International Earth Rotation and Reference Systems Service (IERS)

http://www.iers.org

Chair of the Directing Board: Tonie van Dam (Luxembourg/USA)
Director of the Central Bureau: Daniela Thaller (Germany)

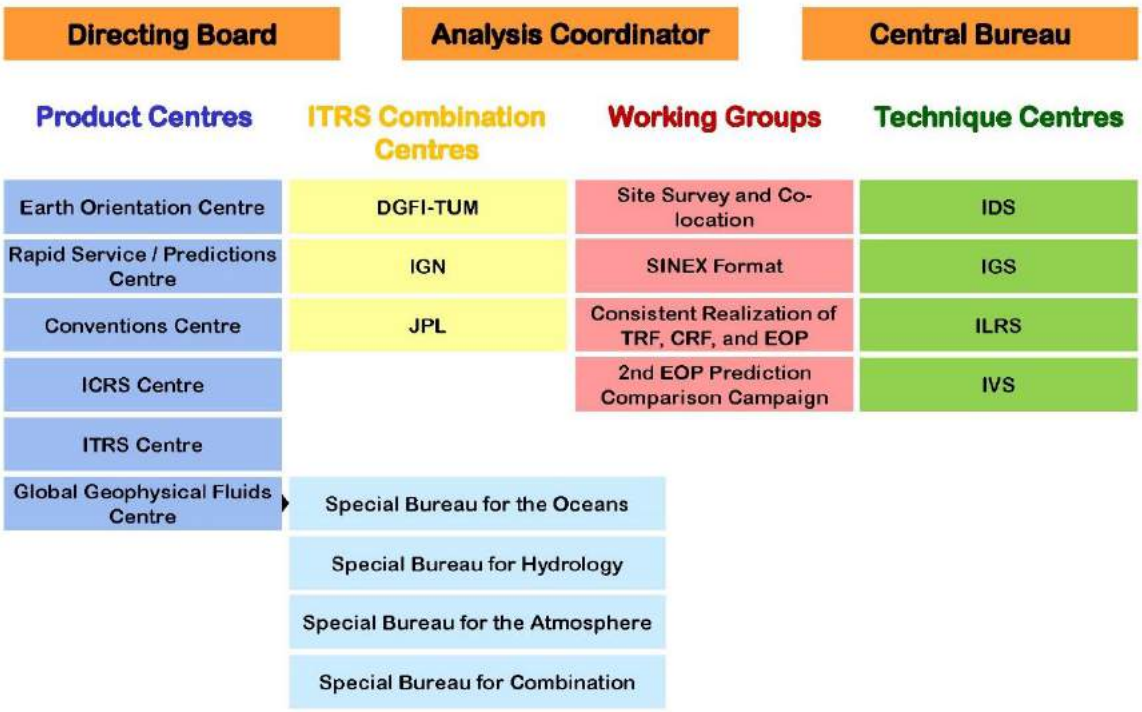
Structure

According to the Terms of Reference, the IERS consists of the following components:

- Directing Board
- Technique Centres
- Product Centres
- ITRS Combination Centre(s)
- Analysis Coordinator
- Central Bureau
- Working Groups

The Technique Centres are autonomous operations, structurally independent from the IERS, but which cooperate with the IERS.

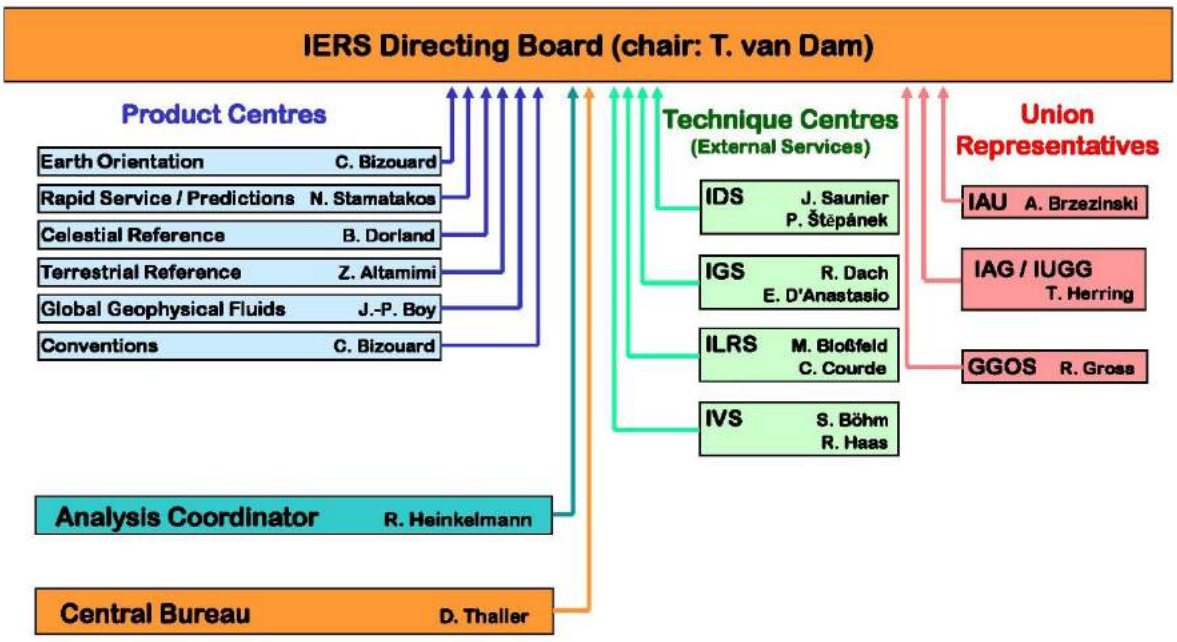
As of June 2023, the IERS consists of the following components:



Responsible persons are (as of June 2023):

