with an associated “epoch at midpoint.” IGS and VLBI solutions are determined from a span of observations and the EOP estimate is provided at the midpoint of this span. Typically IGS orbits are determined over a 24-hour period

and VLBI intensives sessions span a 1-hour period. The “Contributor” column contains the most recently available input at the time of each UTC solution. Although major contributors, the 24-hr VLBI solutions are not shown in the table since the time between observations and availability to the EOP solutions is generally greater than 7 days. Table 4a lists the most recent major input contributors for each polar motion Nxdaily solution. For example, by the polar motion 17:00 UTC <MJD> solution time, the most recently computed IGS rapid observation solution (IGS rapid), which has an epoch at midpoint of 12:00 UTC noon from the previous day, <MJD-1>, is available. In addition, there are two IGS ultras available that contain an epoch at midpoint after the IGS rapid. By 21:10 UTC <MJD>, the IGS has produced an updated IGS ultra, the 18-hr solution, and the corresponding EOP solution will use this latest data. Similarly, the 03:10 UTC and 09:10 UTC solutions will have later IGS ultra data available as shown in the table. Finally, for the next day, <MJD+1>, the sequence of IGS Rapids and Ultras will repeat – the 17:00 UTC <MJD+1> solution will have the next IGS rapid solution whose midpoint was at 12:00 UTC <MJD> along with the next 6-hr and 12-hr Ultras.

In Table 4b, there is a pattern for UT1–UTC that is similar to that described above for polar motion. In addition to the IGS contributions, the VLBI intensives series are included. While the IGS contributions have a consistent update time, the VLBI intensives updates are not as regular as the IGS updates. For example, new IGS ultra rapid observations are regularly provided every 6 hours with only a handful of missed or late solutions each year; whereas, a few VLBI intensives could be late or missing each month. So, the contributors shown for each solution are only an ideal case that occurs less than 100% of the time. 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, Luzum, Stetzler, & Shumate (2012).

Each Nxdaily EOP solution file (which are located in separate sub-directories) has an identical format to the original 17:00 UTC solution. As shown in Figure 3, 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 09:10 UTC <MJD+1> EOP solution will also make an estimate of the EOP value for the same 00:00 <MJD+1> epoch.

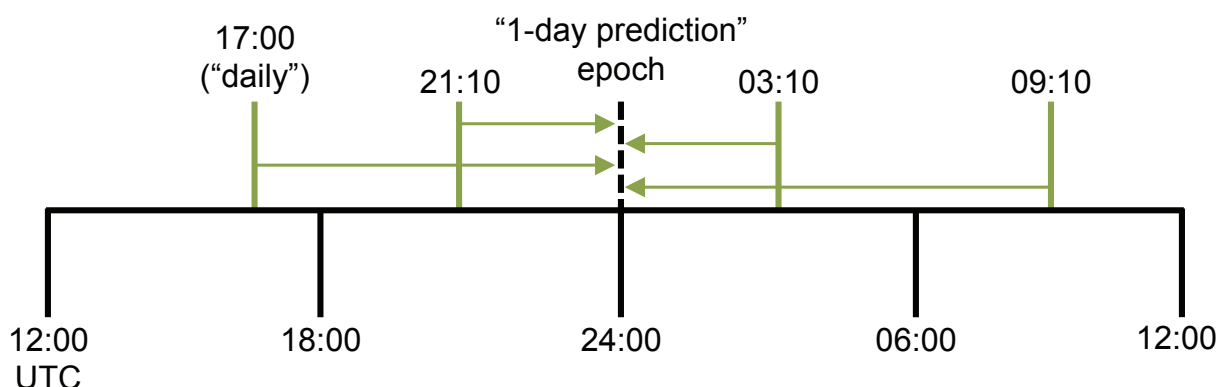


Fig. 3: Timeline of N_{xdaily} EOP 1-day prediction solutions in relation to the EOP “daily” solution produced at 17:00 UTC. Each EOP solution update time is shown by the vertical green lines at 17:00, 21:10, 03:10 and 09:10 UTC, respectively. At each of these times, the latest observations are obtained. For example, at 03:10 UTC, the latest IGS ultra rapid observation, the 0-hour solution, is obtained (at the vertical black line labeled 24:00), and so the EOP solution for the “1-day prediction epoch” should be improved from that determined earlier at 17:00 and 21:10 UTC because of this additional, more recent, input observation.

Unfortunately, unlike the AR 2017 Tables 3a, 3b, 3c, and 3d, the prediction days (especially the 0 and 1-day predictions) for polar motion and UT1–UTC RMS residuals, shown in Tables 3a, 3b, 3c, and 3d, do not follow an expected pattern. The expected pattern was that as more observations become available (as shown in Figure 3 and Table 4b), the RMS values would become smaller; however, for 2018, the resulting statistics do not follow this pattern in most cases. The exact causes for these surprising results are under investigation, and it is hoped that any findings could be presented at a future conference in 2019.

A flowchart that shows the algorithm used in determining the CPOs is shown in Figure 4. Celestial pole offsets are predicted for up to 90 days in advance using a combination of projected empirical models and autoregressive components. The empirical models are fit to past VLBI observations of dX and dY and the autoregressive [AR(4)] components are fit to the residuals between the past VLBI observations and models. The empirical models for dX and dY are composed of offsets, rates, annual and semiannual periodic terms as well as terms with periods of 423.28 days (free-core nutation), 9.1 years, and 27.55 days. In addition the residuals from the model starting with the observations of the four days preceding the date of prediction are used in autoregressive adjustments. Expected errors associated with the predictions are computed based on the past performance of the process. In addition, a bias, based on several years of past observations compared to the 14 C04 solution, is computed and applied to ensure consistency with the 14 C04 solution. 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 RMS differences between the daily predictions and the 14 C04 for 2018 are provided in Table 5.

The results in Table 5 contain the RMS of the differences between CPO predictions produced by the daily EOP solutions (as described in the previous paragraph) and the 14 C04 combination solution for 2018. As anticipated with the improved prediction algorithm, there is an improvement in the Table 5 results for 2018 as compared to 2017. For all the dX and dY prediction days, there is at least a 10% improvement for 2018 versus 2017; and there is improvement for the $d\psi$ and $d\epsilon$ derived predictions as well. While the $d\psi$ and $d\epsilon$ improvements are less than 3% for the first few prediction days, the increase in accuracy becomes steadily larger for longer prediction days.

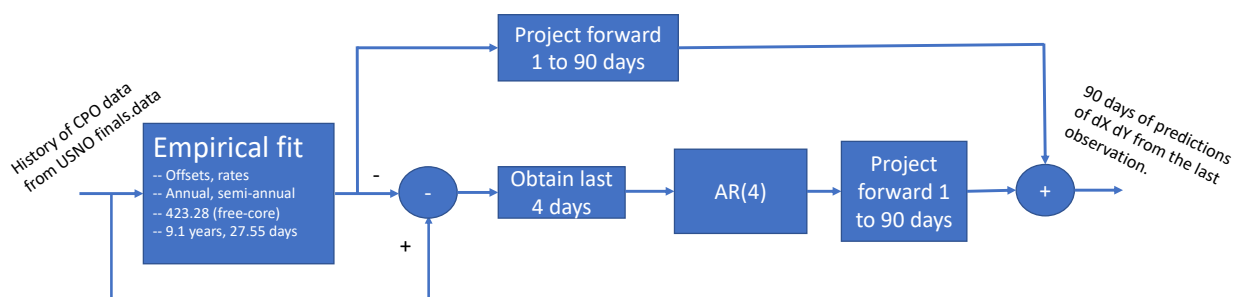


Fig. 4: Flowchart of CPO prediction algorithm. Predictions out to 90 days are made from a) combining an extrapolated empirical model forward in time and b) an extrapolated autoregressive fit to residuals of past CPO observations minus an empirical fit.

Predictions of TT–UT1, up to 1 October 2029, 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.*, 2011).

Table 4: Available data for each Nxdaily solution is listed in Table 4a) for Polar Motion and Table 4b) for UT1–UTC. The 24-hr VLBI contributors are not included due to a > 7 day latency between observation and EOP solution integration. (Note that 00:00 refers to midnight UTC; -06:00 refers to 18:00 UTC of the previous day; +06:00 refers to 06:00 UTC of the current day, etc.)

(a) Major contributors to the Polar Motion EOP solution for each Nxdaily solution.

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

(b) Major contributors to the UT1–UTC EOP solution for each Nxdaily solution.

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 ¹	—	AAM LOD ¹	—	AAM LOD ¹	—	AAM LOD ¹	—
INT2/3 VLBI ²	+08:00	INT2/3 VLBI ²	+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 ²	+08:00	IGS 0 hr Ultra	+12:00
UTGPS	00:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	INT2/3 VLBI ²	+08:00
INT1 VLBI ³	-05:00	UTGPS	00:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00
IGS 6 hr Ultra	-06:00	INT1 VLBI ³	-05:00	UTGPS	00:00	IGS 12 hr Ultra	00:00
IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	INT1 VLBI ³	-05:00	UTGPS	00:00
		IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	INT1 VLBI ³	-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 reported EOP is the observation midpoint.

¹ The AAM LOD inputs contain 7.5 days of hourly forecast data from 00:00 to 18:00 hours.

² INT2 Intensives are observed Saturday and Sunday and INT3 Intensives are observed on Monday. Both sets of Intensives have an epoch midpoint of approximately 08:00 UTC.

³ INT1 Intensives are observed Monday through Friday with a midpoint epoch of approximately 19:00 UTC. The “Epoch and Midpoint” value of -05:00 is an idealized scenario.

Table 5: *RMS of the differences between the nutation prediction (also known as celestial pole offset) series produced by the daily solutions and the 14 C04 combination solution for 2018.*

Days in Future	dX (mas)	dY (mas)	d ψ (mas)	d ϵ (mas)
0	.10	.10	.26	.10
1	.10	.10	.26	.10
5	.10	.10	.26	.10
10	.10	.10	.26	.11
20	.11	.11	.28	.11
40	.14	.13	.34	.13

Center Activities for 2017

On 29 March 2018, the IERS RS/PC Bulletin A solutions for UT1–UTC, Polar Motion, LOD, and CPO were transitioned to be consistent with the 14 C04 EOP series. In addition, the code that combined CPO observations was updated to use dX and dY inputs from all the VLBI contributions, and the CPO predictions were updated according to the algorithm shown in Figure 4.

During 2018, several changes to the input data series or the usage of such data were made. A list of these upgrades is as follows:

- a) On 10 May 2018, the systematic corrections for the IAA VLBI 24-hour data series were updated to ensure better consistency with the 14 C04 series;
- b) On 17 May 2018, the contribution of the US Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) to the Atmospheric Angular Momentum (AAM) inputs was upgraded to version 1.4.3eop of the Navy Global Environmental Model (NAVGEN);
- c) In late July 2018, a new version of the EO matrix calculator (based on the IERS Conventions 2010 v_1.2.0 Celestial Intermediate Pole and Origin and the Terrestrial Intermediate Origin (CIP/CIO/TIO) paradigm) was made available at <http://maia.usno.navy.mil/t2c36cipcio/t2c36cipcio.html>;
- d) On 16 August 2018, the method for identifying "duplicate" input epochs (epochs of observations within 0.01 days) to the EOP software was modified; and
- e) On 23 August 2018, the USNO VLBI 24-hour and intensive data series were upgraded from the usno2017b to the usno2018b series.

Table 6: Predicted values of TT–UT1, 2019–2029. 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)	Table 6 cont.			
2019	Jul 1	69.358	0.000010	2024	Oct 1	72.	1.358
2019	Oct 1	69.5	0.162	2025	Jan 1	72.	1.411
2020	Jan 1	69.6	0.162	2025	Apr 1	72.	1.463
2020	Apr 1	69.8	0.215	2025	Jul 1	72.	1.514
2020	Jul 1	69.9	0.273	2025	Oct 1	72.	1.562
2020	Oct 1	70.0	0.335	2026	Jan 1	73.	1.609
2021	Jan 1	70.2	0.399	2026	Apr 1	73.	1.654
2021	Apr 1	70.3	0.465	2026	Jul 1	73.	1.697
2021	Jul 1	70.4	0.532	2026	Oct 1	73.	1.738
2021	Oct 1	70.5	0.600	2027	Jan 1	73.	1.778
2022	Jan 1	70.7	0.668	2027	Apr 1	73.	1.816
2022	Apr 1	70.8	0.736	2027	Jul 1	73.	1.853
2022	Jul 1	70.9	0.803	2027	Oct 1	73.	1.887
2022	Oct 1	71.0	0.870	2028	Jan 1	74.	1.921
2023	Jan 1	71.2	0.936	2028	Apr 1	74.	1.953
2023	Apr 1	71.	1.000	2028	Jul 1	74.	1.983
2023	Jul 1	71.	1.064	2028	Oct 1	74.	2.012
2023	Oct 1	72.	1.126	2029	Jan 1	74.	2.039
2024	Jan 1	72.	1.186	2029	Apr 1	74.	2.065
2024	Apr 1	72.	1.245	2029	Jul 1	74.	2.090
2024	Jul 1	72.	1.302				

Efforts continued in the following areas as well:

- Studying combined U.S. Navy AAM and OAM inputs to improve polar motion predictions (Stamatakis *et al.*, 2016a and 2016b; Stamatakis *et al.* 2017a, 2017b, 2018a, 2018b, and 2019);
- Studying methods to better optimize the use of the UTGPS and IGS Ultra-rapid observations for LOD inputs to the EOP solution;
- Upgrading the simulation environment algorithms used to test changes to codes, input data series, and configurations to the EOP software and processing;

- d) Continuing efforts to test other optimal estimation techniques to replace the WSCS in the EOP combination. (These new optimal estimation techniques would stack and combine normal equations, which is the desired future methodology for combining EOPs as stated by the IERS.);
- e) Continuing efforts to improve the EOP prediction algorithms. (These efforts would involve literature searches of advanced algorithms, prototyping, testing, and evaluation.);
- f) Using the Very Long Baseline Array (VLBA) estimates as additional UT1–UTC inputs to the EOP solution (Stamatakos, Luzum, Zhu, & Boboltz (2012));
- g) Planning for the use of a new VLBI w-series intensive series (using the Mauna Kea to Wettzell baseline) as an additional input series to a test EOP solution;
- h) Investigating the publishing of a new version EOP solution file that has the following characteristics: i) updated daily, ii) contains EOP data going back to 1973, iii) re-solved combination results for one year in the past, and iv) re-computed polar motion and UT1–UTC prediction data for one year in the future.

Rapid Service Input Data Contributors and Products

A list of the observational and forecast inputs to the EOP combination and prediction solutions are provided in Table 7a (and Table 7b lists a few non-observational and non-forecast inputs); in addition, these tables indicate which EOPs are used from each contributor.

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

Daily and Bulletin A weekly EOP solutions can be obtained from the primary Earth Orientation (EO) server at <http://maia.usno.navy.mil> and <ftp://maia.usno.navy.mil>, and from the backup EO server at <http://toshi.nofs.navy.mil> and <ftp://toshi.nofs.navy.mil>. An additional backup mirror of the daily and Bulletin A EOP data is now hosted by NASA's

Archive of Space Geodesy Data server at <ftp://cddis.gsfc.nasa.gov/pub/products/iers>. Users may also request a weekly machine-readable version of the IERS Bulletin A containing the current 365 days' worth of predictions via the document request form at <http://maia.usno.navy.mil/docrequest.html>.

Table 7a: *Operational input data used in the IERS Bulletin A EOP combination and prediction software. All the observational and forecast data used in operations is listed in the Contributor Column. For each contributor, a check mark is provided under each EOP column if that particular EOP is used operationally. For example, the GSFC intensives (GSF Int) is used in the combination and prediction software, and the EOP that is used is UT1–UTC; no other EOPs from this contributor are used in the software.*

Contributor	PM-x	PM-y	UT1–UTC	LOD	$d\psi$	$d\epsilon$	dX	dY
IAA VLBI	✓	✓	✓				✓	✓
GSFC VLBI	✓	✓	✓				✓	✓
USNO VLBI	✓	✓	✓				✓	✓
IVS VLBI	✓	✓	✓				✓	✓
GSFC Int. ^a			✓					
USNO Int.			✓					
GSI ^b Int.			✓					
ILRS ^c	✓	✓						
IAA ^d ILRS ^e	✓	✓						
MCC ^f SLR	✓	✓						
IGS	✓	✓		✓				
UTGPS			✓					
NCEP AAM ^g				✓				
NAVGEN AAM ^g				✓				

^a The word “Int” is an abbreviation of the word Intensive.

^{b, c, d, e, f} Defined in the Acronyms of the Appendix of this report.

^g Both observational and forecast inputs are available.

Table 7b: *Miscellaneous input data available to the IERS Bulletin A EOP solution. The IERS EOC solution is used in diagnostic calculations and plots and is used in polar motion predictions. The IERS RS/PC solution is used in diagnostic calculations and plots and is used as the a prior solution to the WSCS.*

Contributor	PM-x	PM-y	UT1–UTC	LOD	$d\psi$	$d\epsilon$	dX	dY
IERS EOC	✓	✓	✓	✓	✓	✓	✓	✓
IERS RS/PC	✓	✓	✓	✓	✓	✓	✓	✓

Table 8 lists the locations and update times of several of the EOP solutions discussed in this report. The first column lists the EOP solution time in UTC. These are the approximate times when an EOP result is computed; if a problem occurs, the solution may actually become available as much as one hour later than what is listed. The second column contains the subdirectory under each FTP or web address listed in the above paragraph where an EOP solution resides. For example, at <http://maia.usno.navy.mil> there exists a subdirectory called “ser7” (i.e., <http://maia.usno.navy.mil/ser7>) where the daily EOP solution computed at 17:00 UTC will be updated each day. Similarly, at <ftp://cddis.gsfc.nasa.gov>, there exists a subdirectory called “eop0300utc” (i.e., <ftp://cddis.gsfc.nasa.gov/pub/products/iers/eop0300utc>), where an EOP solution update computed at approximately 03:10 UTC will be uploaded each day.

Table 8: *EOP solution locations and update times.*

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

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

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

Center Staff The Rapid Service/Prediction Center staff (at the USNO EO Department) consisted of the following members:

Dr. Christine Hackman	Director; Head, Earth Orientation (EO) Department
Mr. Nick Stamatakos	Project Director and Lead Scientist; Chief, EOP Combination and Prediction (EOP C/P) Division
Ms. Merri Sue Carter	Assists in daily operations and support; Research Astronomer, EOP C/P Division
Mr. Nathan Shumate	Assists in daily operations and support, research, and software maintenance; Astronomer, EOP C/P Division
Ms. Maria Davis	Assists in daily operations and support, research, and software maintenance; Astronomer, EOP C/P Division

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Report contributors: Nick Stamatakis, Maria Davis, Nathan Shumate, Merri Sue Carter; Report reviewer: Christine Hackman

3.5.3 Conventions Centre

Introduction

The Conventions Centre provides updated versions of the IERS Conventions in electronic form following approval by the IERS Directing Board (DB) and printed versions at less frequent intervals than the electronic updates, mainly when major changes are introduced. The Centre is operated jointly by L'Observatoire de Paris (OP) and the U.S. Naval Observatory (USNO).

