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Commission 19 ROTATION OF THE EARTH
(ROTATION DE LA TERRE)

PRESIDENT	**Aleksander Brzeziński**
VICE-PRESIDENT	**Chopo Ma**
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PROCEEDINGS BUSINESS AND SCIENCE SESSIONS, 5 August 2009

1. Introduction

The IAU Commission 19 meeting during the XXVII IAU General Assembly in Rio de Janeiro was held on Wednesday 5 August 2009, sessions 3 (14:00–15:30) and 4 (16:00–17:30). It was attended by about 40 participants. The meeting was split into three sessions.

Session I (14:00–14:30) was the Commission business meeting. It began with a report on the C19 activities during the triennium 2006–2009. Then the composition of new Organizing Committee for the triennium 2009-2012 was announced. Next, the President proposed some modifications to the Commission Terms of Reference and briefly discussed the membership issues. Finally, the upcoming President presented his plans for the Commission's activities in the next triennium. A summary of Session 1 is given in Section 2 below.

Session II (14:30–15:30) was devoted to the reports of the following Services and Working Groups: International Earth Rotation and Reference Systems Service (IERS), International VLBI Service for Geodesy and Geodynamics (IVS), Standards Of Fundamental Astronomy (SOFA), IERS Conventions Center, IERS Working Group on Prediction, IAG's Global Geodetic Observing System (GGOS). A summary of the reports can be found in Section 3.

Session III (16:00–17:30) was the science session on themes defined in the C19 Terms of Reference. It was composed of four invited presentations concerning the important developments in monitoring and modeling variations in Earth rotation, and two contributed reports on the recent research projects and scientific achievements in Germany and PR China. Section 4 below contains summaries of those scientific presentations.

2. Business Session

2.1. *IAU Commission 19 triennial report 2006–2009*

The most important scientific developments related to the objectives of the Commission were described in the C19 triennial report 2006–2009 (Brzeziński *et al.*, 2008). Some important issues were also discussed in the services / WG's reports and scientific presentations during this meeting; see sections 3 and 4 below for summaries.

Commission 19 was one of the participating commissions in organizing the Joint Discussion 6 "Time and Astronomy" during this Assembly. In addition, members of C19 were involved in organization of several meetings devoted to the subject of Earth rotation and reference systems:

- conference series "Journées Systèmes de Référence Spatio-Temporels", in Paris (2007) and in Dresden (2008);
- the 6th Orlov Conference "The study of the Earth as a planet by methods of geophysics, geodesy and astronomy" in Kiev, Ukraine, 2009;

- sessions during the worldwide scientific meetings:
  - IUGG General Assembly 2007 in Peruggia,
  - EGU General Assemblies 2007, 2008 and 2009 in Vienna,
  - AGU Fall Meetings 2006, 2007, 2008 in San Francisco,
  - Earth Tide Symposium 2008 "New Challenges in Earth's Dynamics" in Jena;
- IERS Workshops on Conventions (2007 in Paris), and on Earth Orientation Parameters (EOP) Combination and Prediction (to be held in October 2009 in Warsaw);
- IVS 2008 General Meeting in St Petersburg, International Workshop on Laser Ranging 2008 in Poznań.

Commission 19 closely cooperated in the last triennium with the following scientific bodies:

- IAG Commission 3 "Geodynamics and Earth Rotation" and its sub-commissions
  - 3.1: Earth Rotation and Earth Tides,
  - 3.3: Geophysical Fluids;
- IAU Div. I Commission 31 "Time";
- IAU Div. I Commission 52 "Relativity in Fundamental Astronomy";
- IAU Div. I WG on Second Realization of International Celestial Reference Frame (ICRF2);
- IAU Div. I WG on Numerical Standards in Fundamental Astronomy (NSFA).

The following two scientific campaigns, closely related to the objectives of C19, were organized recently:

- IERS EOP Prediction Comparison Campaign (EOP-PCC), between July 2005 and March 2008;
- CONT08: two-week campaign of continuous VLBI sessions, scheduled for observing during the second half of August 2008.

