# REPORT ON ACTIVITIES OF THE SUB-WORKING GROUP 1 "PRECESSION/NUTATION" OF THE IAU/IAG JOINT WORKING GROUP ON THEORY OF EARTH ROTATION

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ABSTRACT. This is the mid–term report of the Sub-WG1 of the IAU/IAG Joint Working Group on Theory of Earth Rotation (JWG_ThER). The main objectives are (1) to provide some feasible enhancements of current precession/nutation model; (2) to give a list of potential future improvements of that model provided by the contributors of the subgroup, and (3) to raise out some open questions which should be discussed within the JWG_ThER.

## 1. INTRODUCTION

This contribution[1] is a continuation of the former report (Getino 2014) of the activities of the subgroup presented at EGU 2014 meeting, held in Vienna in April 2014. Here, we focus on some potential actions that could be undertaken in a relatively short term, having in mind the proximity of next General Assemblies of the International Association of Geodesy (IAG GA, 22 June 2015, Prague) and the International Astronomical Union (IAU GA, 2 August 2015, Honolulu).

In particular, we propose feasible enhancements of the current precession/nutation models by completing the changes needed to get full consistency between the new precession theory and the nutation one, and by clarifying the nomenclature to the users. As it is well known both issues are of paramount importance for the objectives of JWG_ThER (e.g., Ferrándiz & Gross 2015).

Besides, we address future improvements of the models. They account for different effects that provide contributions above or near the 10 $\mu$as level and might play a role for observational demands, geophysical interpretation, or better consistency. However, it seems quite unlikely that they can be incorporated in an immediate future, since they could entail a change in the basic Earth model considered in IAU2000A nutation.

## 2. CURRENT PRECESSION/NUTATION MODEL

The XXIVth IAU GA (Manchester 2000) resolution B1.6 adopted a new IAU precession–nutation model (Mathews et al. 2002, MHB2000), fully implemented through IAU 2000A model and IAU 2000B for users needing lower accuracy. The nutational part of the theory represents a clear improvement over the IAU 1980 nutation model, whereas the precessional one is basically that of IAU 1976, updated with corrections to precession rates. It was the cause for an encouraging of the development of new expressions for precession consistent with the IAU 2000A. Finally, this task was accomplished in the XXVIth IAU GA (Prague 2006) where the solution by Capitaine et al. (2003, P03) was adopted as IAU precession model by Resolution B1.

At the highest levels of precision the matching of P03 precession theory with IAU 2000A nutational part is not direct. Some nutation terms must be corrected to keep consistency (Capitaine & Wallace 2006), due to changes of some relevant parameters derived from P03. The main adjustments are due to the inclusion of $J_2$ rate and to the change in the value of the obliquity $\varepsilon_0$, both considered in P03.

[1] Due to some health problems of J. Getino, A. Escapa is temporarily acting as Co–Chair of Sub-WG1.

The first one contributes to Poisson terms (mixed secular) in nutation both in longitude $\psi$ and obliquity $\varepsilon$ (Capitaine & Wallace 2006, Escapa et al. 2014). In addition, it also originates some out of phase terms (Escapa et al. 2015). Numerically some of those contributions are relevant at 1 $\mu$as level. Both of them are shown in Tables 1 & 2. As it can be seen the adjustments worked out in both investigations (Table 1) shows a high level of agreement in spite of the different methods used to derive those contributions.

| Argument | | | | | Period | $t\,d\psi$ ($\mu$as/cJ) | | $t\,d\varepsilon$ ($\mu$as/cJ) | |
|---|---|---|---|---|---|---|---|---|---|
| $l_M$ | $l_S$ | $F$ | $D$ | $\Omega$ | Days | CW2006 | EGFB2015 | CW2006 | EGFB2015 |
| +0 | +0 | +0 | +0 | +1 | -6793.48 | 47.8 | 48.0 | -25.6 | -25.6 |
| +0 | +0 | +0 | +0 | +2 | -3396.74 | -0.6 | -0.6 | – | – |
| +0 | +0 | +2 | -2 | +2 | 182.63 | 3.7 | 3.5 | -1.6 | -1.5 |
| +0 | +0 | +2 | +0 | +2 | 13.66 | 0.6 | 0.6 | – | – |

