

COMMISSION 4

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EPHEMERIDES (*EPHEMERIDES*)

Toshio Fukushima
George H. Kaplan
George A. Krasinsky
Jean-Eudes Arlot, John A. Bangert,
Catherine Hohenkerk, Martin Lara,
Elena V. Pitjeva, Sean E. Urban,
Jan Vondrak

PROCEEDINGS BUSINESS SESSIONS, Session 4 of August 7th, 2009

1. Introduction

Dr. George Kaplan, the current Vice-President of the Commission was nominated to be the new President. Dr. Catherine Hohenkerk was elected to be the next Vice-President of the Commission. As for the Membership of the Organizing Committee, Dr. Vondrak stepped down and Drs William Folkner of JPL and Steve Bell of HMNAO have been added. In the below, we present summaries of the reports from various institutions presented at the business session.

Toshio Fukushima

2. United States Naval Observatory, U.S.A.

This report covers activity in the Astronomical Applications (AA) Department since the XXVIth General Assembly in Prague. The AA Department employs 13 scientists in three divisions: The Nautical Almanac Office (NAO), the Software Products Division (SPD), and the Science Support Division (SSD). During the reporting period, A. Monet, formerly at USNO's Flagstaff Station, was appointed chief of the SPD and J. Bartlett transferred to the SPD staff from USNO's Astrometry Department. G. Kaplan became a part-time contractor to USNO, working within the AA Department. M. Murison transferred to the Flagstaff Station.

Kaplan served as vice president of Commission 4, and J. Bangert and S. Urban served on the organizing committee. Bangert also served as a member of the Standards of Fundamental Astronomy (SOFA) reviewing board. J. Hilton served as a member of the inter-division Working Group on Cartographic Coordinates and Rotational Elements. M. Efroimsky chaired the local organizing committee for IAU Symposium 261, held in April 2009 at Virginia Beach USA.

Publication of *The Astronomical Almanac* and *The Astronomical Almanac Online*, *The Nautical Almanac*, *The (U.S.) Air Almanac*, and *Astronomical Phenomena* continued as a joint activity between Her Majesty's Nautical Almanac Office of the United Kingdom and the NAO. A new memorandum of understanding between the parent organizations, governing the collaboration, became effective in August 2008. *The Astronomical Almanac* for 2009, released in January 2008, was the first edition to incorporate the resolutions adopted by the IAU in 2006. *The Air Almanac* transitioned from a paper publication to an electronic (CD-ROM) publication effective with the 2009 edition.

Significant progress was made on a major revision of *The Explanatory Supplement to the Astronomical Almanac*, in collaboration with P.K. Seidelmann (Univ. of Virginia) and numerous contributors. The book is expected to be sent to the printer by the end of 2009.

Version 3.0 of the Naval Observatory Vector Astrometry Subroutines (NOVAS), which implements relevant IAU resolutions adopted from 1997 through 2006, will be released by the end of 2009. The software will be available in both Fortran and C editions.

Version 2.2 of the *Multiyear Interactive Computer Almanac* (MICA), which incorporates NOVAS 3.0, was in the final stages of testing as of August 2009. MICA is available for computers running Microsoft Windows and Apple Mac OS operating systems.

All USNO departmental Web sites were consolidated into a single Web portal accessible at <http://www.usno.navy.mil/USNO>. Prior to the consolidation, usage of the AA Department Web site varied from about 0.5 to 2.8 million visits per month.

A modest research program in positional astronomy, dynamical astronomy, and navigation continued within the department. Research topics included the spin evolution of Iapetus, the theory of bodily tides, determination of asteroid masses, and new methods of celestial navigation.

Other projects underway at USNO and of interest to Commission 4 include the USNO CCD Astrograph Catalog (UCAC), and observations of solar system bodies made with the Flagstaff Astrometric Scanning Transit Telescope (FASTT). Additional information on these projects can be found at <http://www.usno.navy.mil/USNO/astrometry/>.

John A. Bangert

3. Her Majesty's Nautical Almanac Office, U.K.

In the reporting period, Her Majesty's Nautical Almanac Office (HMNAO) has been operating within the UK Hydrographic Office (UKHO), a trading fund of the United Kingdom's Ministry of Defence. HMNAO has three staff, two based at UKHO in Taunton, Somerset and one at Rutherford Appleton Laboratory in Didcot, Oxfordshire. As two of the staff will reach retirement age within the next reporting period, a recruitment process has been initiated. The first interview cycle was unsuccessful and the second is now under way. If successful, it is hoped to have a new member of staff in place before the end of 2009. It is planned that HMNAO's final complement will be four people. Despite operating within the UKHO for the past three years, HMNAO does not yet have a business plan, nor does it have appropriate means to sell its astronomical products. Our nautical products are sold successfully through the UKHO distributor network but our astronomical customers do not associate this distributor chain with HMNAO's astronomical products. New methods of distributing this material still have to be found. Concerns also exist about the peripheral nature of HMNAO within UKHO, its profile and the difficulty in attracting new staff to the group.