The website of Commission 19 http://iau-comm19.cbk.waw.pl/ was an important form of contact with the members of C19 and other researchers working in related fields. All decisions or actions of C19 were taken after email discussion with either the Commission Organizing Committee or the entire membership. The bibliography received from the Commission members during the preparation of the triennial report has been regularly updated and further extended by adding the references found in the worldwide internet data-bases such as SAO/NASA ADS. The current list which is available from the Commission website consists of more than 200 papers published between 2006 and 2009.

2.2. *Organization issues: elections, ToR and membership*

After elections conducted by email in February 2009 the following new OC of C19 for the term 2009–2012 was proposed for approval by the IAU General Assembly:

- President: Harald Schuh (Austria),
- Vice-President: Cheng-Li Huang (PR China),
- Past-President: Aleksander Brzeziński (Poland),
- OC members at large:
  - Christian Bizouard (France),
  - Benjamin Chao (Taiwan),
  - Richard Gross (USA),
  - Wiesław Kosek (Poland),
  - David Salstein (USA).

The representatives of the IAG, IERS and IVS to the C19 OC will be announced soon.

The organizing Committee of C19 discussed before the IAU General Assembly modifications to the C19 Terms of Reference, taking into account critical remarks of the IAU members. All changes adopted by the OC and accepted by the participants of this meeting concern the last section of the ToR, entitled "Organization". We will write this section below with all new changes in italics; the whole document is available from the C19 website.

Terms of Reference of C19, section "Organization":

The organization of the Commission is governed by the IAU statutes, by-laws and working rules which are available from the IAU website: http://www.iau.org/administration/statutes_rules/.

The Commission consists of its members and is chaired by the President. To coordinate its activity, the Commission forms the Organizing Committee (OC).

Each IAU member who is interested in the participation in the Commission activity may be a member of the Commission. No election procedure for a membership is established; only recommendation from the Commission 19 OC is needed.

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The IAU General Assembly elects the President and Vice-President of the Commission for a 3-year term coordinated with the IAU General Assemblies. This term is not renewable. Candidates are proposed by the Commission from its members through voting and are elected by the IAU General Assembly. The Vice President is *normally* proposed to the General Assembly as the President for the next term.

The Organizing Committee includes ex-officio members (the present Commission President, the present Commission Vice-President, the past Commission President, and representatives from the IAG, the IERS, the IVS) and up to 5 additional members at large. *The representatives of the IAG, IERS and IVS are supposed to represent also the other Services that are not in the OC: the IGS, IDS and ILRS.* At-large members are nominated by the OC, selected by the Commission members through the voting and elected by the IAU General Assembly. As a rule, an OC member cannot serve more than two successive terms unless (s)he is elected as the President or Vice-President.

The Commission may propose Working Groups to fulfil specific tasks at the Commission level as well as at the Division level.

Representatives of the Services providing Earth orientation parameters (IERS, IVS, IGS, ILRS, IDS) should be invited to the Commission 19 Business Meetings and other events and report there.

The last organizational issue discussed during the meeting concerned the membership of C19. According to the IAU website, Commission 19 consists of 155 members. However, among them about 50 never responded to the email inquiries. Paragraph 42 of the IAU Working Rules, states "Before each General Assembly the Organizing Committee may (. . .) decide to terminate the Commission membership of persons who have not been active in the work of the Commission". The President and OC of C19 tried to clarify the status of the inactive members of C19. Unfortunately, this action could not be finished before the IAU GA in Rio: therefore it should be continued by the new OC of C19. But an even more important task for the OC will be to attract to C19 young scientists who are active in the related research fields. But first they must become members of the IAU. The procedure, which is described in p.III of the IAU Working Rules http://www.iau.org/administration/statutes_rules/working_rules/, is quite long therefore should be started sufficiently early to be completed before the next IAU GA.

2.3. *Plan of the IAU Commission 19 activities 2009–2012*

Harald Schuh, Vienna University of Technology, Vienna, Austria
President-Elect, IAU Commission 19

What are the recent developments and new challenges in Earth rotation research?

