4. EPHEMERIDES (EPHEMERIDES)

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I. Introduction

This report covers the period from 1 July 1984 to 30 June 1987. The ephemerides that have been published during this period have made use of the new system of astronomical constants adopted at the XVIth General Assembly of the IAU in Grenoble. Yet some difficulties have arisen because of the lack of catalogues or maps of the heavens established for the epoch J2000.0. This is awkward for observers of comets and minor planets and, for that reason, Commission 20 decided, at the New Delhi meeting of IAU that there would be a gradual introduction of the J2000.0 system as far as those bodies are concerned.

The first issue of an IAU Commission 4 Circular has been sent to all the members of the Commission in May 1987. The aim of it is to exchange information in between general assemblies and generally to establish a link between the members of the commission. It is hoped that these members will contribute to the next issues of this circular.

II. International and National Ephemerides

1. THE FUNDAMENTAL SYSTEM

Starting with the volume for the year 1988 the Apparent Places of Fundamental Stars (APFS) are based on the mean positions and proper motions which will be published in the Fifth Fundamental Catalogue (FK5). The basic part of this catalogue, containing the classical 1535 fundamental stars, will become available for general use with its publication which is scheduled for the end of 1987. Further details concerning the status of the work on the the FK5 are given in the report of commission 8 in this volume.

In order to provide the users of the already published Apparent Places of Fundamental Stars volumes for 1984 through 1987 with positions on the basis of the FK5, corrections FK5-FK4 to the FK4 stars are given in an appendix to the volume of the Apparent Places of Fundamental Stars for the year 1988. The corrections are the result of the systematic and individual improvement of the FK4, computed for the epoch and the equinox of the beginning of the years 1984 to 1988.

2. PRINTED EPHEMERIDES

H.M. Nautical Almanac Office, Royal Greenwich Observatory, Herstmonceux Castle, United Kingdom and the Nautical Almanac Office, U. S. Naval Observatory, Washington, D.C., USA have continued to cooperate in the production and publication of the unified almanacs, namely, the Astronomical Almanac, the Nautical Almanac, the Air Almanac and the Astronomical Phenomena. Beginning with 1987, the Air Almanac was published as a single issue for a full year. Sight Reduction Tables for Air Navigation, vol. 1, epoch 1990 have also been published.The

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data, either composed or in machine readable form, have been supplied upon request for other countries. The Nautical Almanac Office of the U.S. Naval Observatory has continued to publish annually the Almanac for Computers containing the polynomial coefficients for computing the positions of the Sun, Moon and planets to the accuracy desired for anytime during the year. H. M. Stationery Office have published The Star Almanac for Land Surveyors for 1986, 1987 and 1988.

Bureau des Longitudes, Paris France, have published yearly the Connaissance des Temps, the Ephémérides astronomiques-Annuaire du Bureau des Longitudes and the Ephémérides Nautiques. The Ephémérides astronomiques-Annuaire du Bureau des Longitudes contain, starting from 1986, ephemerides of the minor planets whose magnitude is smaller than 10, at opposition during the year and, also, starting from 1987, ephemerides of periodic comets going through perihelion during the year. Bureau des Longitudes published also three Supplement to Connaissance des Temps : Ephémérides des satellites de Jupiter, Saturne et Uranus (Editions de Physique) that give the differential coordinates of the satellites and tables for the computation of the mutual phenomena of the Galilean satellites of Jupiter- Phénomènes et Configuration des Satellites Galiléens de Jupiter, since 1980- Configuration des Huit Premiers Satellites de Saturne, since 1985. Bureau des Longitudes have also produced the following ephemerides, published in the Notes Scientifiques et Techniques du Bureau des Longitudes (designated by S followed by a number) : Ephéméride de la comète de Halley pour 1985-1986-Courbes de visibilité (S006), Observation de la comète de Halley en 1985-1986 (S007), Excentricités et inclinaisons moyennes des orbites des satellites galiléens de Jupiter (S009), Ephémérides des petites planètes de 1986 à 1988 (S010, S011, S016), Détermination d'orbites de comètes pour 1986 et 1988 (S014, S017, S019).

The Institute for Theoretical Astronomy, Leningrad, USSR, have published The Astronomical Yearbook and the Ephemerides of Minor Planets.