- Product centres
  - Earth Orientation Centre: *Christian Bizouard (France)*
  - Rapid Service/Prediction Centre: *Nick Stamatakos (USA)*
  - Conventions Centre: *Christian Bizouard (France), Nick Stamatakos (USA)*
  - ICRS Centre: *Bryan Dorland (USA), Jean Souchay (France)*
  - ITRS Centre: *Zuheir Altamimi (France)*
  - Global Geophysical Fluids Centre: *Jean-Paul Boy (France), Tonie van Dam (Luxembourg)*
    - Special Bureau for the Oceans: *Henryk Dobslaw (Germany)*
    - Special Bureau for Hydrology: *Jianli Chen (Hong Kong)*
    - Special Bureau for the Atmosphere: *David Salstein (USA)*
    - Special Bureau for Combination: *Tonie van Dam (Luxembourg)*
- ITRS Combination Centres
  - Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM): *Manuela Seitz (Germany)*
  - Institut National de l'Information Géographique et Forestière (IGN): *Zuheir Altamimi (France)*
  - Jet Propulsion Laboratory (JPL): *Richard Gross (USA)*
- Analysis Coordinator: *Robert Heinkelmann (Germany)*
- Central Bureau: *Daniela Thaller (Germany)*
- Working groups
  - IAG/IERS Working Group on Site Survey and Co-location: *Ryan Hippenstiel* (USA), *Sten Bergstrand (Sweden)*
  - Working Group on SINEX Format: *Daniela Thaller (Germany)*
  - IAG/IAU/IERS Joint Working Group on the Consistent Realization of TRF, CRF, and EOP: *Robert Heinkelmann (Germany), Manuela Seitz (Germany)*
  - Working Group on the 2nd Earth Orientation Parameter Prediction Comparison Campaign: *Jolanta Nastula (Poland), Henryk Dobslaw (Germany)*

The current members of the Directing Board (representatives of scientific unions and of IERS' components) are:



Overview

The International Earth Rotation and Reference Systems Service continues to provide Earth orientation data, terrestrial and celestial references frames, as well as geophysical fluids data to the scientific and other operationally oriented communities.

Earth orientation data have been issued on a sub-daily, daily, weekly, and monthly basis, and new global geophysical fluids data were added. The Earth Orientation Centre improved its software and applied several corrections to the 14 C04 EOP series. The Rapid Service / Prediction Centre transitioned their EOP solution to be consistent with the 14 C04 for polar motion, UT1-UTC, and celestial pole offsets.

The IERS continued to ensure that the user community has the most up-to-date terrestrial reference frame by providing the International Terrestrial Reference Frame 2020 (ITRF2020). The three ITRS Combination Centres (DGFI, IGN, JPL) improved their combination software for ITRF2020 and made test analyses with preliminary data. The final re-analysis data from IDS, IGS, ILRS, and IVS were submitted in April 2021, and in April 2022 ITRF2022 was released by the ITRS Centre. The ITRS Combination Centres at DGFI and JPL published DTRF2020 and JTRF2020 in 2023. The ITRS Centre and the corresponding working group also participated in surveys of co-located sites.

A new realization of the International Celestial Reference System (ICRF3) was officially adopted by IAU on January 2019. Comparisons were made between the ICRF3 and preliminary versions of the Gaia optical reference frame.

Work on technical updates to the IERS Conventions (2010) was continued, with updates of existing content, expansion of models, and introducing new topics. Several chapters have been revised by the Conventions Centre. A new printed version of the Conventions is in preparation. This version will incorporate a new style so that the main document will be greatly reduced in length, which will enhance the usability of the conventions for the general practitioner.

Members of the Working Group (WG) on Site Survey and Co-location participated in several local tie measurements. Automated monitoring with terrestrial instruments was further developed. Additional local tie surveys were collected following a call from the ITRS Centre, in preparation for ITRF2020. The WG on SINEX Format worked (with other IERS components) on modifications and revisions of the format, particularly for the provision of loading corrections and of SLR range biases in SINEX files. These new blocks were already applied for SINEX files generated along with the ITRF2020 computation. The WG on Site Coordinate Time Series Format, responsible for the definition of a common exchange format for coordinate time series for all geodetic techniques, was dissolved in May 2020. At the same time the IAG/IAU Joint Working Group on the Consistent Realization of TRF, CRF, and EOP was also established as an IERS WG. It will compute multi-technique CRF-TRF solutions together with EOP in one step, which will serve as a basis to quantify the consistency of the current conventional reference frames and EOP as well as to assess the consistency of reprocessed and predicted EOP. A new WG on the 2nd Earth Orientation Parameter Prediction Comparison Campaign was established in March 2021. It will re-assess the various EOP prediction capabilities by collecting and comparing operationally processed EOP predictions from different agencies and institutions over a representative period of time, with the aim to evaluate the accuracy of final estimates of EOP, to identify accurate (reliable) prediction methodologies, and to assess the inherent uncertainties in present-day EOP predictions.

The IERS continued to issue Technical Notes, Annual Reports, Bulletins, and electronic newsletters. It co-organized two GGOS/IERS Unified Analysis Workshops (UAW), October 2–4, 2019 in Paris and October 21–23, 2022 in Thessaloniki. The final reports provide thorough

summaries of the workshops as well as conclusions and recommendations from the discussions (see GGOS and IERS websites).[1]

The IERS Data and Information System (DIS) at the web site www.iers.org, maintained by the Central Bureau, has been updated, improved and enlarged continually. It presents information related to the IERS and the topics of Earth rotation and reference systems. As the central access point to all IERS products it provides tools for searching within the products (data and publications), to work with the products and to download them. The DIS provides links to other servers, among these to about 10 web sites run by other IERS components.

Publications

The following IERS publications and newsletters appeared between mid-2019 and June 2023:

- IERS Technical Note No. 40 (2020): Z. Altamimi and W. R. Dick (eds.): Description and evaluation of DTRF2014, JTRF2014 and ITRF2014
- IERS Annual Report 2018
- IERS Bulletins A, B, C, and D (daily[2] to half-yearly)
- IERS Messages Nos. 378 to 477

IERS Directing Board

The *IERS Directing Board* (DB) met twice each year to decide on important matters of the Service such as structural changes, overall strategy, creating working groups, launching projects, changing Terms of Reference, etc. Due to the pandemic situation, the DB meetings between 2020 and 2022 were held as virtual meetings.

- Meeting No. 69 in San Francisco, December 8, 2019;
- No. 70, video conference, May 13, 2020;
- No. 71, video conference, November 18, 2020;
- No. 72, video conference, May 4 and 20, 2021.
- No. 73, video conference, November 10 and December 9, 2021
- No. 74, video conference, May 12 and June 9, 2022
- No. 75, video conference, December 7, 2022
- No. 76 in Vienna, April 23, 2023

Among the most important decisions made by the DB in 2019–2023 were the following:

- Elected Tonie van Dam as Chair of the Directing Board (2021–2024).
- Confirmed extended list of IERS Associate Members.
- Dissolved Working Group on Site Coordinate Time Series Format.
- Established IAG/IAU Joint Working Group on the Consistent Realization of TRF, CRF, and EOP also as an IERS WG.
- Established Working Group on the 2nd Earth Orientation Parameter Prediction Comparison Campaign.
- Established Working Group for preparing the usage of the GENESIS mission for future reference frame realizations.