- Scientific Services (IVS, IGS, ILRS, IDS, ...) provide the highest quality EOPs, which are combined by the IERS in the frame of GGOS, the IAG Global Geodetic Observing System.
- Hourly time resolution and high precision allow investigation of a lot of small (second order) effects that have been hidden by the measurement noise in the past.
- Global models of geophysical fluids have been considerably improved in the last years (atmosphere, oceans, hydrology, ...) which allow detailed studies of EOP excitation.
- New instruments and technological developments w.r.t. Earth rotation (e.g. ring-laser, excellent clocks, ...).

Possible activities of IAU C19 for the next term:

- Organize a dedicated Workshop or Symposium on Earth Rotation (jointly with IAG Commission 3?).
- Organize a special issue on Earth rotation of an international journal (e.g. Journal of Geodesy).
- Follow new technological achievements with relevance for EOP research (e.g. optical clocks, . . .) and make proposals on applications.
- Establish even better collaboration with neighboring disciplines (oceanography, meteorology, hydrology, . . .).
- Encourage interdisciplinary endeavors with the aims of improving the understanding of processes and interactions in the Earth system in view of global change.
- Establish a new IAU/IAG Working Group on "Theory of Earth rotation".

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3. Working Groups and Services report

3.1. *Report of the International Earth Rotation and Reference Systems Service*

Chopo Ma, NASA/Goddard Space Flight Center, Greenbelt MD, USA
Chair, IERS Directing Board

The Earth Orientation PC established a web service for EOP values and the Earth orientation rotation matrix. A new EOP series IERS 05 C 04 was issued consistent with ITRF2005. The Rapid Service / Prediction PC changed Bulletin A to match IERS 05 C04. It also initiated a Working Group on Prediction. The ITRS PC released ITRF2005 based on time series of SINEX files containing site positions and EOP as combined by the Technique Centers, where available. It issued a call for participation for ITRF2008, now in progress. The ICRS PC increased VLBI observations in the southern hemisphere, edited the IERS Technical Note 35 on ICRF2, and drafted resolution B3 on the ICRF2 for the IAU General Assembly. The Conventions PC updated various chapters in the online version of the IERS Conventions 2003 (McCarthy & Petit, 2003) and is preparing for new Conventions (2009).

The Global Geophysical Fluids Center was reviewed by IERS Directing Board and will be reconstituted. A Call for Proposals was released in May 2009 emphasizing the renewal of existing operational products and inclusion of new operational products.

A Working Group was established to study EOP prediction at various time scales. The Site Survey and Co-location WG was reconstituted with new charter, chair and membership. The Combination WG was ended on completion of Combination Pilot Project, and a WG on Combination at the Observation Level was begun. The ICRF2 WG compiled its work in IERS Technical Note No. 35 for presentation to the IAU.

The Central Bureau further developed the IERS Data and Information System (DIS) based on modern technologies for internet-based exchange of data and information using XML and the generation and administration of ISO metadata. The DIS provides access to and visualization of IERS data products as well as links to IERS components. The Central Bureau organized a number of workshops with the abstracts and presentations available on the IERS web site. Publications included two Technical Notes, No. 34 "The International Celestial Reference System and Frame" (Souchay & Feissel-Vernier, 2006), and No. 35 "The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry" (Fey & Gordon, 2009). The online version of those IERS Technical Notes is available from www.iers.org.

3.2. *The IVS on its way to the next generation VLBI system VLBI2010*

Harald Schuh, Vienna University of Technology, Vienna, Austria
Chair, IVS Directing Board

The International VLBI Service for Geodesy and Astrometry (IVS) is well on the way to fully defining a next generation VLBI system, called VLBI2010 (Petrachenko *et al.*, 2009). The goals of the new system are to achieve 1-mm position accuracy over a 24-hour observing session and to carry out continuous observations, i.e. observing seven days per week, with initial results shall to be delivered within 24 hours of taking the data. These goals require a completely new technical and conceptual design of VLBI measurements. Based on extensive simulation studies, strategies have been developed by the IVS to significantly improve its product accuracy through the use of a network of small ($\sim$ 12-m) fast-slewing antennas, a new method for generating high precision delay measurements, and improved methods for handling biases related to system electronics, deformations of the antenna structures, and radio source structure. As of June 2009, the construction of ten new VLBI2010 sites has already been funded, which will improve the geographical distribution of geodetic VLBI sites on Earth and provide an important step towards a global VLBI2010 network.

