

# IAU Commission A2 – Rotation of the Earth

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## Annual Report 2019

### 100<sup>th</sup> anniversary and Centennial Celebration of IAU Commission A2/Commission 19

July 28, 2019, marked the 100<sup>th</sup> birthday of Commission A2. Together with the IAU, which was created during the Constitutive Assembly of the International Research Council in Brussels (July 18-28, 1919), 32 Standing Committees were created on the last day of the Assembly. Among these was the “Standing Committee 19 on Latitude Variations” in order to study polar motion. In 1922 the Standing Committee was transformed into “Commission 19 on Variation of Latitude”, and in 1964 it was renamed into “Commission 19 on Rotation of the Earth”. In 2015, after the restructuring of the IAU, the Commission’s designation was changed into “Commission A2 on the Rotation of the Earth”.

Since 100 years, the Commission has been encouraging collaboration in observation and theoretical studies of Earth rotation, the development of new observation techniques and the development of strategies and methods for improving the accuracy of Earth rotation changes and reference frames. It has been ensuring the agreement and continuity of different (geodetic/astronomical) reference frames and their densifications, and it has been linking the astronomical community to international organizations that are responsible for providing Earth Orientation Parameters (EOP) and terrestrial and celestial reference frames (ITRF/ICRF), such as the International Association of Geodesy (IAG), the International Earth Rotation and Reference Systems Service (IERS), and the technique services IVS (Very Long Baseline Interferometry), ILRS (Satellite Laser Ranging), IGS (Global Navigation Satellite Systems), and IDS (Doppler Orbitography and Radio positioning Integrated by Satellite). Through a multitude of dedicated Symposia (among them various IAU Symposia and IAU Colloquia), Workshops, and through its Working Groups, the Commission has been fostering research and discussion on Earth rotation and reference frames within the international scientific community.

On the occasion of its 100<sup>th</sup> anniversary, the Commission held a **Centennial Celebration in Paris, October 7**, as part of the “*Journées 2019: Astrometry, Earth rotation and Reference systems in the Gaia era*” (see below). During this celebration, Commission A2 looked back at its history and the developments in Earth rotation monitoring and research during the last century and provided an outlook into the future of Earth rotation research.

### **Co-organization of the “*Journées 2019: Astrometry, Earth rotation and Reference systems in the Gaia era*” in Paris, France, October 7-9, 2019**

The *Journées 2019: Astrometry, Earth rotation and Reference systems in the Gaia era* were organized jointly by the IAU Commissions A1 (Astrometry) and A2 at the Observatoire de Paris (IAP amphithéâtre) from October 7- 9, 2019. It gathered 120 scientists from all over the world, for a large part members of Commissions A1 and A2. The meeting comprised dedicated sessions on the Gaia mission, Earth Rotation and Geodynamics (observations, analysis, models), ICRF and astrogeodesy, and Space navigation and solar system dynamics. In their presentations, the participants reported about exciting investigations and demonstrated the high scientific relevance of the topics covered by the Commissions. During the meeting, the 100<sup>th</sup> anniversary of Commission A2 was celebrated in the frame of a dedicated session, reviewing the enormous achievements in Earth rotation and reference systems/frames research over the past century and discussing prospective scientific challenges and potentials. The detailed meeting programme and proceedings can be assessed at:

<https://syrtte.obspm.fr/astro/journees2019/>

## Successful completion of the Joint Working Group on Theory of Earth Rotation and Validation (JWG TERV)

Joint WG of IAU Commission A2 and the International Association of Geodesy (IAG)

Chair: José Manuel Ferrándiz, Spain

Vice-Chair: Richard Gross, USA

After the IAU General Assembly 2018, Commission A2 kept in operation its IAU CA2/IAG JWG TERV until the General Assembly (GA) of the IUGG/IAG 2019 in Montreal, Canada, after which the JWG formally ended. The end-of-term reports of the JWG TERV and each of its three Sub-WGs/SWG) were presented in the IUGG/IAG General Assembly and can be accessed at <https://web.ua.es/es/wgterv/>. A summary of them is published in the IAG Travaux 2015-2019 (Drewes and Kuglitsch, 2019), as part of the IAG Commission 3 report, as well as in the IAG Symposia series (Ferrándiz, Gross, Escapa et al. 2020). The activity of the JWG was crucial to unveil that a significant part of the unexplained variance of the determined EOP series is due to systematic errors, inconsistencies, and need of updating old model components.