[1] https://ggos.org/event/uaw-unified-analysis-workshop-2019/ and https://www.iers.org/IERS/EN/Organization/Workshops/workshops.html

[2] Most users consider the "Bulletin A" IERS RS/PC product to contain EOP estimates updated at both daily and weekly intervals. The daily products are meant to be machine-readable; whereas, the weekly, original Bulletin A product is in a human-readable format and produced on Thursdays.

- Decided on establishing a new procedure for regularly (i.e. yearly) updating ITRF by adding data of the most recent years. The next update is foreseen already for 2024.

Technique Centres

The Technique Centres (TC) are autonomous independent services, which cooperate with the IERS:

- *International GNSS Service* (IGS)
- *International Laser Ranging Service* (ILRS)
- *International VLBI Service for Geodesy and Astrometry* (IVS)
- *International DORIS Service* (IDS)

For details about the work of the TCs, see their individual reports to IAG.

Product Centres

Earth Orientation Centre

Primary scientist: Christian Bizouard (France)

Overview

According to the IERS Terms of Reference, the IERS Earth Orientation Centre (EOC) is responsible for monitoring Earth Orientation Parameters including long-term consistency, publications for time dissemination (DUT1) and leap second announcements. Earth Rotation Parameters (ERPs: Polar motion, Universal Time (UT1), Length of Day (LOD) and Celestial pole offsets) are available to a broad community of users in various domains such as astronomy, geodesy, geophysics, space sciences and time. ERPs are initially collected in the form of combined solutions derived by the Technique Centres (IGS, IVS, ILRS and IDS). Two main solutions are computed: a long-term solution (IERS C01) that starts in 1846 and extends 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. The EOC is located at Paris Observatory.

Activities during the period 2019–2023

The EOC improved its software and applied several corrections to the 14 C04 EOP series. ITRF2020 was implemented in the EOP products starting with 14 February 2023. The official IERS 20 C04 final solution replaced the 14 C04 series. No leap seconds were issued through Bulletin C due to an acceleration of Earth's rotation.

In October 2019, the EOC organized the *Journées Systèmes de Référence Spatio-temporels "Astrometry, Earth Rotation and Reference System in the Gaia era"* and edited the proceedings. A similar workshop planned for 2020 had to be postponed due to the Corona pandemic.

In addition, members of the EOC had a flourishing scientific activity, reflected by several scientific papers in peer-review journals and a book with de Gruyter.

Selected publications

Bizouard, C. (2020): Geophysical modelling of the polar motion, de Gruyter Studies in Mathematical Physics 31, 370 p., DOI 10.1515/9783110298093

Bizouard, C. (ed.) (2020): Proceedings of the Journées Systèmes de Référence Spatio-temporels 2019 "Astrometry, Earth Rotation and Reference System in the Gaia era". Paris: Observatoire de Paris. *Includes several contributions by the EOC.*

Bizouard, C.; Nurul Huda, I.; Ziegler, Y.; Lambert, S. (2020): Frequency dependence of polar motion resonance, Geophysical Journal International 220(2):753–758, DOI 10.1093/gji/ggz463

Couhert, A.; Bizouard, C.; Mercier, F.; Chanard, K.; Greff, M.; Exertier, P. (2020): Consistent determination of the three first-degree Earth gravity coefficients, Journal of Geodesy 94(12), DOI 10.1007/s00190-020-01450-z

Lambert, S.; Nurul-Huda, I.; Ziegler, Y.; Richard, J. -Y.; Liu, N.; Gattano, C.; Rosat, S.; Bizouard, C. (2019): Measurement of Earth's Nutation by VLBI: Direct Estimates from VLBI Delays and a Discussion on the Error. In: International VLBI Service for Geodesy and Astrometry 2018 General Meeting Proceedings: "Global Geodesy and the Role of VGOS – Fundamental to Sustainable Development", Eds. K. L. Armstrong, K. D. Baver, D. Behrend, NASA/CP-2019-219039, p. 204–208

Nurul Huda, I.; Lambert; S., Bizouard; C.; Ziegler, Y. (2020), Nutation terms adjustment and implication for the Earth rotation resonance parameters, Geophysical Journal International 220(2), 759–767, DOI 10.1093/gji/ggz468

Nurul Huda, I. (2019): Etude des propriétés rhéologiques globales de la Terre à l'aune des observations VLBI, thèse de doctorat en Astronomie et Astrophysique (Observatoire de Paris)

Puente, V.; Richard, J. Y.; Folgueira, M.; Capitaine, N.; Bizouard, C. (2019): Comparison of VLBI-based Luni-solar Nutation Terms. In: Proceedings of the 24th European VLBI Group for Geodesy and Astrometry Working Meeting, 17–19 March 2019, Las Palmas de Gran Canaria, Spain, Eds. R. Haas, S. Garcia-Espada, and J. A. López Fernández, ISBN 978-84-416-5634-5, pp. 257–226

Rapid Service/Prediction Centre

Primary scientist: Christine Hackman (USA), until Dec. 2020. Nick Stamatakos (USA), since Dec. 2020
Production director and lead project scientist: Nick Stamatakos (USA)

Overview

The Rapid Service/Prediction Centre (RS/PC) provides high-quality Earth orientation estimates/predictions on a rapid turnaround basis, primarily for real-time-users. It issues the weekly IERS Bulletin A and corresponding data files, as well as daily and four-times-daily EOP estimate/prediction values. The centre also conducts research toward improving the accuracy and/or production robustness of its products. Lastly, the centre maintains a web-based Earth orientation matrix calculator that provides the full direction cosine matrix between celestial and terrestrial reference frames based on IERS conventions and given calendar date and time inputs.

Activities and publications during the period 2019–2023

In an effort to improve its EOP combination and short-term prediction results, the RS/PC contracted with Virginia Tech University to develop a better smoothing, weighted cubic spline (SWCP) implementation. The resulting new spline software was developed in MATLAB, and has the ability to combine state and derivate inputs (such as UT1–UTC and LOD). It was used to aid in improving the pre-processing of IGS Ultra Observation LOD and AAM forecasts before using those series as inputs to the newly-developed SWCP. Using the newly developed pre-processing and SWCP resulted in gains of 40% in 0-day prediction accuracy and 25% in 1-day prediction accuracy. Longer term prediction accuracies are still being reviewed (Stamatakos et al. 2021).

The RS/PC continued to study the effects of implementing atmospheric angular momentum (AAM) and oceanic angular momentum (OAM) values/predictions in its Polar Motion EOP

estimation/prediction algorithms. Findings were published in posters presented at the AGU 2020 fall meeting and the EGU 2021 spring meeting.

