THE GOAL OF THE IAU/IAG JOINT WORKING GROUP ON THE THEORY OF EARTH ROTATION

J.M. FERRÁNDIZ[1], R.S. GROSS[2]
[1] Dept. Applied Mathematics, University of Alicante
PO Box 99, E-03080 Alicante, Spain
e-mail: jm.ferrandiz@ua.es
[2] Jet Propulsion Laboratory, California Institute of Technology
Pasadena, USA
e-mail: richard.s.gross@jpl.nasa.gov

ABSTRACT. In 2012 the International Association of Geodesy (IAG) and the International Astronomical Union (IAU) initiated a process to establish a Joint Working Group (JWG) on Theory of Earth Rotation with the purpose of promoting the development of improved theories of the Earth rotation which reach the accuracy required to meet the needs of the near future as recommended by, e.g., GGOS, the Global Geodetic Observing System of the IAG. The JWG was approved by both organizations in April 2013 with the chairs being the two authors of this paper. Its structure comprises three Sub Working Groups (SWGs) addressing Precession/Nutation, Polar Motion and UT1, and Numerical Solutions and Validation, respectively. The SWGs should work in parallel for the sake of efficiency, but should keep consistency as an overall goal. This paper offers a view of the objectives and scope of the JWG and reports about its initial activities and plans.

1. INTRODUCTION

The International Association of Geodesy (IAG) and the International Astronomical Union (IAU) set up a new Joint Working Group on the Theory of Earth Rotation recently in 2013. A draft of a proposal to establish the JWG was initiated around the time of the IAU XXVIII General Assembly held in Beijing in August 2012 where the Joint Discussion 7 coordinated by IAU Division I and a business meeting of IAU Commission 19 took place. The draft was completed and opened to suggestions and discussions at the beginning of the next year and circulated among members of IAU C19 and IAG. Afterwards the revised document was put forward with the conformity of the proposed members, and the IAU C19 Organizing Committee, the IAU Division A Organizing Committee, and the IAG Executive Committee approved the final JWG proposal in April 2013.

According to the proposal, the purpose of the new JWG is to *"promote the development of theories of Earth rotation that are fully consistent and that agree with observations and provide predictions of the Earth Rotation Parameters (ERP) with the accuracy required to meet the needs of the near future as recommended by, e.g., GGOS, the Global Geodetic Observing System of the IAG".*

Let us recall that IAG has organized all its observation activities under the umbrella of GGOS in order to respond to the scientific challenges associated with rapidly increasing requirements for geodetic observations (Plag et al 2009). Pursuing that end, GGOS 2020 demands improved consistency to all IAG products and accuracy of the order of 1 mm to the frames of reference, besides stability in time of 0.1 mm/y (Plag and Pearlman 2009). The former accuracy in position, measured on the Earth surface, corresponds roughly to an angle of 30 μas from the Earth's centre.

From the observational side, the accuracy and performance of the major techniques is increasing. A good example is provided by the new generation of VLBI. A number of stations compliant with the 2010 specifications are already in operation, are being deployed or have been approved by their respective funding institutions. Besides, the various IAG services are committed to reach GGOS goals. Therefore, it can be expected that series of more accurate Earth Orientation Parameters (EOPs) will be produced in a few years. In addition, it can also be expected that series of the whole set of EOPs at a sub-daily rate will also be produced in a few years, following the experience of continuous VLBI campaigns (Nilsson et al. 2010). That would be useful to overcome deficiencies in the models used to describe diurnal of sub-diurnal variations of EOPs (Böhm et al 2012).

Currently, series of EOPs are provided by several Analysis Centers and by the International Earth Rotation and Reference Systems Service (IERS), the international body in charge of both Earth rotation monitoring and prediction and of the realization and maintenance of the International Celestial Reference Frame and the International Terrestrial Reference Frame (ICRF and ITRF, respectively), with the assistance of other IAG servicies.