3.3. *SOFA 2006-2009*

Patrick Wallace, Rutherford Appleton Laboratory, Chilton, UK
Chair, SOFA Review Board

SOFA (Standards Of Fundamental Astronomy) is a service operated by Division I to provide authoritative fundamental-astronomy algorithms, for example precession-nutation models. The activity is carried out by an international board that includes both astronomers and software experts, and has cross-membership with the IERS Directing Board. SOFA's products are disseminated through a website: http://www.iau-sofa.rl.ac.uk/.

During the period 2006-2009, the SOFA software collection has grown from 121 routines to 160, the increase being due to the introduction of the IAU 2006 precession. The software has a core of 41 canonical models, used by 67 astronomy-related routines and supported by 52 vector-matrix utilities.

The triennium saw the development of a second version of the SOFA software, this time in the C programming language and supported in parallel with the existing Fortran version. At the same time, the SOFA licensing conditions have been made more liberal, to harmonize with IAU/IERS practices in general and to encourage the widest possible use.

Considerable thought has been given to SOFA's formal position within the IAU organization, with the object of raising its profile and increasing user confidence while at the same time complying with IAU statutes, bye-laws and working rules. These discussions are still in progress.

3.4. *Report of the IERS Conventions center*

Gérard Petit, Bureau International des Poids et Mesures, Sèvres Cedex, France
and
Brian Luzum, U.S. Naval Observatory, Washington DC, USA
Principal scientists, IERS Conventions Center

The IERS Conventions Center is provided jointly by the BIPM and the USNO. The Conventions Center provides updated versions of the Conventions in electronic form, after approval of the IERS Directing Board. In the mean time, work on interim versions is also available by electronic means. The Center works with the help of an Advisory board for the IERS Conventions update. All updates since the last registered edition, the IERS Conventions 2003 (McCarthy & Petit, 2003) are provided in the web page http://tai.bipm.org/iers/convupdt/convupdt.html.

In the triennium 2006–2009, the main achievements have concerned the following chapters of the Conventions. Chapter 4 (Terrestrial reference systems and frames) has been rewritten to account for ITRF2005. Chapter 5 (Transformation between the ITRF and GCRS) has been completely rewritten to implement the IAU 2000–2006 resolutions and corresponding terminology. In Chapter 6 (Geopotential), a section on the ocean pole tide has been added. In Chapter 7 (Displacement of reference points), sections have been added or rewritten for the conventional ocean tide loading, for the ocean pole tide loading, and for technique-dependent effects. Chapter 9 (Atmospheric propagation) has been completely rewritten for optical signals and for radio signals. Chapter 10 (General relativistic models for space-time coordinates and equations of motion) has been modified in line with IAU recommendations and a new section has been added.

The IERS Workshop on Conventions was held in September 2007 to plan a new registered edition of the IERS Conventions. At the workshop, relevant models for inclusion in the Conventions and long-term technical and institutional issues were discussed as well as determining milestones for achieving the next registered edition. For an executive summary, see http://www.bipm.org/utils/en/events/iers/workshop_summary.pdf.

In an effort to make the IERS Conventions more efficient to maintain and more user-friendly, a series of changes have been initiated. The Conventions Update page has been modified to not only include information and links to past updates, but to also provide information and links to planned and possible changes. A new web page of additional, supporting material has been created. In an effort to work towards providing standardized software, a software template was revised to be analogous to the new IAU Standards of Fundamental Astronomy (SOFA) software template. Implementation of this template on existing draft software and additional standardization of code was begun in 2008.

It is planned that the next registered edition of the Conventions be issued at the end of 2009.

