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DIVISION I
COMMISSION 19

ROTATION OF THE EARTH

ROTATION DE LA TERRE

PRESIDENT	**Harald Schuh**
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	IVS representative: Oleg Titov
	IERS representative: Bernd Richter
	IAG representative: Zinovy Malkin

PROCEEDINGS BUSINESS AND SCIENCE SESSIONS, 29–30 August 2012

1. Introduction

During the XXVIII IAU General Assembly in Beijing IAU Commission 19 - Rotation of the Earth - held a business meeting and a scientific meeting. The business meeting was held on Wednesday, 29 August 2012 during session 1 (08:30-10:00). It was attended by about 35 participants, and six reports were given. First the activities of IAU Commission 19 during the past triennium (2009–2012) were highlighted by the Commission president. Afterwards, the Commission secretary presented the results of the elections for the next triennium (2012–2015) and a list of new members of the Commission. The designated Commission president provided an outlook into the next triennium, before the representatives of the international bodies and services IAG (International Association of Geodesy), IVS (International VLBI Service for Geodesy and Astrometry), and IERS (International Earth Rotation and Reference Systems Service) gave reports about recent activities. A summary of the business meeting is given below in Section 2. The scientific meeting was held on Thursday, 20 August 2012 during sessions 1 and 2 (08:30-12:30). Eleven presentations were given, and about 40 participants attended the sessions. Summaries of the presentations are provided below in Section 3.

2. Business Meeting

2.1. *Activities of IAU Commission 19 - Rotation of the Earth (2009–2012)*

Harald Schuh, Chengli Huang, Florian Seitz

Organizational issues:

- Establishing a Commission's Secretary (Florian Seitz, TU Munich)
- Setting up and maintaining the C19 website: www.iau-comm19.org, including a section on the history of C19.

- Collaboration with other IAU Commissions and with IAG (IAU Resolution 2009 on the ICRF and were also approved as IAG/IUGG Resolutions in 2011)
- Contributing to Division I issues
- Contacts with IAU Bureau
- Update of the Commission 19 member list (see Section 2.2)
- Organizing the C19 OC elections for the term 2012 - 2015 (see Section 2.2).

Conferences and publications

- Co-organisation of the Joint GGOS/IAU Science Workshop 'Observing and Understanding Earth Rotation', Shanghai, October 25–28, 2010 with about 90 international participants
- Co-organisation of a Special Issue on Earth Rotation in the Journal of Geodynamics, 20 papers submitted, 13 papers accepted
- Co-organisation of the Journées Systémes de Référence Spatio-Temporels 2010 in Paris, and 2011 September 19–21 in Vienna, about 100 participants
- Supporting sessions on Earth rotation at EGU 2010, 2011, 2011 in Vienna, at AGU in San Francisco, and at IUGG (2011, Melbourne)
- Preparation of the IAU General Assembly in Beijing, including two own Scientific Sessions on Earth Rotation and co-organisation of the Joint Discussion 7 on Space-Time Reference Systems for Future Research
- Triennial (scientific) report of C19 to IAU (Transactions IAU: Reports on Astronomy 2009–2012)

2.2. *Results of the elections for the new triennium (2012–2015) and new members of the Commission*

Florian Seitz

In February 2012 the Commission Secretary submitted a list of candidates, based on nominations from the members, for the offices of President (1 candidate), Vice-President (2 candidates) and OC (8 candidates). An electronic vote was conducted among all Commission members. Results were submitted to the parent Division for approval.

Offices for the term 2012–2015:

- President: Cheng-Li Huang (PR China)
- Vice-President: Richard Gross (USA)
- Secretary: Florian Seitz (Germany)
- Past President: Harald Schuh (Austria)
- OC member: Christian Bizouard (France), 2nd term
- OC member: Ben Chao (Taiwan), 2nd term
- OC member: Wieslaw Kosek (Poland), 2nd term
- OC member: David Salstein (USA), 2nd term
- OC member: Vladimir Zharov (Russia), 1st term
- IVS representative: Oleg Titov (Australia)
- IERS representative: NN.
- IAG representative: Zinovy Malkin (Russia)

During the last triennium, one active member, Anne-Marie Gontier, sadly passed away. Three members retired from the Commission (Francois E. Barlier, Leslie V. Morrison, Fabian Roosbeek), and 15 young scientists at post-doc level who are very active in the field of Earth rotation were invited to become new members of Commission 19.

