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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Introduction (1)

- IAU/IAG Joint Working Group on Theory of Earth Rotation: Sub-Working Group 1 “Precession/Nutation”
- Chair:
  - J. Getino, Spain
- Members (16):
  - Y. Barkin*, Russia; N. Capitaine, France; V. Dehant*, Belgium; A. Escapa*, Spain; J. Ferrándiz*, Spain; M. Folgueira*, Spain; A. Gusev, Russia; R. Gross, USA; T. Herring, USA; CL. Huang*, China; J. Müeller*, Germany; Y. Rogister, France; H. Schuh, Germany; J. Souchay*, France; V. Zharov, Russia; J. Vondrák*, Czech Republic
- Correspondent members (2):
  - G. Kaplan*; USA; S. Urban*, USA
- Chairs of SWG 2 & 3:
  - A. Brzeziński*, Poland; R. Heikelmann, Germany

(*) Contributors to this report

Introduction (2)

- Continues former report at EGU 2014 (http://web.ua.es/en/wgther)
- Here, we focus on the following potential actions, having in mind the proximity of next General Assemblies of IAG (22 June, Prague) and IAU (2 August, Honolulu) :
  - Feasible enhancements of current precession/nutation model by
    - Completing the changes needed to get full consistency between the new precession theory and the nutation one
    - Clarifying nomenclature of the involved models
  - Future improvements of the models:
    - Accounting for different effects that provide contributions above or near the 10 μas level and might play a role for observational demands and/or geophysical interpretation or better consistency
    - Some of them requires a careful analysis, since they could entail a change in the basic Earth model considered in IAU2000A nutation

Current precession/nutation model (1)

- XXIVth IAU GA (Manchester 2000) resolution No. B1. 6 adopted IAU precession-nutation model (Mathews et al. 2002, MHB2000):
  - IAU 2000A (0.2 mas level) or IAU 2000B (1 mas level)
  - Nutational part is a clear improvement over IAU 1980 nutation model
  - Precessional part is basically that of IAU 1976 (Lieske et al. 1977), updated with corrections to precession rates
  - Encouraged the development of new expressions for precession consistent with the IAU 2000A

- XXVIth IAU GA (Prague 2006) resolution No. B1 adopted IAU precession model (Capitaine et al. 2003, P03):
  - Precession component of IAU 2000A replaced by P03 precession theory

Current precession/nutation model (2)

- At the highest levels of precision, the replacement of the IAU 2000 precession part by P03 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 (*H* is almost identical) are due to:
  - ***The inclusion of J_2 rate in P03:***
    - It contributes to Poisson terms (mixed secular) in nutation both in longitude and obliquity (Capitaine & Wallace 2006). In addition, it also originates some out of phase terms (Escapa et al. 2013)
  - ***The change in the value of the obliquity ε_0 in P03:***
    - Affects nutations in longitude through a scale factor *sin* (ε_0), accounted by Capitaine & Wallace (2006)
    - Changes all the reference rigid Earth nutation amplitudes in longitude and obliquity via Kinoshita's functions $B(\varepsilon_0)$ (Escapa et al. 2013)

Current precession/nutation model (3)

Numerically the total adjustments are (shown > 1 μas):

- J_2 rate, Poisson terms (μas/cJ): Capitaine & Wallace 2006, Escapa et al. 2013 – *high agreement*

l	l'	F	D	Ω	$t*d\psi$		$t*d\varepsilon$	
0	0	0	0	1	47.8	48.0	-25.6	-25.6
0	0	0	0	2	-0.6	-0.6	-	-
0	0	2	-2	2	3.7	3.5	-1.6	-1.5
0	0	2	0	2	0.6	0.6	-	-

- J_2 rate, out of phase terms: Escapa et al. 2013 *(new)*

l	l'	F	D	Ω	$d\psi$	$d\varepsilon$
0	0	0	0	1	-1.4	-0.8

Current precession/nutation model (4)