3.5. *Activities of the IERS Working Group on Prediction (WGP)*

William Wooden, U.S. Naval Observatory, Washington DC, USA
WG Chair

The IERS Working Group on Prediction (WGP) was tasked to determine what Earth orientation parameter prediction products are needed by the user community and to examine the fundamental properties of different input data sets and algorithms with a goal of improving the prediction process. The WGP establishment grew out of IERS Rapid Service/Prediction Center (RS/PC) concerns about the continued relevance of current products, new accuracy requirements, the impact of new data sets, viable new prediction methodologies, and the desire to build on the interest generated by the EOP Prediction Comparison Campaign organized under the umbrella

of the IERS by the Vienna University of Technology and the Space Research Center, Warsaw, and the efforts of the IERS Combination Pilot Project. The WGP expectations include definitive user requirements, a comprehensive look at prediction methods, a comprehensive look at new data sets, and a definitive assessment of the current state-of-the-art in EOP prediction.

The first task of the WGP was to determine whether the current RS/PC products, which were developed more than 15 years ago, are adequate or whether modifications and/or improvements are necessary to meet more stringent requirements. A short EOP user survey was developed by the WGP and posted on the RS/PC website www.iers.org/MainDisp.csl?pid=71-49. The IERS invited participation from those on the IERS mailing lists, those who receive IERS RS/PC products, and any others thought to have an interest in EOP predictions (see IERS Message No. 104, www.iers.org). The survey confirmed that there is a large class of operational users that need daily predictions up to 30 days in advance in tabular format with one-day spacing. Other classes of users have different needs. Some users would like to improve long term predictions and although it is an interesting problem, the emphasis on shorter term forecasts as described by the terms of reference under which the IERS RS/PC currently operates has been re-validated by the survey results. However, there is a need for increased accuracy, and the efforts of the WGP to examine algorithms and incorporate potential new sources of data appear to address that need. In addition there seems to be a growing interest in daily and sub-daily predictions which will require more timely measurements of EOP quantities and some increased processing capability.

The second task of the WGP was to examine the fundamental properties of various input data sets and algorithms. A repository of test data sets was established containing a general test set from 2000-2006, a test set for polar motion loops, large amplitude annual/Chandler polar motion, and large and small UT1 changes. Analysis of the test data sets confirms that the polar motion loop periods are the most challenging. The activities of the WGP members have been reported at recent EGU and AGU meetings. In addition a special session of the 2007 Journées meeting, "Prediction, Combination and Geophysical Interpretation of Earth Orientation Parameters," contained an overview of WGP activities, a panel discussion on the prediction of EOP, and numerous papers devoted to all aspects of the problem (see Proc. Journées Systemes de Référence Spatio-Temporels 2007, N. Capitaine (ed.), pp. 143–229, Paris Observatory). An IERS Workshop on EOP Combination and Prediction will be held at the Space Research Centre in Warsaw, Poland from 19-21 October 2009 to provide specific recommendations to improve current techniques/IERS products based on the analysis done to date. The final product of the WGP will be an IERS Technical Note summarizing the activities of the WGP and providing the current state-of-the-art in EOP prediction.

3.6. *Global Geodetic Observing System (GGOS) and its Relation to IAU*

Harald Schuh, Vienna University of Technology, Vienna, Austria

GGOS is the Global Geodetic Observing System of the International Association of Geodesy (IAG); see (H-P. Plag & M. Pearlman, 2009) and the website www.ggos.org. It provides observations of the three fundamental geodetic observables and their variations, that is, the Earth's shape, the Earth's gravity field and the Earth's rotational motion. GGOS integrates different geodetic techniques, different models and approaches in order to ensure a long-term, precise monitoring of the geodetic observables in particular by bringing together geometrical and physical measurements. GGOS provides the observational basis to maintain a stable, accurate and global reference frame and in this function is crucial for all Earth observation and many practical applications. GGOS contributes to the emerging Global Earth Observing System of Systems (GEOSS) not only with the accurate reference frame required for many components of GEOSS but also with observations related to the global hydrological cycle, the dynamics of atmosphere and oceans, and natural hazards and disasters. GGOS acts as the interface between the geodetic Services of the IAG and the IAU and external users such as GEOSS and United Nations authorities. With this the geodetic community can provide the global geosciences with a powerful tool consisting mainly of high quality products, standards and references, and of theoretical and observational innovations. In the presentation special emphasis was given to the relation between GGOS and IAU Commission 19.

