Sub-Working Group 1
"Precession/Nutation" of the IAU/IAG
Joint Working Group on Theory of Earth Rotation and Validation

Alberto Escapa\textsuperscript{1,2}, Juan Getino\textsuperscript{3}

\textsuperscript{1}University of Alicante, Spain; \textsuperscript{2}University of León, Spain;
\textsuperscript{3}University of Valladolid, Spain;

\texttt{Alberto.Escapa@ua.es}

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Introduction

- IAU/IAG Joint Working Group on Theory of Earth Rotation and Validation:
  - Sub-Working Group 1 “Precession/Nutation”

- Chair:
  - J. Getino, Spain; A. Escapa, Spain (Vicechair)

- Members (17):
  - Y. Barkin†, Russia; N. Capitaine, France; V. Dehant, Belgium; S. Dickman, USA; J. Ferrándiz, Spain; M. Folgueira, Spain; A. Gusev, Russia; R. Gross, USA; T. Herring, USA; CL. Huang, China; J. Müller, Germany; R. Ray, USA; Y. Rogister, France; J. Souchay, France; J. Vondrák, Czech Rep.; M. Zhang, China; V. Zharov, Russia

- Correspondent members (5):
  - G. Kaplan; USA; C. Ron , Czech Rep.; H. Schuh, Germany; D. Thaller, Germany; S. Urban, USA

- Chairs of SWG 2 & 3:
  - A. Brzeziński, Poland; R. Heikelmann, Germany
Introduction

- Following the terms of reference of IAG/IAU Joint WG on Theory of Earth Rotation and Validation, **SWG1** devotes to:
  - Precession-Nutation
  - Astronomical components of Polar Motion (PM) associated with the multipole structure of the Earth (geophysical effects in nutation, mainly FCN and S1 signals are considered by SWG2 “Polar motion and UT1”)
- In particular, **main targets are focused (but not limited to)** on:
  - Pointing out feasible enhancements of current IAU 2006/2000 Precession-Nutation model
  - Reporting future improvements of the model
Introduction

Some issues were proposed in the previous term (http://web.ua.es/es/wgterv/documentos/swg1-report-iag-2015.pdf):

- Clear terminology of IAU 2006/2000 combinations
- Full consistency between nutation and precession parts (precession → nutation)

However, it is necessary to deepen some aspects:

- Full consistency between nutation and precession parts (nutation → precession)
- Different effects that provide contributions about the 10 µas level
- ...

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### Current IAU prec./nut. standards

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<td></td>
<td></td>
<td>Souchay et al. 1999</td>
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<tr>
<td>Precession</td>
<td></td>
<td>IAU 1976 (*)</td>
<td></td>
<td>IAU 2006</td>
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<td></td>
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<td>Lieske et al. 1977</td>
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<td>Capitaine et al. 2003, 2005</td>
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<td></td>
<td>IAU 1979</td>
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</table>

(*) We have considered the starting point of the period of validity of a standard the date of approval, although usually it enters in force some years later

Current IAU prec./nut. standards

- Current IAU precession/nutation model is, de facto, comprised of three theories:
    - XXIVth IAU GA (Manchester 2000) resolution No. B1. 6
    - Resolution B1.6 recognizes it as “precession-nutation model” but the precessional part is an update of IAU 1976 (Lieske et al. 1977) precession and obliquity rates
    - Nutational part improves IAU 1980 nutation model through model IAU 2000A (0.2 mas level) or a shorter version model IAU 2000B (1 mas level)
Current IAU prec./nut. standards

- It is computed through:
  - **REN2000** (Souchay et al. 1999) rigid Earth Hamiltonian nutation series of figure axis
  - **Transfer function** for a non-rigid Earth model (Mathews et al. 2002):
    - Three symmetrical layers
    - Mantle anelasticity and ocean tides
    - Internal couplings at fluid core boundaries
  - The short period nutations, of astronomical nature, do not form part of the model (periods greater than 2 days in the GCRS) and are provided by IERS (Resolution B1.7)
  - There is no IAU official model for Free Core Nutation (IERS Conventions 2010)
Current IAU prec./nut. standards

- Precession model (Capitaine et al. 2003, P03):
  - XXVIth IAU GA (Prague 2006) resolution No. B1
  - It replaces the precession part of the IAU200A precession-nutation model
  - In fact, it can be properly viewed as the substitution of IAU 1976 (Lieske et al. 1977)
  - A main novelty (as official model, see Williams 1994) is the inclusion of a time rate of change in the dynamical form factor, mainly due to post-glacial rebound,

\[ \frac{dJ_2}{dt} = -3.0 \times 10^{-9} \text{ century}^{-1} \]
Current IAU prec./nut. standards

- In addition to accuracy requirements, the development of IAU 2006 precession responds to the demand of being consistent with both dynamical theories and the IAU 2000 nutation.

