PART 3

REPORTS OF MEETINGS OF COMMISSIONS

COMPTES RENDUS DES SEANCES DES COMMISSIONS

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

COMMISSION 4: EPHEMERIDES (EPHÉMÉRIDES)

Report of Meetings 14, 15, 16, 20 and 21 August 1979

PRESIDENT: V.K. Abalakin SECRETARY: J.H. Lieske

14 August 1979

ADMINISTRATIVE MATTERS

Participants stood in silence in memoria of Dr. E.W. Woolard and Prof. Y. Hagihara. The President summarized the current status of the Commission and distributed the draft agenda for the Commission meetings during the General Assembly. The agenda was approved with some amendment. The President proposed lists of the new officers of the Commission for the next three years and of the new members of the Commission. The meeting agreed that both lists should be put to the Executive Committee (see "Membership of Commissions"). New Commission members are: A. Bandyopadhyay, P. Bretagnon, J. Chapront, B. Emerson, A. Fiala, M.A. Fursenko, N.I. Glebova, J. Henrard, R.W. King Jr., H. Kinoshita, B. Kolaczek, I.I. Mueller, R.D. Reasenberg, H. Schwan, A.S. Sochilina, E.M. Standish Jr., and A. Yamazaki. New consulting member is M.L. Smith.

The President indicated that a symposium (or a colloquium) on Reference Systems for Earth Dynamics is being planned to be held in Poland in 1980, and that the support of the IAU was desired. The meeting agreed to consider this item in a later session.

REPORT OF ALMANAC OFFICES

G.A. Wilkins explained the background to the changes in the publications of the Royal Greenwich Observatory (RGO) and of the U.S. Naval Observatory (USNO) described in the Report of Commission 4 (Trans. IAU XVIIB, Part 1, p. 2); those who requested the ephemerides data in advance did not want high precision but needed only the data on phenomena or low precision ephemerides in most cases. He showed copies of the first issues in the revised series, that is of "Astronomical Phenomena 1981" and of "Planetary and Lunar Coordinates for 1980-1984". The next issue of the latter publication would refer to the years 1984 to 2000 and should be available in 1982. The name "Astronomical Almanac" would replace the two current names for the "AE". Those requiring the data of the Astronomical Almanac in advance would receive them as computer listings or on magnetic tape.

P.K. Seidelmann then outlined the principal changes that had been introduced into the Astronomical Almanac. The publication will be reformed and organized into sections by subject. The hourly apparent lunar ephemeris will be replaced by shorter power series for direct calculation of the lunar position for any time. Physical ephemerides will be given for all the planets and observing ephemerides for all the satellites. An ephemeris for the solar system barycentre, transformation matrices for the reduction of apparent places, and standard stellar source lists will be included. The brighter star list will be expanded, accurate locations of instruments will be given periodically, and a revised explanation and glossary of terms will be introduced. The independent Day Numbers, first differences and fixed tables for unit conversions will be eliminated.

It was pointed out that a 5-term series based upon Economized Chebyshev Polynomials would be employed, since the USNO experience with users indicates a "familiarity" with power series and a "fear" of Chebyshev polynomials. French experience is the opposite -- Chebyshev polynomials are accepted by users.

B. Morando described the new presentation of the "Connaissance des Temps" (CdT) and other publications issued by the Bureau des Longitudes (BdL). Over three hundred years after its first issue the CdT for 1980 will have an entirely new presentation for economic reason, by listing the coordinates of the Sun, Moon, planets, and Galilean satellites in Chebyshev polynomial form. The phenomena and configurations of the Galilean satellites, the mean places of the FK4 and FK4 Sup stars, and Day Numbers are no longer presented. The new CdT contains an external section of explanations and examples, including those for the star place reduction and the new system of astronomical constants. The "Annuaire du Bureau des Longitudes" does not present scientific articles on astronomy, geophysics, physics and geography. These articles are now a part of a book entitled "Encyclopédie Physique et Spatiale" issued in separate volumes every year. The "Annuaire" itself is now an extended almanac for amateurs and for astronomers that wish to look up astronomical phenomena or positions of celestial objects without higher precision.