IERS Conventions web and ftp sites are located at: a) <http://iers-conventions.obspm.fr/>, b) <http://maia.usno.navy.mil/conventions/>, and c) <ftp://maia.usno.navy.mil/conventions>. The printed IERS Conventions (2010), IERS Technical Note 36, is available in electronic form at these URLs and at <https://www.iers.org/TN36>. Updates continue to be provided in electronic form and are configuration managed starting in 2018. Conventions versions, starting with v 1.0.0 through the latest update, v 1.3.0, are found at the following URLs:

- a) http://iers-conventions.obspm.fr/conventions_versions.php and
- b) http://maia.usno.navy.mil/conventions/conventions_versions.php

The IERS Conventions Centre continues to work with the IAU Division A Commission on Fundamental Standards that deals with celestial and terrestrial reference systems/frames and the transformations among them, time scales, precession-nutation models, Earth rotation and polar motion, including physical models (e.g., Earth's gravity field, solid Earth-tide modeling), star catalogs, ephemerides of Solar System bodies, special and general relativistic models for time and space.

Technical Content of the IERS Conventions

During 2018, changes in the technical content included the following:

- a) On 1 February, 2018, i) the reference to the former *mean pole* in Chapter 6 was replaced with the term *mean figure axis*, ii) several minor changes to the text in Chapter 6, Section 6.1 were made, and iii) Section 7.1.4 in Chapter 7 was rewritten to include the *secular pole* and remove the former *mean pole*; and
- b) On 28 December, 2018, i) the Conventions has replaced the concept of the *mean pole* with the *secular pole* in Chapters 6 and 7, ii) the definition of secular pole has been added to the Glossary, iii) the code IERS_CMP_2015.F has been removed from Chapter 7, as the Conventions no longer supports the *mean pole*, and iv) the subroutine CALC2JD.F has been renamed to correspond to subroutine called in DAT.F (Chapter 7).

The organization of the Conventions web pages changed in 2018. Figures 1 and 2 illustrate the changes that were implemented. Under

the Conventions menu, the “Conventions Updates” tab was replaced by “Conventions Versions”. When one selects that tab, one is taken to the IERS Conventions (2010) Packaged Content page, where one can scroll down to see each of the versions —the latest version being at the top and the oldest version, v 1.0.0 (the official IERS Conventions (2010) created 15 December 2010), at the bottom of the page.

In addition, in order to address some users concerns to have direct links to the latest updated conventions and to the official 2010 Conventions from the home page, two Quick Links on the far left of the home page were created, namely *Updated* and *Official* Conventions.

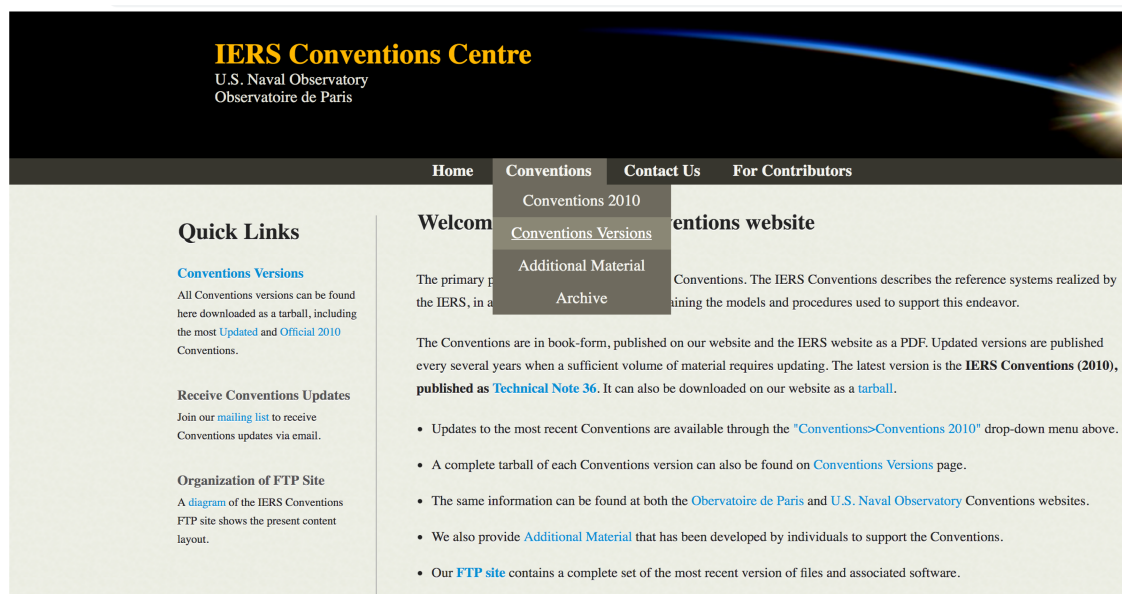


Fig. 1: Change in web design that occurred in 2018. The *Conventions Versions* link replaced the former *Conventions Updates* link. (Web site designed by Maria Davis.)

Conventions Software

Software recommended for use in connection with the IERS Conventions consists largely of the library maintained by the IAU Standards of Fundamental Astronomy (SOFA) available at <http://www.iausofa.org>. The 15th release of this library was made available recently. It implements four new routines, corrects another and enhances seventeen others. Further details regarding the specifics of the release can be found at http://www.iausofa.org/current_changes.html.

Major Conventions Update

In anticipation of rewriting the IERS Conventions within the next few years, a call for participation was made. Many experts volunteered to be Chapter Editors-in-Chief, Chapter Experts and Assistant Experts, along with a Software Editor. The table below lists the Conventions major revision chapters along with the latest associated list of filled and vacant

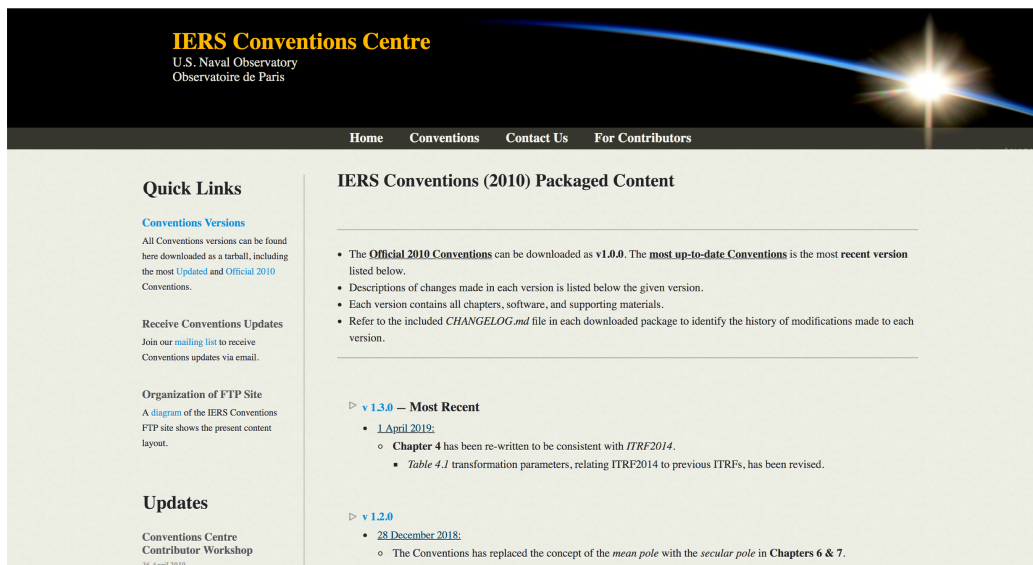


Fig. 2: Change in web design that occurred in 2018 (continued). Version numbers are listed in the new web site, whereas the older site had each chapter updated date listed.

positions. There are still many positions vacant, and we urge those reading this report to reach out to colleagues to inform them of open positions or to consider volunteering by submitting a curriculum vitae along with a possible letter of support from their sponsoring institution.

As part of the Conventions update, the Conventions staff has begun using the GitLab web-based DevOps lifecycle tool to implement a more robust and comprehensive configuration management scheme for Conventions updates. (A training class led by Maria Davis from the Conventions staff was held in early October 2019 to aid those unfamiliar with using GitLab, and in addition, the Conventions Centre staff can provide more assistance after the training class.)

In addition, Slack instant messaging has been implemented to enhance communication among Chapter contributors. Many of the re-write staff have signed up and are utilizing Slack to provide quick turnaround for discussions and dissemination of information regarding the Conventions. All contributors were notified via email and via Slack instant messaging of proposed simplifications to the Conventions text. An example from Chapter 5 was provided to contributors to guide them in this recommendation. Lastly, all contributors were notified of the 2019 Unified Analysis Workshop in Paris, France, where Conventions-related topics was discussed among various disciplines of the IERS, Global Geodetic Observing System (GGOS), and other associated organizations.

Table 1: *Status of participation in the IERS Conventions major update. A letter “Y” in the Applicant column indicates that at least one person has agreed to participate in this function; a letter “N” indicates that no one is serving in this function.*

#	Chapter Title	Position	Applicant
1	General Definitions and Numerical Standards	Chapter Editor-in-Chief	Y
		Chapter Expert	Y
		Assistant Chapter Expert	Y
2	General Relativistic Models for Space-Time Coordinates and Equations of Motion	Chapter Editor-in-Chief	Y
		Chapter Expert	Y
		Assistant Chapter Expert	Y
3	Celestial Reference System and Frame	Chapter Editor-in-Chief	Y
		Chapter Expert	Y
		Assistant Chapter Expert	Y
4	Terrestrial Reference Systems and Frames	Chapter Editor-in-Chief	Y
		Chapter Expert	Y
		Assistant Chapter Expert	Y
5	Transformation Between the International Terrestrial Reference System and the Geocentric Celestial Reference System	Chapter Editor-in-Chief	Y
		Chapter Expert	N
		Assistant Chapter Expert	Y
6	Geopotential	Chapter Editor-in-Chief	Y
		Chapter Expert	Y
		Assistant Chapter Expert	Y
7	Displacement of Reference Points	Chapter Editor-in-Chief	Y
		Chapter Expert	Y
		Assistant Chapter Expert	Y
8	Tidal Variations in the Earth’s Rotation	Chapter Editor-in-Chief	N
		Chapter Expert	Y
		Assistant Chapter Expert	Y
9	Models for Atmospheric Propagation Delays	Chapter Editor-in-Chief	N
		Chapter Expert	N
		Assistant Chapter Expert	Y
10	General Relativistic Models for Propagation	Chapter Editor-in-Chief	N
		Chapter Expert	Y
		Assistant Chapter Expert	Y
	Software Associated with Chapters 1 through 10	Software Editor-in-Chief	Y

Acknowledgements

The Conventions web pages at OP <http://iers-conventions.obspm.fr/> and USNO <http://maia.usno.navy.mil/conventions/> were maintained and improved. The IERS Conventions Centre would like to acknowledge the work of Maria Davis from USNO and Teddy Carlucci from OP for their work on the updated IERS web and ftp sites.

**Conventions Centre
Staff**

- Nick Stamatakos (USNO), co-director since 1 January 2016. (Per existing agreement between the IERS DB and the IERS Conventions, the USNO co-director has become the representative to the IERS Directing Board on 01 January 2019.)
- Christian Bizouard (OP), co-director since 1 September 2016 (and the representative to the IERS Directing Board through 31 December 2018).
- Sébastien Lambert (OP)
- Maria Davis (USNO)
- Dennis McCarthy (USNO, contractor)

Nick Stamatakos, Christian Bizouard

3.5.4 ICRS Centre

The International Earth Rotation and Reference System (IERS) International Celestial Reference System (ICRS) Centre is tasked with the maintenance of the International Celestial Reference System (ICRS) and the International Celestial Reference Frame (ICRF) for the international astronomical and geodesy communities. Responsibilities are shared jointly between Paris Observatory (PO) and the U.S. Naval Observatory (USNO). Critical ICRS and ICRF-relevant activities from 2018 are described for both OP and USNO in the following sections.

Paris Observatory IERS ICRS Centre Activities During 2018 Construction of the ICRF3

Staff of the ICRS Centre at Paris Observatory worked on the construction of the Third Realization of the International Celestial Reference Frame (ICRF3) in the frame of activities of the Working Group on ICRF3 created at the XXVIII IAU General Assembly in 2012. The mission of the WG-ICRF3 concluded with the proposal to and adoption by the XXX IAU General Assembly in August 2018 of a catalog of radio source positions which realize the ICRS (Charlot et al. 2020). Resolution B2 of the XXX IAU General Assembly (IAU 2019) resolves that as from 1 January 2019 ICRF3 is the fundamental realization of the International Celestial Reference System (ICRS). The ICRF3 is aligned onto ICRF2 (Fey et al. 2015) and represents a significant improvement in terms of radio source characterization, position accuracy and total number of sources. Objects in the new frame had been used to orientate the Gaia DR2 catalog onto the ICRS, as will be the case of the Gaia final catalog.

The ICRF3 is represented by three catalogs at bands S/X, K and X/Ka with 4536, 824 and 678 objects respectively (<http://iers.obspm.fr/icrs-pc/newwww/icrf>).

Monitoring of the ICRS

Monitoring the ICRS is a mission of the IERS ICRS Centre. This includes verifications of the stability of the axes of the system materialized through the frame, identification of the possible deformations of the frame and tracking the astrometric evolution of its defining sources. Another aspect of this activity consists on the analysis of individual solutions submitted by the VLBI analysis centres to the International VLBI Service (IVS).

The IERS ICRS Centre at Paris Observatory developed the tools for determining the orientation of the axes, characterizing the deformations of the frame and analyzing the astrometric quality of radio source positions (Lambert 2013). Until mid-2018 these analyses were focused on the monitoring of the defining sources of the ICRF2 and contributed to selection of the defining sources of ICRF3.

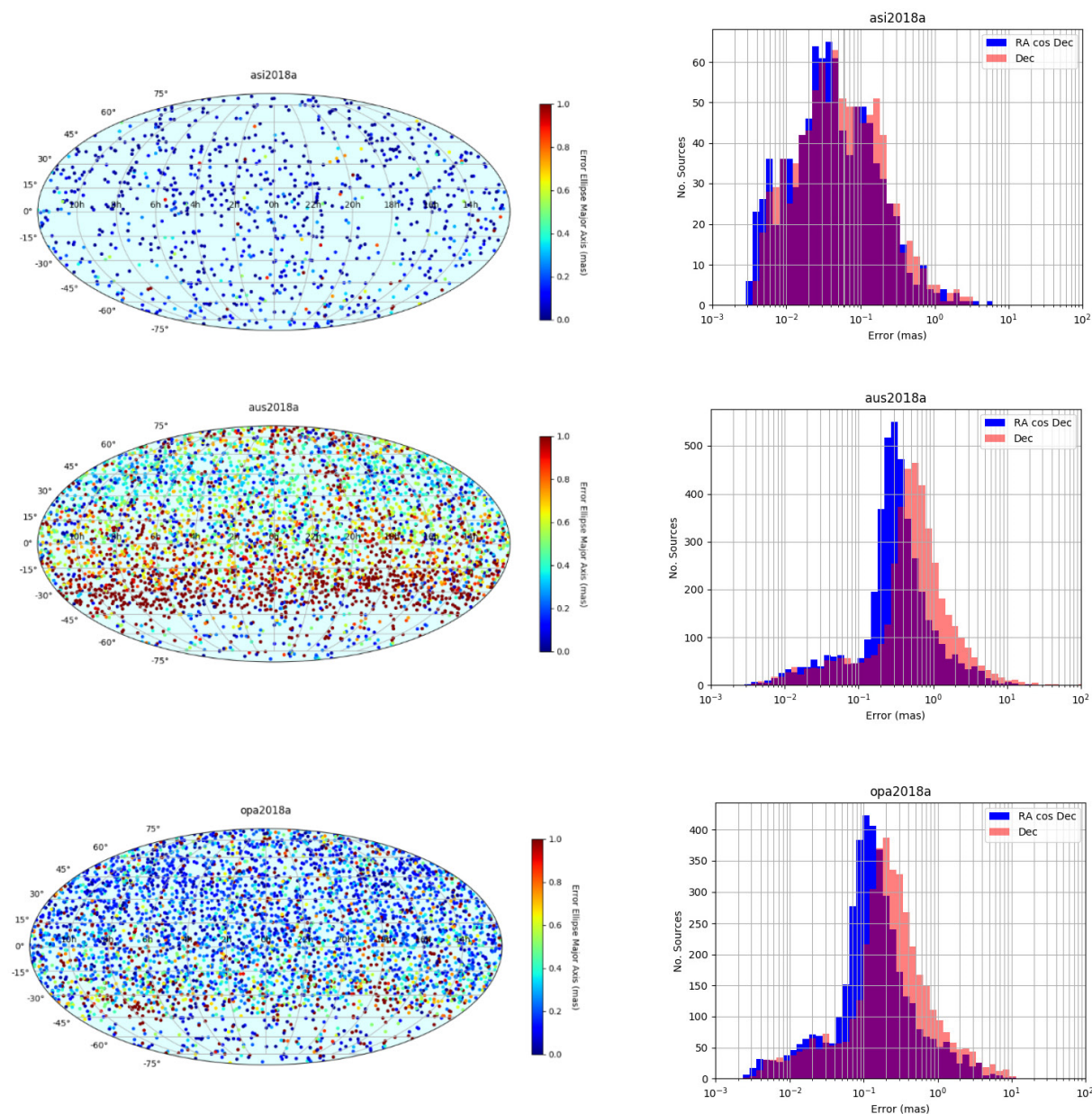


Fig. 1: Left: sky distribution of the catalogs highlighting the overall positional error computed as the major axis of the error ellipse. Right: distribution of the standard errors on source position.

Analysis of recent VLBI catalogs Data

We analyzed three catalogs submitted to the International VLBI Service for Geodesy and Astrometry (IVS) in 2018. The catalogs were respectively submitted by the Space Geodesy Centre of the Italian Space Agency (ASI/CGS; solution asi2018a), by Geoscience Australia (aus2018a) and by Paris Observatory (opa2018a). The aus2018a catalog was obtained with the OCCAM geodetic VLBI analysis software package (Titov et al. 2004), whereas the other two catalogs were obtained with Calc/Solve (Ma et al. 1986).

Since the catalogs were released before the date of adoption of the ICRF3, their individual frames had been oriented on ICRF2. However, in our analysis we have compared them to ICRF2 and to the catalog representing ICRF3 in the S/X bands (ICRF3X in this report). The second Gaia data release (DR2; Prusti et al. 2016; Brown et al. 2016, 2018; Mignard et al. 2018) has been used also as a reference for comparison.

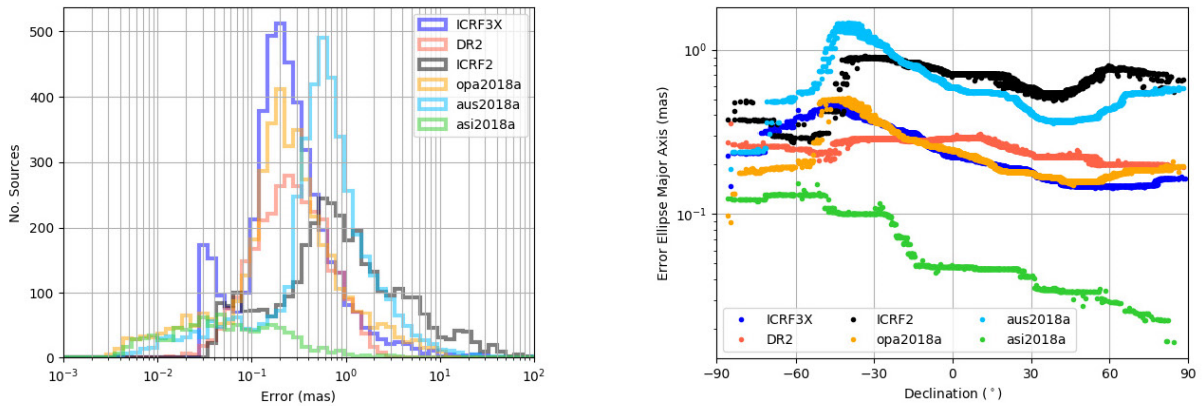


Fig. 2: Left: overall comparison of the standard error distribution. Right: standard errors in source positions as a function of the declination smoothed by taking the running median within bins of 15 degrees.