- ε_0 change, **global rescaling**: Capitaine & Wallace 2006, Escapa et al. 2013 – *high agreement*

l	l'	F	D	Ω	$d\psi$	
0	0	0	0	1	-8.1	-8.1
0	0	2	-2	2	-0.6	-0.6

- ε_0 change, **consistency of rigid solution *(new)***: Escapa et al. 2013

l	l'	F	D	Ω	$d\psi$	$d\varepsilon$	$t*d\psi$	$t*d\varepsilon$
0	0	0	0	1	-7.5	0.8	-8.1	-
0	0	2	-2	2	0.5	-	-	-

- ε_0 change, total correction: **rescaling + rigid consistency** (μas, μas/cJ):

l	l'	F	D	Ω	$d\psi$	$d\varepsilon$	$t*d\psi$	$t*d\varepsilon$
0	0	0	0	1	-15.6	0.8	-8.1	-

❑ Open question (to be discussed):

➢ Should the current numerical values of the adjustments to MHB2000 nutations (Capitaine & Wallace 2006) be completed?

Current precession/nutation model (5)

- Hence, nowadays some combinations in use are (Urban and Kaplan 2011):

  (1) P03 (prec., IAU 2006) + MHB2000 (nut. part, IAU 2000A)

  (2) P03 (prec., IAU 2006) + MHB2000 (nut. part, IAU 2000A) + Adjustments to MHB2000 (nutational part, C&W 2006)

- (2) is considered in IERS Conventions 2010, Standards of Fundamental Astronomy (SOFA), and Explanatory Supplement to the Astronomical Almanac

- As recognized by Urban and Kaplan (2011), there are used different names to designate the former combinations, e.g.:

Comb.	(1)	(2)
IERS	IAU 2006/2000A	IAU 2006/2000A$_{R06}$
SOFA	IAU 2006/2000A (suffix “00A”)	IAU 2006/2000A (suffix “06A”)
Exp. Supp.	IAU 2006/2000A	IAU 2006/2000A$_{R}$

Current precession/nutation model (6)

- Open questions (to be discussed):
  - Should combination P03 (prec., IAU 2006) + MHB2000 (nut. part, IAU 2000A) + Adjustments to MHB2000 be officially supported by IAU/IAG JWG_ThER through some action?
  - Should IAU/IAG JWG_ThER suggest or recommend a clear terminology for the models/algorithms in use, e.g., Kaplan (2009), Urban & Kaplan (2011), etc.?

Future improvements of the model (1)

- After IAU2000 adopted model on nutation (Mathews et al. 2000), scientific contributions related with SWG1 issues have been focused mainly on new second order effects
- Second order effects comprise terms arising from crossing first order contributions in the perturbation sense (mathematical), and also not modelled (or ill modelled) terms whose magnitude is small (physical)
- These effects provide corrections of the order of some tens of μas (or more):
  - Observational demands
  - Geophysical interpretation
  - Better precession-nutation consistency

Future improvements of the model (2)

- Next, we list some topics contributed by the members and correspondents of this subgroup
- There is an extended description of some of them that will be added (with permission of the contributors) to this presentation at the WG on Theory of Earth Rotation web (http://web.ua.es/en/wgther)
- We have listed them following a chronological order as they contacted the chair of SWG1
- For brevity, it is just indicated the name of the member/correspondent of the SWG1, although some works are the result of a cooperation with other colleagues
- Several issues are presented in different talks of these Journées, we encourage you to attend them to obtain more details of the research directly from their authors
- There are other talks also of interest for this SWG1

Future improvements of the model (3)

- **J. Souchay (proposals)**:
  - **To study the influence of the Moon when considering it as a triaxial, not pointlike object**: old computations indicated an effect at the µas level
  - **To study the precession-nutation in primary ages of the solar system, when the Moon was considerably closer to the Earth**: It should gather quite a good number of specialists, combining rigid and non rigid aspects
- **C. Huang:**
  - **Earth nutation and its coupling with the magnetic field:** in a displacement field approach the contribution of the Electromagnetic Coupling to FCN is one order of magnitude smaller than in MHB2000
  - **New theory of Earth rotational modes (app. to FCN)**: by using the Galerkin method and developing a linear operator and a new multiple layer spectral method, it was obtained in a first result a period of 435 sidereal days for the FCN (***Session 4, tomorrow 09:00-10:20****, Do we need various assumptions to get a good FCN? - A new multiple layer spectral method by* ***Huang & Zhang***)
  - **A generalized theory of the figure of the Earth interior**: using a new potential/figure theory and real surface layers data, obtaining a value for the dynamic flattening *H = 1/306.88*

