IAU/IAG
JOINT WORKING GROUP ON
IMPROVING THEORIES AND
MODELS OF
THE EARTH'S ROTATION

Report of the IAU/IAG JWG on Improving Theories and Models of the Earth's Rotation

(IAU/IAG JWG ITMER)

Chair: José M. Ferrándiz (Spain)
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Origin and main purpose

- ***The IAU/IAG JWG on Improving Theories and Models of the Earth's Rotation (ITMER) was created by the International Association of Geodesy (IAG) on July 2019, and its Terms of Reference approved by the IAG Executive Committee in December 2019.***
- ***On the IAU side, it was formally approved as a Commission A2 WG in February 2021***
- **Its main purpose is contributing to the implementation of the 2018 IAU Resolution B1 on Geocentric and International Terrestrial Reference Systems and Frames, the 2019 IAG Resolution 5, and the 2021 IAU Resolution B2 on Improvement of the Earth's Rotation Theories and Models. *The last one is the most specific and mandates:***
  - ***To encourage a prompt improvement of the Earth rotation theory regarding its accuracy, consistency, and ability to model and predict the essential EOP;***
  - ***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 the IAU, IUGG/ 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; and***
  - ***That the IAU acts in close cooperation with IUGG/IAG and other concerned organizations.***

Web site (directly operated)

It is https://web.ua.es/wgitmer and contains the basic info, links & updates

Terms of Reference (ToR)

- **The IAU web site displays a short version, accessible from C. A2 page or from**

https://www.iau.org/science/scientific_bodies/working_groups/321/

- **A longer version of ToR is published in The Geodesist Handbook 2020**

(https://link.springer.com/article/10.1007/s00190-020-01434-z)

Functional organization

Due to the various methods and expertise required for the treatment of the three kinds of EOP, the tasks are distributed among three sub-WGs that should work in parallel:

1. **Precession/Nutation: *Chair: Alberto Escapa***
2. **Polar Motion and UT1: *Chair: Aleksander Brzezinski***
3. **Numerical Solutions and Validation. *Chair: Robert Heinkelmann***

- ***Each SWG is entrusted with its own tasks and goals*.**

Comments

Despite the impressive advance of the observing techniques, our capability to improve the accuracy of the determination and prediction of EOP had not been improved accordingly. The activity of two successive working groups of C.A2, joint with the International Association of Geodesy (IAG), showed the need of improving the underlying theories. The last of them was the IAU/IAG JWG on Theory of Earth rotation and validation (TERV)

- **The three kinds of EOP are affected by Earth rotation theories to different extents. The precession and nutation (PN) angles have the highest variations (> 9 as), but their excitation is mainly astronomic and their *unmodeled changes deviate from the IAU2000 and IAU2006 theories some 200 μas*. That level of accuracy is now unsatisfactory because the current goal is about 33 *μas*, equivalent to 1 mm on the Earth's surface and imposed not only by the development of astrometry at the *μas* level, but also by the monitoring of global change**
- ***A part of the PN variance yet unexplained by theories is susceptible of removal because certain small inaccuracies and inconsistencies are known and can be fixed at short to medium term.* Another part poses different problems since it is due to geophysical excitations to a large extent, as happens to the so-called free core nutation (FCN)**

Comments

- ***Geophysical excitations** appear as **dominant** terms in the equations that govern the evolution of the remaining three EOP, namely **the Earth rotation parameters or ERP** (**polar motion and UT1** - or ERA = Earth rotation angle). Therefore, their modeling must consider different observed geophysical signals in the input*
- *The agreement among e.g., observed time series of ERP and those of effective angular momentum of Earth components (ocean, atmosphere, hydrology…) and mass variations has advanced a lot in recent years. However, some theoretical issues are not yet solved*
- **A main need is a better separation of precession nutation (PN) and polar motion (PM):**
  - *Some 40 years after its introduction, their separation is still based on partly-heuristic definitions (in fact and according to the 2000 IAU Res. B1.7, treating functions with unknown non-periodic components as superposition of purely periodic terms and classifying their periods) with no full translation into mathematical expressions*
  - *This problem is becoming more relevant as the temporal resolution of the techniques is expected to increase – from 1 EOP determination in 24 h sessions made twice a week*