Table 1: Contributions due to $J_2$ rate (mixed secular). CW2006 and EGFB2015 mean Capitaine & Wallace (2006) and Escapa et al. (2015), respectively. Those contributions less than 0.5 ($\mu$as/cJ) are completed with –.

| Argument | | | | | Period | $d\psi$ ($\mu$as) | | $d\varepsilon$ ($\mu$as) | |
|---|---|---|---|---|---|---|---|---|---|
| $l_M$ | $l_S$ | $F$ | $D$ | $\Omega$ | Days | CW2006 | EGFB2015 | CW2006 | EGFB2015 |
| +0 | +0 | +0 | +0 | +1 | -6793.48 | NC | -1.4 | NC | -0.8 |

Table 2: Contributions due to $J_2$ rate (out of phase terms, nutations). The abbreviations are the same as in Table 1, NC meaning not considered.

The second adjustment affects nutations in longitude through a scale factor $\sin\varepsilon_0$ accounted by Capitaine & Wallace (2006) and also computed in Escapa et al. (2015). Besides it also influences all the reference rigid Earth nutation amplitudes in longitude and obliquity (Escapa et al. 2015), via the orbital functions $B(\varepsilon_0)$ introduced by Kinoshita (1977). For brevity, we refer to the first as 'global rescaling' and to the later as 'consistency of rigid solution'. Those contributions, at the 1 $\mu$as level, are displayed in Tables 3 & 4. Again the effects worked out in both researches (Table 3) provide identical values.

| Argument | | | | | Period | $d\psi$ ($\mu$as) | |
|---|---|---|---|---|---|---|---|
| $l_M$ | $l_S$ | $F$ | $D$ | $\Omega$ | Days | CW2006 | EGFB2015 |
| +0 | +0 | +0 | +0 | +1 | -6793.48 | -8.1 | -8.1 |
| +0 | +0 | +2 | -2 | +2 | 182.63 | -0.6 | -0.6 |

Table 3: Contributions due to change in the value of the obliquity $\varepsilon_0$ (global reescaling). The abbreviations are the same as in Table 1.

Let us remark that the adjustments related to the change of the reference rigid Earth nutations (Table 4) are of the same order of magnitude than those due to the global rescaling. Hence, a consistent treatment of the change in the value of the obliquity $\varepsilon_0$ should lead to consider the total corrections ($\mu$as, $t$ in cJ)

$$d\psi = (-15.6 - 8.1t)\sin\Omega,\ d\varepsilon = 0.8\cos\Omega, \tag{1}$$

rather than only those displayed in Table 3.

Some of the adjustments due to changes of the precession theory, those from Capitaine & Wallace (2006), are considered in the current IERS Conventions (2010). However, there is no explicit mention in any IAU resolution about the inclusion of those adjustments, which are necessary to ensure compatibility between P03 and MHB2000.

In this way we face with two combinations: (1) P03 (precession, IAU 2006) + MHB2000 (nutation, IAU 2000A) and (2) P03 (precession, IAU 2006) + MHB2000 (nutation, IAU 2000A) + adjustments to MHB2000 (Capitaine & Wallace 2006).

As it was pointed by Urban & Kaplan (2011) this fact has also originated the use of different terminology for designating the same model depending on the source. For example, IERS Conventions (2010)

| Argument | | | | | Period | $d\psi$ ($\mu$as) | $d\varepsilon$ ($\mu$as) | $t\,d\psi$ ($\mu$as/cJ) | $t\,d\varepsilon$ ($\mu$as/cJ) |
|---|---|---|---|---|---|---|---|---|---|
| $l_M$ | $l_S$ | $F$ | $D$ | $\Omega$ | Days | EGFB2015 | | | |
| +0 | +0 | +0 | +0 | +1 | -6793.48 | -7.5 | 0.8 | -8.1 | – |
| +0 | +0 | +2 | -2 | +2 | 182.63 | 0.5 | – | – | – |

Table 4: Contributions due to change in the value of the obliquity $\varepsilon_0$ (consistency of rigid solution). The abbreviations are the same as in Table 1. None of these contributions are present in Capitaine & Wallace (2006).

designates (1) as IAU 2006/2000A and (2) as IAU 2006/2000A$_{\rm R06}$. Standards of Fundamental Astronomy (SOFA, e.g., Hohenkerk 2012) uses IAU 2006/2000A (suffix "00A") for (1) and IAU 2006/2000A (suffix "06A") (2). Explanatory Supplement to the Astronomical Almanac (2013) names (1) as IAU 2006/2000A and (2) as IAU 2006/2000A$_{\rm R}$. Therefore, there is a clear need of uniformizing the terminology.