As of 24 October 2019, the U. S. Naval Observatory's IERS RS/PC web/FTP sites (maia.usno.navy.mil and toshi.nofs.navy.mil) and the IERS Conventions web site (maia.usno.navy.mil/conventions), were taken offline as they undergo modernization. An Amazon gov-Cloud site that would host EOP results may be available sometime in late 2021; whereas, a USNO-sponsored site to host the web-based Earth orientation matrix calculator and IERS Conventions would take longer.

Stamatakos, N., McCarthy, D., and Salstein, D.: IERS Rapid Service Prediction Center Use of Atmospheric Angular Momentum for Earth Rotation Predictions, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-1917, DOI 10.5194/egusphere-egu21-1917

Conventions Centre

Primary scientists: Christian Bizouard (France), Nick Stamatakos (USA)

Overview

The Conventions Centre is continuing work on technical updates to the IERS Conventions (2010), with updates of existing content, expansion of models, and introducing new topics as needed. The Conventions site is located at: http://iers-conventions.obspm.fr, Observatoire de Paris.

Activities and publications during the period 2019–2023

Until 24 October 2019, the conventions was co-hosted at maia.usno.navy.mil; however, due to a continued modernization effort of the maia site, a USNO-sponsored site to host the Conventions is delayed probably beyond calendar year 2023.

A versioning system has been implemented to handle intermediate updates of the conventions. The centre continued recruiting a group of talented experts in the field to work on updating the IERS Conventions. In 2018, it issued a Call for Participation in the next IERS Conventions. As of June 2023, over 15 experts have agreed to aid with this rewrite of the IERS Conventions.

ICRS Centre

Primary scientists: Bryan Dorland (USA), Jean Souchay (France)

Overview

The IAU has charged the IERS with the responsibility of monitoring the International Celestial Reference System (ICRS), maintaining its current realization, the International Celestial Reference Frame (ICRF), and maintaining and improving the links with other celestial reference frames. Starting in 2001, these activities have been run jointly by the ICRS Centre (Observatoire de Paris and US Naval Observatory) of the IERS and the International VLBI Service for Geodesy and Astrometry (IVS), in coordination with the IAU.

Activities during the period 2019–2023

Involvement by ICRS Centre personnel in the construction of the celestial reference frame from VLBI programs has continued, in particular from the participation in extensive observing programs. The ICRS Centre has fulfilled various tasks devoted to the monitoring of ICRF sources, the link with the dynamical system (in particular through LLR), the construction of new updates of the LQAC (Large Quasar Astrometric Catalogue) and of the LQRF (Large Quasar Reference Frame). A new realization of the International Celestial Reference System

(ICRF3) was officially adopted by IAU on January 2019. Comparisons were made between the ICRF3 and preliminary versions of the Gaia optical reference frame.

Selected publications

Dorland, B.; Secrest, N.; Johnson, M.; Fischer, T.; Zacharias, N.; Souchay, J.; Lambert, S.; Barache, C.; Taris, F. (2020): The Fundamental Reference AGN Monitoring Experiment (FRAMEx). In: Proceedings of the Journées 2019 "Astrometry, Earth Rotation, and Reference Systems in the GAIA era", Observatoire de Paris, Paris, France, 7–9 October 2019, Ed. C. Bizouard, pp. 165–171

Fischer, T.C.; Secrest, N.J.; Johnson, M.C.; Dorland, B.N.; Cigan, P.J.; Fernandez, L.C.; Hunt, L.R.; Koss, M.; Schmitt, H.R.; Zacharias, N.: Fundamental Reference AGN Monitoring Experiment (FRAMEx). I. Jumping Out of the Plane with the VLBA. The Astrophysical Journal 906(2), id. 88, 19 pp., DOI 10.3847/1538-4357/abca3c

ITRS Centre

Primary scientist: Zuheir Altamimi (France)

Overview

The main activities of the ITRS Centre during the period 2019–2023 include the maintenance of the ITRF network, database and website. The ITRS Centre, according to the IERS ToR, is responsible, among other duties, for the maintenance and update of the ITRF network database and its provision to the users through the ITRF website. 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 ITRF web site, available at <http://itrf.ign.fr>, provides an interface to consult the IERS network database. Site and point information can be requested online; it contains approximate coordinates of the sites, the list of their points as well as their descriptions, their DOMES numbers and the list of ITRF versions in which they have been computed. Subsets of points can be selected and their ITRF coordinates can be requested at any epoch in any ITRF version if their coordinates are provided in the requested ITRF version.

Main activities and publications during the period 2019–2023

The main activities of the ITRS Centre during this period include:

- Preparation for ITRF2020. After the release of the ITRF2020 Call for Participation (CfP) which was published at the end of 2018 (see: http://itrf.ign.fr/doc_ITRF/CFP-ITRF2020.pdf), the ITRS Center continued the dialog with the 4 Technique Centers (TCs) for the preparation of their inputs to the ITRF2020. The ITRS Center emphasized the need for the TCs to implement the new recommended models which are annexed to the ITRF2020 CfP. The ITRS Center has in particular attended most meetings of the analysis working groups of the Technique Centres (in 2019: IDS, IGS, ILRS and IVS).
- The ITRS Center hosted the Unified Analysis Workshop 2019 at Institut de Physique de Globe de Paris, during 2–4 October, 2019. A number of the technique presentation addressed the preparation for the ITRF2020, including the implementation of updated models and analysis strategies.
- At the initiative of the ITRS Center, and with the help of the IERS Central Bureau, an IERS Technical Note (# 40) was published in order to, primarily; acknowledge the activities of the ITRS Combination Centers at DGFI and JPL, beside the ITRS Combination Center at IGN which is part of the ITRS Center (Altamimi and Dick,

2020). It includes the description of both DTRF2014 and JTRF2014, as well as their inter-comparisons with respect to the official IERS solution, the ITRF2014. The Technical Note was also intended to include evaluations of the three solutions by the IERS Technique Centers (IDS, IGS, ILRS and IVS) who constantly provide input solutions to the ITRF. In addition to DGFI, JPL and ITRS Center contributions, the Technical Note includes contributions from IDS, ILRS and IVS. A specific article by the ITRS Center evaluates the two solutions DTRF2014 and JTRF2014 with respect to the ITRF2014 (see IGN ITRS Combination Center Report below).