Overview of the catalogs

The number of sources in each catalog, the mean epoch of the observations, and the median positional errors (for RA cos DEC, Dec, and for the error ellipse major axis) are reported in Table 1. The ASI solution contains the smallest number of sources. However, these are sources that have the best positional errors, and in consequence the median standard error is neatly smaller than that for the other catalogs. The standard error of the AUS positions is larger than that of OPA in a factor of 2.

Table 1: *Statistic information of the catalogs here reported. N is the number of sources. The mean epoch corresponds to the average of the mean observational epochs of each source. N is the number of sources, E_{RA^*} , E_{Dec} are respectively the median standard errors in right ascension (scaled by $\cos \text{dec}$) and in declination, E_{EEMA} is the median major axis of error ellipses. Unit is μas .*

	N	Epoch	E_{RA^*}	E_{Dec}	E_{EEMA}
opa2018a	4160	2009.24	128.13	216.75	218.07
aus2018a	4267	2009.72	313.24	551.00	554.66
asi2018a	944	2009.24	39.36	48.40	49.48

The sky distribution of the radio sources in each catalog is plotted in Figure 1 together with the distribution of the standard errors. In the sky

maps, the color indicates the overall error computed as the major axis of the error ellipse, calculated using the correlation information between the coordinates as provided in the catalogs.

The error distribution, including that of the catalogs used as reference in the comparisons (ICRF2, ICRF3X and Gaia DR2) and the dependence of the error on the declination are displayed in Figure 2, for which we took the running median error within windows of 15 degrees.

Figure 2 shows a clear declination-dependent error for the individual catalogs and reflects the parameters of Table 1. Both AUS and ASI solutions show larger errors at mid-latitudes in the southern hemisphere, very probably due to the network asymmetry and the lower number of observations in the south. The OPA solution presents a smoother deformation, almost in coincidence with that of ICRF3X. The improvement of ICRF3 with respect of ICRF2 is visible on the plots, both in precision and deformation. The Gaia DR2 solution does not show such systematic effects (the Gaia scanning law allows to cover both hemispheres symmetrically).

Comparison with ICRF2, ICRF3 and Gaia DR2

Figure 3 displays the differences in declination between the catalogs and the references averaged within bins of 15 degrees. All three catalogs share the common feature of large (0.1-mas level) zonal differences with the ICRF2. A similar comparison with Gaia DR2 reveals that for ASI and OPA solutions the zonal deformation is much smaller, which is not the case for the AUS catalog. The same conclusion is valid for the zonal differences with respect to ICRF3X. Since Gaia DR2 is not expected to present zonal deformations, Figure 3 suggests that recent VLBI catalogs are less deformed than ICRF2.

We used for the catalog comparisons the 16-parameter transformation accounting for rotations around the three axes, a glide, and degree-2 electric- and magnetic-type deformations (see e.g., Mignard and Klioner 2012). The coordinate differences $\Delta\alpha$ and $\Delta\delta$ between a catalog and a reference catalog read

$$\begin{aligned}\Delta\alpha \cos \delta &= R_1 \cos \alpha \sin \delta + R_2 \sin \alpha \sin \delta - R_3 \cos \delta - D_1 \sin \alpha + D_2 \cos \alpha + M_{20} \sin 2\delta \\ &+ (E_{21}^{\text{Re}} \sin \alpha + E_{21}^{\text{Im}} \cos \alpha) \sin \delta - (M_{21}^{\text{Re}} \cos \alpha - M_{21}^{\text{Im}} \sin \alpha) \cos 2\delta \\ &- 2 (E_{22}^{\text{Re}} \sin 2\alpha + E_{22}^{\text{Im}} \cos 2\alpha) \cos \delta - (M_{22}^{\text{Re}} \cos 2\alpha - M_{22}^{\text{Im}} \sin 2\alpha) \sin 2\delta, \\ \Delta\delta &= -R_1 \sin \alpha + R_2 \cos \alpha - D_1 \cos \alpha \sin \delta - D_2 \sin \alpha \sin \delta + D_3 \cos \delta + E_{20} \sin 2\delta \\ &- (E_{21}^{\text{Re}} \cos \alpha - E_{21}^{\text{Im}} \sin \alpha) \cos 2\delta - (M_{21}^{\text{Re}} \sin \alpha + M_{21}^{\text{Im}} \cos \alpha) \sin \delta \\ &- (E_{22}^{\text{Re}} \cos 2\alpha - E_{22}^{\text{Im}} \sin 2\alpha) \sin 2\delta + 2 (M_{22}^{\text{Re}} \sin 2\alpha + M_{22}^{\text{Im}} \cos 2\alpha) \cos \delta,\end{aligned}$$

where α and δ are the coordinates of the object in the reference catalog. We used weighted least-squares to solve the system, with weights computed using the available covariance information (i.e., the standard errors on individual source coordinates and their correlation). The values of the transformation parameters adjusted to the catalogs compared

to the ICRF2, the ICRF3X and Gaia DR2 and their standard errors are reported in Figure 4. The resulting statistics after removal of systematics are reported in Table 2. Figure 4 reveals that the results are similar independently from the set of sources used for the comparisons. The comparisons with ICRF2 show the presence of significant deformations, particularly D3 and E20, associated to the purely zonal deformations in $\cos \delta$ and $\sin 2\delta$, respectively, along the polar axis of the celestial frame. These deformations range between 10 and 80 μas depending on the individual solution. The analysis of the transformation onto ICRF3X shows that the only remaining significant deformations are those represented by D2 and D3; their values suggest that an offset between the equators of ICRF2 and ICRF3 could be the origin of this deformation. The transformation parameters with respect to Gaia DR2 show the presence of a rotation, certainly due to the fact that the individual VLBI solutions have been aligned to ICRF2 and Gaia's frame has been oriented onto ICRF3. Also deformations are visible dependent on declination, confirming the curves in Figure 2, right.

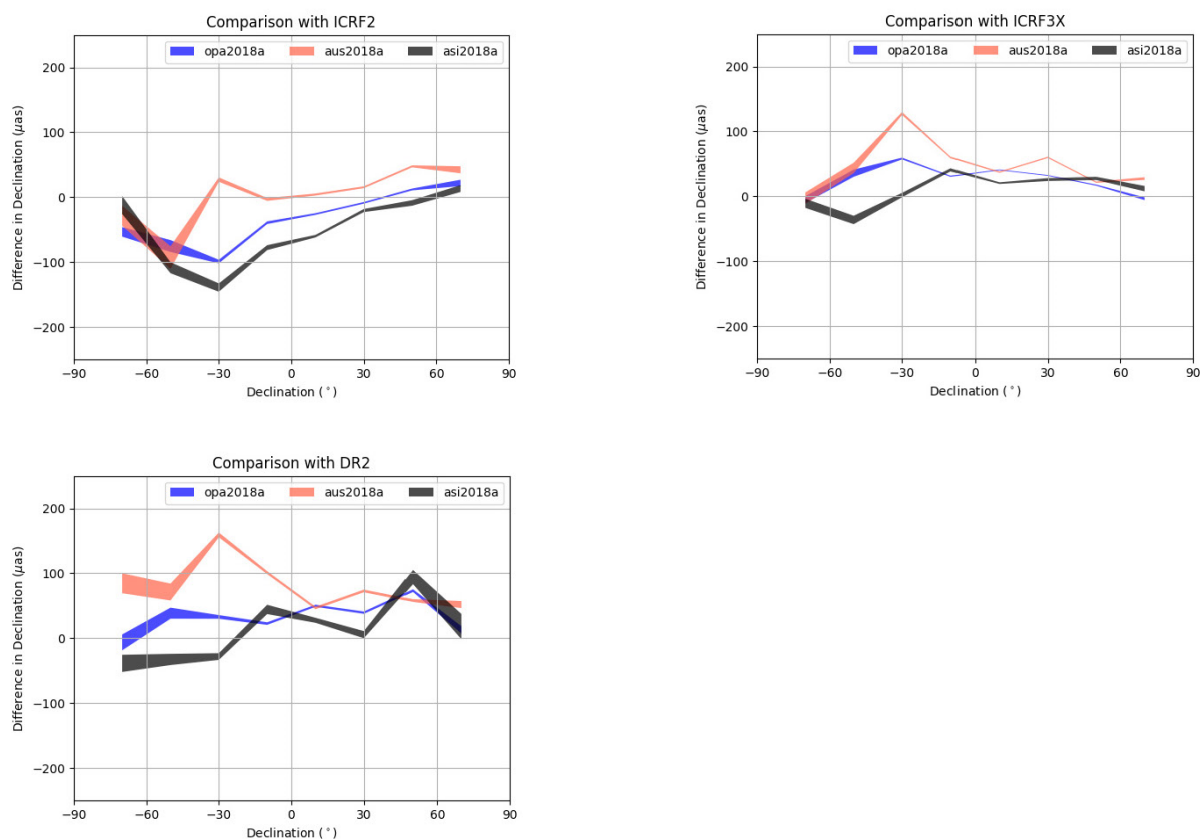


Fig. 3: Differences in declination between the catalogs and the references (ICRF2: top left; ICRF3X, top right; Gaia DR2, bottom) averaged in bins of declination of width 15° .

Table 2: Statistics of the differences of the catalogs to ICRF2, ICRF3X and Gaia DR2 with different sets of common sources, and after removal of large-scale systematics. RA* stands for RA cos_dec. Unit is μ as.

2a. With respect to ICRF2, N: number of sources common in ICRF2 and each individual catalog.

	N	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec
opa2018a	3398	103.39	123.15	0.63	0.62	102.20	118.45	0.62	0.57
aus2018a	3359	124.76	146.58	0.71	0.70	124.46	145.09	0.71	0.68
asi2018a	893	96.73	122.20	1.57	1.87	91.27	110.24	1.40	1.52

2b. With respect to ICRF2, N: number of ICRF2 defining sources common in ICRF2 and each individual catalog.

	N	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec
opa2018a	295	53.43	72.62	0.89	1.28	50.36	62.28	0.79	0.94
aus2018a	294	64.31	80.18	1.08	1.33	63.42	75.66	1.05	1.19
asi2018a	295	73.19	92.90	1.60	2.04	64.24	73.42	1.23	1.27

2c. With respect to ICRF2, N: number of sources common to all catalogs.

	N	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec
opa2018a	727	62.76	82.07	0.76	0.96	60.61	73.90	0.71	0.78
aus2018a	727	86.84	101.77	1.15	1.19	86.36	99.84	1.14	1.14
asi2018a	727	94.45	119.26	1.61	1.94	88.44	105.94	1.41	1.53

2d. With respect to ICRF3X, N: number of sources common in ICRF3X and each individual catalog.

	N	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec
opa2018a	4149	89.76	90.13	1.02	0.75	77.10	85.25	0.75	0.67
aus2018a	4234	117.42	127.78	1.07	1.01	107.53	121.35	0.89	0.91
asi2018a	941	64.11	70.28	1.63	1.67	57.91	66.81	1.33	1.51

2e. With respect to ICRF3X, N: number of ICRF3 defining sources common in ICRF3X and each individual catalog.

	N	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec
opa2018a	303	51.13	37.52	1.52	0.71	23.39	24.00	0.32	0.29
aus2018a	300	61.85	62.67	1.66	1.51	39.76	45.27	0.69	0.79
asi2018a	273	46.65	47.30	1.28	1.17	38.55	42.17	0.87	0.93

2f. With respect to ICRF3X, N: number of sources common to all catalogs.

	N	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec
opa2018a	727	56.28	43.87	1.55	0.78	31.16	32.51	0.48	0.43
aus2018a	727	72.74	73.05	1.80	1.55	54.31	60.33	1.00	1.05
asi2018a	727	60.66	67.34	1.65	1.74	53.54	63.62	1.28	1.55

2g. With respect to Gaia-DR2, N: number of sources common in DR2 and each individual catalog.

	N	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec
opa2018a	2781	297.77	318.88	2.30	2.23	296.66	315.79	2.29	2.19
aus2018a	2816	344.25	358.40	1.89	1.68	342.91	355.05	1.87	1.65
asi2018a	775	218.50	222.77	2.47	2.65	214.37	218.13	2.38	2.54

2h. With respect to Gaia-DR2, N: number of sources common to all catalogs.

	N	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec	Std_RA*	Std_Dec	Chi2_RA*	Chi2_Dec
opa2018a	727	209.01	218.12	2.60	2.80	207.00	212.41	2.55	2.66
aus2018a	727	230.90	239.01	2.53	2.58	228.00	232.25	2.47	2.43
asi2018a	727	211.60	219.81	2.42	2.70	207.84	214.90	2.34	2.58

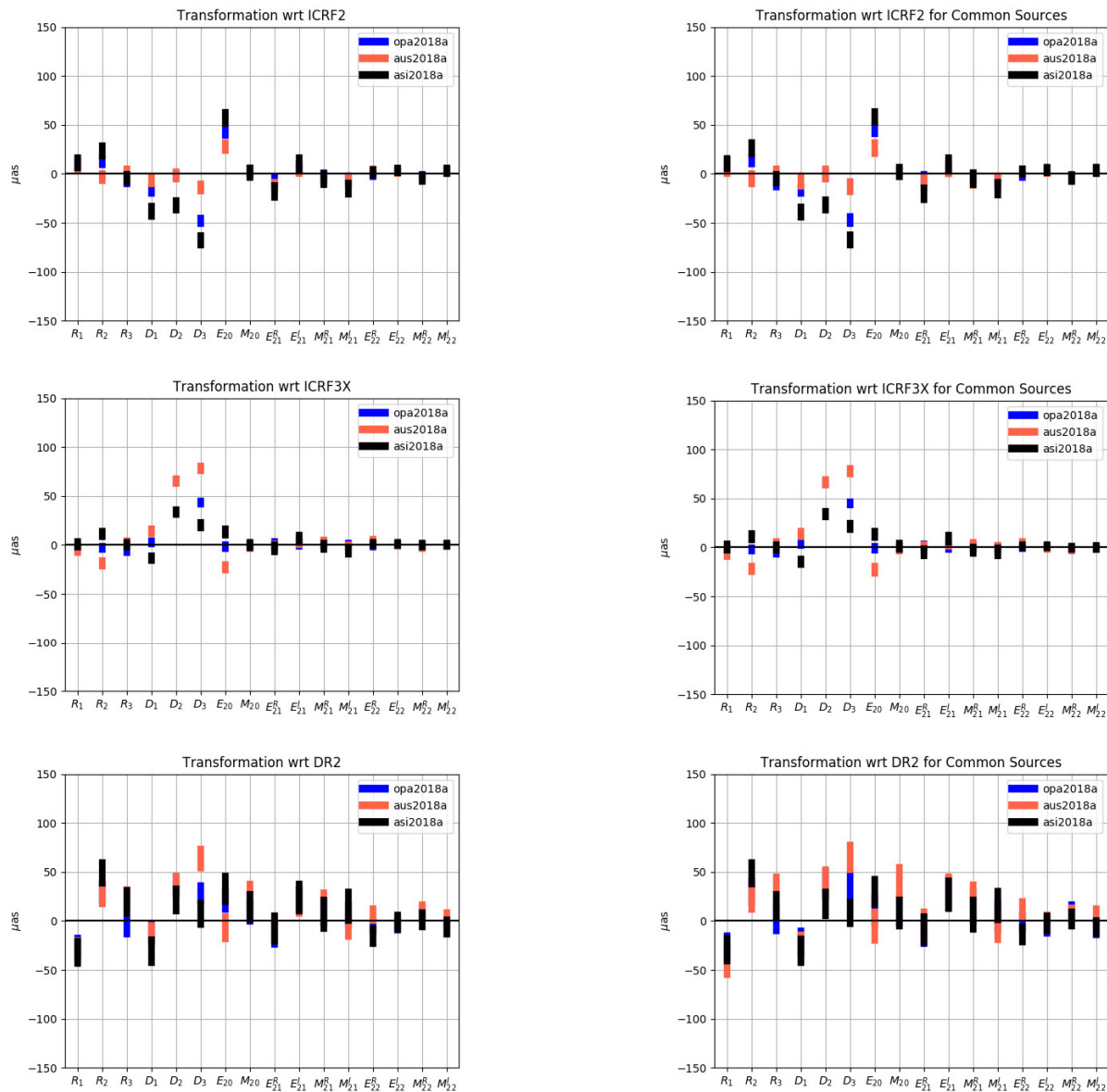


Fig. 4: Transformation parameters between the catalogs under analysis and the reference frames (ICRF2: up, ICRF3X: middle, Gaia DR2: down). The plots on the left represent parameters computed with sources common to each individual catalog and the frame used as reference (from top to bottom they correspond to the statistics in tables 2a, 2d and 2g); the plots on the right represent parameters computed with sources common to all the catalogs involved in the comparisons, including the references (from top to bottom they correspond to the statistics in tables 2c, 2f and 2h).

Galactic aberration has been accounted for in the computation of ICRF3X source positions. A part of the detected zonal differences between ICRF3X and Gaia DR2 and the three analyzed catalogs is imputable to the uncorrected Galactic aberration that moves sources towards the Galactic center following a glide of amplitude close to $5 \mu\text{as/yr}$ (e.g., Kovalevsky 2003; Titov et al. 2011). Considering that the epochs of ICRF3 and Gaia DR2 are close (2015.0 and 2015.5 respectively), this

effect is expected to be of around $30 \mu\text{as}$ in D_2 and D_3 for the epochs of the individual catalogs (around 2009), explaining part of the results.

Conclusions and recommendations

Three individual catalogs submitted to the IVS in 2018 are analyzed in this report. The axes of their frames are consistent with ICRF2 (to which they have been aligned) at the level of $30 \mu\text{as}$ except for zonal deformations in $\cos \delta$ and $\sin 2\delta$ for which the amplitude of the difference reaches about $70 \mu\text{as}$ (likely a combination of effects including the Galactic aberration and a network improvement). Compared to ICRF3X their axes are consistent to less $10 \mu\text{as}$, but zonal deformations in $\cos \delta$ peaking around $70 \mu\text{as}$ are present. All three catalogs are consistent with Gaia DR2 within μas .

For a better evaluation of the consistency of the VLBI products and a better maintenance of the reference frame, we encourage analysis centers to submit solutions aligned to the new reference ICRF3. These catalogs should be as complete as possible, i.e., processing as much VLBI sessions as possible since 1979. Analysis strategies should be rigorously documented and motivated. The main points that will be scrutinized in the next reports will be the zonal systematics, their relation with the Galactic aberration, and the agreement with the current (DR2) and future releases of Gaia.