From all those findings and the research in progress, it was possible to conclude that at least a partial update of the Earth rotation theory was needed and feasible within a reasonable time span. On that basis, the JWG chair proposed a resolution, entitled “Improvement of the Earth’s Rotation Theories and Models”, that was adopted by the IAG at its General Assembly 2019 in Montreal (available at [https://iag.dgfi.tum.de/fileadmin/IAG-docs/IAG\\_Resolutions\\_2019.pdf](https://iag.dgfi.tum.de/fileadmin/IAG-docs/IAG_Resolutions_2019.pdf)). It encourages the prompt improvement of the Earth rotation theory in regards to its accuracy, consistency, and ability to model and predict the essential EOPs; encourages consistency between reference frames and the definition of the EOPs including its theories, equations of motion, and models; and encourages the development of new models that are closer to the dynamically time-varying real Earth.

## Proposal of two new Joint Working Groups under Commission A2

### Joint Working Group on Improving Theories and Models of the Earth’s Rotation (JWG ITMER)

Joint WG of IAU Commission A2 and the International Association of Geodesy (IAG)

Chair: José Manuel Ferrándiz, Spain

Vice-Chair: Richard Gross, USA

The main purpose of this JWG is proposing consistent updates of the Earth rotation theories and models and their validation. The associated tasks will contribute to the implementation of the **IAU Resolution B1 (2018)** on Geocentric and International Terrestrial Reference Systems and Frames, and the **IAG Resolution 5 (2019)** on Improvement of the Earth’s Rotation Theories and Models. The last resolution is the most specific for the WG assignment, and mandates *(1) to encourage a prompt improvement of the Earth rotation theory regarding its accuracy, consistency, and ability to model and predict the essential EOP, (2) that the definition of all the EOP, and related theories, equations, and ancillary models governing their time evolution, must be consistent with the reference frames and the resolutions, conventional models, products, and standards adopted by the IAG and its components, and (3) that the new models should be closer to the dynamically time-varying, actual Earth, and adaptable as much as possible to future updating of the reference frames and standards.*

Objectives and expected outcomes:

The JWG is committed to derive supplementary models for the celestial pole offsets (CPO) evolution, in part of semi-empirical and semi-analytical nature, and able to increase significantly the explained variance of the current theories and models. According to the recommendations of the 2019 GGOS-IERS Unified Analysis Workshop, the priority tasks of building such models will include:

- updating the amplitudes of the leading nutations of the IAU2000 theory and testing shortened series for certain operational purposes
- correcting the inconsistencies found in the precession-nutation models
- test the available FCN models (for explaining CPO variance) and consider whether the IERS should recommend FCN models or not

To develop and publish a fully dynamically consistent theoretical approach to support those models will require a continuation of the activity until the end of the term. Theoretical developments must also address to advancing in all the aspects made explicit on Resolution 5, like using a consistent framework for all the Earth orientation parameters (EOP), with regard to reference systems and frames, background models, standards, and adaptation of the developments to the current knowledge of the dynamic Earth, from its inner components to its outer layers.

### **Joint Working Group on the Consistent realization of TRF, CRF, and EOP**

Joint WG of IAU Commission A2, International Association of Geodesy (IAG) Sub-Commission 1.4, International Earth Rotation and Reference Systems Service (IERS)

Chair: Robert Heinkelmann, Germany

Vice-Chair: Manuela Seitz, Germany

The JWG addresses the requirements of the **IUGG Resolution 3 (2011)** urging, the **IAG Resolution 2 (2019)** recommending that *“highest consistency between the ICRF, the International Terrestrial Reference Frame (ITRF), and the Earth Orientation Parameters (EOP) [...] should be a primary goal in all future realizations”* and the **IAG Resolution 5 (2019)** resolving that *“[...] the EOP, and related theories, equations, and ancillary models governing their time evolution, must be consistent with the reference frames and the resolutions, conventional models, products, and standards adopted by the IAG and its components,[...]”*.

Many applications, e.g. in geodesy, astronomy, or navigation, rely on the consistency between terrestrial (TRF) and celestial (CRF) reference frames and EOP, and they require a very high level of accuracy of the related parameters. Currently, TRF and CRF are determined independently of each other. The releases of the terrestrial and celestial frames do not happen at the same time. Individual Working Groups (CRF) or Combination Centers (TRF) compute the frames through reprocessing / combination efforts every five to ten years. In this way, the frames are computed based on different input data and on different analysis models in case of updates of the conventional models. For geodetic and astrometric data analyses and other purposes, the reference frames and the EOP are customarily applied in prediction mode. Accordingly, values have to be given beyond the data time span considered for the reference frame realization. The predicted EOP require consistency to the frames and to the reprocessed EOP at the same time. It is impossible to fulfill both requirements, when new reference frame releases become available.