- Chapter 4 of the IERS Conventions has been re-written by the ITRS Center team which includes the following updates (IERS ITRS Center, 2019):
    - A description of ITRF2014, with its associated equations, to model the nonlinear station motions due to seasonal signals and post-seismic deformation of stations subject to major earthquakes.
    - A description of the mathematical model used in the ITRF combination.
    - A revision of Table 4.1, listing the transformation parameters relating ITRF2014 to previous ITRFs.
    - Improvements in wording and the removal of unnecessary paragraphs.
- Resolutions on ITRS/ITRF. The ITRS Center has prepared the text of an IUGG resolution on the ITRF which was adopted at the occasion of the IUGG General Assembly 2019 in Montreal, Canada, see:
  http:\\ www.iugg.org/resolutions/2019%20IUGG%20GA%20Resolutions.pdf.
- At its 9th Session, the UN-GGIM Committee of Experts supported the agreement of the Subcommittee on geodesy on the adoption of the International Terrestrial Reference System and the International Terrestrial Reference Frame as the standard for scientific, geospatial and operational geodetic applications. The ITRS Center has significantly contributed to the text of that agreement.
- 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 http://itrf.ign.fr, and should be sent to domes@ign.fr. An updated list of all available DOMES number is available at http://itrf.ign.fr/doc_ITRF/iers_sta_list.txt. The IERS site information is available to the users through the ITRF website interface. Several new stations, mainly GNSS permanent stations where added to the ITRF network and database.
- Finalization and publication of the ITRF2020. The ITRF2020 is provided as an augmented terrestrial reference frame that precisely models nonlinear station motions for both seasonal (annual and semi-annual) signals present in the station position time series and Post-Seismic Deformation (PSD) for sites impacted by major earthquakes. We evaluate the accuracy of the ITRF2020 long-term origin position and time evolution by comparison to previous solutions, namely ITRF2014, ITRF2008 and ITRF2005, to be at the level of or better than 5mm and 0.5mm/yr, respectively. The ITRF2020 long-term scale is defined by a rigorous weighted average of selected VLBI sessions up to 2013.75 and SLR weekly solutions covering the 1997.75–2021.0 time span. For the first time of the ITRF history, the scale agreement between SLR and VLBI long-term solutions is at the level of 0.15 ppb (1mm at the equator) at epoch 2015.0, with no drift. To accommodate most of ITRF2020 users, the seasonal station coordinate variations are provided in the CM as well as in the Center of Figure frames, together with a seasonal

geocenter motion model. While the PSD parametric models were determined by fitting GNSS data only, they also fit the station position time series of the three other techniques that are colocated with GNSS, demonstrating their high performance in describing site post-seismic trajectories.

- A website dedicated to the ITRF2020 results was established, providing to the users all the necessary information, including the computational strategy, scale and geocenter time series, station position residual time series and illustrations, as well as SINEX file per technique netoworks. A specific DOI is also assigned to the ITRF2020 data set.
- A full an open access article on ITRF2020 is available (Altamimi et al. 2023), published in Journal of Geodesy, detailing the analysis strategy as well as the main geodetic and geophysical results.

Altamimi, Z. and W.R. Dick (Eds.), (2020), Description and evaluation of DTRF2014, JTRF2014 and ITRF2014, IERS Technical Note 40, Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie. 167 p., ISBN 978-3-86482-137-0.

Altamimi, Z., Rebischung, P., Collilieux, X., Métivier, L., Chanard, K. (2023) ITRF2020: an augmented reference frame refining the modeling of nonlinear station motions. J Geod 97(47). https://doi.org/10.1007/s00190-023-01738-w

Altamimi, Z., Rebischung, P., Collilieux, X., Métivier, L., Chanard, K. (2022) ITRF2020 [Data set]. IERS ITRS Center Hosted by IGN and IPGP,

https://doi.org/10.18715/IPGP.2023.LDVIOBNL

Altamimi, Z., Rebischung, P., Collilieux, X., Métivier, L., Chanard, K., 2022, ITRF2020 and the IVS contribution, Proceedings of the IVS General Meeting 2022.

IERS ITRS Center, (2019), Chapter 4 of the IERS Conventions (Terrestrial reference systems and frames), available at https://iers-conventions.obspm.fr/chapter4.php.

Global Geophysical Fluids Centre

Primary scientist: Jean-Paul Boy (France)
Co-chair: Tonie van Dam (Luxembourg/USA)

Overview

The Global Geophysical Fluid Centre (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 (http://loading.u-strasbg.fr/GGFC). These include fluid motions with 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 until Dec. 2020, H. Dobslaw from Jan. 2021), 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.

Activities and publications during the period 2019–2023

The Special Bureau for the Atmosphere (SBA) is concerned with the atmospheric information that is needed for a number of geodetic issues. During the period of this report, the SBA maintained series of the atmospheric angular momentum (AAM) vector, which can be used for analysis and predictions of Earth rotation parameters.

The Special Bureau for the Oceans (SBO) is responsible for collecting, calculating, analysing, archiving, and distributing data relating to non-tidal changes in oceanic processes affecting the Earth's rotation and related parameters. A new website for the SBO hosted at GFZ Potsdam has been established (https://isdc.gfz-potsdam.de/ggfc-oceans/). The SBO invites all interested colleagues working in the field to contribute new ocean model simulations and/or ocean reanalyses as well as geodetically relevant derived quantities to the GGFC.

The Special Bureau for Hydrology (SBH) 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) and GRACE Follow-On satellite gravity measurements. The NASA GLDAS and GRACE/GRACE Follow-On data products are updated on a regular basis. SBH also provides gravity spherical harmonic representations of model-derived TWS changes. A new website for the SBH hosted at the Hong Kong Polytechnic University (PolyU), has been established (https://www.polyu.edu.hk/lsgi/ggfc/).

At the beginning of 2017, GFZ Potsdam as one of the providers of combinational products introduced major changes to their data series (atmospheric, oceanic and hydrological loading). The products are consistent with the GRACE/GRACE-FO atmosphere and ocean dealiasing product AOD1B RL06, which is going to be replaced with RL07 by the end of the year 2021. It is expected that the combination product will be reprocessed back to the year 1975 shortly after the publication of AOD1B RL07.

In addition, GGFC produces loading time series (geocenter motion, time-variable gravity field and surface displacements) for the next reference frame ITRF2020. All products are available at http://loading.u-strasbg.fr/GGFC/itrf2020.php.

ITRS Combination Centres

Three ITRS Combination Centres (CCs) are responsible for providing ITRF products by combining ITRF inputs. Within the time frame covered by this report the CCs focused on the computation of the new ITRS realization 2014.

ITRS CC at DGFI-TUM

Primary scientist: Manuela Seitz (Germany)

Overview

DGFI-TUM has been acting as one of the ITRS Combination Centres within the IERS since 2001. The related activities are embedded into DGFI-TUM's research on the realization of Global Terrestrial Reference Frames within the research area Reference Systems.