Validation of the Gaia catalogue in the CU9

The Gaia mission goal is to create an extraordinarily precise three-dimensional map of about one billion stars throughout our Galaxy and beyond. The Gaia mission through its successive releases delivers an astronomical catalogue and data archive of unprecedented scope, accuracy and completeness. A large pan-European team of expert scientists and software developers known as DPAC (Data Processing and Analysis Consortium) is responsible for the processing of Gaia's data with the final objective of producing the Gaia Catalogue. Coordinated by the DPAC Executive, the consortium is sub-divided into nine smaller, specialist units known as Coordination Units, or CUs, with each unit being assigned a unique set of data processing tasks.

Some members of the ICRS Centre belong to the CU9/WP944 group, responsible for validation of Gaia Catalogue Data Release with the validation Test Report. The aim of these tests is to check that Gaia data is coherent compared to other known catalogues, so to accept or not them for publication. In 2018, we have updated external catalogues files, tests code and reports (VTS 060) to validate QSO and AGN which will be included in the next Gaia Catalogue Data Release DR3. These tests include rotation, cross-matching and completeness of these sources compared with QSO and AGN from external catalogues. The external catalogues used are ICRF3, LQAC-5, GIQC, SDSS DR14Q, specific catalog as AGN's in Extended Sources Catalog where the class

probability for QSO and AGN is well defined. Other large catalogues are involved, as MilliQuas and unWISE Data.

In the following we show some results of our VTS:

LQAC4GMAG cross-matched with GAIA DR2 (VTS_060_01)

```

Crossmatch radius:          1.0 arcsec
Crossmatched size and
percentage:                 323 774 / 443 725 : 73%
Not found in Gaia:         127 238 / 443 725 : 29%
Multiple cross matches:    7 230 / 323 774 : 2 %
NonDuplicated Sources:     309 257/443 725 : 70%
NaN or 0 values in Gaia data need
for VTS: 0/323774 : 0.0%

```

Rotation between ICRF3 and GAIA DR2 (VTS_060_04) :

Rotation angles R1 R2 R3, Deformation D1 D2 D3,
with respective errors, in μ as

R1	R2	R3	D1	D2	D3
13.18	-7.94	0.23	62.42	-69.84	-147.31
σ R1	σ R2	σ R3	σ D1	σ D2	σ D3
26.92	25.79	23.98	25.73	24.51	25.71

Study of the quasars with the Gaia DR2

Gaia Data Release 2 (GDR2) contains more than 550,000 quasars (Mignard et al. 2018). This number comes from the cross matching to bona fide quasars repositories as allWISEagn (Assef et al. 2018) and the LQAC-4 (Gattano et al. 2018), providing that the matched sources have zero proper motion and parallax as computed from Gaia sequence of measurements. And yet the direct comparison of the GDR2 to other, denser quasar repositories, as the Gaia Initial Quasar Catalog (Andrei et al. 2014) and the MilliQuas (Flesch 2017), leaves out as many as 50% of that number (Liao et al. 2018) or more, within the range of Gaia observable magnitudes. The discrepancy arguably arises because of morphological issues as optical jets and emitting blobs along the jets, or magnitude variability which can be associated to transient changes of the photocenter or simply deterioration of its determination due to photon noise. As a result spurious proper motion or even parallax can turn up, and the quasar would not at principle be shorthanded as such.

N. Liu et al. (2018) investigate the systematic errors in the very long baseline interferometry (VLBI) positions of extragalactic sources (quasars) and the global differences between Gaia and VLBI catalogs, using the GDR1 positions as the reference and study the positional offsets of the second realization of the International Celestial Reference Frame (ICRF2). They select a sample of 1032 common sources among the catalogs and adopt two methods to represent the systematics: considering the differential orientation (offset) and declination bias; analyzing with the vector spherical harmonics (VSH) functions.

They find that: the significant declination bias between Gaia DR1 and ICRF2 catalogs reported in previous studies is possibly attributed to the systematic errors of ICRF2 in the southern hemisphere. It declination-dependent systematics may exist in the VLBI positions, to need further investigations in the future Gaia data release and the next generation of ICRF.

Also, there is great interest in building unbiased catalogues of quasars for a range of important astrophysical questions. These include understanding the quasar phenomenon itself and the growth and occurrence of supermassive black holes through cosmic time, the use of quasars as probes of intervening material and their role in re-ionization of both hydrogen and helium, and for the UV background levels throughout the universe. Thus the more diverse are the ways to assert a quasar amid the Gaia data releases, the less biased is the approach to those astrophysical questions. Conversely, the most varied are the means employed for the analysis, the largest is the sureness on the answers and the best becomes the chance to spot interesting objects or spurious detections.

In the frame of the ICRS Centre activities, Andrei et al. (2019) used observational data to check the power of the Maximum Entropy Principle on finding the behavior of the luminosity function of quasars. They carry out statistical tests showing the evaluation of the results. Even from limited observational information, over the number of quasars with a certain magnitude, at a given redshift, they find the probability for all values of the luminosity in that redshift from the principle. In this work we do not assume any specific luminosity function of the quasars. The research concludes that that the approach from the Maximum Entropy Principle leads to make estimates outside observational limits. The method therefore is promising when applied on large scale over the Gaia quasars data releases, either to check the luminosity function itself and its extension beyond the Gaia range of magnitudes, as well as an alternative method to spot outliers.

Construction of the LQAC-5 catalogue

In the frame of the ICRS Centre and during the whole year 2018, we constructed the fifth release of the Large Quasar Astrometric Catalogue. Since the previous release LQAC-4 (Gattano et al. 2018), a large number of quasars have been discovered, in particular those coming from the last release DR14Q of the SDSS. Moreover, for cross-matched objects, we have taken advantage of the very accurate determinations of the quasars identified within the recent Gaia DR2 catalogue. Following the same procedure as in the three previous release LQAC-4, we have compiled the large majority of all the objects fully reckoned as quasars (from their redshift and absolute magnitude) recorded so far. Our goal was to record their best coordinates and substantial information

concerning their physical properties such as the redshift as well as multi-bands apparent and absolute magnitudes. Emphasis was given to the results of the cross-matches with the recent Gaia DR2 catalogue.

New quasars coming from the DR14Q release were cross-matched with the previous LQAC-4 compilation with a 1'' search radius, in order to add the objects without counterpart to the LQAC-4. A similar cross-match was done with Gaia DR2 to identify the known quasars detected by Gaia. Thus, we could improve significantly the positioning of these objects, and in parallel we could study the astrometric quality of the individual catalogues of the LQAC-5 compilation. Finally, a new method was used to determine absolute magnitudes.

The LQAC-5 (Souchay et al. 2019) contains 592 809 objects. This is roughly 34% more than the number of objects recorded in the LQAC-4. Among them, 398 697 quasars were found in common with the Gaia DR2, with a 1'' search radius. That corresponds to 67.26% of the whole population in the compilation. The LQAC-5 delivers to the astronomical community a nearly complete catalogue of spectroscopically confirmed quasars (including a small proportion of compact AGNs), with the aim of giving their best equatorial coordinates with respect to the ICRF2 and with exhaustive additional information. For more than 50% of the sample, these coordinates come from the very recent Gaia DR2. The LQAC-5 catalog is available at the CDS via anonymous ftp to <http://cdsarc.u-strasbg.fr>.

Search for systematics effects on the tie between the Gaia and VLBI realizations of the CRF

Because of the coincident astrometric progress brought by the Gaia intermediate catalogues (and the final one within the next three years), and by the adoption of the ICRF3 as well as with the forthcoming higher frequencies CRF realizations, much effort has been conveyed into studying the systematics of the radio and optical definitions of the celestial frame.

In the frame of the ICRS Center, Taris et al. (2018) describe the magnitude variations of 47 targets that are suitable for the link between the Gaia and VLBI reference systems. They conclude that if the coordinates of the targets were affected by a white-phase noise with a formal uncertainty of about 1 mas it would affect the precision of the link at the level of 50 μ as. J.-C. Liu et al. (2018) investigate the systematic errors in VLBI positions of quasars and the global differences between Gaia DR1 and the ICRF2 using 1032 common sources to find a significant declination bias attributed to the systematic errors originating from the ICRF2 in the southern hemisphere. They remarked that a comparison of the VLBI and Gaia proper motions shows that the accuracies of the components of rotation and glide between the two systems are 2–4 μ as/yr, based on about 600 common sources. Abellán et al. (2018) have studied a complete radio sample of active galactic nuclei

with the VLBI technique and for the first time successfully obtained high-precision phase delay astrometry at Q band (43 GHz). They found that discrepancies arise in the orientation of the core-shifts determined through the different methods. In some cases the discrepancies could be explained by curvatures in the jets and departures from conical jets. Voitsik et al. (2018) present of a pilot project with the participation of the “Kvazar-KVO” radio interferometry array in observations carried out with the European VLBI Network. The aim of the project was to conduct and analyze multi-frequency (1.7, 2.3, 5.0, 8.4 GHz) observations of the parsec-scale jets of 24 active galactic nuclei. Mignard et al. (2018) remark that the Gaia DR2 contains the astrometric parameters for more than half a million quasars. This set defines a kinematically non-rotating reference frame in the optical domain and a subset with accurate VLBI positions allows the axes of the reference frame to be aligned with the ICRF.

Gattano et al. (2018) present the LQAC-4, which contains 443,725 objects, and for more than 50% of the sample accurate coordinates are found in the GDR1. Paine et al. (2018) present an all-sky sample of 567,721 AGNs in GDR1, selected using WISE two-color criteria. The catalog has fairly uniform sky coverage beyond the Galactic plane, with a mean density of 12.8 AGNs per square degree. Guo et al. (2018) used a near-zero proper motion criterion in conjunction with WISE [W1-W2] color to select quasar candidates, and as a result they present a catalog of 662 753 quasar candidates, with a completeness of about 75% and a reliability of 77.2%.

Photometric follow-up of QSO's from the ICRF

One of the key programs of the ICRS Centre is the photometric follow-up of QSOs which are very time consuming due to the very large amount of ICRF targets to monitor. Generally, these programs are done in the frame of international calls for proposal. This last point could be an issue when the total observation time requested is important. To avoid these constraints the SYRTE department of Paris Observatory planned to build a robotic telescope dedicated to the monitoring of QSOs magnitudes. The first part of this project began in 2015 by the choice of a site with a good atmosphere, characterized by its seeing. We chose Saint-Véran (altitude 3000m), in the French Alps, near the Italian border, for implementing a site seeing monitoring campaign (<http://stveran.obspm.fr/index.php?page=statistiques>). This site is known since 1960 when France initiated a site search campaign to build a 4m telescope. The goal of our campaign is to show, with modern instruments, that the site seeing, together with the number of clear nights in a year, is effectively the expected one.

Thus, it has been demonstrated in 2016 that the median value of the seeing is 1'' (mode seeing is 0.7'') which made this site a very good

one, probably one of the best in Europe. These measurements were obtained with a commercial apparatus, covered by a Non-Disclosure Agreement. The quality of the measurements was hence compared against the ones obtained by a DIMM telescope. The clear nights represent approximately 50% of the year, this amount being obtained by an AllSky camera which is able to count the visible stars in the sky every minute.

In the second step of this project, the SYRTE laboratory proposed to robotize a test telescope (0.50m) already on site since 2015. It is owned by a French amateur astronomers association, AstoQueyras. The goal of this part of the project is to show that it is possible to operate a telescope remotely from Paris in an “extreme” site. This second part of the project began in 2017 by the automation of the instrument. The first “remote light” was obtained from Paris Observatory on the January 23rd, 2018. Another “first remote light” was obtained by amateur astronomers on April 15th, 2018. During the year 2018 other tests were performed in order to check the entire configuration of the telescope, including dome, remote software control, etc. In September 2018 the concrete pillar for the scheduled 1m telescope was built. In parallel with these tests, the year 2018 was also the funding dossier creation phase of the 1m telescope, dossier that will be submitted in 2019.

Naval Observatory IERS ICRS Centre Activities During 2018

USNO concentrated on eight primary areas of work in support of maintenance and improvement of the Celestial Reference Frame:

1. Support to the International Celestial Reference Frame-3 (ICRF3) working group in the development and release of ICRF3
2. Completion of the USNO Robotic Astrometric Telescope (URAT) nearby stars and bright stars southern hemisphere surveys
3. Development and deployment of the Deep South Telescope (DST) at Cerro Tololo Interamerican Observatory (CTIO)
4. Execution of a deep, Near InfraRed (NIR) survey in the northern hemisphere using the United Kingdom Infrared Telescope (UKIRT)
5. Management of ICRS/ICRF observations utilizing the Very Long Baseline Array (VLBA)
6. Development, jointly with Paris Observatory, of the Fundamental Reference AGN Monitoring Experiment (FRAMEx)
7. Improving the astrometry of AllWISE with Gaia results
8. Use of machine-learning to identify possible reference frame AGN in NIR data along the galactic plane

ICRF3 USNO participated as a member of the IAU-sanctioned ICRF3 Working Group. Work included support for the execution and analysis of VLBA Calibrator Survey (VCS)-type Very Long Baseline Array (VLBA) S/X-band observing sessions under USNO's 50% timeshare agreement with the National Radio Astronomy Observatory (NRAO) and support for VLBA K-band and X/Ka band observations as ICRF3 sources (see below for details). Work also included generation and analysis of numerous ICRF3 prototype global VLBI solutions for comparison with those generated by other ICRF3 Working Group members at different Very Long Baseline Interferometry (VLBI) analysis centers. USNO has continued to expand the Radio Reference Frame Image Database (RRFID), a Web accessible database of radio frequency images of ICRF sources, which is available at <http://rorf.usno.navy.mil/rrfid.shtml>. ICRF3 was adopted by the IAU at its XXXth General Assembly in August 2018 and has replaced the previous realization, ICRF2, on January 1, 2019 (Charlot et al. 2020).

URAT Nearby Stars Using two years of USNO Robotic Astrometric Telescope (URAT) observations in combination with USNO CCD Astrograph Catalog (UCAC) 4 and Southern Proper Motion 4 (SPM4) catalog data, parallaxes of southern stars were obtained. A catalog of 916 newly discovered nearby stars with first trigonometric parallaxes was published before the Gaia DR2 release (Finch et al. 2018). This catalog significantly improved the completeness of nearby stars known to be within 25 pc of the Sun.

URAT Southern Hemisphere Bright Star Survey While the core of optical astrometric data for the next few decades is expected to come from the Gaia mission (Mignard et al. 2018), there are limitations with Gaia. Specifically, the Gaia focal plane physically saturates at $G=12$ in regular observing mode. The second Gaia data release (April 2018) contains astrometric results for some stars in the 3.5 to 6 magnitude range, observed with special "bright star modes". However, at this point it is unclear if and when the Gaia project will be able to release accurate results for all bright stars.

In order to address this gap in the optical reference frame, USNO continues with the UBAD survey at NOFS and the URAT bright star program at CTIO (see 2017 annual report). Observations with the USNO astrograph (URAT) concluded in June 2018 when the instrument was decommissioned to make room for a new program (see below). All bright stars south of declination $+25^\circ$ were observed with URAT over 2.7 years yielding typically several hundred images per star. Reductions of the data for both UBAD and URAT continued throughout the calendar year 2018. Release of an integrated bright star catalog covering all bright stars, and aligned to the Gaia reference frame, is expected in

2020.

Deep South Telescope (DST)

A fraction of ICRF sources (about 10%) display abnormally large optical vs. radio position differences when comparing Gaia results with VLBI data. In order to investigate this further, USNO acquired a new 1-meter telescope to be deployed at Cerro Tololo Interamerican Observatory (CTIO) in Chile. This Deep South Telescope (DST) was built by PlaneWave Instruments in 2018 and first light was obtained in December at the PlaneWave factory near Los Angeles in California (see Figure 5).

A 4k by 4k CCD camera has been ordered to provide a 35 arcmin field of view at 0.515 arcsec/pixel resolution. A wheel with 8 filters (wide bandpass, *B*, *V*, *R*, *I*, *g*, *r*, *i*) is on order as well. Deployment to Cerro Tololo, Chile is expected in 2019. The initial DST optical observing program aiming at about 200 selected ICRF sources with high cadence observing is part of a new joint USNO/Paris Observatory collaboration (FRAMEx, see below for more information).



Fig. 5: DST (model PW1000) at PlaneWave Instruments, Compton, CA, USA, December 2018. As shown, DST telescope is undergoing acceptance testing.

**USNO UKIRT K-Band
Hemispherical Survey**

USNO, in collaboration with the Institute for Astronomy (IfA) at the University of Hawaii (UH); the School of Physics and Astronomy, Nottingham University; Institute of Astronomy, University of Cambridge; and the Institute for Astronomy, University of Edinburgh, continued a K-band multi-year, northern hemisphere survey in the Near InfraRed (NIR) using the United Kingdom Infrared Telescope (UKIRT). This survey is targeted for completion in the 2021 time frame. When completed, the K-band survey will provide a catalog to fainter than 18th magnitude that complements the VISTA Hemisphere Survey in the southern hemisphere (McMahon 2013).

When combined with the J-band UKIRT survey (Dye et al. 2018), the K- data will provide deep photometric and astrometric data for two of the three standard NIR astronomical photometry bands. Figure 6 shows the progress of the survey through December 2018. When incorporating K-band data from earlier, directed surveys, approximately 60% of the northern sky had been completed through the end of 2018.

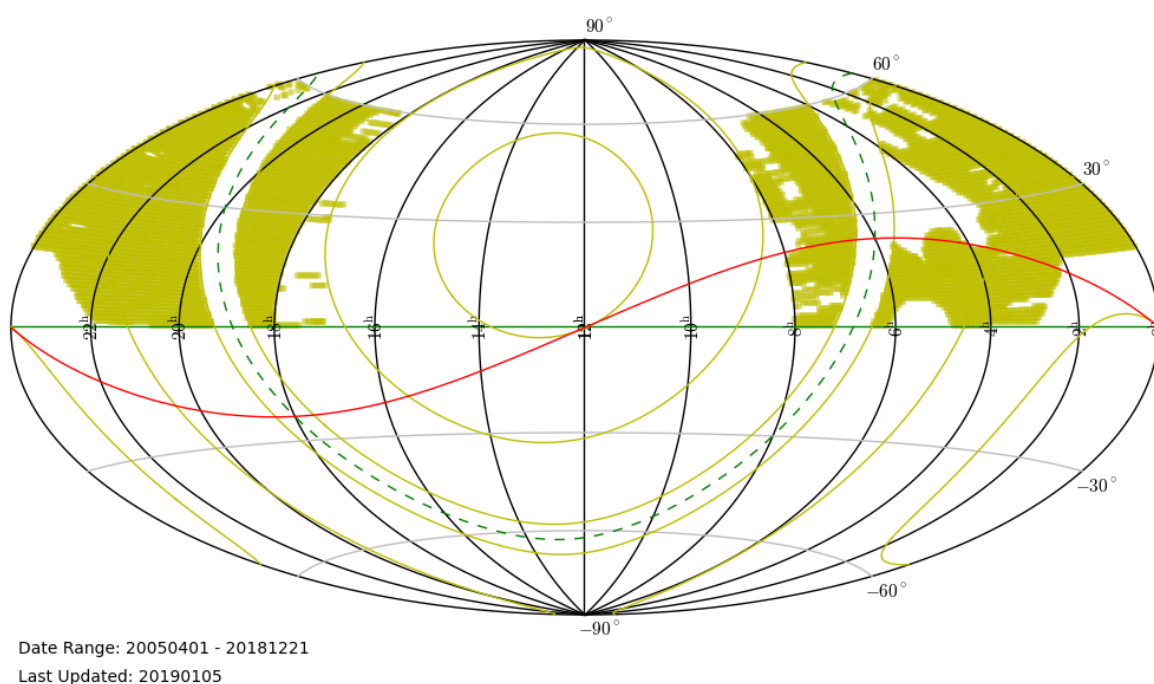


Fig. 6: UKIRT K-band survey progress, as of Dec 2018. Note that the galactic plane and the region centered around the North Galactic Pole (RA 12 h 51', DEC +27 deg 07') were previously surveyed; the current survey fills in the gaps. Also note that UKIRT cannot observe above DEC +60 deg; this "polar cap" will be filled in with dedicated observations using a different telescope at a later time.