The Astronomical Almanac, *The Nautical Almanac* and *Astronomical Phenomena* continue as joint publications with the US Naval Observatory. *The Star Almanac* and *the UK Air Almanac* and the quinquennial products Rapid Sight Reduction Tables and *NavPac* and *Compact Data* continue as UKHO products. Indeed, the 2011-2015 edition of *NavPac* and *Compact Data* will be available at the beginning of 2010 which will include updates to the *NavPac* PC software. *The Astronomical Almanac* is fully compatible with all IAU resolutions including those of IAU GA 2006. Starting with the 2011 edition, lunar librations will be based on the rotation ephemeris of the Moon in DE403/LE403. *The Astronomical Almanac Online*, the web companion of the book, continues to be updated and expanded including material such as lunar occultation maps of the planets, Pluto and minor planets. HMNAO staff have also contributed to the new edition of *The Explanatory Supplement to The Astronomical Almanac* due for publication in early 2010. They have also participate in other research projects such as a study of the migratory patterns of the Sooty Shearwater.

HMNAO continues to operate six web sites; <http://www.hmnao.com>, its general web site, <http://websurf.hmnao.com>, offering "dynamic" data for the general public, <http://asa.hmnao.com>, a mirror of *The Astronomical Almanac Online*, <http://www.eclipse.org.uk>, solar and lunar eclipse data for 1501 to 2100CE inclusive, <http://www.crescentmoonwatch.org>, a public participation project and <http://iau-sofa.hmnao.com>, the SOFA web site. Further developments of these sites are planned in the next reporting period.

Steve Bell

4. Institute of Applied Astronomy, Russia

(a) Fundamental ephemerides. During the 2006–2009 the regular publication of *The Russian Astronomical Yearbook* is continued. Planetary and lunar ephemerides are based on numerical model EPM2004 available to outside users via <ftp://quasar.ipa.nw.ru/incoming/EPM2004>. Ephemerides for planetary configurations, eclipses and occultations, as well as the

ephemerides of the Moon (as Tchebyshov polynomials) and the mutual phenomena in the system of the Galilean satellites of Jupiter are updated and located at <http://quasar.ipa.nw.ru/PAGE/EDITION/RUS/rusnew.htm>. The P03 precession and IAU2000A nutation theories have been introduced into practice. The sidereal time is calculated from Earth rotation angle and by new formula of Equation of the Equinoxes accepted by “IERS Conventions 2003”. Fundamental catalogues FK6 and HIPPARCOS have been used for calculation of star ephemerides. The parameters concerned the new concept of CIO and elements of the matrix for conversion from ICRS to CIRS are given.

(b) Special ephemerides. *The Naval Astronomical Yearbook* (annual issues for 2006–2009) and biennial *The Nautical Astronomical Almanac* (issues 2007–2008, 2009–2010) have been published. The basic purpose of producing the Almanac is to increase its applicability without essential increase of its volume and to give the same accuracy as NAY does. The explanation and part of auxiliary tables are given in both Russian and English versions.

(c) Software. Constructing numerical dynamical models, fitting the ephemerides to observations, as well as preparation of the ephemerides for publishing are carried out in the framework of the universal program package ERA (Ephemerides for Research in Astronomy). The Windows and DOS versions are available via anonymous FTP <ftp://quasar.ipa.nw.ru/incoming/ERA>. The Linux version is developed. The first electronic version of *The Personal Astronomical Yearbook (PersAY)* has been constructed. It is intended for calculation of the ephemerides published in the Astronomical Yearbook, including the topocentric ephemerides for any observer. The system PersAY is implemented as the Win32 application on the basis of the package ERA. The first version of PersAY for interval 2000–2015 based the fundamental ephemerides DE405/LE405 and EPM2004 is available on <ftp://quasar.ipa.nw.ru/pub/PERSAY/persay.zip>. The electronic system the *Navigator* for solution of basic naval astronavigating problems by the mode of remote access is in progress.

(d) Research work. The updated Ephemerides of Planets and the Moon — EPM2008 (Pitjeva 2009, Proc. IAU Symp. 261) have been constructed by the simultaneous numerical integration of the equations of motion of the major planets, the Moon, the Sun, 301 biggest asteroids, 21 trans-Neptunian objects and the lunar physical libration accounting for the perturbations due to the solar oblateness and the massive ring of small asteroids. Some tests have been made for estimating influence other TNO on the motion of planets. Their perturbations have been modeled by the perturbation from a circular ring having a radius 43 AU and the estimated mass $M_{TNO\,ring} = (498 \pm 14) \cdot 10^{-10} M_\odot$ (5σ). The parameters of EPM2008 (65 ones for the lunar part and about 260 ones for the planet part) have been fitted to lunar laser ranging measurements 1970–2008, as well as to 550000 planet and spacecraft observations 1913–2008 of different types. EPM2008 have been oriented to ICRF by including into the total solution the 118 ICRF-base VLBI measurements of spacecraft 1989–2007 near Venus and Mars. The numerical ephemerides of the main satellites of the outer planets have been constructed and fitted to modern photographic and CCD observations. These ephemerides are used for improving the ephemerides of their parent planets and publication in the Russian Astronomical Yearbook.