The Japanese Ephemeris, the Nautical Almanac and the Abridged Nautical Almanac have continued to be published for the years 1986, 1987 and 1988 by the Hydrographic Department of Japan, Tokyo. All the volumes are compiled in accordance with the recommendations of IAU. No serious changes in the contents have been made after the volume for 1985 in which was introduced a new scheme of computation based on the fundamental reference frame of FK5, numerical integration for the coordinates of the bodies in the solar system, day numbers in rectangular coordinates etc. The Japanese Ephemeris from 1985 onwards contains the explanation of the method on which the new ephemerides are based. The Japanese Ephemeris for 1988 contains a new table " The orbital longitude and latitude of the Moon reduced from the lunar occultation observations " which replaces the former " Redduction from Ephemeris Time to Universal Time". The Polaris Almanac for Azimuth Determination, the Altitude and Azimuth Observation Almanac for Antartic Observation and the Abstract from the Japanese Ephemeris have also been published yearly by the Hydrographic Department of Japan.

The Indian Astronomical Ephemeris, Tables of Sunrise, Sunset, Moonrise, Moonset and Rashtriya Panchang, in thirteen languages giving details on the indian calendar and festival dates have been published by the Positional Astronomy Center, Calcutta, India.

3. EPHEMERIDES ON FLOPPY DISKS

For 1986 the Floppy Almanac was introduced by the Nautical Almanac Office, U. S. Naval Observatory. This is a disk that can be run on IBM compatible PCs and provides in an user friendly mode capability for computing in various coordinate systems the positions of the Sun, Moon, planets and stars. Topocentric phenomena and positions can be computed. The program is also available for Microvax Computers on RX 50 diskettes, or for VM CMS systems for the IBM 370, 4300, 3000 computers. A user's guide is available to accompany the software. The Floppy Almanac can be used to compute the data for other almanacs. Using projected values of delta T, issues of the Floppy Almanac are available through the year 2000.

Bureau des Longitudes have issued the following softwares on floppy disks : Programme de Concordance des Calendriers et Fêtes Religieuses, Ephémérides de redécouverte des Comètes, Ephémérides des Satellites de Jupiter, Saturne et Uranus (for IBM compatible PCs).

4. BASIS OF THE EPHEMERIDES

The Jet Propulsion Laboratory (JPL) Ephemerides continue to be improved as newer and more accurate observational data become available. The ephemerides are now fitted to over 80 000 observations- meridian transits, astrolabes, photometry, radar, S/C tracking and ranging, ring and disk occultation timings and radio measurements of thermal emissions. Comparisons of the various datatypes have led to increased understanding of the systematic errors present in some of the earlier optical data types. As such, present ephemerides, for the outer planets in particular, are significantly improved over those of DE200.

Reference frame studies have included the establishment of the JPL Radio Frame and the Dynamical Reference Frame of the Lunar/Planetary Ephemerides, determination of ties between the various reference systems and development of the concept of the dynamical equinox as a reference point for the modern ephemerides and the connection of other coordinate systems to this reference point. Ties between VLBI and optical frames have been established via the observations of radio stars by JPL in collaboration with French astronomers. A link has been determined between the VLBI and the Ephemeris frame through the use of differential VLBI. Very Large Array measurements of Jupiter, Saturn, Uranus and Neptune provide both a tie between the outer planet ephemerides and the radio frame and a means of improving the ephemerides themselves.

5. LONG-TERM EPHEMERIDES

Bureau des Longitudes have published, on floppy disks for Macintosh microcomputers Solution Approchée (ELP 2000-85) du mouvement de la Lune valable sur plusieurs milliers d'années : P. Bretagnon and J.-L. Simon, from Bureau des Longitudes have published Planetary Programs and Tables from -4000 to +2800 (Willmann-Bell, Inc) that provide time-dependent expansions of the longitude and radius vector of the Sun and the heliocentric coordinates of the planets. Bureau des Longitudes have also published Tables des Positions du Soleil, des Planètes et de la Lune entre 1950 et 2020 (Note scientifique et technique du Bureau des Longitudes n°S012).

The following U. S. Naval Observatory Circulars have been prepared : N° 169, Phases of the Moon 2000-2049, n°170, Solar Eclipses 1991-2000.

B. D. Yallop and C. Y. Hohenkerk, of the Royal Greenwich Observatory have published, in 1985, Compact Data for Navigation and Astronomy for the years 1986 to 1990.

J. Laskar and R. A. Jacobson have published An Analytical Ephemeris of the Uranian Satellites, fitted on earth-based and Voyager data (*Astron. Astrophys.* in press).

III. Theoretical work related to the ephemerides

B. Guinot, of the Bureau International des Poids et Mesures and P. K. Seidelmann of the U.S. Naval Observatory have circulated a reprint of a paper titled " Timescales, their history, definition and interpretation". This paper was prepared to help achieve the agreement required of the working Group on reference frames established by the IAU in 1985.