Realizations of the ITRS are based on the combination of space geodetic observations of the four techniques VLBI, SLR, GNSS, and DORIS at globally distributed geodetic observatories. Respective input data are provided by the corresponding technique services (IVS, ILRS, IGS, IDS). The combination strategy developed at DGFI-TUM is based on the combination of normal equation systems, which allows for a pure physically realization of the origin and scale of the reference frames.

Activities and publications during the period 2019–2023

The CC at DGFI-TUM prepared and calculated the ITRS 2020 realization DTRF2020. In the framework of the development of the DOGS software and the compilation of a new DOGS version, the combination part DOGS-CS was improved with respect to the precision of the reference epochs of the parameters. This improves also all parameter transformations considering parameter epochs (e.g., the epoch transformation and the change of parameterization). Furthermore, now all meta-data given in the SINEX files can be stored in the DOGS internal format and transferred well through the combination process. In addition, the software APROPOS was developed, which allows for the approximation of post-seismic station motions by a combination of logarithmic and exponential functions. Thereby, also the relaxation time is considered as an unknown parameter. Thus, non-linear optimization algorithms are applied. The software is used within the DTRF2020 computation process to approximate post-seismic station motions, which are then reduced from the station positions (on normal equation level) in a preparatory step. During 2020, preliminary input data for the ITRS 2020 realization were provided by all Technique Services. These data were analyzed in order to test the new version of the DOGS-CS software and to give feedback to the Technique Centres.

In 2021 and 2022, the DTRF2020 was calculated covering the input data series from VLBI, SLR, GNSS, and DORIS from the beginning of the observation techniques between 1980 and 1994 to the end of 2020. The DTRF2020 is a linear frame and provides station positions at the reference epoch 2010.0 and velocities for 3594 station solutions for a network of 1829 stations. Consistently with the DTRF2020, Earth Orientation Parameter (EOP) time series are estimated. The DTRF2020 is characterized by the following features: it accounts for non-tidal station position displacements caused by atmospheric, hydrological and oceanic mass re-distributions provided by geophysical models. Moreover, it considers for the first time post-seismic deformations (see above). It is the first TRF solution that combines GNSS with VLBI data to realize the TRF scale. Furthermore, it is based on the combination of normal equation systems which reduces the impact of the technique-specific solutions (inclusive the respective datum realization) on the combined products. The DTRF2020 release contains, besides the solution itself, various data that allow the DTRF2020 to be applied by including non-linear station motions as well as to be used for detailed analyses of station and datum parameter time series. DTRF2020 is computed in parallel with ITRF2020. Due to its identifying features, It can be used as an independent reference frame and for evaluating the ITRF2020 to ensure a high quality of the IERS reference system and EOP products.

Angermann D., Bloßfeld M., Seitz M., Rudenko S.: Comparison of latest ITRS realizations: ITRF2014, DTRF2014 and JTRF2014. In: Altamimi Z., Dick W. R. (Eds.), IERS Technical Note No. 40, 2020

Bloßfeld M., Seitz M., Angermann D., Seitz F.: DTRF2014: DGFI-TUM realization of the International Terrestrial Reference System (ITRS). In: Altamimi Z., Dick W. R. (Eds.), IERS Technical Note No. 40, 2020

Glomsda M., Bloßfeld M., Seitz M., Seitz F. : Benefits of non-tidal loading applied at distinct levels in VLBI analysis. Journal of Geodesy, 94(9), 10.1007/s00190-020-01418-z, 2020

Glomsda M., Bloßfeld M., Seitz M., Seitz F.: Correcting for site displacements at different levels of the Gauss-Markov model – a case study for geodetic VLBI. Advances in Space Research, 10.1016/j.asr.2021.04.006, 2021

Glomsda M., Bloßfeld M., Seitz M., Angermann D., Seitz F.: Comparison of non-tidal loading data for application in a secular terrestrial reference frame. Earth, Planets and Space, 74(1), 10.1186/s40623-022-01634-1, 2022

Seitz M., Bloßfeld M., Angermann D., Seitz F.: DTRF2014: DGFI-TUM's ITRS realization 2014. Advances in Space Research, 69(6), 2391-2420, 10.1016/j.asr.2021.12.037, 2022

ITRS CC at IGN

Primary scientist: Zuheir Altamimi (France)

Main activities and publications during the period 2019–2023

- *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 below, 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 ppb at epoch 2010.0 and 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 and possible effects due to VLBI antenna gravity deformations. 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. Analysing 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. We expect that this scale offset will greatly minimize the scale discrepancy between SLR and VLBI in the coming ITRF2020 solution.
- *Contribution to the IERS Technical Note 40*. As reported in the ITRS Center report, this issue, an IERS Technical Note (# 40) was published in order to, primarily, acknowledge the activities of the ITRS Combination Centers at DGFI and JPL, beside the ITRS Combination Center at IGN which is part of the ITRS Center (Altamimi and Dick, 2020). The Technical Note includes in particular a specific article by the ITRS Center which evaluates the two solutions DTRF2014 and JTRF2014 with respect to the ITRF2014 (Altamimi et al., 2020). The article concludes in particular that (1) SLR and VLBI intrinsic and discrepant scales coexist in the DTRF and JTRF 2014 solutions, and (2) with respect to ITRF2014 and assuming that its scale is homogeneous, the scale offsets and rates between SLR and VLBI solutions embedded in DTRF2014 and JTRF2014 are respectively 1.32 and 1.21 ppb at epoch 2010.0 and 0.04 and 0.01 ppb/yr. These results are in almost perfect agreement with the results of ITRF2014 analysis.

Altamimi, Z., P. Rebischung, X. Collilieux, and L. Métivier (2020), ITRS Center evaluation of DTRF2014 and JTRF2014 with respect to ITRF2014. In: Altamimi, Z. and W. Dick (Eds.), 2019, IERS Technical Note 40, Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2020. 167 pp., ISBN 978-3-86482-137-0

Métivier, L., Altamimi, Z., and Rouby, H. (2020), Past and present ITRF solutions from geophysical perspectives, Advances in Space Research (65)12: 2711–2722, DOI 10.1016/j.asr.2020.03.031

Métivier, L., H. Rouby, P. Rebischung, and Z. Altamimi (2019), ITRF2014, Earth figure changes and geocenter velocity: implications for GIA and recent ice melting, Journal of Geophysical Research 125, e2019JB018333, DOI 10.1029/2019JB018333

See also the report of the ITRS Centre above.