The set of EOPs currently in use was agreed upon following the recommendation of an IAU Working Group on Nutation (Seidelmann 1982) and comprises five angles used to transform station coordinates between ICRF and ITRF:

- Precession/nutation (dX, dY in the so-called *new* paradigm or $d\varepsilon$, $d\Psi$ in the *old* one)
- Earth Rotation Angle (ERA, formerly GMST or GAST - Greenwich Mean or Apparent Sidereal Times)
- Polar Motion (x, y)

Let us recall that the transformation is specified by five EOPs instead of the minimum of three parameters (which is the number of independent angles needed to specify the transformation from a given frame to another) because an intermediate reference system is used, corresponding to the Celestial Intermediate Pole (CIP), which nowadays replaces the former Celestial Ephemerides Pole (CEP).

Other interesting properties (Seidelmann 1982) that favored the adoption of five EOPs were that both sets of nutation angles and polar motion (PM) were free from diurnal components either in the "inertial" or the "body-fixed" reference systems, respectively. Besides, nutations are caused by mainly astronomically driven, predictable effects, while PM are caused by mainly geophysical, difficult to predict effects.

Precise definitions of the main and auxiliary parameters and frames can be found in the IERS Conventions 2010 (Petit and Luzum 2010), Supplement to the Nautical Almanac (Urban and Seidelmann 2013) or SOFA (Standards of Fundamental Astronomy) documentation (Hohenkerk et al 2010), for instance.

Let us further recall that IAU adopted a new nutation theory in 2000, based on MHB2000 (Mathews et al. 2002) as well as a new precession model in 2006 (Hilton et al. 2006), based on P03 by Capitaine et al. (2003). They are known as IAU 2000 nutation model and IAU 2006 precession model, or shortened names as IAU2000/2006.

The real accuracy of the series of EOP is difficult to assess. Recent estimates of accuracies of individual solutions corresponding to different techniques and analysis centers, when compared to combined solutions, can be found in the IERS Annual Report 2011 (Dick 2011, section 3.5.1). As for the current precession/nutation models, the most predictable component of Earth rotation, a reference value can be settled about 140 to 150 μas, in terms of wrms of the observation-model differences (Capitaine et al. 2009, 2012). Let us notice that the remarkable efforts made in the last years to improve the models have not been accompanied by a significant reduction of the residual wrms.

Given the values of those uncertainties/inaccuracies, we must conclude that the goal of the new JWG is really quite challenging.

2. TERMS OF REFERENCE

The terms of reference (ToR) of the JWG are:

1. A main objective of the Joint Working Group (JWG) is to assess and ensure the level of consistency of Earth Orientation Parameter (EOP) predictions derived from theories with the corresponding EOPs determined from analyses of the observational data provided by the various geodetic techniques. Consistency must be understood in its broader meaning, referring to models, processing standards, conventions etc.

2. Clearer definitions of polar motion and nutation are needed for both their separation in observational data analysis and for use in theoretical modeling.

3. Theoretical approaches must be consistent with IAU and IAG Resolutions concerning reference systems, frames and time scales.

4. Searching for potential sources of systematic differences between theory and observations is encouraged, including potential effects of differences in reference frame realization.

5. The derivation of comprehensive theories accounting for all relevant astronomical and geophysical effects and able to predict all EOPs is sought. In case more than one theory is needed to accomplish this, their consistency should be ensured.

6. There are no *a priori* preferred approaches or methods of solution, although solutions must be suitable for operational use and the simplicity of their adaptation to future improvements or changes in background models should be considered.

7. The incorporation into current models of corrections stemming from newly studied effects or improvements of existing models may be recommended by the JWG when they lead to significant accuracy enhancements.

3. DESIRED OUTCOMES

It is desired that the JWG:

1. Contribute to improving the accuracy of precession-nutation and EOP theoretical models by proposing both new models and additional corrections to existing models.

2. Clarify the issue of consistency among conventional EOPs, their definitions in various theoretical approaches, and their practical determination.