The joint working group has the objectives to

- 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.

The joint working group will further

- investigate the impact of different analysis options, model choices and combination strategies on the consistency between TRF, CRF, and EOP,
- study the differences between multi-technique and VLBI-only solutions,
- study the possible contributions to EOP and frame determination by the LLR technique,

- study the differences between EOP derived by VLBI solutions at different radio wavelengths in cooperation with the IAU Division A WG Multi-waveband Realisations of International Celestial Reference System,
- study the differences between EOP derived by VLBI solutions improved through Gaia (optical) data in cooperation with the proposed IAU Division A WG on VLBI-Gaia topics,
- study the effects on the results, when different data time spans are considered
- compare the practically achievable consistency with the quality requirements deployed by IAG GGOS
- derive conclusions about future observing systems or analysis procedures in case the quality requirements cannot be met with the current infrastructure and approaches.

### **Proposal for GA Symposium “Reference systems and their ties with the rotation of the Earth and other Solar System bodies” to be held in 2021 in Busan, Republic of Korea**

By December 15, 2019, a proposal was submitted to hold an IAU Symposium “*Reference systems and their ties with the rotation of the Earth and other Solar System bodies*” as part of the XXXI IAU General Assembly in Busan, Republic of Korea, between August 18-22, 2021.

The proposal was prepared under the Lead of Commission A2 jointly together with Commission A1 (Astrometry) and the Inter-Division A-F WG Cartographic Coordinates & Rotational Elements (WGCCRE).

It is also supported by the coordinating Division A (Fundamental Astronomy), Commission A3 (Fundamental Standards), the IAU CA2/IAG/ IERS JWG on Consistent Realization of TRF, CRF and EOP, and the IAU CA2/IAG JWG on Improving Theories and Models of the Earth’s Rotation (ITMER).

The key topics of the proposed IAU Symposium are:

- State of the art, new developments and scientific challenges in Gaia and VLBI observations
- Next generation Celestial Reference Frame: towards a combined radio and optical multi-band CRF
- Practical aspects of defining and maintaining reference systems and frames for Solar System bodies (planets, moons, asteroids, comets)
- Relating and combining celestial and planetary reference frames
- Rotation of the Earth and other Solar System bodies: theories, models, and analysis
- Internal structure of planetary bodies and its connection with their rotation
- New and emerging measurement systems
- Future space astrometry and its ties with astrophysics

Celestial and planetary reference systems provide the fundamental framework for referencing astronomical and space-geodetic observations. Precise realizations of these systems, the so-called reference frames, are of paramount importance for positioning and navigation on Earth and across the Solar System as well as for the measurement of time. Celestial and planetary reference frames are connected through orientation and spin of the planetary bodies. Thus, precise reference frames fundamentally require precise knowledge of the rotation of the Solar System bodies both in a theoretical and observational point of view. Besides, the knowledge of the rotation of Solar System bodies is precious for studying their internal structure and geophysical phenomena.

Emerging observation technologies, such as planetary probes and the astrometric Gaia mission, contribute to new data types for the determination of celestial reference frames and rotation models. The Symposium will address challenges and opportunities related to the analysis and combination of well-established and new observation techniques leading to next generation reference frames and rotation series at the highest level of consistency and accuracy. Therefore topics include new scientific results from astrometric observations and rotation series in astronomy, geodynamics and internal structure modeling.

## **Scientific conferences**

During 2019 members of Commission A2 were deeply involved in the organization of scientific sessions dedicated to Earth rotation and Reference Frames in the framework of conferences and scientific meetings of various international organizations. In particular, Commission A2 members contributed strongly to the *EGU General Assembly in Vienna, Austria* (Session G2.2: The International Terrestrial Reference Frame: Elaboration, Usage and Applications; Session G3.1: Earth Rotation: Theoretical aspects, observation of temporal variations and physical interpretation), the *IUGG General Assembly in Montreal, Canada* (Session G01: Reference Systems and Frames; Session G04: Earth Rotation and Geodynamics; Session G06: Monitoring and Understanding the Dynamic Earth With Geodetic Observations), and the *AGU Fall Meeting in San Francisco, USA* (Session G11A/G23C: Reference Frames: Determination, Usage, and Application; Session G41A/G31B Fifty Years of Lunar Laser Ranging and Earth and Planetary Rotation).