The New IAU/IAG Joint Working Group on Theory of Earth Rotation

José M. Ferrándiz and Richard S. Gross

Abstract

The Earth's rotation is considered to be one of the three pillars of modern Geodesy. 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 the Theory of Earth Rotation with the purpose of promoting the development of improved theories of 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.

Keywords

Earth rotation • Geodesy • Geodynamics

1 Introduction

The International Association of Geodesy (IAG) and the International Astronomical Union (IAU) established 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 General Assembly held in Beijing in August 2012 where a business meeting of IAU Commission 19 took place. The draft was opened to suggestions and discussions at the beginning of the next year and circulated among members of IAU C19 and IAG. Afterwards the IAU C19 Organizing Committee, the IAU Division A Steering Committee, and the IAG Executive Committee approved the final JWG proposal in April 2013.

1.1 Purpose

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"*.

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1.2 Context

Let us recall that GGOS 2020 demands accuracy of the order of 1 mm to the frames of reference, besides stability in time of 0.1 mm/year (Plag and Pearlman 2009). The former accuracy in position, measured on the Earth surface, corresponds roughly to an angle of 30 μas.

From the observational side, the accuracy and performance of the major techniques are increasing. A good example is provided by the new generation of VLBI systems. A number of stations compliant with the VLBI2010 specifications are already in operation, in addition to those being deployed or that have been approved by their respective funding institutions. Besides, the various IAG services are committed to reach GGOS goals. Therefore, in the next few years it is expected that there will be new series of more accurate Earth Orientation Parameters (EOPs). Moreover, following the experience of the continuous VLBI campaigns (Nilsson et al. 2010; Böhm et al. 2012), the whole set of EOPs will be produced at sub-daily intervals.

Currently, series of Earth Orientation Parameters (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). Recent analyses of the main features of EOP, ICRF and ITRF appear in articles like Bizouard and Gambis (2009), Fey et al. (2004) and Altamimi et al. (2011), respectively. Additional information can be found in various IERS Technical Reports.

The set of EOPs currently in use was agreed upon following the recommendation of an IAU Working Group on Nutation (Seidelmann 1982) and was modified by Resolutions B1.7 and B1.8 adopted at the IAU XXVI General Assembly in 2000, which entered in force in 2003.

Let us recall that the transformation of the coordinates referred to ICRF and ITRF 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 system is used, the Celestial Intermediate Reference System, with the Celestial Intermediate Pole and Origin (CIP and CIO, respectively). Note the CIP replaced the formerly used Celestial Ephemeris Pole (CEP).

The five EOPs are:

- Precession/nutation (dX, dY in the CIO-based paradigm or $d\varepsilon$, $d\psi$ in the equinox-based system)
- Earth rotation angle (ERA, or in the equinox-based paradigm GMST or GAST - Greenwich Mean Sidereal Time or Greenwich Apparent Sidereal Time)
- Polar motion (x, y)

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

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.

On time scales shorter than a day, polar motion consists largely of ocean tidally driven variations having amplitudes as large as about 0.3 milliarcseconds (mas). On time scales longer than a day, polar motion consists largely of: (1) an annual wobble having a nearly constant amplitude of about 100 mas, (2) the Chandler wobble having a variable amplitude ranging between about 100 and 200 mas, (3) quasi-periodic variations on decadal time scales having an amplitude of about 30 mas (known as the Markowtiz wobble), and (4) a trend of about 3.5 mas/year. The variations longer than a day are caused largely by changes in the mass distribution of the Earth's mantle and global surface geophysical fluids (see, e.g., Gross 2007 for a review of polar motion).

On time scales shorter than a day, length-of-day (LOD) variations consist largely of ocean tidally driven variations having amplitudes as large as about 0.2 milliseconds (ms). On time scales longer than a day, LOD consists largely of: (1) solid body and ocean tidally driven variations having amplitudes as large as about 0.4 ms, (2) intraseasonal variations having excursions as large as about 0.4 ms caused largely by intraseasonal variations in the zonal winds, (3) a semiannual variation having a nearly constant amplitude of about 0.3 ms caused largely by semiannual variations in the zonal winds, (4) an annual variation having a nearly constant amplitude of about 0.4 ms caused largely by annual variations in the zonal winds, (5) interannual variations having excursions as large as about 0.4 ms caused largely by interannual variations in the zonal winds, (6) decadal-scale variations having excursions as large as about 4 ms caused largely by core-mantle interactions, and (7) a trend of about 1.8 ms/century caused largely by both tidal dissipation in the Earth-Moon system and by glacial isostatic adjustment (see, e.g., Gross 2007 for a review of LOD variations).

Concerning nutations, let us 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 various series of EOP is difficult to assess. Recent estimates of the precision 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), especially Sects. 3.5.1 and 3.5.2. To provide some reference values extracted from that source, uncertainty of VLBI estimations of the celestial pole is about 80–90 µas in average. In the case of the terrestrial pole, VLBI uncertainty goes up to about 170 µas, whereas GPS estimations are about 50–70 µas in average. The real accuracy of the various series of EOP is likely to be worse than this because of the presence of errors that the series have in common.

The situation is worse for the predictions of EOP values. For instance, tables 3 and 4 of Sect. 3.5.2 of the IERS AR 2011 show that the wrms (weighted root mean square) of the differences between EOP predictions produced by the daily solutions and the 05/08 C04 combination series are always larger than 150 µas for each EOP.

As for the current IAU2000/2006 precession/nutation models, the most predictable component of Earth rotation, a reference value can be settled about 140–150 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: Jose M. Ferrándiz (representing IAU)
Vice-Chair: Richard Gross (representing IAG)

Table 1 Members by sub working groups

SWG	1 Precession/nutation	2 Polar motion and UT1	3 Numerical solutions and validation
Chair	**J Getino**, Spain	**A Brzezinski**, Poland	**R Heinkelmann**, Germany
Members	Y Barkin, Russia	**BF Chao**, Taipei	**BF Chao**, Taipei
	N Capitaine, France	W Chen, China	W Chen, China
	V Dehant, Belgium	**J Ferrándiz**, Spain	**V Dehant**, Belgium
	A Escapa, Spain	**R Gross**, USA	**J Ferrándiz**, Spain
	J Ferrándiz, Spain	**CL Huang**, China	D Gambis, France
	M Folgueira, Spain	SG Jin, China	E Gerlach, Germany
	A Gusev, Russia	W Kosek, Poland	**R Gross**, USA
	R Gross, USA	J Nastula, Poland	**CL Huang**, China
	T Herring, USA	**J Ray**, USA	B Luzum, USA
	CL Huang, China	D Salstein, USA	Z Malkin, Russia
	J Mueller, Germany	**H Schuh**, Germany	JF Navarro, Spain
	Y Rogister, France	**F Seitz**, Germany	**J Ray**, USA
	H Schuh, Germany	WB Shen, China	**Y Rogister**, France
	J Souchay, France	D Thaller Germany	ME Sansaturio, Spain
	V Zharov, Russia	**QJ Wang** , China	**H Schuh**, Germany
		YH Zhou, China	**F Seitz**, Germany
			M Thomas, Germany
			QJ Wang, China

Members of more than one SWG are in bold

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 as indicated in Table 1, containing the membership list, by typing their names in bold.

5 Additional Information

A dedicated web site of the JWG 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/

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Part VI

Observation Systems and Services