J. Laskar (Bureau des Longitudes) has obtained a new solution for the motion of the pole of the ecliptic using his own general planetary theory, the VSOP82 theory by P. Bretagnon and the theory of the rotation of a rigid earth established in 1977 by Kinoshita. He obtains new formulae for the precession valid for 10 000 years

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(Secular terms of classical planetary theories using the results of general theory- *Astron. Astrophys.* , 1986, 157, 59).

M. Chapront-Touzé and J. Chapront have computed the secular variations of the fundamental arguments of the lunar theory to the fourth power of the time (ELP2000-85 : A semi-analytical lunar ephemeris adequate for historical times. *Astron. Astrophys.* in press).

A test for the continuity requirement at the 1984 changeover has been performed. Simultaneously the connection between the radio system and optical system has been discussed by Aoki et al. (*astrometric Techniques,* 123-131). Th. Hirayama, H. Kinoshita, M.-K. Fujimoto and T. Fukushima have found an analytical expression of TDB-TDT with an accuracy at the 5ns level (in press in the proceedings of the IAG symp.1987).

Gutzwiller and Schmidt have published in the *Astronomical Papers prepared for the use of the American Ephemeris and Nautical Almanac* vol. XXIII, Part I, a paper on "The motion of the Moon as computed by the method of Hill, Brown and Eckert".

The following papers have been issued as Technical Notes of H. M. Nautical Office : n° 57 B. D. Yallop, 1986. Ground Illumination ; n°62 B. D. Yallop and C. Y. Hohenkerk ; 1985. Coefficients for calculating the Greenwich Hour Angle and Declination of stars ; n°63 C. Y. Hohenkerk and A. T. Sinclair, 1985. The computation of angullar atmospheric refraction at large zenith angles ; n°64 B. D. Yallop, 1986. Algorithms for calculating the dates of Easter ; n°65 C. Y. Hohenkerk, 1986. Determination of polynomial coefficients from B-spline coefficients. Astronomical and calendarial data up to to 1992 were published in the Royal Greenwich Observatory Astronomical Information Sheets, as were also the following notes : n°48 B. D. Yallop and C. Y. Hohenkerk, 1985. Closest approach of Polaris to the North Celestial Pole in AD 2100 ; n°50 B. D. Yallop, 1987. Earliesr sighting of the New Moon in 1987.

A. S. Sochilina, of the Institute for Theoretical Astronomy in Leningrad, USSR, has published a paper On the Choice of Reference Frame in Investigations of High Satellites Motions in *Bull. Inst. Astr. Leningr.* 15, n°9 (172), 481-485, 1986.

M. Ilyas (Malaysia) has studied how to unify the various lunar calendars and how to predict the earliest visibility of the lunar crescent in the context of Islamic calendar (*J. Roy. Astron. Soc. Can.* 80, 1986, 134-141, 328-335).

IV. Observations in view of improving the ephemerides

D. Pascu has made photographic observations of the Martian moons, of Jupiter and the Saturnian satellites I-VIII with the 26-inch refractor of the U.S. Naval Observatory in Washington . D. Pascu and P. K. Seidelmann have continued to make observations of Jupiter XIV, Saturn XII, XIII and XIV, Uranus I-V and Neptune I and II with the Mark 4 CCD Camera of the Space Telescope Widefield Planetary Camera Team on the 61-inch telescope at Flagstaff, Arizona. K. J. Johnson, of the Naval Research Laboratory, C. M. Wade of National Radio Astronomy Observatory and G. H. Kaplan, T. S. Carrol and P. K. Seidelmann of the U. S. Naval Observatory have made observations of minor planets 1, 2, 4 and 10 with the Very Large Array in Soccoro, New Mexico.

The last three years have seen improvement in Lunar Laser Ranging data quality and the development of Lunar Laser Ranging Network. Recent equipment and software improvements at the stations have resulted in approximately 5cm ranges (the data prior to 1984 had ranges over 10cm accuracy) ; data are currently being acquired from three stations : CERGA site (France), Manui (Hawaii-USA) and McDonald (Texas-USA). An analysis of the seventeen-year Lunar Laser Ranging data set yields a value for the GM of the Earth of 398 600.437 +/- 0.006 km^3/s^2 in the solar system barycentric frame and 398 600.443 +/- 0.006 km^3/s^2 in the geocentric system, comparable to Lageos (the Lunar Laser Ranging result agrees with the Lageos result within one standard