- In the case of the replacement of IAU 2000 precession part by P03 this circumstance was early recognized by Capitaine et al. (2005), who noted that some nutation terms must be corrected to keep consistency (precession $\rightarrow$ nutation, considered in the first SWG1 term).

- In the same line, second order terms of a rigorous nutation theory (Ferrándiz et al., last Tuesday) provide contributions to longitude and obliquity rates not considered, or updated, in IAU 2006 precession (nutation $\rightarrow$ precession).
Current IAU prec./nut. standards

- Precession → nutation adjustments (>1μas) derived by Capitaine & Wallace 2006 (1) and Escapa et al. 2013 (2) are:

  - \( J_2 \) time rate contributions:

<table>
<thead>
<tr>
<th>Arguments</th>
<th>Mixed secular (1,2)</th>
<th>Out-phase (NEW, 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( t^*d\psi (\mu as/cJ) )</td>
<td>( t^*d\epsilon (\mu as/cJ) )</td>
</tr>
<tr>
<td>( I ) ( I' ) F D ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 0 0 0 1</td>
<td>47.8</td>
<td>-25.6</td>
</tr>
<tr>
<td>0 0 0 0 2</td>
<td>-0.6</td>
<td>--</td>
</tr>
<tr>
<td>0 0 2 -2 2</td>
<td>3.7</td>
<td>-1.6</td>
</tr>
<tr>
<td>0 0 2 0 2</td>
<td>0.6</td>
<td>--</td>
</tr>
</tbody>
</table>

- Changes in \( \epsilon_A \) contributions:

<table>
<thead>
<tr>
<th>Arguments</th>
<th>Rescaling (1,2)</th>
<th>Rigid Earth consistency (NEW, 2*)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( d\psi (\mu as) )</td>
<td>( d\psi (\mu as) )</td>
</tr>
<tr>
<td>( I ) ( I' ) F D ( \Omega )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 0 0 0 1</td>
<td>-8.1</td>
<td>-7.5</td>
</tr>
<tr>
<td>0 0 2 -2 2</td>
<td>-0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

(*) Rescaling subtracted from rigid Earth consistency contributions
Current IAU prec./nut. standards

- However, there has been no IAU resolution, or recommendation, about the way in which matching IAU2006 and IAU 2000 theories

- Partial precession→nutation adjustments (Capitaine & Wallace 2006, previous table) are considered in IERS Conventions 2010 and SOFA, giving rise to the combinations

  1. \( P_{03} \) (prec., IAU 2006) + MHB2000 (nut. part, IAU 2000A)

- Besides there is non-uniform terminology (Urban & Kaplan 2011):

<table>
<thead>
<tr>
<th>Comb.</th>
<th>(1)</th>
<th>(2)</th>
</tr>
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<tbody>
<tr>
<td>IERS</td>
<td>IAU 2006/2000A</td>
<td>IAU 2006/2000A(_{R06})</td>
</tr>
<tr>
<td>SOFA</td>
<td>IAU 2006/2000A (suffix “00A” )</td>
<td>IAU 2006/2000A (suffix “06A” )</td>
</tr>
</tbody>
</table>
Current IAU prec./nut. standards

Hence, two questions arise concerning possible supplements, or recommendations, to IAU resolutions:

- Establishing the way in which full consistency between P03 (precession, IAU 2006) and MHB2000 (nutation, IAU 2000A) must be achieved and provide the values of the adjustments (e.g., for precession → nutation Capitaine & Wallace 2006 and Escapa et al. 2013)

- Establishing a clear terminology to designate the models in use
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Areas of enhancement

- Within the context of SWG1, there have been several enhancements of IAU2000 nutation model.
- They refer to “small” terms (second order) comprising:
  - Contributions arising from crossing first order terms in the perturbation sense (mathematical).
  - Contributions whose magnitude is small (physical).
  - Contributions ill-modelled.
- Their magnitude is about some tens of μas (or more), needed for:
  - Observational demands.
  - Geophysical interpretation.
  - Better precession-nutation consistency.
- There have also been some enhancement of IAU2006 (Vondrák et al. 2011) and its possible update (Liu & Capitane, last Tuesday).
Areas of enhancement

Next, we list some topics contributed by the members and correspondents (in alphabetic order) of this subgroup for this meeting and also those sent to IUGG 2015 and to Journées 2014 (previous term)

For the sake of brevity, we just mention the first author although in some cases they are the result of a collaborative research

Other interesting issues have been presented in different talks and lectures in these days, we encourage to obtain more details of the research directly from their authors

Please, let us recall that SWG1 summaries talks are available at http://web.ua.es/en/wgterv
Areas of enhancement