2.3. *Outlook into the upcoming triennium (2012–2015)*

Chengli Huang, Richard Gross, Harald Schuh and Florian Seitz

Current achievements of geodesy allow to investigate a lot of smaller effects and geophysical factors and to stimulate further studies of EOP excitation:

• In observation: the precision reaches at 1 mm (or 30 micro-as) and 0.1 mm/year for position (or angle) and velocity respectively, and time resolution reaches hourly even near real time and continuous;

• In services: Very precise and dense EOP and ITRF/ICRF are provided by IERS and other services such as IVS, IGS, ILRS, and IDS.;

• In new techniques and instruments: Ring-laser and optical clocks become more mature and almost ready for services;

• In theoretical models: New precession/nutation models, global geophysical fluids (atmosphere, oceans, hydrology, etc.) models have been considerably improved, but there are still open questions.

Planed activities of C19 (as a bridge, a platform and a service) for the next term:

• Follow new technological achievements with relevance for EOP research (e.g. optical clocks) and make proposals on applications;

• Cooperate with related services (IERS, GGOS, IAG, IVS, ILRS, .) to provide reliable products (EOP, ITRF/ICRF, conventions, ...);

• Promote collaboration with neighbouring disciplines (oceanography, meteorology, hydrology, etc.) to improve the understanding of processes and interactions in the Earth system especially in view of global change;

• Jointly organize workshops/symposia/sessions dedicated to earth rotation;

• Establish of a new IAU/IAG working group on the theory of Earth rotation;

• Update C19's Terms of Reference

2.4. *Report of the IAG to IAU Commission 19 (2009–2012)*

Zinovy Malkin

Three IAG bodies are most closely cooperate with the IAU Commission 19. They are Commission 1 'Reference Frames', Commission 3 'Earth Rotation and Geodynamics' and Global Geodetic Observing System (GGOS).

Commission 1 activities and objectives deal with the theoretical and practical aspects of definition of reference systems and reference frames. Three sub-commissions participated in the IAU C19 related activities.

SC 1.1 'Coordination of Space Techniques' coordinates efforts that are common to more than one space geodetic technique, such as models, standards and formats, as well as combination methods and approaches, common modelling and parameterization standards, and combination strategies.

SC 1.2 'Global Reference Frames' is engaged in scientific research and practical aspects of the global reference frames, and investigation the requirements for the definition and realization of the terrestrial reference systems (TRS) and frames (TRF).

SC 1.4 'Interaction of Celestial and Terrestrial Reference Frames' investigates the impact of astronomical and geophysical modelling on the analysis of space geodetic observations and consistency between the TRF, CRF, and EOP, as well as collocation on Earth and in Space for CRF, and ICRF realization.

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Commission 3 studies the entire range of physical processes associated with the motion and the deformation of the solid Earth. Its purpose is to promote, disseminate, and to help coordinate corresponding researches.

The main IAU C19 related activity is performed in the sub-commission 3.3 'Earth Rotation and Geophysical Fluids'. The objective of the SC 3.3 is to serve the scientific community by supporting research and data analysis in areas related to variations in Earth rotation, gravitational field and geocenter, caused by mass re-distribution within and mass exchange among the Earth's fluid sub-systems along with associated geophysical processes.

2.5. *IVS activity highlights 2009–2012*

Dirk Behrend and Harald Schuh

The International VLBI Service for Geodesy and Astrometry (IVS) continued to fulfil its role as a service within the IAU by providing necessary products for the densification and maintenance of the celestial reference frame as well as for the monitoring of Earth orientation parameters (EOP). Here we report on highlights of the service work during the report period focusing on special campaigns, products, and outreach.

• Meetings. During the report period the IVS held two General Meetings, one in Hobart, Tasmania, Australia in February 2010 and the other in Madrid, Spain in March 2012. Further, two Technical Operations Workshops were held at MIT Haystack Observatory in Westford, MA, USA in April 2009 and May 2011, respectively. Another important meeting was the VLBI2010 Workshop on Technical Specifications in Bad Kötzting, Germany in March 2012.

• ICRF2. The Second Realization of the International Celestial Reference Frame (ICRF2) was adopted at the XXVII IAU General Assembly in Rio de Janeiro, Brazil as Resolution B3. The ICRF2 replaced the previously used first realization (ICRF) effective 1 January 2010.