**USNO 50% timeshare of the
Very Long Baseline Array
(VLBA)**

As described in the 2017 IERS ICRS report, USNO now schedules 50% of the observing time for the Very Long Baseline Array (VLBA), the National Science Foundation (NSF)/National Radio Astronomy Observatory (NRAO) facility that consists of ten 25-m radio telescopes that span a baseline from Hawaii in the west to the US Virgin Islands in the east (see Figure 7). This facility is used to support astrometry of reference frame objects, geodesy, and astronomical and astrophysical research, including into reference frame objects.

During the time period 2017–2018, USNO provided a significant amount of VLBA time to the development of ICRF3. This included observations in both the S/X bands (PI: D. Gordon, NASA/GSFC) as well as K-band (PIs: A. deWitt, HartRAO; C. Jacobs, NASA/JPL). USNO-provided VLBA time improved S/X source precision by a factor of 3x or better, and provided approximately 99% of the observations that were used to develop the K-band reference frame.



Fig. 7: Very Long Baseline Array (VLBA) Telescope located at Pie Town, New Mexico. The array consists of ten such telescopes, spanning a baseline from Hawaii in the west to the US Virgin Islands in the east.

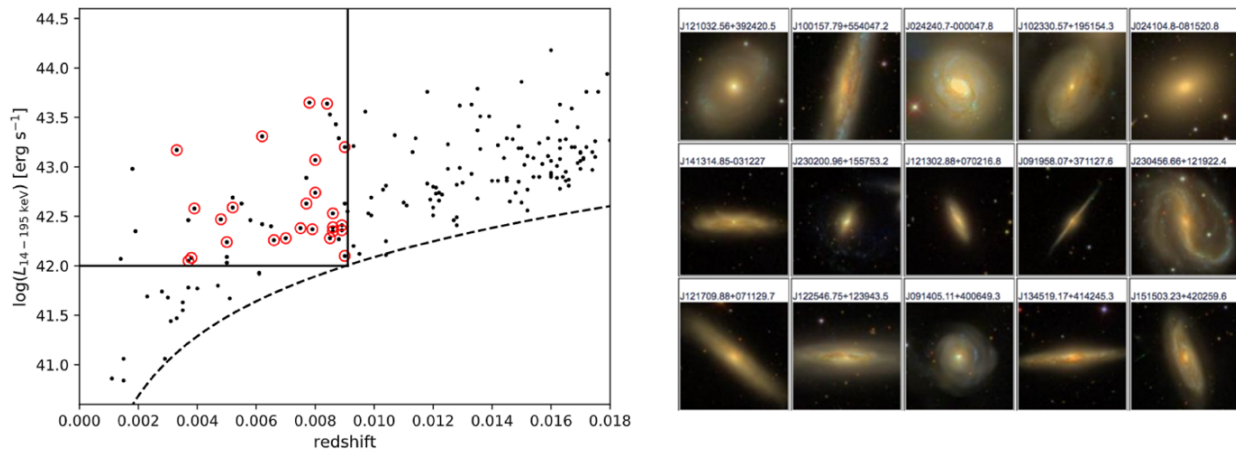


Fig. 8: Left: luminosity limit of BAT 105-month catalog as a function of redshift, showing our volume-limited selection box. Objects circled in red are those within a declination range of -30 to $+60$ deg. Right: SDSS thumbnails of 15/25 of our sample.

Fundamental Reference Frame AGN Monitoring Experiment (FRAMEX)

The Fundamental Reference AGN Monitoring Experiment (FRAMEX) was conceived at a May 2018 USNO-Paris Observatory IERS ICRS Centre meeting. The purpose of FRAMEX is to study representative samples of AGN/quasars to understand the physical processes potentially involved in optical-radio positional offsets seen in many ICRF sources. We defined two samples for study: a volume-limited sample of local AGN and a sample of quasars with significant optical-radio (Gaia-VLBI) positional offsets. Observations of the latter sample, which are being taken with the new USNO Deep South Telescope (DST; PI: Zacharias, see above) have just begun, so in the following we discuss only the volume-limited sample.

Using the Swift/BAT 105-month catalog (Oh et al. 2018), which contains a highly reliable and unbiased sample of AGN selected using hard X-rays (14–195 keV), we selected a volume-complete sample of AGN with hard X-ray luminosities above 10^{42} erg s $^{-1}$, which gives a distance limit of ~ 40 Mpc for the depth of the 105-month catalog. We further selected those objects between declinations of -30 and $+60$ deg for observability with the VLBA, as well as with other USNO and USNO partner assets. This resulted in 25 objects (see Figure 8).

These objects are being observed on a bimonthly basis using a portion of USNO's 50% timeshare of the VLBA to monitor for core shifts, which at the physical resolution of these nearby objects (< 1 pc) corresponds to changes in accretion structure. Simultaneous observations with the Swift X-ray Telescope (XRT) are also carried out. This allows for changes seen in non-thermal emission (i.e., radio synchrotron) to be compared to thermal emission (i.e., traced by inverse-Compton up-scattering of thermal UV accretion disk photons by the hot X-ray corona), thus providing insight into findings from optical ground-based monitoring (e.g., Taris et al. 2018). The first observation epoch has

already revealed an important result, that AGN may not follow the “fundamental plane” (FP) of black hole (BH) activity (e.g., Merloni et al. 2003) as previously inferred using lower resolution VLA observations (Figure 8, from Fischer et al. 2020). This relationship is important to multi-wavelength CRF work, as it implies a coupling of the thermal and non-thermal emission in AGN, normalized by BH mass. Any sign of decoupling, for example objects not following the FP, would potentially indicate that AGN radio and optical (the latter tracing the accretion disk emission) positions and luminosities will not necessarily be correlated, potentially introducing an additional source of scatter in CRF work.

AllWISE Revised Astrometry

Data from the Wide-Field Infrared Survey Explorer (WISE; Wright et al. 2010) have been an unexpected boon for CRF work, as the extreme sensitivity of its first three bands (3.4, 4.6, and 12-micron) to AGN-dominated objects (i.e., quasars) and deep survey coverage allowed for the creation of a large (1.4 million objects) and extremely reliable (stellar contamination < 0.04%) sample of quasars (using the AllWISE catalog; Secrest et al. 2015) that allowed for the Gaia CRF to be made non-rotating (Lindgren et al. 2018). WISE has continued to take data in its two shorter wavelength bands since its initial release, with the deepest catalog released at the beginning of 2019 (unWISE; Schlafly et al. 2019). WISE will likely continue to serve various roles in current and future CRF work, and so optimization of WISE for astrometric purposes is a worthwhile endeavor. To this end, at the 2018 USNO-Paris Observatory IERS ICRS Centre Meeting USNO suggested using Gaia as a reference catalog to revise the coordinates of the AllWISE/unWISE catalogs, which suffer from zonal errors due to the ground-based catalogs their native astrometry is based on (2MASS positions + UCAC4 proper motions). Preliminary results have been a success, with the zonal errors being largely removed (Figure 10). These results are anticipated to be published by mid-2020.

Galactic Plane QSOs

A consistent goal in the production of catalogs for CRF work is homogeneity and uniformity (see, for example, the 2017 annual report). The presence of large gaps and under-dense regions in catalogs may introduce systematics that adversely affect the quality of the CRF. For multi-wavelength (i.e., non-radio) work, the biggest such gap is the Galactic plane (GP). Gaia counterparts are scarce for AGN seen behind the GP, which can exhibit extinction well in excess of $E(B-V) > 2$ mag. However, future astrometric missions such as GaiaNIR (Hobbs et al. 2016) will likely detect AGN deep into the GP, and so it is important to find these AGN. Towards this goal, USNO has undertaken a novel research program that utilizes a machine learning technique to assign an AGN probability, or likelihood, based on a source's near-IR magnitudes

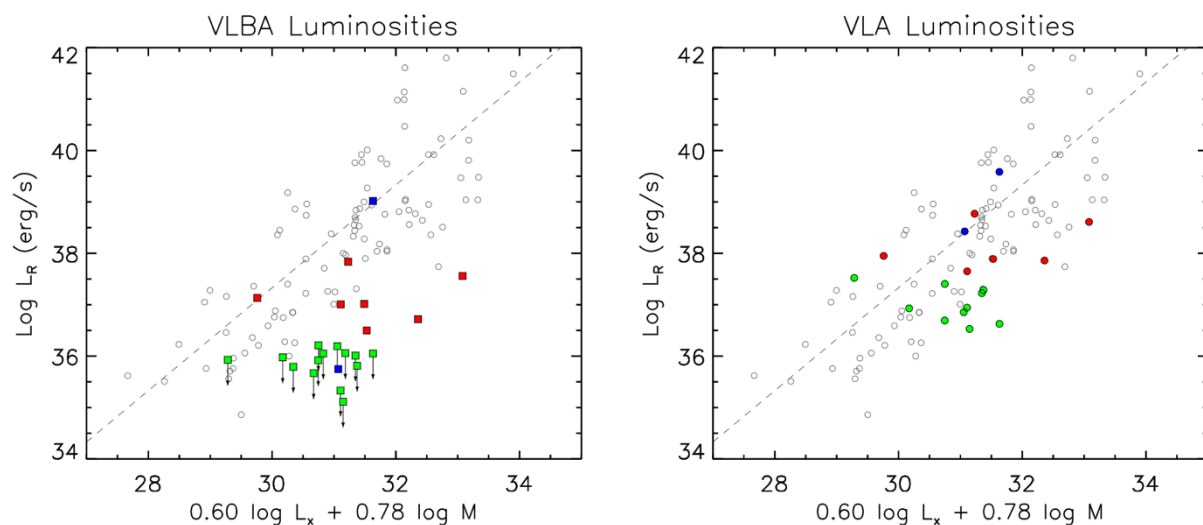


Fig. 9: Left: distribution of our volume-limited sample on the FP (Merloni et al. 2003) using simultaneous XRT and VLBA observations. Most objects are undetected upper-limits (arrows); although many are on the FP when using lower-resolution VLA data (right).

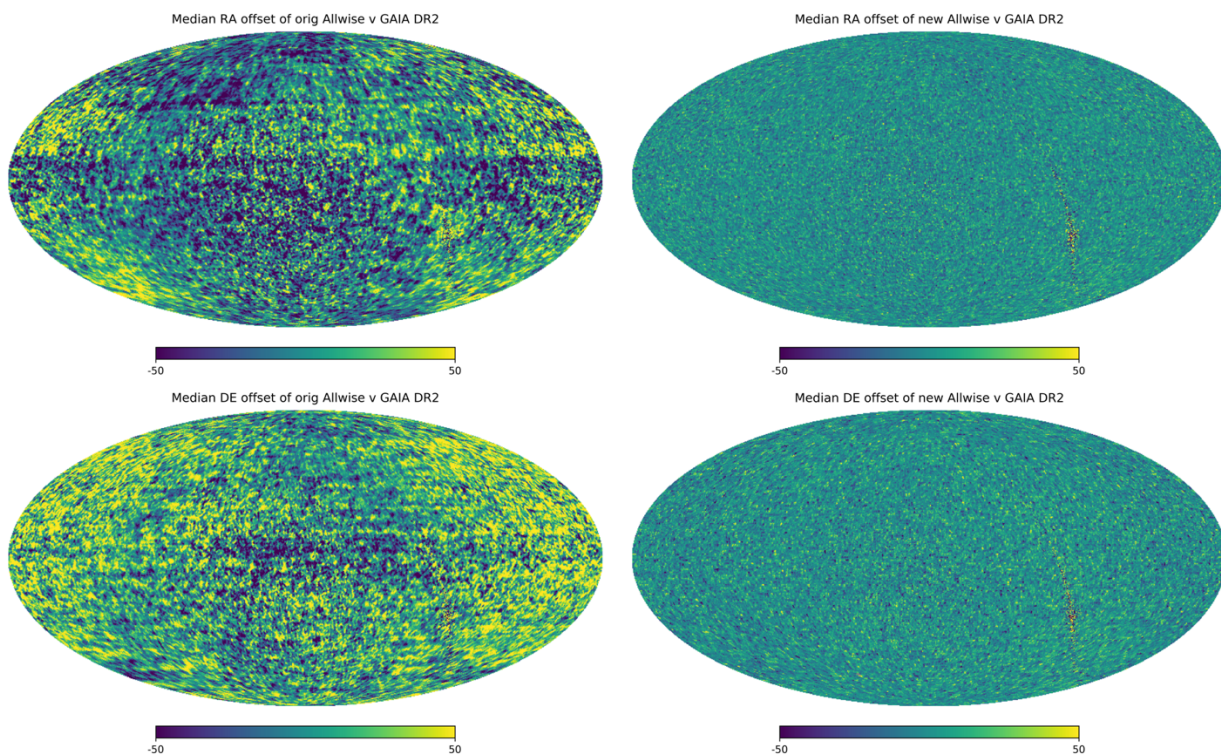


Fig. 10: Left: median AllWISE-Gaia positional offsets in RA (top) and Dec (bottom). Right: positional offsets after astrometric re-reduction using Gaia as the reference catalog. The auxiliary axis is in units of mas.

(J , H , K) as well as the known value of the Galactic extinction (e.g., Schlafly & Finkbeiner 2011) at its position and any optical counterpart it may or may not have. Preliminary results are highly promising, with the classifier performing 100 to 200 times better than random chance. USNO has an approved NIR spectroscopic program to confirm these AGN candidates using UKIRT, although logistical problems prevented any spectroscopic observations from being executed in 2018. We show our sample candidates, which so far use near-IR data from the UKIDSS GP survey (Lucas et al. 2008), in Figure 11.

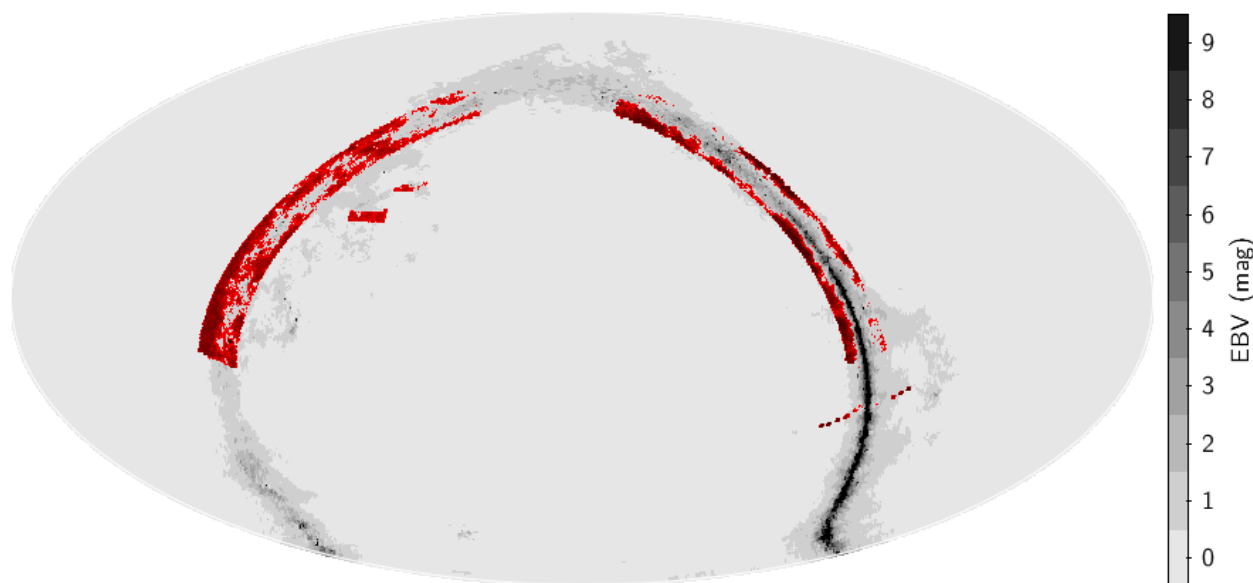


Fig. 11: Sample of GP candidates (red) overlaid on the Galactic extinction map of Schlafly & Finkbeiner (2011), plotted in equatorial coordinates, showing AGN access deep into the GP.

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3.5.5 ITRS Centre

This report summarizes the activities of the IERS ITRS Centre during the year 2018.

ITRF2020 Call for Participation

After detailed consultations with the IERS Technique Centres, the ITRS Centre finalized and published the ITRF2020 Call for Participation at the end of year 2018. The call specifies in particular the type of the long time series of station positions and Earth Orientation Parameters to be submitted by the individual techniques to the ITRF2020. In addition, the call recommends a number of model updates and effects to be considered by the four techniques in their reprocessing efforts. These models updates and effects are annexed to the ITRF2020 Call for Participation which is posted at the ITRF web site: http://itrf.ign.fr/doc_ITRF/CFP-ITRF2020.pdf

Contribution to the ISO Standard on ITRS

The ITRS Centre has actively contributed to the writing of the ISO standard on the ITRS. The document is intended to provide the basic information and definitions related to the International Terrestrial Reference System (ITRS), its realizations and how to access these realizations. At the end of the year 2018, the ISO standard on ITRS was at its DIS (Draft International Standard) stage and has been approved by the ISO member countries. The final standard document is expected to be published by the end of year 2019.

Participation to the activities of the UN-GGIM subcommittee on Geodesy

The ITRS Centre contributes actively to the activities of the UN-GGIM subcommittee on Geodesy and is chairing a Working group related to the geodetic infrastructure. The ITRS Centre has in particular contributed to the writing of the implementation plan of the Roadmap on the Global Geodetic Reference Frame for Sustainable Development, and attended the subcommittee related meetings.

Maintenance of the IERS network

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

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

Several new stations, mainly GNSS permanent stations were added to the ITRF network and database.

ITRF web site

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

The maps of the ITRF networks can be displayed depending of the measurement techniques and of the ITRF realization. Velocity vectors can be displayed as well as tectonic plates. The dynamical map can help users to familiarize with ITRF products and can be used for educational purpose. It can also be an interesting tool to select IERS sub-network depending on the measurement techniques, co-located hosted instruments or ITRF versions. ITRF94, ITRF96, ITRF97, ITRF2000, ITRF2005, ITRF2008 and ITRF2014 solutions are available for download.

Preparation for a new ITRF web site

The ITRS Centre has started an 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 new web site which was expected to be operational beginning 2016 experienced some delay, unfortunately, and will hopefully be available by the end of 2019.