4. Scientific presentations

4.1. *Optical reference frames for monitoring Earth rotation (invited)*

Jan Vondrák, Astronomical Institute Prague, Czech Republic

Some years ago, we collected about 4.5 million optical astrometric observations of latitude / universal time / altitude variations, made at 33 observatories in 1899.7 - 2002.6. These observations, brought into the system of the Hipparcos Catalogue, served to determine Earth Orientation Parameters. When doing so, we found that a large proportion of observed stars were double or multiple, which caused problems when extrapolating their positions far from the mean epoch of Hipparcos Catalogue, 1991.25. Therefore, we started improving the positions, and in particular proper motions, by combining the observations with their positions in ARIHIP, Tycho-2 and Hipparcos catalogues to derive an Earth Orientation Catalog (EOC). The main goal was to create a new and improved reference frame for long-term Earth rotation studies, by using the best available star catalogues and their combination with the rich observational material of the existing program of measuring Earth orientation in the 20th century. So far, three versions of EOC have been produced : EOC-1 (based only on meridian observations, Vondrák & Ron, 2003), EOC-2 (based on all observations, Vondrák, 2004), EOC-3 (improved EOC-2 by adding periodic motions of 586 stars, Vondrák & Štefka, 2007) and EOC-4 (Vondrák & Štefka, 2009). The last version, EOC-4, was constructed by a new procedure that removed disadvantages of its predecessors. The main improvements were more precise amplitudes of periodic parts, more double stars detected (599) and consistency with space-based observations at the Hipparcos mean epoch. The catalog EOC-4, containing nearly 5 thousand stars, has already been used to derive a new solution of EOP from optical astrometry in the 20th century (JD6, this IAU GA).

4.2. *Long-period tidal effects on Earth rotation (invited)*

Richard S. Gross, Jet Propulsion Laboratory, Pasadena CA, USA

Tidal forces due to the gravitational attraction of the Sun, Moon, and planets deform the solid and fluid regions of the Earth causing the Earth's inertia tensor to change and thus causing the Earth's rotation to change. Here, available models of the (1) elastic response of the solid Earth, (2) inelastic response of the solid Earth, and (3) dynamic response of the oceans to the tide raising potential at periods greater than a day are compared to length-of-day (lod) observations from which atmospheric and nontidal oceanic effects have been removed. Spectra of the residual lod observations exhibit prominent peaks at the tidal frequencies, most but not all of which are eliminated when an elastic body tide model is removed. While inelastic effects are only a few percent of the elastic, it is shown that it is important to include both the in-phase and out-of-phase terms when removing them from lod observations. Of the oceanic tide models evaluated, models constrained by data are shown to perform better than those not constrained by data. The sum of the Yoder *et al.* (1981) elastic body tide model, Wahr & Bergen (1986) inelastic body tide model, and Kantha *et al.* (1998) ocean tide model was found to do the best job of removing tidal effects from lod observations, particularly at the fortnightly tidal frequency. The model recommended by the IERS Conventions 2003 (McCarthy & Petit, 2003) was found to do the worst job.

4.3. *Recent progress in modeling precession-nutation (invited)*

Nicole Capitaine, Observatoire de Paris, Paris, France

The IAU 2006/2000 precession-nutation has been adopted in two stages. The first stage (IAU 2000 Resolution B1.6) was the adoption of the IAU 2000 precession-nutation, which has been implemented in the IERS Conventions 2003 (McCarthy & Petit, 2003). The second stage (IAU 2006 Resolution B1) was the adoption of the P03 Precession (Capitaine *et al.*, 2003; Hilton *et al.*, 2006) (i.e. the IAU 2006 precession) as a replacement for the precession part of the IAU 2000A precession-nutation, beginning on 1 January 2009. Expressions and procedures for implementing the new precession-nutation have been provided by Capitaine & Wallace (2006) and Wallace & Capitaine (2006); they have been implemented in Chapter 5 of the IERS Conventions updated in 2009 (http://tai.bipm.org/iers/convupdt/convupdt_c5.html) and the Standards Of Fundamental Astronomy (SOFA). The difference between IAU 2006 and IAU 2000 lies essentially in the precession part, though very small changes are needed in a few of the IAU 2000A nutation amplitudes in order to ensure compatibility with the IAU 2006 values for ϵ_0 and the J_2 rate. Whenever these small adjustments are included in the periodic terms (e.g. in

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the SOFA and IERS implementations), the notation "IAU $2000A_{R06}$" can be used to indicate that the nutation has been revised for use with the IAU 2006 precession.