• IYA09. As an activity for the International Year of Astronomy 2009, the IVS organized a very large astrometry session. On 18/19 November 2009, thirty-four VLBI antennas observed the largest astrometry session ever scheduled.

• CONT11. In September 2011, a 15-day continuous VLBI observation campaign called CONT11 was observed. The network consisted of thirteen IVS stations, nine in the northern hemisphere and four in the southern hemisphere, giving the best geographical distribution and coverage in the series of CONT campaigns.

• IVS Live. IVS Live is a generalized version of the IYA09 dynamic Web site, developed to provide an easy access to the entire IVS observing plan. It has grown into a new tool that can be used to follow the observing sessions organized by the IVS, navigate through past or coming sessions, or search and display specific information related to sessions, sources (especially the most recent VLBI images) and stations. The IVS Live user interface and all its functionalities are accessible at the URL: http://ivslive.obs.u-bordeaux1.fr/.

• VLBI2010. The IVS has been developing the next generation VLBI system, commonly known as the VLBI2010 system. A VLBI2010 Project Executive Group (V2PEG) has been created to provide strategic leadership. A number of VLBI2010 projects are underway; several antennas have been erected and construction of about ten antennas is at various stages of completion. Further projects are in the proposal or planning stage. The next generation IVS network is growing, with an operational core of stations becoming available within the next few years, plus further growth continuing into the foreseeable future.

2.6. *Report of the IERS to IAU Commission 19 (2009–2012)*

Wolfgang Dick and Chopo Ma

The International Earth Rotation and Reference Systems Service continued to provide Earth orientation data, terrestrial and celestial references frames, as well as geophysical fluids data to the scientific and other communities. Work on new realizations of the International Terrestrial Reference System (ITRF2008) and the International Celestial Reference System (ICRF2) was finished. Investigations for the next International Terrestrial Reference Frame (ITRF2013) were started. Also discussion started about the next International Celestial Reference Frame (ICRF3), and an IAU Division 1 Working Group on ICRF3 was proposed. In 2009, Bulletin B was revised following a survey which was made among the community. In order to be consistent with ITRF2008, the IERS EOP C04 was revised again in 2011. The new solution 08 C04 is the reference solution which started on 1 February 2011. The system of the Bulletin A was changed to match the system of the new 08 C 04 series. In 2012, 4x/day EOP Combination and Prediction solutions became operational. The IERS Conventions (i.e. standards etc.) have been updated regularly and new revised edition was published at the end of 2010. Work on technical updates to the Conventions (2010) was started.

The Global Geophysical Fluids Centre (GGFC) restructured to allow for the establishment of operational products. It consists now of four Special Bureaus for Oceans, Hydrology, Atmosphere, and Combination. Three new working groups were established in 2009, 2011, and 2012: 1) Working Groups on Combination at the Observation Level; 2) Working Group on SINEX Format; 3) Working Group on Site Coordinate Time Series. The Working Group on Site Survey and Co-location was re-organized in 2012, and 'survey operational entity' was established within the ITRS Center.

The following IERS publications and newsletters appeared in print between 2009 and 2012: A.L. Fey, D. Gordon, and C.S. Jacobs (eds.): The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry, 2009 (IERS Technical Note No. 35); G. Petit and B. Luzum (eds.): IERS Conventions (2010), 2010 (IERS Technical Note No. 36); IERS Annual Reports 2007 and 2008–2009; IERS Bulletins A, B, C, and D (weekly to half-yearly); about 60 issues of IERS Messages. A technical note on ITRF2008 and annual reports for 2010 and 2011 are in preparation. The central IERS web site www.iers.org and about 15 individual web sites of IERS components have been updated, improved and enlarged continually.