Local ties of ITRF co-location sites

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

At the occasion of the ITRF2014 analysis, several new local tie SINEX files and corresponding reports were submitted to the ITRS Centre. All past and new local surveys used in the ITRF2014 computation are now available via the ITRF web site: http://itrf.ign.fr/local_surveys.php.

Other activities

- Participation in most meetings of the analysis working groups of the Technique Centres (in 2018: IDS, IGS, ILRS and IVS);
- Convening and organizing EGU and AGU sessions on reference frames and ITRF.

*Zuheir Altamimi, Bruno Garayt, Xavier Collilieux,
Paul Rebischung, Laurent Métivier*

3.5.6 Global Geophysical Fluids Centre

The Global Geophysical Fluid Center (GGFC, <http://loading.u-strasbg.fr/GGFC>) of the International Earth Rotation and Reference Systems Service (IERS) provides the community with models of geodetic effects (Earth rotation, gravity and deformation) due to the temporal redistribution of the Earth geophysical fluids. These include fluid motions within the solid Earth (core and mantle) as well as motions at the Earth's surface (ocean, atmosphere and continental hydrology). 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 Ocean SBs have been firmly established since the creation of the GGFC in 1998. The operational Combination Products SB was established in 2009 to host new datasets that model the mass movement of combined environmental fluids such as atmosphere + ocean. There is finally a non-operational component of the GGFC, the GGFC Science and Support Products, serving 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. Since 2016, J.-P. Boy acts as the chair of GGFC, with T. van Dam as a co-chair.

Special Bureau for the Atmosphere

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

Calculations of atmospheric angular momentum (AAM) are made from a number of global meteorological operational analyses and re-analyses, and are archived at the SBA. Long-term archives are at Atmospheric and Environmental Research in the file <http://files.aer.com/aerweb/AAM/>. It should be noted that these have different file names from previous versions, because the host institution changed from an ftp to a different server.

AAM from analyses and forecasts are updated daily at NOAA on <http://ftp.cpc.ncep.noaa.gov/long/aam/>. On-line readme files on these two sites are useful in documenting the data sets.

Operational atmospheric analyses are fields determined from observations during the epoch they are valid from the resident atmospheric analysis system in use at that time. Thus the systems, the main components of which are atmospheric forecast models and data assimilation

systems, have changed over the years. In contrast, atmospheric reanalysis systems use a constant analysis system to reprocess the historical atmospheric observational data. Thus the earlier periods are analyzed with a more advanced system than existed during their era, and the whole record of reanalysis is more suitable for long-term studies. The reanalyses were developed for consistent climate studies, and we use them here for long-term geodetic studies.

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

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

During 2018, the SBA fields of AAM were updated by Dr. Y. Zhou of the Shanghai Astronomical Observatory, China. These were for the full years of 2017 and 2018, as well as the early part of 2019.

Special Bureau for the Ocean

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

publications pertaining to the effect of the oceans on the solid Earth can be obtained. Additional information about the SBO can be found in an unpublished manuscript available through the SBO Publications website at https://euler.jpl.nasa.gov/sbo/sbo_publications.html and in the SBO chapter of IERS Technical Note 30, Proceedings of the IERS Workshop on Combination Research and Global Geophysical Fluids.

During 2018, NASA mandated that all NASA Centers, including JPL, disallow the use of ftp to access web sites and download files. So during 2018, the SBO web site was re-written to remove access by ftp, replacing it with https. The SBO web site can now be accessed and files downloaded using either https (web interface) or curl and wget (command line interface).

Also during 2018, SBO products from the ECCO/JPL ocean model were updated. The kf080h data assimilating run of the ECCO/JPL ocean model was discontinued and replaced by a new run, kf080i, that assimilates the latest version of the altimetry data. Daily values of oceanic angular momentum, oceanic excitation functions, and oceanic center-of-mass from the kf079 (simulation) and kf080i (data assimilating) runs of the ECCO/JPL ocean model are now available from 02 January 1993 through 19 February 2019. These values can be extended back to 06 January 1949 using the corresponding values from a 50-year-long simulation run of the ECCO/JPL ocean model whose results are also available through the SBO website.

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

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

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

Special Bureau for Hydrology

The Special Bureau for Hydrology (<http://www.csr.utexas.edu/research/ggfc/>) provides access to data sets of terrestrial water storage (TWS) variations from major climate and land surface models and GRACE (Gravity Recovery and Climate Experiment) satellite gravity measurements. The web site contains TWS estimates from five numerical models, the NCEP (National Center for Environmental Prediction) reanalysis, the ECMWF (European Center for Medium Range Weather Forecasting) reanalysis, the CPC (Climate Prediction Center) Land Data Assimilation System (LDAS), the NASA's Global Land Data Assimilation System (GLDAS), and the NOAA LandWorld land dynamics model. Global gridded TWS changes estimated from GRACE time-variable gravity observations are also provided in our online data archive (at <http://www2.csr.utexas.edu/research/ggfc/dataresources.html>). The NASA GLDAS and GRACE data products are updated on a regular basis.

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

In addition, TWS change estimates from historical GRACE release-01 and release-04 products are also provided in our online data archive (at <http://www2.csr.utexas.edu/research/ggfc/dataresources.html>). Some other data sets available in the SBH online data archive include daily hydrological excitations of polar motion and length-of-day computed from the NCEP/NCAR Reanalysis and the list of global major artificial reservoirs and their capacities. We have updated the monthly GLDAS TWS estimates to extend the coverage from January 2002 to September 2018. The new GRACE release-06 monthly TWS estimates with decorrelation and 300 km and 500 km Gaussian smoothing applied have been provided for the period April 2002 to August 2016 (the last 7 GRACE R06 solutions will be released by the GRACE team in early 2019).

Combinational Products

A complete list of the available combination products is provided below:

- UNB Vienna Mapping Function Service (<http://unb-vmf1.gge.unb.ca/Products.html>), M. Santos, University of New Brunswick, Canada.

- AAM analysis (and forecast) series from various atmospheric models (<http://files.aer.com/aerweb/AAM/>), D. Salstein, Atmospheric and Environmental Research, USA.
- Vienna Mapping Function Service, AAM analysis, Atmospheric loading and time-variable gravity (<http://ggosatm.hg.tuwien.ac.at/index.html>), J. Boehm & M. Schindelegger, Technical University of Vienna, Austria.
- Time-variable gravity field and AM from various hydrology models and from GRACE (<http://www.csr.utexas.edu/research/ggfc/>), J.-L. Chen, University of Texas at Austin, USA.
- Atmospheric (<http://vlbi.gsfc.nasa.gov/services/aplo/>), non-tidal oceanic (http://vlbi.gsfc.nasa.gov/services/ocean_load/) and hydrological (http://vlbi.gsfc.nasa.gov/services/hydro_load/) loading, D. MacMillan, NASA Goddard Space Flight Center, USA.
- Atmospheric, oceanic and hydrological loading, AM and time-variable gravity (<http://isdc.gfz-potsdam.de/esmdata/>), H. Dobslaw & R. Dill, GFZ, Potsdam, Germany.
- Atmospheric, oceanic and hydrological loading (<http://geophy.uni.lu/>), T. van Dam, University of Luxembourg, Luxembourg.
- Atmospheric, oceanic and hydrological loading and time-variable loading (<http://loading.u-strasbg.fr>), J.-P. Boy, EOST/IPGS, University of Strasbourg, France.

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

3.6 ITRS Combination Centres

3.6.1 Deutsches Geodätisches Forschungsinstitut der TU München (DGFI-TUM)

In 2018, the ITRS Combination Centre at DGFI-TUM focused on the investigation of the impact of considering non-tidal loading corrections on ITRS realizations, in particular on the geodetic datum parameters and the station positions. Furthermore, the institute focused on the continuation of the research activities on the consistent realization of ITRS and ICRS.

Considering non-tidal loading signals in ITRS realizations

The DTRF2014 solution is the first ITRS realization considering non-tidal atmospheric and hydrological loading corrections. According to the combination strategy of DGFI-TUM, the correction values are applied at the normal equation level. The atmospheric and hydrological model values are based on the NCEP and the GLDAS model, respectively, and are provided by Tonie van Dam (GGFC). As the non-tidal signals possess in particular dominant annual and semi-annual signals, a significant effect on the estimated positions and velocities of stations with short observations time spans must be expected. The left panel of Figure 1 shows a global overview of the station the observation time intervals of the DTRF2014 solution. The majority of stations contributed continuous observations over more than 2000 days to the DTRF2014, whereas in some regions (e.g. Japan, right panel of Figure 1) due to e.g., earthquakes, the DTRF2014 is based on rather short observation intervals. In order to validate the impact of the non-tidal loading corrections on the DTRF2014 solution, we compared station positions and velocities computed with and without the corrections. Figure 2 shows the position and velocity differences for all DTRF2014 stations. In particular stations with very short observation time spans (< 2.5 yr) benefit from the achieved strong smoothing of the station position time series. Position changes of up to 40 mm and velocity changes of up to 4 mm/yr are reached.

Due to the characteristics of the non-tidal loading signals which are dominated by annual and semi-annual periods with a phase lag of half a year between the Northern and Southern hemisphere, the consideration of the non-tidal loading also impacts the datum parameters, i.e. the origin and scale. We performed Fast Fourier Transform analysis (FFT analysis) of the datum parameter time series and found that the typical annual signal disappears when atmospheric and hydrological loading corrections are applied (see Figure 3).

Similar investigations are made for VLBI analysis, in which considering all three loading components (atmospheric, hydrological and oceanic loading) on observation level. For the scale time series the same result as above was obtained: the annual signal vanishes completely when all loading components are considered. The correction of atmospheric loading only, however, leads just to a small smoothing of the signal. Besides the station positions and the datum parameters, the baseline length repeatabilities and also the a posteriori variance factor improved, quantifying the overall improvement of the TRF solution.

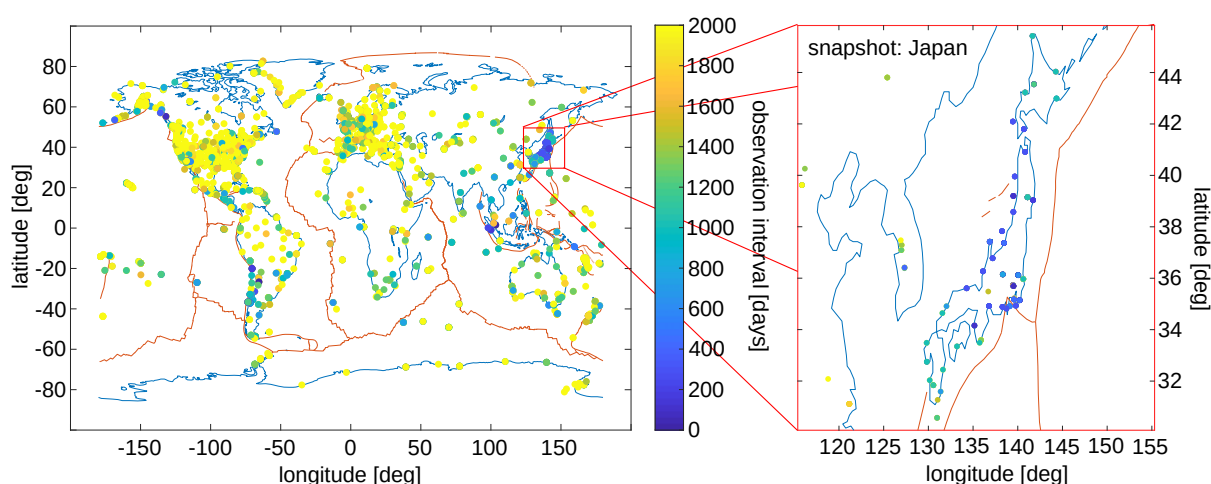


Fig. 1: DTRF2014 station observation intervals (left panel: global plot, right panel: snapshot of Japan).

Consistent realization of ITRS and ICRS

With the Resolution No. 3 of the International Union of Geodesy and Geophysics (IUGG) adopted by the General Assembly in 2011, the IUGG urged “that highest consistency between the ICRF, the ITRF, and the EOP as observed and realized by the IAG and its components such as the IERS should be a primary goal in all future realizations of the ICRS”. So far, the highest consistency could not be achieved, as three independent IERS product centres are in charge of computing the terrestrial and celestial reference frame as well as the EOP, and the products are computed from different input data series.

At DGFI-TUM, various studies and test combinations have been performed to estimate all three components (CRF, TRF and EOP) in a common adjustment. The joint parameter estimation was based on 11 years (2005.0–2016.0) of homogeneously processed VLBI, GNSS, and SLR single-technique solutions. Several types of combined solutions were computed varying the selections of local ties, the EOP combination setups, and the weighting of the techniques in order to be able to obtain conclusive results. The impacts of the different combination setups on the TRF, the EOP and finally the CRF were investigated.

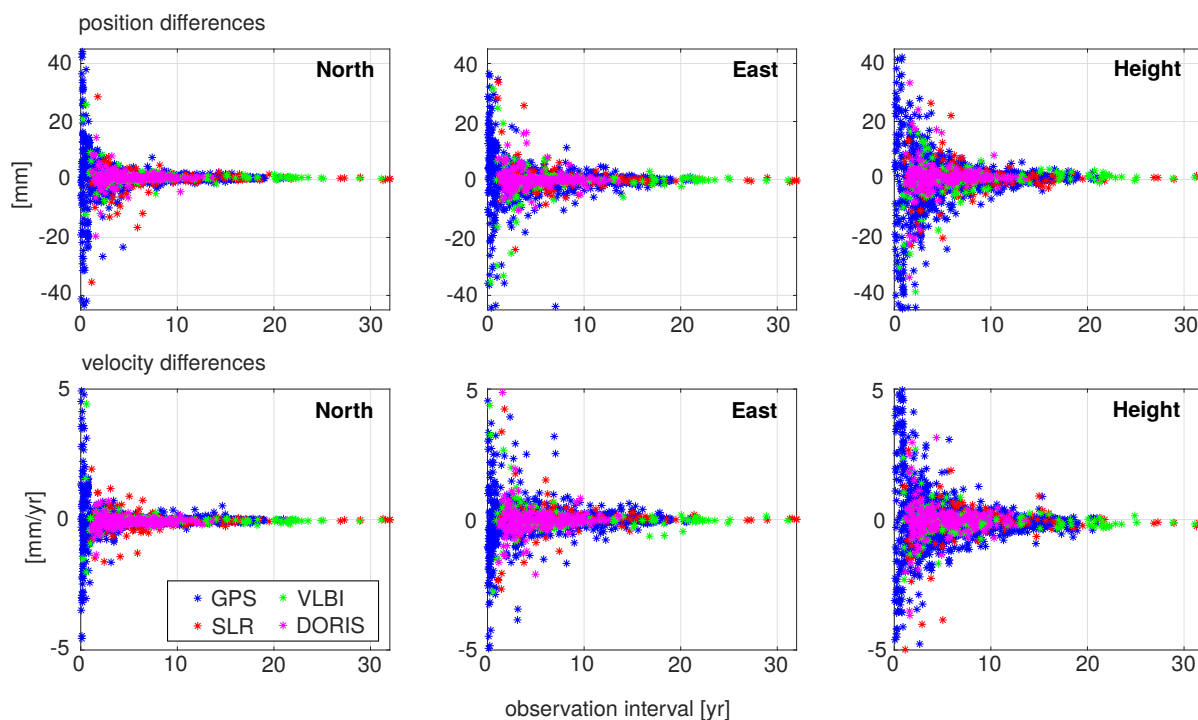


Fig. 2: Station position and velocity differences for DTRF2014 solutions with considering non-tidal loading (official solution) and without applying the corrections.

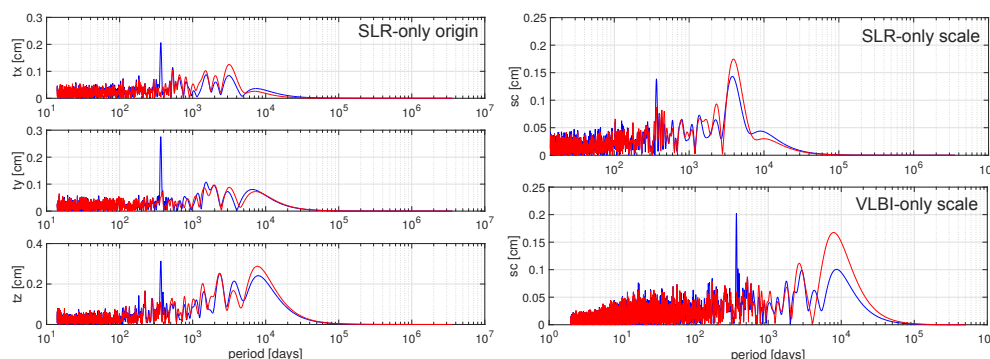


Fig. 3: Amplitude spectra of the Fast Fourier Transform analysis of translation and scale parameter time series of DTRF2014 input data. The weekly SLR and session-wise VLBI solutions are computed with and without the correction of non-tidal loading signals.

The results are published in Kwak et al., 2018. A key aspect is the impact of the combination on the CRF, which is realized from VLBI observations only, up to now. Figure 4 demonstrates the benefits of source positions w.r.t. a VLBI-only solution. In particular, the declinations of the VLBA Calibrator Survey (VCS) sources and newly added sources (not included in ICRF2) are improved significantly as demonstrated by decreasing standard deviations. As the standard deviations of the non-VCS sources including defining sources are much smaller than those of the VCS sources, their changes are hardly recognizable in Figure

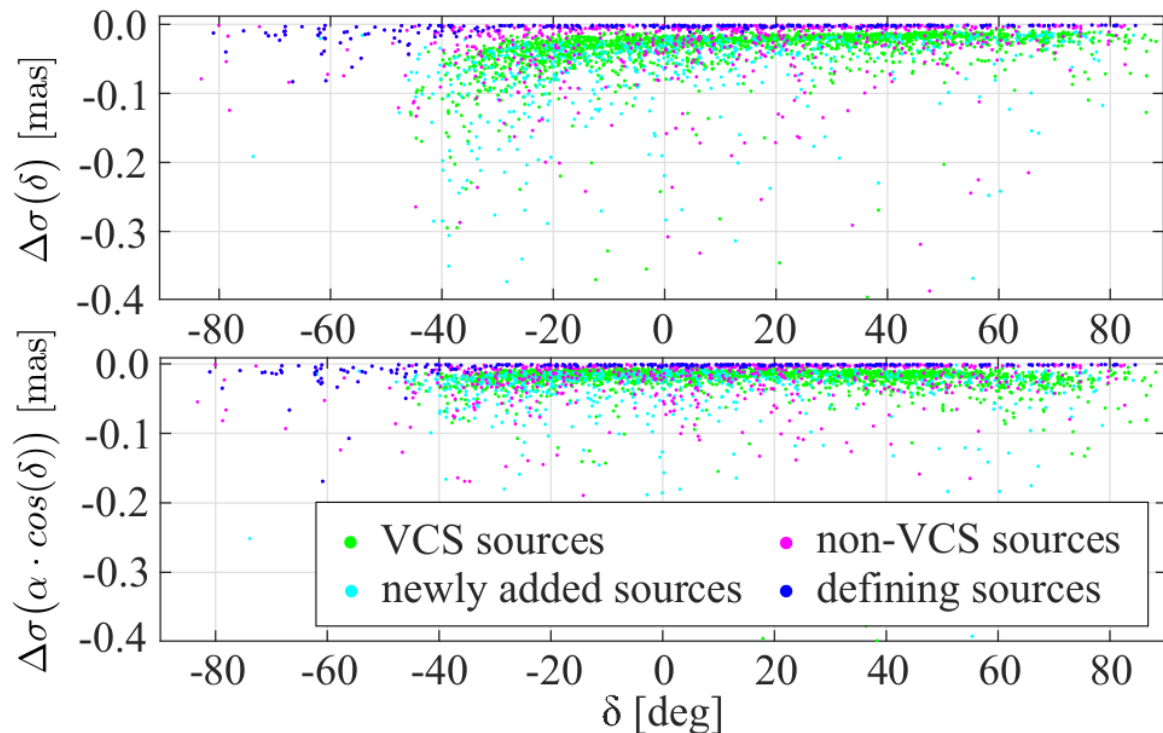


Fig. 4: Differences of radio source declination and right ascension standard deviations of the combined VLBI, GNSS and SLR solution in comparison to the VLBI-only solution. The standard deviations of the VCS sources (green) and newly added sources (cyan), which were not included in ICRF2, are improved significantly, which is indicated by the negative differences displayed in the figure.