- **Refinements on precession, Nutation, and Wobble of the Earth (V. Dehant, Tuesday talks by Dehant, Reiker, Zhu et al.)**
  - Basic Earth Parameters (BEP) were determined from VLBI series
  - Interpretation in terms of / better understanding
    - Coupling mechanisms at core-mantle boundary (topographic, gravitational, viscous, and electromagnetic torques)
    - Coupling between the global rotation and the inertial waves in the fluid core
    - Coupling between the global rotation and large scale vortices
    - Role of precession and nutation forcing for the liquid core
    - Interaction between the Free (Inner) Core Nutation and waves such as the inertial waves

- **Work in the frame of the ERC RotaNut – Rotation and Nutation of a wobbly Earth (European Research Council under ERC Advanced Grant 670874)**
Areas of enhancement

ERC Advanced Grant RotaNut Rotation and Nutation of a wobbly Earth

Observation data

Models

Laboratory experiments

Earth Interior

Celestial mechanics

Atmosphere forcing

Tidal + non-tidal ocean forcing

Observation

Nutation model

Predictions

Residuals

Better understanding of the Earth interior!

New model!
Areas of enhancement

- Constraining the anelastic attenuation in the Earth mantle trough Chandler wobble (Y. Register)
  - Chandler wobble and frequency dependency of the ratio between gravity variation and vertical displacement for a simple Earth model with Maxwell or Burgers rheologies (Ziegler et al., submitted to Proceedings of the 2015 IAG)

*Period and quality factor as a function of the first or second viscosity for a Burgers rheology*

Two rigidities are equal

First rigidity=3 Second rigidity
Areas of enhancement


Phase kappa and amplitude delta of the gravimetric factor at the Chandler frequency
## Areas of enhancement

<table>
<thead>
<tr>
<th>Author</th>
<th>Topic</th>
<th>Meeting</th>
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<tr>
<td>V. Dehant</td>
<td>✓ Modeling of nutation and interior of the Earth</td>
<td>IUGG15</td>
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<tr>
<td></td>
<td>✓ Nutations of the planet Mars</td>
<td></td>
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<tr>
<td>J. M. Ferrándiz</td>
<td>✓ Reference frames in Earth rotation theories</td>
<td>IUGG15</td>
</tr>
<tr>
<td>J. Müller</td>
<td>✓ Determination of polar motion, UT and a few nutation coefficients from the analysis of LLR-only data</td>
<td>IUGG15</td>
</tr>
<tr>
<td>C. Ron</td>
<td>✓ Geomagnetic excitation of Earth's orientation</td>
<td>IUGG15</td>
</tr>
<tr>
<td>W. Shen</td>
<td>✓ Effects of lateral inhomogeneity on nutation</td>
<td>IUGG15</td>
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<tr>
<td>Y. Barkin</td>
<td>✓ Study of the perturbed rotational motion of the Earth</td>
<td>JSR2014</td>
</tr>
<tr>
<td>A. Brzeziński</td>
<td>✓ Atmospheric and Oceanic Excitation of the Free Core Nutation Estimated from Recent Geophysical Models</td>
<td>JSR2014</td>
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<td>✓ On estimation of the high frequency geophysical signals in Earth rotation by complex demodulation</td>
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<tr>
<td>V. Dehant, M. Folgueira</td>
<td>✓ Topographic coupling at core-mantle boundary in rotation and orientation changes of planets</td>
<td>JSR2014</td>
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<tr>
<td>A. Escapa</td>
<td>✓ Direct effects of the rotation of the inner core</td>
<td>JSR2014</td>
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<td></td>
<td>✓ Influence of the triaxiality of the Earth</td>
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<tr>
<td>J. M. Ferrándiz</td>
<td>✓ Consistency among nutation and precession theories</td>
<td>JSR2014</td>
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<tr>
<td>J. Getino</td>
<td>✓ New perturbation technique to integrate higher orders in the Earth rotation theory</td>
<td>JSR2014</td>
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<th>Author</th>
<th>Topic</th>
<th>Meeting</th>
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</table>
| C. Huang     | ✓ Earth nutation and its coupling with the magnetic field  
✓ New theory of Earth rotational modes (app. to FCN)  
✓ A generalized theory of the figure of the Earth interior | JSR2014 |
| J. Müller    | ✓ Nutation determined from only Lunar Laser Ranging (LLR) data                                                                                                                                         | JSR2014 |
| J. Souchay   | ✓ 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 (proposal) | JSR2014 |
| J. Vondrák   | ✓ Numerical integration of Brzeziński’s broad-band Liouville equations                                                                                                                               | JSR2014 |
Areas of enhancement

- As we can conclude there are many additional open issues:
  - Should we move to another more complex model or should the IAU2000 basic Earth model preserved?
  - How to merge all the different effects, worked out with quite different formalisms, into a global precession/nutation model ensuring consistency?
  - How long?
  - ...
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