3. Scientific Meeting

3.1. *The International Association of Geodesy (IAG) and its Global Geodetic Observing System (GGOS)*

Harald Schuh

In the last 10 years GGOS has been developed as a key component of the IAG. A proposal for GGOS has been developed by the GGOS planning group (2001–2003), and in July 2003, GGOS has been accepted as IAG Project by IAG EC and IAG Council (endorsed by IUGG, Resolution No. 3). Since 2007 GGOS is an integral component of IAG along with Services and Commissions, and during the implementation phase (2009–2011) the organizational structure has been revised, and the Terms of Reference have been set up. GGOS works with the IAG components to provide the geodetic infrastructure necessary for monitoring the Earth system and global change research (IAG Bylaws). In 2009, the

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fundamental publication 'GGOS: Meeting the Requirements of a Global Society on a Changing Planet in 2020' has been released (Eds. H.-P. Plag, M. Pearlman, Springer) which provides the main arguments for GGOS and its goals:

- GGOS vision: 'Advancing our understanding of the dynamic Earth system by quantifying our planet's changes in space and time.'
- GGOS mission:

1. To provide the observations needed to monitor, map and understand changes in the Earth's shape, rotation and mass distribution.
2. To provide the global frame of reference that is the fundamental backbone for measuring and consistently interpreting key global change processes and for many other scientific and societal applications.
3. To benefit science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built.

- GGOS goals:

1. To be the primary source for all global geodetic information and expertise serving society and Earth system science.
2. To actively promote the sustainment, improvement and evolution of the global geodetic infrastructure needed to meet Earth science and societal requirements.
3. To coordinate with the international geodetic services that are the main source of key parameters needed to realize a stable global frame of reference and to observe and study changes in the dynamic Earth system.
4. To communicate and advocate the benefits of GGOS to user communities, policy makers, funding organizations, and society.

3.2. *Impact of IERS Conventions (2010) on VLBI-derived EOP*

Robert Heinkelmann and Harald Schuh

VLBI is the only technique for directly connecting the celestial and terrestrial reference frames and thus it is a major contributor for the determination of Earth Orientation Parameters (EOP). The VLBI data analysis involves a number of models and other analysis options. The models applied to VLBI and further space-geodetic techniques are specified through the IERS Conventions, while the VLBI-specific models are defined by the International VLBI Service for Geodesy and Astrometry (IVS). The IERS Conventions and its current version (IERS Conventions 2010) are believed to represent state of the art models, which have to be used for the determination of inter-technique products, such as the IERS EOP C04 08. For single technique, e.g. VLBI-based, products, the application of other models might be more appropriate. Quantifying systematic and other effects on the EOP is a major issue for the assessment of the quality and consistency of the EOP and the reference frames. The paper presents the impact of each model update on the EOP given by empirically comparing two solutions; one obtained using the old and one using the new conventions. The impact of the complete convention update can be obtained applying all changes at once. Implications following the new IERS Conventions 2010 are interpreted and commented from the VLBI-analysis point of view.

3.3. *Optical identification of ICRF reference radio sources*

Oleg Titov

We started an optical spectroscopic program to identify ICRF2 reference radio sources in optics and measure their redshifts. Five large optical facilities were involved in this

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program: The Big Telescope Azimuthal (BTA), Special Astrophysical Observatory, Russia; the New Technology Telescope (NTT), ESO, Chile; Gemini North and South Telescopes, Gemini Consortium, Hawaii and Chile, correspondingly, the Nordic Optical Telescope (NOT), Canary, Spain). More than 250 optical targets were observed, and around 200 red shifts were measured to date. Most of the objects are in the southern hemisphere.

Proper identification of the fiducial objects in different wavelengths is important to establish a reliable link between radio and optical ICRS realizations, once the Gaia mission is launched in the near future. We have identified several radio sources in close proximity of the galactic stars (separation of less than 4 arcseconds), and one radio source (IVS B1946-582) was reported to be perfectly aligned with the foreground optical object (separation is less than 0.3 arcseconds) at the galactic latitude -30 degrees. We believe that the number of similar cases will grow dramatically, when Gaia tracks the areas near the Galactic plane.

This group includes scientists from several countries, who provide theirs contribution in different ways.

3.4. *A new theory of precession and nutation for the Earth*

Enrico Gerlach, Sergei Klioner and Michael Soffel

The rotational motion of the Earth in space is described by the theory of precession and nutation, which gives the motion of the Celestial Pole in the Geocentric Celestial Reference System (GCRS). To include adequately the various processes involved in Earth rotation the currently used models of precession and nutation, most of them being analytical theories, are not sufficient to keep up with the accuracy provided by the observational data.