4. However, they improve also in particular for the higher southern latitudes.

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

This report summarizes the activities of the ITRS Combination Centre at IGN during the year 2018.

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.

Investigation of the scale discrepancy between SLR and VLBI

The scale of ITRF2014 was defined in such a way that it has zero scale and zero scale rate with respect to the arithmetic average of the implicit scales of SLR and VLBI solutions as obtained by the stacking of their respective time series. The resulting scale and scale rate differences between the two solutions (SLR and VLBI) are $1.37 (\pm 0.10)$ ppb at epoch 2010.0 and $0.02 (\pm 0.02)$ ppb/yr. The level of the scale agreement between SLR and VLBI confirms the ITRF2008 finding and is an indication of the persistent scale offset between the two technique solutions. These results suggest that there is still an urgent need for investigation on the causes of the scale discrepancy, e.g., range biases in case of SLR [Appleby et al., 2016] and possible effects due to VLBI antenna gravity deformations [Sarti et al. 2009, 2010]. The ILRS has initiated a pilot project on systematic errors including the range biases which will be estimated in the ILRS solution to ITRF2020. A preliminary SLR test solution was made available to the ITRS center by Cinzia Luceri from the Italian Space Agency (ASI) where estimated range biases were taken into account. Analyzing the time series of this SLR test solution showed a clear scale offset of about 1 ppb with respect to the ILRS solution which was used in the ITRF2014 as illustrated by Figure 1. We expect that this scale offset will greatly minimize the scale discrepancy between SLR and VLBI in the coming ITRF2020 solution.

Contribution to the Hotine Marussi Symposium 2018

The Head of the ITRS Center convened a session during the Hotine Marussi Symposium 2018 entitled "Theory of modern geodetic reference frames and Earth's rotation". A presentation on behalf of the ITRF team at IGN was made at the session dealing with a "Review of Reference Frame Representations for a Deformable Earth". A written paper was also submitted to the IAG series of this symposium.

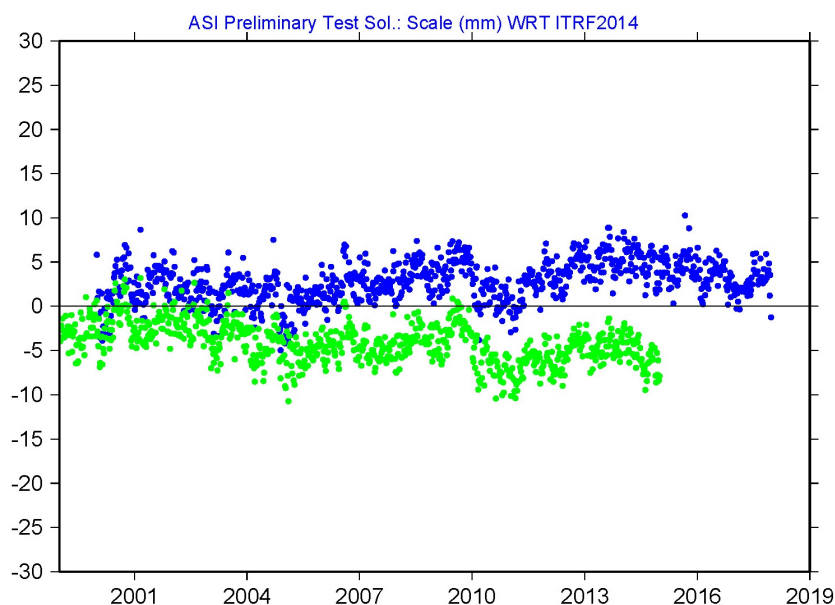


Fig. 1: Scale discrepancy between ASI preliminary solution (blue) where range biases are estimated and ILRS solution (green) used in the ITRF2014 computation

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3.6.3 Jet Propulsion Laboratory (JPL)

Introduction

The Jet Propulsion Laboratory is continuing to develop an approach to determining ITRF-like terrestrial reference frames based upon the use of a Kalman filter/smoothers (Wu et al., 2015). Kalman filters are commonly used to estimate the 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 positions and velocities of geodetic observing stations and associated EOPs along with their full covariance matrices. The data consist of time series of observed VLBI, SLR, GNSS, and DORIS station positions and EOPs along with the data measurement covariance matrices. In addition, measurements from ground surveys of the positions of reference marks of co-located stations are used to tie the technique-specific station networks to each other. The Kalman filter and smoother for reference frame determination software (KALREF) being developed at JPL combines these measurements to determine ITRF-like reference frames subject to constraints imposed on the allowed evolution of the station positions. KALREF includes options for constraining the stations to move linearly or to move linearly and seasonally. Through the use of stochastic models for the process noise, the station positions can be constrained to exactly follow this linear or linear and seasonal 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). The sequential estimation approach to determining terrestrial reference frames that is being developed at JPL has been used to determine JTRF2014, JPL's realization of a terrestrial reference frame using the ITRF2014 input data sets (Abbondanza et al., 2017).

During 2018, besides continuing to analyze the JTRF2014 solution, JPL also continued to both explore the possibility of accounting for regional deformation of the crust and mantle when determining TRFs and to develop a sequential estimation approach to jointly determine terrestrial and celestial reference frames (CRFs).

JTRF2014

An article comparing and contrasting JPL's sequential estimation approach to determining terrestrial reference frames to the approaches taken by IGN and DGFI has been written (Abbondanza et al., 2019). By representing the TRF by time series of smoothed station positions, JPL's approach results in a sub-secular reference frame wherein the frame origin is the quasi-instantaneous center-of-mass of the Earth system as given by SLR and the frame scale is the quasi-instantaneous average of the VLBI and SLR scales. In contrast, the IGN and DGFI approaches

result in secular frames that capture the long-term, mean origin and scale.

Regional Deformation

Current generation terrestrial reference frames, like JTRF2014, suffer from biases introduced by the space-time sampling pattern of the input space-geodetic measurements, particularly by the gaps in the spatial distribution and temporal history of the space-geodetic observing stations. During 2018, JPL continued its efforts to improve terrestrial reference frames by developing procedures to account for gaps in the spatial distribution and temporal history of observing stations by: (1) reconstructing the history of the deformation of the Earth's global surface from GRACE measurements and geophysical fluid models of the processes that are causing the Earth's surface to be deformed and observing stations to be displaced, (2) using the reconstructed deformation field to construct spatial and temporal correlations of the expected station displacements, and (3) including the spatial and temporal correlations in a Kalman filter solution for an ITRF-like reference frame. By accounting for gaps in the spatial distribution and temporal history of observing stations when determining the frame, biases caused by those gaps are expected to be reduced, particularly in the geocenter and scale parameters of the frame because those parameters are determined solely from observations taken by the non-uniformly distributed SLR and VLBI stations.

During 2018, GRACE gravity data and atmospheric, oceanic, and hydrologic loading models continued to be used to compute the correlation between the GRACE-observed or modeled load at some test point on the Earth's surface (e.g., a space-geodetic observing station) and all other grid points of the data or model. After removing linear trends as well as annual and semiannual periodic terms from each data set, the spatial correlation patterns from these data sets generally agreed with each other on regional (sub-continental) scales, but major disagreements were seen on larger (inter-continental) scales. A regional filter on the correlation maps was therefore applied in order to extract only the continental-scale spatial patterns common in all the data sets. Trial reference frame solutions using the continental-scale correlations were determined with the geocenter and scale parameters of the solutions being found to exhibit improved stability and closer agreement to the ITRF2014 geocenter and scale.

Joint Determination of Terrestrial and Celestial Reference Frames

Currently, terrestrial and celestial reference frames are determined separately from each other. This leads to inconsistencies between the frames and the Earth Orientation Parameters (EOPs) that link them together, consequently degrading their quality. During 2018, JPL continued its efforts to improve terrestrial reference frames by continuing to

develop the capability to jointly and consistently determine the TRF with the CRF and EOPs. To do this, KALREF is being extended to include the processing of celestial pole offsets and source coordinates. This will allow the proper motions of radio sources, which are not accounted for in current CRF solutions, to be taken into account.

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3.7 IERS Working Groups

3.7.1 Working Group on Site Survey and Co-location

Focus of the latest years have been directed towards deformation studies of VLBI reflectors, and resulted in a set of articles significantly enhancing the knowledge of individual telescopes. These studies have been able to separate the internal deformation parameters of the VLBI telescopes, aliasing as several millimetres movements of the telescope in previous and current analysis (undetected in “classic” local tie measurements). In order to get full benefit of these measurements, more telescopes need to be measured – of particular urgency are those telescopes about to be decommissioned (as their time series will be of little use for future analysis unless the telescopes get characterized). This is a maintenance issue for the telescope operators and the geodetic society, and a requirement to fulfil the GGOS/VGOS objectives.

Such activities are being undertaken, and we foresee more publications in 2019. For example, first photogrammetric deformation analysis measuring focal-length variations of VGOS telescopes using unmanned aerial systems were performed. Members of the WG also participated in a successful bid “Large-scale dimensional measurements for geodesy” (GeoMetre, 18SIB01) in the European Metrology Programme for Innovation and Research (EMPIR), commencing in 2018 and running for three years.

Publications related to the WG objectives

- GeoMetre Project, Large-scale dimensional measurements for geodesy.
<https://www.euramet.org/research-innovation/search-research-projects/details/project/large-scale-dimensional-measurements-for-geodesy/>
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- IVS 2018 General Meeting Proceedings “Global Geodesy and the Role of VGOS – Fundamental to Sustainable Development”, edited by Kyla L. Armstrong, Karen D. Baver and Dirk Behrend. NASA/CP-2019-219039, 2019, online: <https://ivscc.gsfc.nasa.gov/publications/gm2018/>
- Cornelia Eschelbach et al.: Extension and Optimization of the Local Geodetic Network at the Onsala Space Observatory
 - Torben Schüller et al.: LEVIKA SBA – Wettzell Radio-Telescope Positioning With a Tailor-Made Analysis Software

- Torben Schüller et al.: Local Radio Telescope Ties from the Wettzell Precision Engineering Surveying Network
- Marisa Nickola et al.: Antenna Parameters and Local Tie between HartRAO 15-m and 26-m Antennas
- Svetlana Mähler et al.: Permanent Reference Point Monitoring of the TWIN Radio Telescopes at the Geodetic Observatory Wettzell
- Iván Herrera Pinzón et al.: Analysis of the Short VLBI Baseline at the Wettzell Observatory
- Dhiman Mondal et al.: A GPS-Based Study to Improve the Accuracy of Local Geodetic Ties at Co-located Sites that Exploits Small-Scale Atmospheric Structure

Sten Bergstrand

3.7.2 Working Group on SINEX Format

General aspects

The IERS Working Group (WG) on SINEX Format was established in early 2011. The Charter of this WG is available on its website maintained at the IERS Central Bureau: <https://www.iers.org/WGSINEX>

Information related to the working group's activities are available there as well, such as agenda and minutes of the meetings held so far. The latest version of the SINEX format is v 2.02. A full format description is available at: <https://www.iers.org/IERS/EN/Organization/AnalysisCoordinator/SinexFormat/sinex.html>

The SINEX format is used by all four space-geodetic techniques to provide their products. In addition, the combined terrestrial reference frame (ITRF) is also provided in SINEX format. To ensure that all technique-specific needs are covered by the SINEX format, representatives from each Technique Service are members of the SINEX Working Group. Additionally, representatives of the IERS ITRF Combination Centers, the IERS Working Group on Co-location and Site Survey, and the IERS Convention Center are involved in the working group. The IERS Analysis Coordinator is an ex-officio member of the working group in order to cover the needs of the combined IERS products.

During the year 2018 there was no special meeting of the working group. All discussions on possible format revisions and additions have been done mainly based on personal communication in conjunction with international conferences and workshops, and partly via email.

Long station names in SINEX

The handling of longer station names in SINEX is a topic of discussion since the Unified Analysis Workshop (UAW) 2017 (see IERS Annual Report 2017). The need for extending the length of the station names came up in recent years in order to have unique station identifiers for the entire global network of GNSS stations. In the case of the SINEX format, a 1-to-1 adoption of the 9-character station names as it is realized for the RINEX-3 files would exceed the 80-character line actually used in SINEX. Several individuals within the IGS are working on suggestions to overcome this problem and to suggest a method for unique station identifications within SINEX in analogy to the 9-character station names defined for RINEX. A final decision was not taken until the end of 2018.

Provision of loading corrections in SINEX

In preparation for the upcoming realization of the terrestrial reference system (which is planned to be ITRF2020), the need to provide loading corrections along with the SINEX solution came up. The ITRF2020 should be generated without correcting the station deformations caused by non-tidal loading effects. The IVS, however, corrects its operational solutions by atmospheric loading effects, and the IVS analysis groups do not want to have two different processing chains in parallel. The

IERS Directing Board agreed that the IVS can submit its contribution to the ITRF2020 with loading corrections applied if these corrections are provided within the SINEX file as well. Therefore, a procedure for SINEX needs to be defined that allows the ITRF Combination Centers to make the loading corrections undone for the entire normal equation systems provided by the IVS. The ITRS Center together with the IVS Analysis Coordinator and the IVS Combination Center started to work on this issue.

Provision of SLR range biases in SINEX

One outcome of the ILRS pilot project on “Station Systematic Error Modelling (SSEM)” was that future solutions provided by the ILRS will include the values (including their sigmas) for range and time biases that have been applied when generating the solution. This makes it necessary that a new block in SINEX is defined to cover the SLR biases. The ILRS Analysis Coordinator together with the ILRS Analysis Standing Committee started to work on this issue. A final decision of the format is foreseen for end of 2019 in order to be prepared for generating the contribution to ITRF2020.

Daniela Thaller on behalf of the SINEX WG

3.7.3 Working Group on Site Coordinate Time Series Format

The IAG services that distribute GNSS, SLR, VLBI and DORIS data and products proposes plots and/or files of coordinates time series for the stations of the tracking networks, as well as web services to display these time series. The aim of this working group is to define a common exchange format for coordinates time series for the geodetic techniques. For details on the goals and on previous work see the reports for 2012 to 2015 and the web site <http://iers.org/WGSCTSF>.

There has been no progress during 2018. Efforts to find a new Chair of the WG have not been successful so far. 75% of the work is done, the requirements are defined, and two different format have been proposed. The next step is to share the formats within the WG and to evaluate them.

Laurent Soudarin

Appendices

Appendix 1: IERS Terms of Reference

The IERS was established as the International Earth Rotation Service in 1987 by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG) and it began operation on 1 January 1988. In 2003 it was renamed to International Earth Rotation and Reference Systems Service. IERS is a member of the ICSU World Data System (WDS). The primary objectives of the IERS are to serve the astronomical, geodetic and geophysical communities by providing the following:

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

IERS is composed of a broad spectrum of activities performed by governmental or selected commercial organizations. IERS collects, archives and distributes products to satisfy the objectives of a wide range of applications, research and experimentation. These products include the following:

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

- Annual report and technical notes on conventions and other topics.
- Long term earth orientation information.

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

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

The IERS accomplishes its mission through the following components:

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

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

TECHNIQUE CENTERS (TC)

The TCs generally are autonomous independent services, which cooperate with the IERS. The TCs are responsible for developing and organizing the activities in each contributing observational technique to meet the objectives of the service. They are committed to produce operational products, without interruption, and at a specified time lag to meet requirements. The products are delivered to IERS using designated standards. The TCs provide, as a minimum, earth orientation parame-

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

PRODUCT CENTERS (PC)

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

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

ITRS COMBINATION CENTER(S)

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

RESEARCH CENTER(S)

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

IERS ANALYSIS COORDINATOR (AC)

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

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

CENTRAL BUREAU (CB)

The Central Bureau is responsible for the general management of the IERS consistent with the directives and policies set by the Directing Board, i.e., acts as the executive arm of the Directing Board. The CB facilitates communications, coordinates activities, monitors operations, maintains documentation, archives products and relevant information and organizes reports, meetings and workshops. Although the Chairperson of the Directing Board is the official representative of the IERS at external organizations, the CB is responsible for the day-to-day liaison with such organizations. The CB coordinates and publishes all documents required for the satisfactory planning and operation of the Service, including standards/conventions/specifications regarding the performance, functionality and configuration requirements of all elements of the Service including user interface functions. The CB operates the communication center for the IERS. It distributes and/or maintains a hierarchy of documents and reports, both hard copy and electronic, including network information, standards, newsletters, electronic bulletin board, directories, summaries of performance and products, and an Annual Report.

DIRECTING BOARD (DB)

The Directing Board consists of the following members:

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

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

- One representative from each Product Center.
- Representative of the Central Bureau.
- IERS Analysis Coordinator.

- Representatives of IAU, IAG/IUGG and GGOS.

The Chairperson is elected by the Board for a term of four years with the possibility of re-election for one additional term. Eligible candidates are members of the DB and IERS Associate Members. The Chairperson does not vote, except in case of a tie. He/she is the official representative of IERS to external organizations.

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

Most DB decisions are to be made by consensus or by a simple majority vote of the members present, provided that there is a quorum consisting of at least one half of the membership. In case of a lack of a quorum, the voting is by correspondence. Changes in the Terms of Reference and Chairperson of the DB can be made by a two third majority of the members of the DB. If a DB member cannot participate in the meeting, he/she can designate a proxy to attend the meeting and vote in the place of the absent DB member. Any appointment of a proxy by a DB member shall be in writing to the CB prior to the meeting, and is valid only for the meeting.

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

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

WORKING GROUPS

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

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

provide the following at least two weeks prior to the IERS Directing Board Meeting where DB approval is requested.

- Draft charter clearly specifying:
 - Proposed goals (two pages at maximum),
 - Proposed structure of the group or project,
 - Working plan including schedule / deadlines including the anticipated end of work,
- Candidate for a chairperson to be appointed by the DB (optional),
- Initial list of members,
- Proposed plans for an operational phase (if applicable),
- Draft IERS message to inform the IERS community.