Comparisons of the IAU 2006/2000 precession-nutation model with VLBI observations, once corrected for an empirical model for the FCN show residuals with a w.r.m.s. of about 130 μas (Capitaine *et al.*, 2009). The residuals would be compatible with corrections of a few tens of μas to the 18.6-yr nutation, which would be absorbed in small corrections to the estimates for a couple of the BEP of the MHB model. This result is consistent with independent fits (Zerhouni *et al.*, 2009) to the LLR celestial pole offsets with respect to the same IAU precession-nutation model and a comparison over 400 years with the INPOP06 numerical integration of Fienga *et al.* (2008) of the GCRS motion of the axis of angular momentum.

Future improvements of the precession-nutation model would require a rigorous consideration in the GR framework, an improvement in the model for the electromagnetic couplings and a specific account for the second order torque. Potential for improvement lies in solving the rotational equations in the X, Y variables (Capitaine *et al.*, 2006) or estimating the BEP parameters in the time domain with a non-linear Bayesian inversion method (see Koot *et al.*, 2008).

4.4. *Monitoring Earth Orientation variations, state of the art and prospective (invited)*

Daniel Gambis, Observatoire de Paris, France

One task of the Earth Orientation Centre of the IERS is to monitor Earth orientation parameters (C04 series) including long term consistency with both celestial and terrestrial reference frames. The combined series C04 is computed and made available to a broad community of users in Astronomy, Geodesy, Geophysics, Space sciences and Time (Bizouard and Gambis, 2009). In addition to the improvement of the precision, it is as well essential to monitor the consistency of EOP with the ITRF. This is now achieved by a yearly comparison between the current C04 series and the EOP solution based on the stacking of IGS and IVS SINEX files using the CATREF software (Altamimi *et al.*, 2006). The current accuracy of the current C04 solution is about 50 μas for pole components, 10 μs for UT1 and 60 μas for nutation offsets. We expect that in a near future there will be a strong evolution in that field. EOP solutions and the terrestrial reference frame will be simultaneously derived in a global combination at the normal equation level (Gambis *et al.*, 2009). The method is based on the fact that techniques have their own strengths and weaknesses. Their combination should benefit from their mutual constraints. A program within the Groupe de Recherches de Géodésie spatiale, GRGS, has been carrying out for several years. Observations derived from the various techniques are processed using unique software (GINS) with same conventional models and constants and inverted using DYNAMO developed by the GRGS. The main difficulties of the procedure lie in the combination strategy to be applied, in particular the way to ensure stability of reference frames over successive weeks and in addition the weighting of the various techniques in the combination. It is likely that future generation of EOP and TRF products will be routinely based on this rigorous combination. The method seems as well promising to study short term variations of EOP.

4.5. *Earth Rotation and Global Dynamic Processes: Research activities in the framework of the German DFG-Research Unit FOR584/2*

Florian Seitz, Technical University Munich, Munich, Germany
and
Harald Schuh, Jurgen Müller, Hermann Drewes, Hansjörg Kutterer, Michael Soffel, Maik Thomas

A coordinated research initiative on the fields of Earth Rotation and Global Dynamic Processes has been organized in a joint program with partners from Germany, Austria and Switzerland. For a period of six years (2006-2012), the program integrates the expertise and competencies on these topics available in 11 participating research and university institutes from various disciplines (geodesy, oceanography, meteorology, geophysics). The group consists of 10 closely inter-related sub-projects with 12.5 funded scientific positions, mainly filled with PhD students. The initiative's main objective is the comprehensive and consistent analysis, modeling, and interpretation of all facets of Earth rotation in interdisciplinary co-operation. Principal research tasks comprehend the processing and analysis of observations (determination of EOP, combined analysis of heterogeneous observation types, integration of Earth rotation, gravity field, and surface deformations) as well as theoretical and numerical modeling (analysis, description, and explanation of relevant physical phenomena and couplings in the Earth system). Through the