## 3. FUTURE IMPROVEMENTS OF THE MODEL

After the adoption of IAU2000 model, scientific contributions related to Sub-WG1 issues have focused mainly on new second order effects. These effects comprise terms arising from crossing first order contributions in the perturbation sense (mathematical), and also not modeled (or ill modeled) terms whose magnitude is small (physical). They provide corrections of the order of some tens of $\mu$as (or more) whose consideration is nowadays necessary.

Next, we outline the topics contributed by some ordinary and correspondents members of this subgroup. Regrettably, the limitation of space does not allow us to provide full explanations on them. We encourage the interested readers to look up the extended mid–term report (Getino & Escapa 2014) available on-line, as well as the papers reported by the contributors in this issue. There, they will find more details on these topics and a list of the proper references. For brevity, it is just indicated the name of the sender, although some works are the result of their cooperation with other colleagues.

- J. Souchay: Proposes to study the influence of the Moon when considering it as a triaxial, not pointlike object; (proposal) to study the precession–nutation in primary ages of the solar system, when the Moon was considerably closer to the Earth.
- C. Huang: Earth nutation and its coupling with the magnetic field; new theory of Earth rotational modes (application to Free Core Nutation); a generalized theory of the figure of the Earth interior.
- J. Müller: Nutation determined from only Lunar Laser Ranging (LLR) data.
- J. Vondrák: Geophysical excitation of nutations by numerical integration of Brzeziński's broad–band Liouville equations.
- Y. Barkin: Study of the perturbed rotational motion of the Earth caused by the weak variation of the mass geometry and the angular momentum of the relative motion of the planet particles.
- V. Dehant & M. Folgueira: Topographic coupling at core-mantle boundary in rotation and orientation changes of planets.
- A. Brzeziński: (JWG_ThER organizational proposal) Convenience of splitting up the scope of Sub-WG1 and Sub-WG2 based on geophysical mechanism: the geophysical excitations of nutations (long period) should be considered by Sub-WG2, while modeling the librations (astronomical) in polar motion by Sub-WG1; atmospheric and oceanic excitation of the Free Core Nutation estimated from recent geophysical models; on estimation of the high frequency geophysical signals in Earth rotation by complex demodulation.
- A. Escapa: Direct effects of the rotation of the inner core; influence of the triaxiality on the Earth rotational motion.
- J. Getino: New perturbation technique to integrate higher orders in the Earth rotation theory.
- J. M. Ferrándiz: Nutation and precession couplings (consistency) due to second order and tidal effects of the non–rigid Earth.

## 4. DISCUSSION

Accordingly to the former sections some questions arise in a natural way. They were opened to the discussion by Sub-WG1 members and, in general, to all JWG_ThER (Ferrándiz & Gross 2015). On the one hand, there are three questions related with the adjustments to IAU 2000A (nutation) induced by IAU 2006 (precession), which could be addressed in a relatively short term:

1. *Should the current numerical values of the adjustments to MHB2000 nutations (Capitaine & Wallace 2006) be completed (see Section 2)?*
2. *Should combination of P03 (precession, IAU 2006) + MHB2000 (nutation, IAU 2000A) + adjustments to MHB2000 be officially supported by IAU/IAG JWG_ThER through some action?*
3. *Should IAU/IAG JWG_ThER suggest or recommend a clear terminology for the models/algorithms in use, e.g., Urban & Kaplan (2012), etc.?*

On the second one, there are some questions related with the future improvement of the current nutation/precession model. However, the integration of described effects (Section 3) into a single consistent theory presents a complex scenery, which requires deeper considerations, for example:

1. *Could IAU2000A basic (symmetric) Earth model be preserved or should we move to another more sophisticated model?*
2. *How to homogenize their theoretical analysis to "plug" them into a global model?*
3. *How much of this task can be carried out in the current term of the JWG_ThER?*

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