IERS ASSOCIATE MEMBERS

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

IAG General Secretary

IAU General Secretary

IUGG General Secretary

President of IAG Commission 1

Chair of IAG Subcommittee 1.1

Chair of IAG Subcommittee 1.2

Chair of IAG Subcommittee 1.4

President of IAG Commission 3

Chair of IAG Subcommittee 3.1

Chair of IAG Subcommittee 3.2

Chair of IAG Subcommittee 3.3

President of IAU Division A

President of IAU Commission A1

President of IAU Commission A2

President of IAU Commission A3

**IERS
CORRESPONDENTS**

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

October 6, 2015

Appendix 2: Contact addresses of the IERS Directing Board

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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 <code>ser7</code> Monthly earth orientation data Web access: http://hpiers.obspm.fr/eop-pc/index.php?index=bulletins ftp access: hpiers.obspm.fr - directory <code>iers/bul/bulb_new</code> Long term earth orientation data Web access: http://hpiers.obspm.fr/eop-pc/index.php?index=eoptable ftp access: hpiers.obspm.fr - directory <code>iers/eop</code> Leap second announcements Web access: http://hpiers.obspm.fr/eop-pc/index.php?index=bulletins ftp access: hpiers.obspm.fr - directory <code>iers/bul/bulc</code> Announcements of DUT1 Web access: http://hpiers.obspm.fr/eop-pc/index.php?index=bulletins ftp access: hpiers.obspm.fr - directory <code>iers/bul/buld</code>
Conventions	Web access: IERS Conventions 2010: http://iers-conventions.obspm.fr/
International Celestial Reference Frame	Web access: http://hpiers.obspm.fr/icrs-pc/newwww/index.php
International Terrestrial Reference Frame	Web access: http://itrf.ensg.ign.fr/ ftp access: itrf.ensg.ign.fr - directory <code>pub/itrf</code>
Geophysical fluids data	Web access: http://loading.u-strasbg.fr/GGFC/

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/www/arc/itrffield>

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://iers-conventions.obspm.fr/>

ICRS Centre

Web site: <http://hpiers.obspm.fr/icrs-pc/newwww/index.php>

ITRS Centre

Web site: <http://itrfield.ensg.ign.fr/>

Global Geophysical Fluids CentreWeb site: <http://loading.u-strasbg.fr/GGFC/>**Special Bureaus:*****Special Bureau for the Oceans***Web site: <http://euler.jpl.nasa.gov/sbo/>***Special Bureau for Hydrology***Web site: <http://www.csr.utexas.edu/research/ggfc/>***Special Bureau for the Atmosphere***Web site: <https://www.aer.com/science-research/earth/earth-mass-and-rotation/special-bureau-atmosphere/>***Special Bureau for Combination***Web site: <http://geophy.uni.lu/>**Technique Centres****International GNSS Service (IGS)**Web site: <http://www.igs.org/>**International Laser Ranging Service (ILRS)**Web site: <http://ilrs.gsfc.nasa.gov/>**International VLBI Service (IVS)**Web site: <http://ivscc.gsfc.nasa.gov/>**International DORIS Service (IDS)**Web site: <http://ids-doris.org/>**ITRS Combination
Centres****Deutsches Geodätisches Forschungsinstitut (DGFI)**Web site: <http://www.dgfi.tum.de/en/international-services/itrs-combination-centre/>**Institut Géographique National (IGN)**Web site: <http://itrf.ensg.ign.fr/>**Jet Propulsion Laboratory (JPL)**Web page: <http://www.iers.org/ITRSCC-JPL>**Working Groups****Working Group on Site Survey and Co-location**Web site: <http://www.iers.org/WGSiteSurvey>**Working Group on 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>.

2MASS	Two Micron All Sky Survey	BEV	Bundesamt für Eich- und Vermessungswesen
AAM	Atmospheric Angular Momentum	BH	black hole
AC	Analysis Centre	BKG	Bundesamt für Kartographie und Geodäsie
AC	Analysis Coordinator	BPS	GGOS Bureau for Products and Standards
ACC	[IGS] Analysis Center Coordinator	c	century
AGGO	Argentinian-German Geodetic Observatory	C/P	Combination and Prediction
AGN	Active Galactic Nuclei	CA	California, USA
AGU	American Geophysical Union	CATREF	Combination and Analysis of Terrestrial Reference Frames
AllWISE	WISE catalogue	CB	Central Bureau
allWISEagn	AllWISE Catalog of Mid-IR AGNs	CC	Combination Centre
AM	angular momentum	CC	Conventions Centre
AOV	Asia-Oceania VLBI Group for Geodesy and Astrometry	CCD	Charge-Coupled Device
APOLLO	Apache Point Observatory Lunar Laser-ranging Operation	CDDIS	NASA Crustal Dynamics Data Information System
APSG	Asia-Pacific Space Geodynamics	CDS	Centre de Données astronomiques de Strasbourg (formerly: Centre de Données Stellaires)
AR	Annual Report	CERGA	Centre d'Etudes et de Recherches Géodynamiques et Astronomiques
AR	autoregressive	CF	Center of Frame [origin of ITRF]
ASC	Analysis Standing Committee	CfA	Harvard-Smithsonian Center for Astrophysics
ASCII	American Standard Code for Information Interchange	CfP	Call for Participation/Proposals
ASI	Agenzia Spaziale Italiana	CGS	Centro di Geodesia Spaziale, ASI
ATML	atmospheric loading	CIO	Conventional International Origin
AUS	Geoscience Australia	CIP	Celestial Intermediate Pole
AWG	Analysis Working Group	CLS	Collecte, Localisation, Satellites
BAS	British Antarctic Survey		
BAT	Burst Alert Telescope		

CM	instantaneous centre of mass of the whole Earth	Dec, DEC	declination
CN	centre of [observation] network	deg	degree
CNES	Centre National d'Etudes Spatiales	Dep.	Department
CNSA	China National Space Administration	DGFI	Deutsches Geodätisches Forschungsinstitut
CODE	Centre for Orbit Determination in Europe	DGFI-TUM	Deutsches Geodätisches Forschungsinstitut at Technische Universität München
CoM	centre of mass	DGNSS	Differential Global Navigation Satellite Systems
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate	DiFX	Distributed FX
COSPAR	Committee on Space Research	DIODE	Détermination Immédiate d'Orbite par Doris Embarqué
CPC	Climate Prediction Center	DIS	IERS Data and Information System
CPF	Consolidated [Laser Ranging] Prediction Format	DIS	ISO Draft International Standard
CPO	celestial pole offset	DLR	Deutsches Zentrum für Luft- und Raumfahrt
CRD	Consolidated Laser Ranging Data Format	dNEH	delta north, east, hight
CRF	Celestial Reference Frame	doi, DOI	Digital Object Identifier
CSR	Center for Space Research, University of Texas	DOMES	Directory Of MERIT Sites (originally; now of more general use)
CSTG	Commission on International Coordination of Space Techniques for Geodesy and Geodynamics	DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)
CTIO	Cerro Tololo Inter-American Observatory	DOR-O-T	DORIS Online Tools
CU	[DPAC] Coordination Unit	DPAC	Data Processing and Analysis Consortium [of the Gaia mission]
curl	Client for URLs (or: Curl URL Request Library)	DST	Deep South Telescope
d	day	DTRF	ITRS realization by DGFI
DB	Directing Board	DUT1	= UT1–UTC
DC	Data Center	E	East [position/coordinate/direction]
DC	District of Columbia, USA	EAM	Effective Angular Momentum
		EC	Executive Committee

ECCO	Estimating the Circulation and Climate of the Ocean	ftp, FTP	File Transfer Protocol
ECMWF	European Centre for Medium-Range Weather Forecasts	GA	General Assembly
EDC	EUROLAS Data Center	GA	Geoscience Australia
EGU	European Geosciences Union	GaiaNIR	Gaia Near Infra-Red [mission]
EGV	Essential Geodetic Variable(s)	GB	Governing Board
EMPIR	European Metrology Programme for Innovation and Research	Gb	gigabit
EMR	Energy, Mines and Resources Canada (replaced by NRCan)	GDR	Gaia Data Release
ENVISAT	Environmental Satellite	GfZ	GeoForschungsZentrum Potsdam
EO	Earth orientation	GGFC	Global Geophysical Fluids Centre
EOC	Earth Orientation Centre	GGIM	= UN GGIM
EOP	Earth Orientation Parameters	GGOS	Global Geodetic Observing System
EOST	École et Observatoire des Science de la Terre	GHz	gigahertz
ESA	European Space Agency	GIOVE	Galileo In-Orbit Validation Element
ESOC	European Space Operations Center, ESA	GIQC	Gaia Initial Quasar Catalog[ue]
Eumetsat	European Organisation for the Exploitation of Meteorological Satellites	GLDAS	NASA's Global Land Data Assimilation System
EVGA	European VLBI [Group] for Geodesy and Astrometry	GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema [Global Orbiting Navigation Satellite System, Russia]
e-VLBI	Electronic transfer VLBI	GLOUP	GLObal Undersea Pressure
FFT	Fast Fourier Transformation	GM	General Meeting
FNMOCC	[US Navy] Fleet Numerical Meteorology and Oceanography Center	GNSS	Global Navigation Satellite System
FP	fundamental plane	GOP	Geodetic Observatory Pecny
FR	full rate	GP	Galactic plane
FRAMEx	Fundamental Reference AGN Monitoring Experiment	GPS	Global Positioning System
		GRACE	Gravity Recovery and Climate Experiment
		GRACE-FO	GRACE Follow-On
		GRAIL	Gravity Recovery and Interior Laboratory
		GRG	DORIS Analysis Center at CNES/CLS (formerly LCA)

GRGS	Groupe de Recherches de Géodésie Spatiale	IERS	International Earth Rotation and Reference Systems Service (formerly: International Earth Rotation Service)
GSC	GSFC Analysis Center		
GSFC	Goddard Space Flight Center	IfE	Institut für Erdmessung [Institute of Geodesy], University of Hannover
GSI	Geospatial Information Authority of Japan (formerly: Geographical Survey Institute)	IGMA	ICG Monitoring and Assessment Task Force
HartRAO	Hartebeesthoek Radio Astronomy Observatory	IGN	Institut National de l'Information Géographique et Forestière (formerly: Institut Géographique National)
HEO	High Earth Orbiter		
HF-EOP	High Frequency EOP	IGR	IGS rapid [products / satellite orbits]
hr	hour, hours	IGS	International GNSS Service (formerly: International GPS Service)
HTTPS	Hypertext Transfer Protocol Secure		
HY	HaiYan / Haiyang / Hai Yang [satellite]	IGS-RTS	IGS Real-Time Service
IAA	Institute of Applied Astronomy, St. Petersburg	IIUL	integrated IGS Ultra LODs
IAG	International Association of Geodesy	ILRS	International Laser Ranging Service
IAU	International Astronomical Union	INA	(Institute of Astronomy of the Russian Academy of Sciences)
ICD	Interface Control Document	INASAN	(Institute of Astronomy of the Russian Academy of Sciences)
ICESat	Ice, Cloud, and land Elevation Satellite	INFN	Istituto Nazionale di Fisica Nucleare [National Institute for Nuclear Physics]
ICG	International Committee on Global Navigation Satellite Systems	Int.	Intensive [VLBI session]
ICRF	International Celestial Reference Frame	IPGS	Institut de Physique du Globe de Strasbourg
ICRS	International Celestial Reference System	IR	infrared
ICSU	International Council for Science	IRIS	International Radio Interferometric Surveying
ID	Identification/Identifier	IRNSS	Indian Regional Navigation Satellite System
IDF	International DOI Foundation		
IDS	International DORIS Service	ISBN	International Standard Book Number

ISC	International Science Council (formerly ICSU)	LDAS	Land Data Assimilation System
ISO	International Organization for Standardization	LEO	Low Earth Orbit(er)
ITRF	International Terrestrial Reference Frame	LLR	Lunar Laser Ranging
ITRS	International Terrestrial Reference System	LoD, LOD	Length of Day
ITU	International Telecommunication Union	lon	longitude
IUGG	International Union of Geodesy and Geophysics	LQAC	Large Quasar Astrometric Catalog[ue]
IVS	International VLBI Service for Geodesy and Astrometry	LRO	Lunar Reconnaissance Orbiter
IWLR	International Workshop on Laser Ranging	LS	least-squares
Jason-CS	Jason Continuity of Service [mission]	LSDM	Land Surface Discharge Model
JCET	Joint Center for Earth Systems Technology, GSFC	LT	local tie
JMA	Japan Meteorological Agency	MA	Massachusetts, USA
JPL	Jet Propulsion Laboratory	mag	magnitude
JTRF	ITRS realization by JPL	mas	milliarcsecond(s)
KALREF	Kalman filter for Reference frames	Mb	megabit
keV	kiloelectronvolt	MCC	Russian Mission Control Centre
kHz	kilohertz	MD	Maryland, USA
LAGEOS	Laser Geodynamics Satellite	MeO, MEO	Métrieologie Optique [Grasse SLR/LLR system]
LAREG	Laboratoire de Recherches en Géodésie	MGEX	Multi-GNSS [Global] Experiment, Multi-GNSS Extension
LARES	Laser Relativity Satellite	MilliQuas	Million Quasars Catalog
LARGE	Laser Ranging to GNSS s/c Experiment	MIT	Massachusetts Institute of Technology
lat	latitude	MJD	Modified Julian Day
LBO	Long Baseline Observatory	MLRO	Matera Laser Ranging Observatory
		Mpc	megaparsec
		MPIfR	Max-Planck-Institut für Radioastronomie / Max Planck Institute for Radio Astronomy
		ms	millisecond(s)
		msec	milliseconds
		N	number

N	North [position/coordinate/direction]	NSOAS	National Satellite Ocean Application Service
N, E	north, east	NT	non-tidal
NASA	U.S. National Aeronautics and Space Administration	NT-AL	non-tidal atmospheric loading
NAVDEM	[U.S.] Navy Global Environmental Model	NT-ATML	non-tidal atmospheric loading
NCAR	U.S. National Center for Atmospheric Research	NT-L	non-tidal loading
NCEP	U.S. National Centers for Environmental Prediction	OAM	Oceanic Angular Momentum
NGEO	National Geophysical Observatory for Geoscience	Obs.	Observatory, Observatoire, Observatório
NGS	U.S. National Geodetic Survey	OC	Organizing Committee
NICT	National Institute of Information and Communications Technology (formerly: CRL)	OCA	Observatoire de la Côte d'Azur
NIR	near-infrared	OHIG	O'Higgins [station]
NISAR	NASA-ISRO Synthetic Aperture Radar [satellite]	OOC	IVS Office for Outreach and Communication
NNR	No-net-rotation, No Net Rotation	OP, OPA	Observatoire de Paris
No., Nos.	Number, Numbers	OS	operating system
NOAA	U.S. National Oceanic and Atmospheric Administration	OSTST	Ocean Surface Topography Science Team
NOFS	[U.S.] Naval Observatory Flagstaff Station	PC	Product Centre
NP	SLR normal point(s)	PI	Principal Investigator
NRAO	U.S. National Radio Astronomy Observatory	PLATO	Performance Simulations & Architectural Trade-Offs
NRCan	Natural Resources, Canada (formerly: EMR)	PM	Polar Motion
NRT	Near Real-Time (products)	PNT	positioning, navigation and timing
ns	nanosecond(s)	POD	Precise [or Precision] Orbit Determination
NSF	US National Science Foundation	POE	Precise Orbit Comparison
		POLAC	Paris Observatory Lunar Analysis Center
		PP	Pilot Project
		ppb	parts per billion (10 ⁻⁹)
		PPP	Precise Point Positioning

PPP-AR	Precise Point Positioning with ambiguity resolution	SB	Special Bureau
ps	picosecond(s)	SBA	Special Bureau for the Atmosphere
PSMSL	Permanent Service for Mean Sea Level	SBCP	Special Bureau for Combined Products / Special Bureau for the Combination Products
PT	Project Team	SBH	Special Bureau for Hydrology
PUL	Pulkovo Observatory	SBO	Special Bureau for the Oceans
QC	quality control	SC	Special Committee
QCB	Quality Control Board	SDev	standard deviation
QSO	Quasi-Stellar Object [quasar]	SDSS	Sloan Digital Sky Survey
QZSS	Quasi-Zenith Satellite System	sec	second(s) [of time]
RA	right ascension	SHOM	Service hydrographique et océanographique de la Marine [Naval Hydrographic and Oceanographic Service]
RB	range bias	SIC	Satellite Identification Code
RDV	Research and Development (sessions) with the VLBA	SINEX	Solution (Software/technique) INdependent EXchange Format
RINEX	Receiver INdependent EXchange format	SIO	Scripps Institution of Oceanography
RMS	Root Mean Square	SIRGAS	Sistema de Referencia Geocéntrico para Las Américas
RRFID	USNO Radio Reference Frame Image Database	SLR	Satellite Laser Ranging
RS/PC	IERS Rapid Service/Prediction Center	SOFA	Standards Of Fundamental Astronomy
RT	real-time	SOKENDAI	Graduate University for Advanced Studies
RT-AC	Real-Time Analysis Center	SPOT	Satellite Pour l'Observation de la Terre
RT-CC	Real-Time Combination Center	SRIF	Square Root Information Filter array
RTCM	Radio Technical Commission for Maritime Services	SRP	solar radiation pressure
RTS	IGS Real-Time Service	SSALTO	Segment Sol multi-mission d'ALTimétrie, d'Orbitographie et de localisation précise
s/c	spacecraft	SSEM	Station Systematic Error Monitoring
SAA	South Atlantic Anomaly	STD	standard deviation
SARAL	Satellite with ARGOS and ALTIKA		
Sat.	satellite		

STM	Science Team Meeting	UAW	GGOS Unified Analysis Workshop
SWOT	Strengths, Weaknesses, Opportunities, and Threats [analysis]	UBAD	USNO Bright-Star Astrometric Database
SWOT	Surface Water Ocean Topography [mission]	UCAC	USNO CCD Astrograph Catalog
SYRTE	Systèmes de Référence Temps-Espace [department]	UCAR	University Corporation for Atmospheric Research
T2L2	Time Transfer by Laser Link	UH	University of Hawaii
TAI	Temps Atomique International (International Atomic Time)	UK	United Kingdom
Tb	terabyte	UKIDSS	UKIRT Infrared Deep Sky Survey
TB	time bias	UKIRT	United Kingdom Infrared Telescope
TBD	to be defined	UKMO	Met Office (formerly: UK Meteorological Office)
TC	Technique Centre	UMBC	University of Maryland, Baltimore County
TEC	Total Electron Content (Total Electron Count)	UN	United Nations
TECU	TEC Unit	UNAVCO	University Navstar Consortium
TIGO	Transportable Integrated Geodetic Observatory	UNB	University of New Brunswick
TIO	terrestrial intermediate origin	UN-GGIM	Global Geospatial Information Management Initiative of the UN
TN	IERS Technical Note	unWISE	unofficial, unblurred coadds of the WISE imaging
ToR	Terms of Reference	URAT	USNO Robotic Astrometric Telescope
TOW	Technical Operations Workshop	URL	Uniform Resource Locator
TRF	Terrestrial Reference Frame	US, U.S.	United States
TT	Terrestrial Time	USGS	U.S. Geological Survey
TU	Technical University	USNO	United States Naval Observatory
TUM	Technische Universität München (Technical University of Munich)	USO	Ultra Stable Oscillator
TVG	time-variable gravity	UT, UT0, UT1	Universal Time
TWS	terrestrial water storage	UTAAM	NCEP [or NOAA] AAM analysis and forecast data
TX	Texas, USA	UTC	Coordinated Universal Time
U	Up [position/coordinate/direction]		