3. Establish guidelines or requirements for future theoretical developments with improved accuracy.

It is clear that the overall goals of the JWG cannot be achieved within only two years of activity, but the first term (until the next General Assembly of both IAU and IAG, i.e., mid 2015) should be used to develop a solid concept of how to reach its aims.

4. STRUCTURE AND OPERATION

The structure of the JWG is more complex than usual because its subject is quite broad and requires the participation of several fields of specialization covering the characteristics of the full set of current EOPs. On the other hand, the establishment of independent JWGs for the different sub-fields would imply a serious risk of obtaining results that would not be consistent with each other. Therefore, the JWG was structured as a whole JWG containing three Sub Working Groups (SWG).

The whole JWG has the following people in charge:

- **Chair**: José M. Ferrándiz (representing IAU)
- **Vice-Chair**: Richard Gross (representing IAG)

In their turn, the three SWGs forming the JWG are:

1. **Precession/Nutation** (Chair: Juan Getino)
2. **Polar Motion and UT1** (Chair: Aleksander Brzezinski)
3. **Numerical Solutions and Validation** (Chair: Robert Heinkelmann)

SWG 3 will be dedicated to numerical theories and solutions, relativity and new concepts and validation by comparisons among theories and observational series. The subjects of SWG 1 and 2 are self-explanatory.

These three SWGs should work in parallel for the sake of efficiency. To guarantee that the SWGs are linked together as closely as the needs of consistency demand, the Chair and Vice-chair of the JWG, Ferrándiz and Gross, will be involved in all SWGs as will the President of C19, Cheng-li Huang. In order to further improve the interaction of the SWGs, a number of people are members of more than one SWG. The up-to-date list of members by SWG can be seen in (Ferrándiz and Gross 2013).

5. ADITIONAL INFORMATION

A dedicated web site of the WG is hosted by the institution of the Chair, the University of Alicante, Spain. It can be accessed directly at `http://web.ua.es/en/wgther/` After the closing of this edition of

the *Journées* on September 18th, the Observatory of Paris kindly provided a time slot for working groups splinter meetings. A short meeting of the JWG on Theory of Earth rotation took place in the afternoon, open to all the attendees of JSR 2013. A brief report of the discussed topics is given in the Appendix.

6. ACKNOWLEDGEMENTS

JMF acknowledges partial support of Spanish government under grant AYA2010-22039-C02-01 from Ministerio de Economía y Competitividad (MINECO). The work of RSG described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Support for that work was provided by the Earth Surface and Interior Focus Area of NASA's Science Mission Directorate.

6. REFERENCES

Böhm, S., Brzezinski, A., Schuh, H., 2012, "Complex demodulation in VLBI estimation of high frequency Earth rotation components", J. Geodyn., 62, 56–58, doi:10.1016/j.jog.2011.10.002.

Capitaine, N., Wallace, P. T., Chapront, J., 2003, "Expressions for IAU2000 precession quantities", A&A, 412(2), pp. 567–586, doi: 10.1051/0004-6361:20031539.

Capitaine, N., Mathews, P. M., Dehant, V., Wallace, P. T., Lambert, S. B., 2009, "On the IAU 2000/2006 precessionnutation and comparison with other models and VLBI observations", Celest Mech Dyn Astron, 103, 179–190.

Capitaine, N., Lambert, S., Yao, K., Liu, J., 2012, "Evaluation of the accuracy of the IAU 2006/2000 precession-nutation", JD7 Space-time reference systems for future research, 28th IAU GA, Beijing (available at `http://www.referencesystems.info/uploads/3/0/3/0/3030024/capitaine_6.07.pdf`).

Dehant, V., 2002, "Report of the IAU Working Group on 'Non-rigid Earth Nutation Theory". In: Rickman H (ed) "Highlights of Astronomy", Vol. 12, pp 117–119.

Dick, W.R. (ed) ,2011, "IERS Annual Report 2011". Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main (online version available at: http://www.iers.org/AR2011/).