ITRS CC at JPL

Primary scientist: Richard Gross (USA)

Overview

The ITRS Combination Centre at JPL focused on research regarding the representation of terrestrial reference frames by time series of smoothed positions of reference stations rather than by a parameterized model of the station positions. A Kalman filter and smoother for reference frames (KALREF) has been developed and used to determine time series representations of terrestrial reference frames. In addition, a square-root information filter for reference frames (SREF) is currently being developed that can be used to not only determine time series representations of terrestrial reference frames but that can also be used to jointly determine time series representations of terrestrial and celestial reference frames.

Activities and publications during the period 2019–2023

During 2019–2023, SREF continued to be developed. SREF allows a variable or fixed time step to be used to propagate the state vector and covariance matrix forward in time, includes a full process noise covariance matrix that will optionally allow regional correlations in station positions to be considered, includes linear, periodic, and postseismic displacement models for the evolution of the station positions, and can optionally process radio source coordinates and celestial pole offsets for joint TRF/CRF determinations. SREF was used to determine JTRF2020, JPL's submission to the IERS for ITRF2020. JTRF2020 was released on February 14, 2023 and SINEX files of the JTRF2020 station positions, including full covariance matrices, are available at <https://sideshow.jpl.nasa.gov/pub/JPL_SREF_PRODUCTS/JTRF2020>. In addition, time series and plots of the JTRF2020 station positions, EOPs, scale, geocenter, and Helmert transformation parameters are available from the JTRF website at <https://www.jpl.nasa.gov/site/jsgt/jtrf/>. Preparations are currently being made to use SREF to extend the JTRF2020 solution forward in time by using newly available observations. The extensions to JTRF2020 are expected to be available on a quarterly basis starting summer 2023.

Abbondanza, C., T. M. Chin, R. S. Gross, M. B. Heflin, J. W. Parker, B. S. Soja, and X. Wu (2020). A sequential estimation approach to terrestrial reference frame determination, Adv. Space Res., 65(4), 1235–1249, DOI 10.1016/j.asr.2019.11.016.

Analysis Coordinator

Analysis Coordinator: Robert Heinkelmann (Germany)

Overview

The Analysis Coordinator 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 Technique Centres products into the single set of official IERS products and the archiving of the products at the Central Bureau or elsewhere.

Activities and publications during the period 2019–2023

The work of the Analysis Coordinator focused on an analysis of the ITRF2014 and a comparison with the two other independent solutions: JTRF2014 and DTRF2014. The differences of these three frames are for the post-seismic deformation models, time-series vs. long-term parameters, least squares vs. Kalman filtering, datum definition and in the weighting and application of local ties and co-motion constraints. The analysis of the various differences of the TRFs needs more time and more dedicated investigations as many aspects cannot be clearly associated being caused by specific analysis or combination decisions. Besides the terrestrial reference frame, the new celestial frame, ICRF3, became effective in the beginning of 2019. ICRF3 fits much better to external high-precision star catalogues, such as DR2 and EDR3 of the ESA Gaia mission, than ICRF2 does, for which a small but systematic deformation was identified. ICRF3 also includes a correction for the aberration caused by the non-linear motion of the Milky Way galaxy w.r.t. other galaxies. The main EOP products of IERS, IERS 14 C04 and USNO finals were investigated and compared as well. During 2019 – 2021 several changes have been done to the IERS 14 C04 product, some of which cause significant differences for users. The effects and the necessity of the change are under investigation. Based on VLBI data analysis the consistency of the three products, TRF, CRF, and EOP, were in the focus of the activities. Besides GNSS, SLR, VLBI and DORIS, the LLR technique recently progressed towards more observations. LLR besides VLBI is the only technique capable of providing CPO and dUT1 estimates and hence, presents an important tool for verification of the celestial set of the EOP. The development of VLBI observations at higher frequencies, namely K- and X-/Ka-bands for ICRF3 and in general presents a novel data set for the verification of IERS products and their consistency. The IERS Analysis Coordinator is very much in favour of further fostering and broadening these observations. VLBI at other frequencies has the potential to provide an independent connection of terrestrial and celestial reference frames and EOP and thus qualifies for high accurate control of the IERS products. In the time frame 2019 – 2021, management efforts have been invested in the preparation of ITRF2020. For this product update, model updates had to be implemented, such as a new sub-daily EOP model, VLBI antenna gravitational deformation, and a new linear model of the mean Earth rotation pole applied for the modelling of pole tides. To oversee these model inclusions in the analysis, the IERS Analysis Coordinator took part in several Analysis Workshops of the four main space geodetic techniques. The Analysis Coordinator co-organized the 2019 and 2022 Unified Analysis Workshops held in Paris, France and in Thessaloniki, Greece, respectively, together with IAG GGOS and developed recommendations from it.

Central Bureau

Director: Daniela Thaller (Germany)

Overview

The Central Bureau coordinates the work of the Directing Board and the IERS in general, organizes meetings and issues publications. It replies to questions of users regarding IERS products and general topics of Earth rotation and reference systems. It maintains an IERS Data and Information System (DIS) based on modern technologies for internet-based exchange of data and information like the application of the Extensible Markup Language (XML) and the generation and administration of ISO standardised metadata. The system provides general information on the structure and the components of the IERS, serves as a portal to websites of all IERS components and gives access to all products.

Activities and publications during the period 2019–2023

The 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, further developments of the IERS DIS concentrated on the enhancement of the data management system and of the interactive tools to visualize and analyse IERS products. Especially security features were updated to meet current standards.

An improved monitoring system was established for the data management system to ensure a timely and error-free provision of the IERS products on the webpages and ftp server. A new feature has been implemented in the data management system, which allows the direct upload of USNO earth rotation data to the servers of the IERS Central Bureau. Further improvements of the IERS DIS included the development of a date converter tool and the availability of csv formatted files on the ftp server. A new user management system has been implemented. A newly developed calendar shows for each IERS product when new product versions were released on the IERS website. For the data exchange in the framework of ITRF 2020, the Central Bureau created internal areas at data server for https upload and download which replaces the former, less secure ftp exchange. In 2022, the ftp server was replaced by HTTPS download and work on a new version of the IERS website was started.

The Central Bureau edited, published and distributed IERS Technical Note No. 40 and IERS Annual Report 2018, as well as IERS Messages Nos. 378 to 477. It compiled reports by IERS to IAU Commission A2 and IAG.

Working Groups

Reports, meeting summaries, presentations and other documents of all working groups are available at the IERS web site.