Comments

- ***Likewise in the background of theories, the whole set of EOP is affected by inconsistencies and inaccuracies in the definition or realization of the two reference systems and frames linked by them, namely the celestial and terrestrial ones.***
- **For instance, the foundations of the nutation theory IAU2000 rely on two different terrestrial reference systems (TRS):**
    1. ***before applying transfer function (TF), a system of Earth's principal axes used in the underlying rigid-Earth theory (REN2000);***
    2. ***then, a principal axes system for the non-rigid Earth named i-system, introduced in 1991 and invoked whenever the MHB2000 TF is applied***
    - ***The authors already pointed that the 3 properties defining the i-system are indeed discordant, but errors were below the accuracy level of that epoch - Mathews and Shapiro (1992)***
    - ***Nowadays discrepancies reach a detectable magnitude - Ferrándiz et al (2020)***
    - ***Moreover, no one of the former two systems has ever been realized, whereas EOP values are determined using well-defined frames (not abstract systems)***

Ongoing actions

- We consider that systematics errors are ever a barrier that prevents improving accuracy, and they must be corrected to the maximum extent we can do it
- Special attention must be paid to Precession-Nutation models, whose theories and models are established by Resolutions of IAU and IUGG and included in the IERS Conventions. *The precedent JWG TERV identified different sources of inaccuracy and assessed the potential effects of a number of them. This JWG ITMER must perform actions and tackle the actual improvement of theories and models.*
- A replacement of the current PN theories looks not feasible at short-term but deriving supplemental models for the celestial pole offsets (CPO) can improve the situation. They
  - Should increase significantly the explained variance of the current theories and models
  - May be of semi-empirical or semi-analytical nature – or mixed
- Some priorities are:

(1) Updating amplitudes of the leading nutations of IAU2000 theory and precession rates

(2) Correcting the main inconsistencies found in the precession-nutation models

(3) Test the available FCN models and consider whether the IERS should recommend them

Selected and recent outcomes

Outcomes of JWG members research in the line of correcting current PN models are promising. ***Some papers on the topic have been published in journals (e.g., Nurul Huda et al 2020, Zhu et al 2021, Ferrándiz et al 2022) or have been presented at meetings lately, e.g., the IVS General Meeting in March or the EGU GA in May 2022***

- **These contributions include the development of several potential corrections to the IAU2006 precession or IAU2000 nutation models, including updating of forced nutation amplitudes and derivation and testing of new free core nutation models. A suitable selection of corrections allows noticeable reductions of the unexplained variance of the CPO, achieving a lowering of the WRMS till nearby 100 μas (about a half)**

In 2022, the JWG chairpeople and some members have convened Earth rotation sessions at:

- **EGU 2022. Session G3.5 "Earth Rotation: Theoretical aspects, temporal variability, physical interpretation, and prediction"**
- **AOGS 2022 Session SE03 on: Earth Rotation: Interpretation, Prediction, Uncertainty and Real-time Geodesy**
- **IAU GA 2022, Div. A Reference Frames & Rotations. MONDAY 8, 10:30-12**

Future and developing activities

More time consuming and with difficult to foresee results are the tasks needed to solve the problems in a more durable way, e.g.:

- **developing a fully dynamically consistent theoretical approach to support the upcoming models**
- **advancing the theory in all the aspects made explicit on resolution IAU B2 of 2021**
  - *using a consistent framework for all the Earth orientation parameters (EOP), regarding reference systems and frames, background models, standards*
  - *adaptation of the developments to the current knowledge of the dynamic Earth, from its inner components to its outer layers, etc.*

Final comments

In the last year and immediately after its official approval by the IAU, the JWG activities were affected by the pandemic. This unexpectedly long situation has produced some delays in the development of the foreseen work and altered the organization and holding of scientific meetings, especially in-person ones

We expected holding a dedicated JWG business session in the 2021 IAU GA, and then in its 2022 continuation, which might have served to make adjustments or updates of membership, ToRs, etc. but we got room and time only for this report

We will hold a meeting-of-opportunity when there is a chance of convening it at some in-person congress – or meet virtually if we have to wait too much time for that

THANK YOU! MERÇI! ¡GRACIAS! 고맙습니다!

