

Triennial report 2021-2024 of the IAU/IAG Joint Working Group on Improving Theories and Models of the Earth's Rotation.

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Overview

This JWG was started in 2019/2020 with the main purpose of proposing consistent updates of the Earth rotation theories and models as well as their validation. Tasks were designed so as to contribute to the implementation of the 2019 IAG Resolution 5 and the 2021 IAU Resolution B2 on Improvement of the Earth's Rotation Theories and Models, which mandate:

- to encourage a prompt improvement of the Earth rotation theory regarding its accuracy, consistency, and ability to model and predict the essential EOPs;
- that the definition of all the EOPs, 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;
- 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.

The JWG has sought to keep a close cooperation with IAG components, particularly its Global Geodetic Observing System (GGOS), the IERS, and other WGs dealing with Earth rotation topics and standards from specific perspectives, as well as with the IAU Commission A3. Continuous coordination has been facilitated through having common members and correspondents, in the main. During the first two years the development of the JWG planned activities was still affected by the COVID-19 pandemic.

As for the outcomes, noteworthy is that the invitation of the JWG chair and the C.A2 VP (also chair of the SWG 1 on precession/nutation) to presenting proposals in the 2022 IERS/GGOS Unified Analysis Workshop (UAW), resulted in concrete recommendations for achieving short-term feasible improvements to the precession and nutation models by means of supplementing theories with some specific corrections, containing among them a few nutation terms of planetary origin besides the lunisolar ones (<https://zenodo.org/record/7352364>). Those corrections were selected from among several sets derived from various session-wise VLBI solutions for celestial pole offsets (CPO), either from IVS single analysis centers or from the combined solutions derived by BKG.

Meeting organization:

The JWG chairing and key people have organized special sessions at conferences of particular relevance to its activity, and splinter meetings open to all interested attendants. They have also co-convened sessions on Earth rotation - or including it - at large meetings and served in several scientific organizing committees.

The COVID-19 pandemic still prevented holding in-person meetings in 2021, but along 2022 some of them already begun to be held in mixed format, virtual and face-to-face, and only at the end of this term can it be said that normality has mostly been restored. The sessions and events in whose organization the JWG has participated are:

- 2021 European Geosciences Union General Assembly (vEGU 2021, virtual only). 19-30 April 2021
 - Session G3.3, “Earth Rotation: Theoretical aspects, observation of temporal variations and physical Interpretation”. Conveners: A. Escapa, S. Böhm, M Karbon, D. Salstein, F. Seitz. <https://meetingorganizer.copernicus.org/EGU21/session/39900>

- SPM7 Business Meeting of the IAU/IAG JWG on Improving Theories and Models of the Earth's Rotation (ITMER). Conveners: J.M. Ferrándiz, R. Gross, April 30, 2021. <https://meetingorganizer.copernicus.org/EGU21/session/41591>
- 2021 Scientific Assembly of the International Association of Geodesy (IAG 2021, virtual). Beijing 28 June - 2 July 2021. Symposium 3: Earth Rotation and Geodynamics, Convener J. Bogusz, Session 3.1 “Earth rotation, low-degree gravitational change and mass transport in geophysical fluids” (Joint with: ICCG). Conveners: JL. Chen, J.M. Ferrándiz, R. Gross, M. Schindelegger, H. Dobsław, J. Li.
- 2022 European Geosciences Union General Assembly (EGU 2022, in-person and virtual), Vienna, 23–27 May 2022. Session G3.5 "Earth Rotation: Theoretical aspects, temporal variability, physical interpretation, and prediction". Conveners: D. Salstein, S. Böhm, A. Escapa, F. Seitz, S. Bruni. <https://meetingorganizer.copernicus.org/EGU22/session/43011>
- 2022 Asia Oceania Geosciences Society (AOGS 2022) annual meeting (virtual only) 1-5 Aug 2022. Session SE03, “Earth Rotation: Interpretation, Prediction, Uncertainty and Real-time Geodesy”. Conveners: JL Chen, J.M. Ferrándiz, R. Gross, H. Dobsław. Merged with Session SE05 (Solid Earth General Session) https://www.asiaoceania.org/aogs2022/public.asp?page=sessions_and_conveners.asp
- 2022 XXI General Assembly of the IAU. Busan, Korea 2-11 August 2022 (in-person and virtual), Division A Meeting, Session 4 - Reference Frames and Rotations. Convener: A. Escapa. https://www.iau.org/science/scientific_bodies/divisions/A/meeting2022/
- First Workshop of Spanish and German IVS Analysis Centers, Alicante 5-6 October 2022 (in-person and virtual). Chairs: H. Schuh, J.M. Ferrándiz
- 2023 European Geosciences Union General Assembly (EGU 2023, in-person and virtual) Vienna, 23-28 April 2023. Session 2.3 "Global Geodetic Observing System with a special focus on Earth Rotation". Conveners: K. Heki, F. Seitz, A. Escapa, D. Salstein, A. Craddock, H. Wolf. <https://meetingorganizer.copernicus.org/EGU23/sessionprogramme/4926>
- 2023 General Assembly of the International Union of Geodesy and Geophysics (IUGG 2023, in-person). Berlin 11-20 July 2023. IAG Symposium G04 “Earth Rotation and Geodynamics”. Convener: J. Bogusz, CL. Huang, S. Rosat, M. Schindelegger. <https://www.iugg2023berlin.org/iag/>
- 2024 European Geosciences Union General Assembly (EGU 2024, in-person and virtual) April 14-19, 2024. Session G3.3 "Earth Rotation: Theoretical aspects, temporal variability, physical interpretation, and prediction". Conveners: J. Śliwińska-Bronowicz, S. Böhm, A. Escapa, D. Salstein, F. Seitz. <https://meetingorganizer.copernicus.org/EGU24/session/49230>

Cooperation with other IAU and IAG components and WGs:

This JWG reports to the IAU Commission A2, Rotation of the Earth. The editors of the IAU outreach magazine *The Catalyst* asked C.A2 for an article explaining the meaning and scope of the two resolutions adopted in 2021 on terrestrial rotation, in a way that would be intelligible without the possession of specific technical knowledge. Besides the said Resolution B2, C.A2 proposed Resolution B1 supporting the protection of geodetic radio astronomy against radio frequency interference. The article was published in the first issue of 2022, (<https://www.iau.org/static/publications/iau-catalyst-06.pdf>, pp. 18-21), its co-authors being all members of JWG.