Therefore our group developed a completely numerical theory to describe the rotational motion of the Earth. This theory, which is based on the model of rigidly rotating multipoles is fully consistent with the post-Newtonian approximation of general relativity and is currently the best available model of precession and nutation for a rigid Earth. It is formulated using ordinary differential equations for the angles describing the orientation of the Earth (or its particular layers) in the GCRS.

In the last 2 years our model was extended towards a more realistic Earth. In detail, we included 3 different layers (crust, fluid outer core and solid inner core) and all important coupling torques, such as gravitational, electro-magnetic and topographic coupling, between them. Further, also the effects of non-rigidity, such as elastic deformation, frequency-dependent tidal deformation are modeled. Relative angular momenta due to atmosphere and ocean are included, using data from the respective state-of-the-art models. In our presentation we discussed all components of our theory in great detail and compared it with the currently used IAU 2000A precession/nutation model.

3.5. *Sub-daily Earth rotation parameters from GNSS and combined GNSS-SLR solutions*

Daniela Thaller, Michel Meindl, Gerhard Beutler, Rolf Dach, Adrian Jäggi and Krzysztof Sośnica

Space-geodetic techniques are capable of determining Earth rotation parameters (ERP) with a high temporal resolution, e.g., with one hour. Especially GNSS with its huge number of observations can determine time series of polar motion (PM) and length of day (LOD) rather well: We achieve a noise level in the time series of PM of about 150-170 micro-arcseconds only. The drawback of estimating sub-daily PM based on satellite

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techniques is the correlation with the parameters of the satellite orbits. Substantially different revolution periods of the satellites included in the solution affect the sub-daily PM series in different ways. Artificial periods showing up in the PM series are functions of the revolution periods of the satellites and the sidereal day (23.93 h). In the case of GPS two revolution periods exactly equal a sidereal day, whereas two revolution periods of GLONASS are considerably shorter than one sidereal day. This situation gives rise to different artificial signals in the PM series of GLONASS-only and GPS-only PM series. The artificial periods present in the SLR solution based on LAGEOS are fully different from GNSS solutions due to a revolution period of only 3.75 h.

Another problem of estimating PM with sub-daily resolution is the one-to-one correlation of a retrograde-diurnal signal in PM on one hand, and the nutation angles and the orbital parameters on the other hand. In order to handle the correlation between retrograde-diurnal PM and the satellite orbits we tested two methods for GNSS and SLR solutions:

1. Applying a constraint prohibiting a retrograde-diurnal signal in the hourly PM series (i.e., constraining the corresponding amplitude to zero);

2. Introducing (and not estimating) the satellite orbits from a solution with a temporal resolution of 24 h for the ERPs.

Both methods work fine in the sense that no retrograde-diurnal signal is present in the resulting 1-hourly PM time series. There are, however, disadvantages for both methods. In the first method, the constraint affects neighbouring frequencies as well, i.e., their amplitudes are not freely estimated anymore. The range of frequencies around the retrograde-diurnal period which are affected depends on the orbital arc length. SLR solutions have the advantage that they are based on longer orbital arcs, usually on 7 d instead of 1 d or 3 d arcs in GNSS solutions. This advantage is counterbalanced by the fact that the revolution period of the LAGEOS is shorter than diurnal which evokes several artificial signals in the PM series (as mentioned above). These artificial signals cannot be avoided by the retrograde-diurnal constraint.

The opposite is true if the second method is used: the artificial periods can be avoided in GNSS and LAGEOS solutions. The disadvantage is, however, that probably other signals are blocked as well.

In combined GNSS-SLR solutions the situation is complicated by the fact that the orbital arc lengths used for LAGEOS and GNSS satellites do not coincide (7 d and 3 d, respectively). We showed that a retrograde-diurnal constraint (method 1) does not remove all correlations between orbits and sub-daily PM if satellites with different orbital arc lengths are involved. For method 2 we showed that fixing the LAGEOS orbits to the solution with 24-h ERPs removes the correlations in such a way that the GNSS orbits do not need to be fixed in addition and therefore can be estimated together with the combined solution.