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Sample of recent contributions on the improvement of P-N models

J M. Ferrandiz, S Belda, S Modiri, M Karbon, R Heinkelmann, A Escapa, H Schuh (2022) "On the prospects of explaining and modeling with higher accuracy the precession-nutation from VLBI solutions" Proc. IVS General Meeting 2022 (submitted)

J.M. Ferrandiz, S. Belda, M.A. Juarez et al., "Accuracy of proposed corrections to the current precession-nutation models: A first assessment", EGU22-4031, https://doi.org/ 10.5194/egusphere-egu22-4031, 2022.

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Ferrándiz, J. M., Juárez, M. A., Belda, S., Baenas, T., Modiri, S., Heinkelmann, R., Escapa, A., and Schuh, H. (2021) Assessing recently improved precession-nutation models, EGU GA 2021, EGU21-10180, https://doi.org/10.5194/egusphere-egu21-10180

Zhu, P., Triana, S.A., Rekier, J. Trinh, A., Dehant, V. (2021) Quantification of corrections for the main lunisolar nutation components and analysis of the free core nutation from VLBI-observed nutation residuals. J Geod 95, 57 https://doi.org/10.1007/s00190-021-01513-9

Modiri, S., Heinkelmann, R., Belda, S., Hoseini, M., Korte, M., Malkin, Z., Ferrándiz, J. M., and Schuh, H. (2021) A First Assessment of the interconnection between celestial pole offset and geomagnetic field variations, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-7235, https://doi.org/10.5194/egusphere-egu21-7235

Sample of recent contributions on the improvement of P-N models (2)

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Triana, S. A., Trinh, A., Rekier, J., Zhu, P., & Dehant, V. (2021) The viscous and Ohmic damping of the Earth's free core nutation. JGR 126,https://doi.org/10.1029/2020JB021042

I Nurul Huda, S Lambert, C Bizouard, Y Ziegler (2020) Nutation terms adjustment to VLBI and implication for the Earth rotation resonance parameters, Geophysical Journal International, Volume 220, Pages 759–767, https://doi.org/10.1093/gji/ggz468

C Bizouard, I Nurul Huda, Y Ziegler, S Lambert, (2020) Frequency dependence of the polar motion resonance, GJI 220, 753–758, https://doi.org/10.1093/gji/ggz463

JM Ferrándiz, A Escapa, S Belda, T Baenas, S Modiri, R Heinkelmann, H Schuh (2020) Improved Precession-Nutation Models: A First Assessment. AGU Fall Meeting 2020, G022-05. ***https://agu.confex.com/agu/fm20/meetingapp.cgi/Paper/755001***

A Escapa, T Baenas, JM Ferrándiz (2020) On the permanent tide and the Earth dynamical ellipticity, EGU GA 2020, EGU2020-21410. https://doi.org/10.5194/egusphere-egu2020-21410

Ferrándiz, J. M., Escapa, A., Baenas, T., Belda, S., and Vigo, M. I. (2020) Effects of the observed Earth's oblateness variation on precession-nutation: A first assessment, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-16509, https://doi.org/10.5194/egusphere-egu2020-16509

Sample of recent contributions on the improvement of P-N models (3)

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Puente, V., Richard, J. Y., Folgueira, M., Capitaine, N., and Bizouard, C., "Comparison of VLBI-based Luni-solar Nutation Terms", in Proceedings of the 24th European VLBI Group for Geodesy and Astrometry Working Meeting, 2019, vol. 24, pp. 257–261.