IAG/IERS Working Group on Site Survey and Co-location

Chair: Sten Bergstrand (Sweden, until Dec. 2019), Ryan Hippenstiel (USA, since Jan. 2020)
Co-chair: John Dawson (Australia, until Dec. 2019), Sten Bergstrand (Sweden, since Jan. 2020)

Overview

Areas of work of the Working Group on Site Survey and Co-location are standards and documentation (guidelines, survey reports, etc.), coordination (share know-how and join efforts between survey teams), research (investigate discrepancies between space geodesy and tie vectors, alignment of tie vectors into a global frame), and cooperation.

Activities and publications during the period 2019–2023

See the report of IAG Commission 1, SC 1.2 (Global Reference Frames), JWG 1.2.2: Methodology for surveying geodetic instrument reference points.

Working Group on SINEX Format

Chair: Daniela Thaller (Germany)

Overview

The SINEX (Solution INdependent EXchange) format is a well-established format used by the technique services of the IERS for several years. The aim of the working group is to maintain the SINEX format according to the needs of the IERS, the technique services (IDS, IGS, ILRS, IVS) and GGOS. The working group is the point of contact if any modifications or extensions

are required. In order to have the best possible interaction with the groups working with the SINEX format (either as output or as input), the analysis and combination groups of all the technique services as well as the relevant components of the IERS and GGOS are represented within the working group.

Activities and publications during the period 2019–2023

In the framework of preparing ITRF2020, two aspects have been developed for the SINEX format:

1) A block for storing the corrections for non-tidal loading effects that were applied at the observation level was defined. This allows to un-do this correction when handling the normal equations provided in the SINEX file.
2) A block for providing the information about range and time biases applied during the SLR estimation process was defined.

Both new blocks have been already used for VLBI and SLR SINEX files, respectively, that were generated for ITRF2020.

IAG/IAU/IERS Joint Working Group on the Consistent Realization of TRF, CRF, and EOP

Chair: Robert Heinkelmann (Germany)
Co-Chair: Manuela Seitz (Germany)

Overview

This IAG/IAU/IERS Working Group will compute multi-technique CRF-TRF solutions together with EOP in one step, which will serve as a basis to quantify the consistency of the current conventional reference frames and EOP as well as to assess the consistency of reprocessed and predicted EOP. From 2016 to 2019 this was an IAG Working Group, since 2020 it has become joint with IAU and IERS.

Activities and publications during the period 2020–2023

See the report of IAG Commission 1, SC 1.4 (Interaction of Celestial and Terrestrial Reference Frames), JWG 1.4.3: Consistent realization of TRF, CRF, and EOP.

Working Group on the 2nd Earth Orientation Parameter Prediction Comparison Campaign

Chair: Jolanta Nastula (Poland)
Co-Chair: Henryk Dobslaw (Germany)

Overview

Earth orientation parameters (EOP) comprising of nutation offsets, pole coordinates, and dUT1 represent a critically needed link between the terrestrial and the celestial reference frame. Predictions of EOP are important for a number of operational activities including navigation of deep-space satellite missions, the pointing of astronomical instruments, or satellite-based positioning on Earth. Various agencies and institutions worldwide therefore maintain capacities to rapidly process space geodetic observations to obtain estimates for the EOPs with short latencies as a basis for the subsequent prediction. The strong interest in EOP forecasting ultimately led to the establishment of the Second Earth Orientation Parameters Prediction Comparison Campaign (2nd EOP PCC) by a Working Group of the IERS.

Between September 2021 and December 2022, the operational part of the 2nd EOP PCC has been performed under the auspices of the IERS within the WG on 2nd EOP PCC. The aim of

the 2nd EOP PCC was re-assessing various EOP prediction capabilities, in particular: collecting and comparing EOP predictions from different institutions over a representative period of time, evaluating the accuracy of final estimates of EOP, identifying both accurate and robust prediction methodologies, assessing the inherent uncertainties in present-day EOP predictions, analysing the impact of various factors (input data used, method applied, reference data, length of prediction etc.) on prediction accuracy.

The EOP PCC Office maintained by Space Research Centre in Warsaw (Poland) was responsible for creating and maintaining the campaign website (http://eoppcc.cbk.waw.pl/), data collecting, routine visualization and final evaluation of all submitted predictions. Valid predictions of all kind of EOP were collected once per week in an operational setting (each Wednesday before 20 UTC). The support of GFZ Potsdam is kindly acknowledged.

Activities and publications during the period 2021–2023

The first online meeting of the WG took place on May 6th, 2021 to discuss details of the campaign with interested participants. The second online meeting of WG, EOP PCC Office and participants was organized on November 25, 2021 to present submission statistics, preliminary scientific results, discuss next steps and receive feedback from participants. The next meeting took place online on December 8, 2022 and its agenda included update on the campaign results, plans for campaign data sharing, publication plans, and idea to extend the campaign duration.

Before the start of the campaign, preparatory actions were taken, i.e. a website was launched and a server was prepared to store predictions in CBK PAN, instructions for participants and a document with technical requirements were prepared. All technical details including instructions for candidate registration, data submission rules, naming, and file formats convention have been made publicly available in the document with general rules for participation in early June 2021.

An open call for participation in pre-operational phase of the 2nd EOP PCC was announced in June 3, 2021. The aim of the test campaign was to check all technical issues, in particular to test participant registration scheme and check correctness of files sent by participants.

An open call for participation in operational phase of 2nd EOP PCC was announced in July 13, 2021. In total, 22 teams with 66 different forecasting methods registered for the campaign.

During the operational phase of the 2nd EOP PCC, i.e. between September 1, 2021 and December 31, 2022, the EOP PCC received 7327 valid predictions of all kinds of EOPs. The forecasts were routinely checked and validated by comparison with observational data. Validation results were periodically sent to participants in the form of reports, and also presented during meetings with participants and conferences.

Two EOP PCC Workshops were organized to present updated campaign results and to receive feedback from participants: the first on February 15–16, 2022 (online) and the second on March 1–3, 2023 (hybrid on-site and online).

The campaign duration was unofficially extended to collect predictions based on EOP data consistent with the new International Terrestrial Reference Frame ITRF 2020.

Kur, T., Dobslaw, H., Śliwińska, J., Nastula, J., & Wińska, M. (2022). Evaluation of selected short - term predictions of UT1 - UTC and LOD collected in the Second Earth Orientation Parameters Prediction Comparison Campaign. Earth, Planets and Space, 74. https://doi.org/10.1186/s40623-022-01753-9

Śliwińska, J., Kur, T., Wińska, M., Nastula, J., Dobslaw, H., & Partyka, A. (2022). Second Earth Orientation Parameters Prediction Comparison Campaign (2nd EOP PCC): Overview. Artificial Satellites, 57(S1), 237–253. https://doi.org/10.2478/arsa-2022-0021