3.6. *Short period ocean tidal effects on Earth rotation: Monitoring and modeling*

Sigrid Böhm and Harald Schuh

Short period variations of Earth rotation, quantified as Earth rotation parameters (ERP), are induced predominantly by diurnal and subdiurnal ocean tides. Secondary causes of such variations are thermal tides of the atmosphere, driven by the diurnal solar heating cycle, and the effect of the lunisolar torque on the triaxial figure of the Earth, called libration. Detailed descriptions of diurnal and subdiurnal ERP variations based on a profound geophysical background are essential for various parameter estimation problems in space geodesy, like processing of special VLBI (Very Long Baseline Interferometry) sessions or GNSS (Global Navigation Satellite Systems) orbit determination. Moreover, the accurate removal of ocean tidal signals from high-frequency Earth rotation enables the examination of minor non-harmonic fluctuations of atmospheric or oceanic origin.

At present, the comparison of observational evidence and geophysical modeling still leaves several unexplained gaps. In this study we presented the results of different approaches for capturing short period ERP variations by means of VLBI. We obtained three sets of tidal coefficients (largely congruent with the terms of the model for diurnal and semidiurnal ocean tidal ERP variations of the IERS Conventions 2010) using VLBI observation data from 1984 to 2010. These empirical tidal ERP models were calculated from highly resolved ERP time series, from demodulated ERP time series, and directly within a global solution. Significant deviations of all major VLBI-based tidal terms to the corresponding conventional model terms were observed. Deficiencies of the IERS Conventions 2010 model are suspected to cause aliased signal in GNSS analysis and are problematic for the analysis of special VLBI sessions (Intensives).

A new research project at the Vienna University of Technology, named SPOT (Short period ocean tidal variations in Earth rotation), aims at developing an up-to-date model for the effects of diurnal and subdiurnal ocean tides on Earth rotation, which satisfies the steadily increasing accuracy requirements of science and navigation applications. The strategies to meet this goal are the employment of a recent empirical ocean tide model from multi-mission satellite altimetry, the thorough revision of the transfer functions, and the direct estimation of the contribution of minor tides from satellite altimetry instead of merely using admittance assumptions.

3.7. *New attempts at prediction and verification of AAM and relationship to Earth orientation parameters*

Christian Bizouard, David Salstein and Daniel Gambis

We reported on new efforts to estimate the value of predictions of the atmospheric excitations for polar motion and Earth rotation. Several atmospheric data centers produce predictions out to a time horizon of some 8 days or longer, from which the atmospheric angular momentum (AAM) is calculated; these results are in use in a number of operational settings. The value of such predictions first can be measured against the state of the atmosphere at the verification hour. Such tendencies are measured also against the tendency of UT1, as well as polar motion, measurements of which are modulated by the Chandler wobble period. In particular, weather center data from the US, Japan, the UK, and the European Centre for Medium Range Weather Forecasts are available for atmospheric predictions based on winds and surface pressures. The general skill of weather forecasts have improved over the last many years, and we estimated if the terms required for AAM calculations are significantly more useful than they were in the past.

3.8. *Application of Earth rotation parameters in Earth system science*

Florian Seitz and Stephanie Kirschner

Variations of Earth rotation are associated with the redistribution and motion of mass elements in the Earth system. On seasonal to inter-annual time scales, the largest effects are due to mass redistributions within atmosphere and hydrosphere. In order to study the Earth's reaction on geophysical excitations, the dynamic Earth system model DyMEG has been developed. It is based on the balance of angular momentum in the Earth system which is physically described by the Liouville equation. This coupled system of three first-order differential equations is solved numerically in DyMEG.

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Simulations of polar motion and length-of-day variations have been performed with DyMEG for time spans of up to 200 years using angular momentum variations from five ensemble runs of a consistently coupled atmosphere-hydrosphere model as model forcing. Besides, deformations induced by tides, loading and variations of Earth rotation were considered. In particular the contribution focused on the simulation results of the Earth's free polar motion (Chandler oscillation). It was shown that the simulations over 200 years (1860-2059) are capable of exciting realistic variations of the Chandler oscillation. The application of an adaptive Kalman filter on DyMEG allows for the simultaneous simulation of Earth rotation and the estimation of critical model parameters, such as physical Earth parameters (e.g. Love numbers).