deviation of the error estimate). The IAU adopted values of the 18.6-year nutation and the precession have been checked against the Lunar Laser Ranging data. The increased accuracy of Lunar Laser Ranging should result in an improved lunar ephemeris. Many papers related to Lunar Laser Ranging or on reference frames, by G. L. Berge, J. O. Dickey, P. B. Esposito, J. L. Fanselow, J. F. Lestrade, R. P. Linfield, W. G. Melbourne, D. O. Muhleman, X. X. Newhall, A. E. Niell R. A. Preston, M. Rapaport, Y. Requième, D. J. Rudy, E. M. Standish, J. G. Williams will be found in the following publications : Proceedings of the IAU Symposium n°128, *The Earth's Rotation and Reference Frames for Geodesy and Geodynamics* , editors G. Wilkins and A. Babcock, D. Reidel, Boston, 1987, in press. The book *Reference Frames* , editors, B. Kolaczek, J. Kovalevsky, I. Mueller , D. Reidel, 1987, in press. The Proceedings of the IUGG Symposium, *Relativistic Effects in Geodesy XIX General Assembly* , Vancouver, 1987.Report on the *MERIT-COTES Campaign on Earth's Rotation and Reference System, Part I : Proceedings of the third MERIT workshop and the Joint MERIT-COTES Working Group Meetings* , editor G. Wilkins, Royal Greenwich Observatory, 1987, in press. Report on the *MERIT-COTES Campaign on Earth Rotation and Reference Systems, Part II : Proceedings of the International Conference on Earth Rotation and the Terrestrial Reference Frame* , editor I. Mueller, Ohio State University, vol. 2, 1985. Proceedings of the IAU Symposium n°109 : *Astrometric Techniques* (Gainesville, Florida, 1984), editors H. K. Eichhorn and R. J. Leacock, Reidel, Dordrecht-Holland, 1986. *Bulletin of the American Astronomical Society* , 1986. Proceedings of the Joint discussion on Reference Frames at th XIX General Assembly of the IAU, *Highlights of Astronomy* , vol. 7 editor J. P. Swings, Reidel, Dordrecht-Holland, 1986. Proceedings of the IAU colloquium n°114 : *Relativity in Celestial Mechanics and Astrometry* , Reidel, Boston, 1985. Special LAGEOS issue of the *Journal of Geophysical Research* , vol. 90, 1985. Proceedings of the international symposium : Figure and Dynamics of the Earth, Moon and PLanets, special issue of the *Monograph Series of the Research Institute of Geodesy, Topography and Cartography* , editor P. Holota, in press, 1987. *Celestial Mechanics* , 37, 329-337, 1985. *Transactions of the American Geophysical Union* , EOS, 67, 16, 259, 1986. Proceedings of the *Fifth International Workshop on Laser Ranging Instrumentation* , editor J. Gaignebet, vol. 1, 19-28, 1985.

The services of the International Lunar Occultation Centre, in Japan, have been continued since 1981. The number of the timing data collected at the centre was 31 370 from 35 countries during the years 1984 to 1986. Reports containing all the reduced data as well as the station coordinates related are published annually.

A campaign for the observations of the mutual phenomena of the Galilean satellites of Jupiter in 1985 has been organized under the auspices of Bureau des Longitudes. Many good observations were made in France, Italy, Spain, Brazil and at the ESO observatory in Chile. Preliminary results will be found in the proceedings of a colloquium held at Bagnères-de Bigorre (*Annales de Physique* , vol.12, 1987).

V. Working Groups having to do with ephemerides

The IAU/IAG/COSPAR Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites has continued to gather informations and will present an updated set of data in the report which will be presented at the Baltimore General Assembly of the IAU. The main changes will affect the radii of Jupiter, Saturn, Uranus, Neptune, Io, Mimas and the Uranian satellites.

A Working Group on astronomical constants has been formed following Resolution C1 of the IAU by the presidents of IAU Commissions 4, 7, 8, 19 and 31. The purpose is to review the current determinations of the astronomical and geodetic constants, provide best estimates, accuracies and sources. The Working Group is composed as follows : B. Morando, president, V. K. Abalakin, W. E. Carter, J. Chapront, B. Chovitz, H. Kinoshita, J. Lieske, J. Schubart, P. K. Seidelmann, E. M. Standish, J. M. Wahr, G. Wilkins, Ya. S. Yatskiv. The working group will send a preliminary report to the General Secretary of the IAU before the end of 1987.

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Following Resolution C2 of the IAU a Working Group on Reference Systems has been formed by the presidents of IAU Commissions 4,7,8 19, 20, 24, 31, 33 and 40. The president of the working group is James A. Hughes. This working group and the working group on astronomical constants met together in Paris in June 1987.

B. MORANDO
President of the Commission.

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