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integral treatment of Earth rotation and related physical phenomena on all relevant time scales, the research also means a valuable contribution to IAG's Global Geodetic Observing System (GGOS). Research highlights in the field of relativity and nutation theory are the extension of the post-Newtonian nutation/precession theory from a rigid to an elastic Earth model and the assessment of precise nutation angles and relativistic parameters from LLR. Activities in the field of consistent modeling of Earth system processes comprehend the assimilation of Earth rotation parameters into an ocean model, the improvement of a forward model for core/mantle interaction, the analysis of climate variability from fully coupled atmosphere-hydrosphere models, and the inversion of a dynamic Earth system model for the estimation of physical Earth parameters from EOP. Research associated with the analysis and interpretation of observations of ring laser gyroscopes has been promoted in order to confirm sub-daily and episodic variations of Earth rotation and improve the sensor orientation using a 3-D FEM topographic model for surface deformation. Advances in the field of combined processing and analysis of both techniques and parameters cover the simultaneous estimation of consistent high-quality time series of EOP and TRF parameters from integrated VLBI, SLR, and GNSS analysis as well as the combination of EOP and 2nd-degree harmonic gravity field coefficients for the separation of mass and motion effects. More detailed information on projects and participants as well as numerical data and results are provided on the research unit's web portal ERIS (Earth Rotation Information System) at www.erdrotation.de.

4.6. *Research activities on Earth rotation and reference systems in China*

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Some of the research activities on Earth rotation and reference systems in China during 2005–2008 were reported in the IAU Commission 19 Triennial Report (Brzeziński *et al.*, 2008). They include 1) EOP and interior geophysics; 2) EOP and surface fluids; 3) EOP prediction; 4) ITRF and ICRF; 5) Data analysis (VLBI, SLR, GPS); 6) observations and instruments; and 7) miscellaneous. Most of them were achieved in Shanghai Astron. Obs. (SHAO), Wuhan Inst. Geodesy and Geophys. (WHIGG), and National Astron. Obs. of China (NAOC). In addition, there were some other related contributions which are briefly described below.

Possible connection between global significant earthquakes and Earth's variable rotation rate was investigated (Ma *et al.*, 2007). The observation of plumb line variation from gravimetry in China and its relation with earthquakes was also studied (Li & Li, 2008).

Research concerning the ITRF2005 showed that this conventional frame does not satisfy the need of monitoring mm-level geodynamic change in construction of mm-level TRF (Zhu *et al.*, 2008). Geocenter motion was also studied using the wavelet transform, and was estimated from the SLR data.

In the Chinese first lunar mission, Chang'E-1, launched on 24 October 2007 and impacting the Moon on 1 March 2009, the Chinese VLBI network (CVN) provided rapid Earth rotation service, tracking and navigation. A new 65-m VLBI antenna is under construction in SHAO and will work from 2012 for astrophysics, geodesy and DSN. A group in SHAO has been working to develop their own software for processing VLBI data for both astrometry and geodesy, including model of high frequency EOP variation. Co-location gauge for the VLBI, SLR and GPS stations in She-shan station, west of Shanghai, was made successfully in 2008 and will be made again in the second half of 2009.

Some experiments in time synchronization between the Earth and satellites were conducted in recent years with the purpose of application for satellite navigation and positioning. For example, the laser time transfer (LTT) payload onboard the Chinese experimental navigation satellite COMPASS-M1 with an orbital altitude of 21500 km was launched in April 13, 2007. After 17 months orbital flight, the LTT payload has maintained its good performance.

5. Closing remarks

The President of Commission 19 thanks the members of the current Organizing Committee of C19 for their active work during the past triennium. He also congratulates the new President, Vice-President, and the OC members on their election and wishes them successful activity during the term 2009–2012.

Aleksander Brzeziński
President of the Commission

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