3.9. *Mass transport and dynamics in the Earth system: Selected scientific questions and observational requirements*

Richard Gross

The solid Earth is subject to a wide variety of forces including external forces due to the gravitational attraction of the Sun, Moon, and planets, surficial forces due to the action of the atmosphere, oceans, and water stored on land, and internal forces due to earthquakes and tectonic motions, mantle convection, and coupling between the mantle and both the fluid outer core and the solid inner core. The solid Earth responds to these forces by displacing its mass, deforming its shape, and changing its rotation. Geodetic observing systems can measure the change in the Earth's gravity caused by mass displacement, the change in the Earth's shape, and the change in the Earth's rotation. Consequently, geodetic observing systems can be used to study both the mechanisms causing the Earth's shape, rotation, and gravity to change, as well as the response of the solid Earth to these forcing mechanisms. As a result, geodetic observing systems can be used to gain greater understanding of the Earth's interior structure and of the nature of the forcing mechanisms including their temporal evolution. A few selected unsolved scientific questions will be examined here as a way of illustrating the role played by geodetic observing systems in general, and Earth rotation measurements in particular, in understanding the Earth and its interacting systems. For example, extending the theory of the Earth's rotation to a triaxial, deformable body with fluid core and oceans will allow observations of the Earth's rotation to be better modeled; improving the accuracy of the observations by developing next generation observing systems will allow smaller signals such as those caused by earthquakes to be studied; and improving determinations of the period and Q of the Chandler wobble will allow the frequency dependence of mantle anelasticity to be better constrained.

3.10. *Second order effects on the Earth precession and nutation: a brief summary*

Josẽ M. Ferrãndiz Juan Getino, Alberto Escapa, Juan Navarro and Pedro Martĩnez-Ortiz

Using current precession-nutation models IAU 2006/2000 with a convenient FCN model allows fittings to different VLBI observational series with a typical magnitude of residuals about 150 μas in CIP offsets. That is quite satisfactory for present needs, but further progress is necessary to meet future accuracy requirements at the millimetre level (30 μas), e.g. as sought by GGOS initiative.

In this presentation we report on some effects that we call of second order, which provide non-negligible contributions to earth rotation including nutation terms reaching some tens of μas. Among them, there are second order terms in the sense of perturbation

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theory, non-linear in the dynamical ellipticity H. In other group we gather terms of various physical origins related to time-varying potentials. We consider here direct effects of the actual rotation of the inner core, effects of the observed J2 variations or unaccounted effects of tidal models on precession and nutation.

The Hamiltonian method has been followed to derive all the solutions. For the second order nutations, the differences between two layers earth amplitudes and rigid ones reach the ten μas level for a few terms in the 18 years and semi-annual bands. The indirect effects, due to the induced change in the value of the precession parameter H are larger than 20 μas in obliquity and 40 μas in longitude for the 18 years nutation. The rotation of the inner core produces a deviation of the Hamiltonian with respect to a steady reference considered when deriving the solution to three-layer earth models. In this case an amplitude larger than 40 μas in longitude is got for the semi-annual periods, while annual and fortnightly amplitudes are around 10 μas.

The observed variations of the earth oblateness parameter J2 also affects nutations with periods resulting of the combination of those of rigid nutations and of J2 harmonic contents as well. Some mixed periodic terms are to be accounted, together with some very long period ones which may interact with the value of the dynamical ellipticity H if neglected. Finally, the modelled tidal variations of the solid earth have been proved to effect precession and nutations at a similar level. Those theoretical approaches show that different effects produce both direct and indirect effects on precession and nutation and provide nutation terms with amplitudes of the order of some tens of micro arc seconds, which are not included in current IAU models as far as we know.

In view of their magnitude, it should be analyzed their actual influence on the accuracy of the precession/nutation models and the convenience of adding some of them as new corrections, keeping the consistency of the whole models.

4. Closing remarks

Over the last triennium strong progress has been made in the field of Earth rotation research. Several conferences, workshops and scientific sessions were dedicated to this topic. Many publications, among them a special issue of the Journal of Geodynamics on Earth rotation, have been released. New observatories contributed to a further improvement of the quality of geodetic parameters in terms of accuracy and temporal resolution, and highly precise time series of parameters related to Earth rotation were computed and provided through international services. Many research projects worldwide analysed underlying physical causes of temporal variations of Earth rotation and thus forged a link into the geoscientific community. Promising attempts have been made to incorporate Earth rotation parameters as boundary conditions into models of geophysical fluids. This way, observations of Earth rotation also provide a direct input to Earth system research. Around 15 young scientists have been attracted as new members to Commission 19 which is very promising and warrants fruitful future activities in the field.

Florian Seitz
Secretary of Commission 19

Harald Schuh
President of Commission 19

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