The interaction with the IAU has not been limited to C.A2, but has been naturally extended to C.A3, "Fundamental Standards" for the better fulfilment of our assignment, as it deals with astronomical standards in general.

Cooperation with GGOS was mandatory according to our Terms of Reference (ToRs) and has developed closely and fruitfully. Maintaining good coordination has run smoothly as expected since the JWG Vice Chair was the Immediate Past President of GGOS till July 2023, and the Chair was inaugurated as chair of the GGOS Science Panel in November 2023. In addition, the chair of SWG 3 on numerical solutions and validation, R. Heinkelmann, belongs to the GGOS Bureau of Products and Standards (BPS), which is the component of GGOS in charge of standards. Therefore, the BPS must be aware of any proposed change of standards in Earth rotation models.

Strong cooperation has also been kept with the IERS, as foreseen in the TORs. Again, this smooth relationship has been facilitated by the existence of common members. In fact, the SWG3 Chair is the current IERS Analysis Coordinator, and among the members of the JWG are the Directors of the Central Bureau, three Product Centers (Earth Orientation, Rapid Service/Prediction and Conventions) and two Special Bureaus (Ocean, Atmosphere). In addition, the JWG and SWG Chairs are collaborating in the editing of Chapter 5 of the upcoming renewed IERS Conventions that will supersede the IERS Conventions (2010) currently in force (Petit & Luzum 2010). Bridges of these kinds have performed satisfactorily, and we believe that they are highly suitable for a successful achievement the highest levels of consistency, given today's stringent accuracy requirements, and the wide community of stakeholders as well.

The JWG has kept a good level of coordination with other WGs dealing with Earth rotation issues, in particular with the IAU/IAG/IERS JWG on the Consistent realization of TRF, CRF, and EOP and with the IERS WG on the Second EOP Prediction Comparison Campaign.

Finally, let us notice that from the IAG side this JWG ITMER ended officially at its General Assembly held in July 2023, and its activity is kept from the IAU side while a new JWG has been started by the IAG to continue advancing in the Earth's rotation improvement jointly with the IAU, focusing on Consistent improvement of Earth rotation theories (CIERT).

Brief account of progress of research and outcomes:

This concise summary highlights significant progress in Earth's rotation research, focusing on short-term improvements in precession-nutation models, advances in FCN modeling, effects of ancillary geophysical models on EOP, exploration of Earth's interior effects, consideration of time variations in Earth's parameters, and miscellaneous advancements contributing to a better understanding of Earth's rotation and prediction accuracy for EOP.

1. **Short-term Improvement of Precession-Nutation Models.** Deviations of the observed precession-nutation parameters from the current models, IAU2000 and IAU2006, are about 200 micro-arcseconds (μas) in terms of WRMS of CPO, far from the target of 33 μas set by GGOS/IAG. Correcting the linear precession terms of dX and dY , as well as the amplitudes of a reduced set of forced nutation terms allows a noticeable WRMS reduction till about 120-130 μas . Other known inconsistencies between the precession and nutation theories can be corrected at the same time, and the revision of the adopted value of the dynamical ellipticity H is in progress.
2. **Advances in FCN Modeling.** Free Core Nutation (FCN), arising from Earth's fluid core resonance, is a main source of the unexplained variance of the determined CPO. Using suitable models permits reducing the WRMS till about 80-90 μas . Two main approaches have been tested: the most common of fitting time-varying amplitudes to an FCN oscillation with fixed frequency or fitting constant amplitudes to a chosen set of frequencies in a band around the FCN one. Recent advancements propose novel approaches for better performance.
3. **Effects of Ancillary Geophysical Models on EOP.** Updates to Earth's rotation theories must consider changes in ancillary geophysical models to maintain consistency with data

analyses in this and various fields. Recent investigations within the JWG framework revealed significant specific differences between current and past geophysical models, impacting nutation and Length-of-Day (LOD) parameters. Efforts are underway to address these inconsistencies and refine the modeling of Earth's rotation parameters.

4. **Exploring Effects of Earth's Interior on Rotation.** Other studies investigated diverse challenging effects of the Earth's interior on nutations. While estimates suggest some effects arising from the core-mantle boundary may be undetectable at present, ongoing research aims to refine understanding and modeling of these intricate processes.
5. **Time-variations of Earth's Dynamical Parameters and Rotation.** Recent studies highlight the need for updated theories to accommodate time-varying Earth parameters to improve EOP models. Inconsistencies between observed and assumed variations in Earth's oblateness and principal axes of inertia require correction for better accuracy.
6. **Second order solutions and miscellaneous:** Various recent studies explore second-order contributions to nutations, investigate polar motion and LOD variations, and address the complex relationship between Earth's rotation and geophysical phenomena. These ongoing efforts promise a deeper understanding of Earth's rotation and more accurate EOP predictions.

Additional and more detailed information for the period 2019-2023 can be found in the report of the JWG appearing in the IAG Reports 2019-2023 (“Travaux de l’AGI”)