Future improvements of the model (4)

- **J. Müller:**
  - **Nutation determined from only Lunar Laser Ranging (LLR) data:** fit of luni-solar nutation coefficients from 44 years of LLR data for nutation periods of 18.6 years, 9.3 years, 1 year, 182.6 days and 13.6 days, by using different realizations of precession/nutation for ICRS-ITRS transformation

- **J. Vondrák:**
  - **Numerical integration of Brzeziński's broad-band Liouville equations:** applied to estimate atmospheric and oceanic excitation of nutation. It is documented that the effect is significant, especially at annual and semi-annual periods, the amplitudes reaching 0.1mas (***Session 4, today 16:00-17:40***, *Geomagnetic excitation of nutation by* ***Ron & Vondrák***)

Future improvements of the model (5)

- **Y. Barkin**:
  - **Study of the perturbed rotational motion of the Earth**: construction of a first-order perturbations theory in Andoyer variables and for the projections of the angular velocity of rotation of the planet caused by the weak variation of the mass geometry and the components of the angular momentum of the relative motion of the particles of the planet
- **V. Dehant & M. Folgueira**:
  - **Topographic coupling at core-mantle boundary in rotation and orientation changes of planets**: four coupling mechanisms (topographic, viscous, gravitational and electromagnetic torques) are computed to revise their relative importance in the terrestrial bodies, with particular emphasis on the topographic coupling (***Session 4, today 14:00-15:30***, *Refinements on precession, Nutation, and Wobble of the Earth by* ***Dehant***)
- **A. Brzeziński (proposal)**:
  - **Convenience of splitting up the scope of SWG1 and SWG2 based on geophysical mechanism**: the geophysical excitations of nutations (long period) should be considered by SWG2, while modeling the librations (astronomical) in polar motion by SWG1

Future improvements of the model (6)

- **A. Brzeziński**:
  - **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** *(**Session 4, today 14:00-15:30**, On application of the complex demodulation procedure for monitoring Earth rotation: comparison with the standard approach using the long periodic EOP components estimated from VLBI data analysis by the VieVS CD software by **Brzeziński, Wielgosz, & Boehm**)*
- **A. Escapa**:
  - **Direct effects of the rotation of the inner core:** due to the differential rotation of the inner core, providing contributions to the nutations at the μas level (not in IAU2000)
  - **Influence of the triaxiality of the Earth:** currently as corrections to polar motion. There is no considered the triaxiality of the core, neither its indirect effects on the nutations, although nowadays there is some work on this issue (Chen & Shen 2010, ***Poster session**, Triaxial Earth's rotation: Chandler wobble, free core nutation and diurnal polar motion by **Sun & Shen***)

Future improvements of the model (7)

- **J. Getino**:
  - **New perturbation technique to integrate higher orders in the Earth rotation theory:** by using a matrix formulation of the equations of motion, the dynamical variables are gathered together in two matrix variables, while the considered model is represented by the matrices of the system. Second order analytical solutions are obtained in a systematic way. The inclusion of new effects is reduced to the redefinition of the matrices of the system
- **J. M. Ferrándiz**:
  - **Consistency among nutation and precession theories:** second order and tidal effects of the non-rigid Earth stemming from the nutation model also contribute to the precession rates, so the precession model is also affected by complex non-rigid nutation interactions (***Session 4, today 16:00-17:40***, *Effects of the tidal mass redistribution on the Earth rotation by* ***Ferrándiz, Baenas, Escapa, & Getino***)

Future improvements of the model (8)

- Open questions (to be discussed):
  - The integration of previous described effects into a single consistent theory present a complex scenery, e.g.:
    - Could IAU2000A basic (symmetric) Earth model be preserved or should we move to another more sophisticated model?
    - How to homogenize their theoretical analysis to “plug” them into a global model?
    - How much of this task can be carried out in this term?

An extended version of this presentation, with a detailed description of the contributions of the members of this SWG1, is available at the web of WG on Theory of Earth Rotation (http://web.ua.es/en/wgther)