Elena V. Pitjeva

5. Institut de Mécanique Céleste et de Calcul des Éphémérides, France

The ephemerides service of IMCCE has three missions:

- performing research activities on the motions of the solar system objects,
- making the French official ephemerides on behalf of Bureau des longitudes,
- providing calculations on request for professional, space agencies and general public.

For the planets, the Sun and the Moon, we use:

- VSOP model (Secular Variations of Planetary Orbits)
- INPOP model (Planetary Numerical Integration of Paris Observatory)

The latter is a brand new 4-D theory based upon a high precision model for planets and the Moon, fitted on space observations, support of the next Gaia mission. INPOP06 has been published (Fienga *et al.* 2008, A&A, 477, 315) and INPOP08 is submitted. Ephemerides “Miriade” are provided on a web server.

For the natural satellites, the NOE model (Numerical Orbit and Ephemerides) is used for the Martian satellites, the Galileans and the main Uranians (Lainey *et al.*, A&A 2006, 456, 783, Arlot *et al.* A&A 2006, 456, 1173). An estimation of the propagation of the ephemerides error

is provided (Desmars *et al.* A&A 2009, 499, 321) and the ephemerides web server (Multi-sat ephemerides) is made in collaboration with the Sternberg Astronomical Institute in Moscow.

Yearly printed publications are:

- Connaissance des temps since 1679 for high precision ephemerides
- Annuaire du Bureau des longitudes since 1795 for the general public
- Ephemerides nautiques, the french nautical almanac for the Navy

An electronic version is available for Connaissance des temps.

Electronic ephemerides are provided through Internet (5 Mhits per month, i.e. 70 000 users per month) at www.imcce.fr. Specific web services are provided in the Virtual observatory framework using VO standard protocols, metadata and VOTable for exchange of self-defined information. The Sky Body Tracker facility identifies any solar system object in any field and is implemented in CDS/Aladin. Asteroid search based upon pre-calculated ephemerides funded on Astorb database (from Lowell observatory), daily updated on the time span 1949-2009 (≈ 450000 asteroids) interfaced with Aladin Sky Atlas V3.6. More objects (all satellites, comets) will be added soon. The time period is going to be enlarged.

William Thuillot, and Jean-Eudes Arlot

6. Jet Propulsion Laboratory, California Institute of Technology, U.S.A.

The development of planetary ephemerides at JPL continues to be driven by needs for planetary missions and improved by observations of spacecraft and other astrometric observations. Current missions with need of improved ephemerides include the MESSENGER mission to Mercury and the New Horizons mission to Pluto and the upcoming Mars Science Laboratory mission.

In the past three years the accuracy of the ephemerides of Venus and Saturn have improved dramatically due to observations from the ESA Venus Express mission and the NASA Cassini mission. The Mars ephemeris accuracy is being maintained by continuing observations of Mars orbiting spacecraft, such observations needed to compensate for the disturbance by asteroids that would otherwise cause the ephemeris accuracy to degrade. The outer planet ephemerides are being slowly improved by continuing ground-based astrometric observations, and some older observations being re-processed against modern ICRF-based star catalogs.

The most recent JPL ephemeris released in DE421. The next release is planned for September 2009, primarily to include data from two encounters of Mercury by the MESSENGER spacecraft and in preparation for its third Mercury encounter in November 2009. Following that the Mars spacecraft VLBI data set will be re-reduced against the recently released ICRF 2.0, followed by an new ephemeris fit in spring 2010.

William M. Folkner

7. National Astronomical Observatory of Japan and Japan Hydrographic and Oceanographic Department, Japan

In National Astronomical Observatory of Japan (NAOJ), Project of enhancing “Calendar and Ephemeris”, which is a basic almanac designed for astronomical observers, teachers and citizens is currently underway. As the first step, NAOJ not only implemented new precession formula adopted by IAU in 2006, but also enhanced its volume from 2009 edition, for example, almost doubled its size and its number of pages. In addition, NAOJ has added more tools to its web site <http://www.nao.ac.jp/koyomi/>, while establishing a web site for mobile phones as well as English version for foreigners living in Japan.

Japan Hydrographic and Oceanographic Department (JHOD) finished occultation observations at the hydrographic observatory at the end of March, 2008 and completely withdrew from astronomical observations. JHOD discontinued the international Lunar Occultation Centre (ILOC) service on March, 2009 and the International Occultation Timing Association (IOTA) took over this role. JHOD delivered the 2010 edition of the Japanese Ephemeris as the final issue, and will publish only Nautical Almanac and Abridged Nautical Almanac hereafter.

Masato Katayama