Ferrándiz, J.M., Gross, R.S., 2013, "The New IAU/IAG Joint Working Group on Theory of Earth Rotation", IAG Symposia Series, Springer (submitted)

Hilton, J.L., Capitaine, N., Chapront, J., Ferrándiz, J.M., Fienga, A., Fukushima, T., Getino, J., Mathews, P., Simon, J.L., Soffel, M., Vondrak, J., Wallace, P., Williams, J., 2006, "Report of the International Astronomical Union Division I Working Group on Precession and the Ecliptic", Celest Mech Dyn Astron, 94(3), pp. 351–367. doi:10.1007/s10569-006-0001-2.

Hohenkerk, C. and the IAU SOFA board, 2010, "SOFA Tools for Earth Attitude". IAU (available at `http://www.iausofa.org`).

Mathews, P.M., Herring, T.A., Buffett, B.A., 2002, 'Modeling of nutation and precession: New nutation series for nonrigid Earth, and insights into the Earth's Interior. J Geophys Res, 107(B4). doi: 10.1029/2001JB000390.

Nilsson, T., Böhm, J., Schuh, H., 2010, "Sub-diurnal earth rotation variations observed by VLBI", Artificial Satellites, Vol. 45, No. 2 2010. doi: 10.2478/v10018-010-0005-8.

Petit, G., Luzum, B. (eds), 2010, "IERS Conventions 2010", IERS Technical Note No. 36. Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main (online version available at: `http://www.iers.org/TN36/`).

Plag, H.-P., Gross, R., Rothacher, M., 2009, "Global Geodetic Observing System for Geohazards and Global Change". Geosciences, BRGM's journal for a sustainable Earth, 9, 96–103.

Plag, H.-P., Pearlman, M., eds., 2009. "Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020", Springer Berlin, 332 pages.

Seidelmann, P. K., 1982, "1980 IAU theory of nutation - the final report of the IAU Working Group on Nutation". Celest Mech, 27, 79–106.

Urban, S.E., Seidelmann, P.K. (eds), 2013, "Explanatory Supplement to the Astronomical Almanac", 3rd edn. University Science Books, Mill Valley.

APPENDIX

The following topics were discussed in the open JWG meeting held at the end of the conference, among others:

1. The need of agreeing a common background among the three Sub-WG so that the main issue of consistency would not be lost as they develop their tasks.

2. The convenience of preparing a prelimminary catalogue of potential sources of inconsistency among different parts of the theory and series of EOP from the various techniques. Inconsistencies may result from many causes: differences among reference systems used in theories and data analysis, realizations of frames, use of different geophysical models, etc. Estimation of magnitudes of their associated effects would help to ascertain which ones may be not negligible when pursuing the global accuracy level of GGOS, 1 mm or 30 μas.

3. Earth models used in different theoretical approaches to EOP also exhibit large variations. Some questions, as adopting triaxial models or taking into account other new geophysical effects, should be addressed in future as well as the possibility of working in terms of reference models/solutions and "anomalies" as done in other fields. Considering the role of theoretical predictions in a scenario in which observational accuracy goes ahead theory was also pointed.

4. Several new effects on nutations have been proposed along the past years. At short-medium term, it would be convenient to test them through analyses of observational data to ascertain the convenience of adopting some of them as new corrections.

5. Regarding future meetings of the WG and presentation of related activities:

   (a) A new splinter meeting of the WG can be held during the next AGU fall meeting in San Francisco. Abstract submission is closed.

   (b) The proposal of a session dedicated to earth rotation submitted to EGU 2014 has been modified to better include WG related presentations. A JWG (SWGx) splinter meeting(s) could be scheduled.

   (c) Another opportunity to meet will be in September 2014, during the Journées that will be held in St. Petersburg

   (d) The chance to meet more often by teleconferencing was also suggested.

   (e) The possibility of holding a dedicated workshop on the Working Group activities would be considered later.