J. Chapront spoke about the efforts at the BdL to develop new theories for the planetary and lunar motions, and suggested the replacement in the CdT of old theories by new ones. He discussed also the advantage of theories against numerical integrations as well as the defects of the present CdT for the planetary motions. The present state of the new solutions could be summarized as: (i) For the major planets, Jupiter and Saturn, comparisons of the solutions with internal numerical integrations show discrepancies less than 0".3 in longitude and 0".1 for the other elements, over a range of 1000 years, and (ii) For Mercury, Venus and the Earth, the discrepancies are less than 0".007 in longitude; 0".035 for Mars. He finally emphasized the importance of the comparison between theories and observations.

Questions were asked re the source of the difference between the Leverrier and Newcomb ephemerides; it was answered that P. Bretagnon has them available on magnetic tape.

A.M. Sinzi reported that, instead of current Besselian Day Numbers, Chebyshev coefficients for the transformation matrices will be tabulated in the "Japanese Ephemeris".

15 August 1979

Joint meeting with Commission 16

CARTOGRAPHIC COORDINATES

G. de Vaucouleurs summarized his work on the determination of the rotation period of Mars, based on an extensive review of all previous ground-based observations.

M.E. Davies, the Chairman of the IAU Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites, presented the Report of the Working Group. See Annex 1.

After some discussion the meeting unanimously agreed that the Report should be adopted as the basis of ephemeris computations. Although the task of the Working Group finished by the approval of the Report, it was agreed that the Group would remain in a reduced form, being composed of few persons with M.E. Davies as Chairman, to inform on improved data, since such data were expected to be available in the near future. See Resolution 1.

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

16 August 1979

Joint meeting with Commissions 7, 8, 19, 24 and 31

NUTATION

P.K. Seidelmann, the Chairman of the IAU Working Group on Nutation, presented the Summary Report of the Working Group. See Annex 2.

T. Sasao argued that the Report should be amended by adopting the nutation theory developed very recently by J.M. Wahr (1979) for the Earth Model 1066A of F. Gilbert and A.M. Dziewonski, instead of Moldensky's model II (1961). Sasao stated that Moldensky's model is already out-of-date while the Model 1066A is one of the most heavily constrained new models. He pointed out that, between the numerical values given in Table 1 of the Report and those proposed by Wahr, there exist discrepancies of up to 0."002 in $\Delta\psi \sin \varepsilon$ and $\Delta\varepsilon$, both for the 18.6 year and six month terms. These discrepancies could not be overlooked when new techniques, such as VLBI and laser ranging, became practical in the near future. Discussion was focussed on the choice of either theory from scientific and practical view points. The President asked for a vote and the theory contained in the Report was favoured by majority mostly due to the feeling that the Wahr's theory should "age" a bit more before being proposed for adoption.

There were also discussions regarding the wording of the Recommendation: one with reference to the Resolution adopted at the General Assembly in Grenoble and the other for the usage of the terminology of "space-fixed", "body-fixed" and "inertial", and "Celestial Reference Pole" and "Celestial Ephemeris Pole". See Resolution 2.

FUNDAMENTAL CATALOGUE (FK5)

W. Fricke presented a bibliography of work done at the Astronomisches Rechen-Institut since the last IAU General Assembly. The tasks required for the construction of the FK5 are the following:

(1) Determination and introduction of the new value of the general precession in longitude;

(2) (a) Determination of the zero point correction to $(\mu_\alpha)_{FK4}$ in order to eliminate the non-precessional motion of the FK4 equinox, and

(b) of the zero point correction to α_{FK4} at the epoch 1950 such that the zero point of α_{FK5} will be identical with the dynamical equinox;

(3) Determination of the equator of the FK5 and application of that correction (certainly small, if not zero) to the δ_{FK4};

(4) Elimination of the inhomogeneities of the FK4 system (including magnitude equation) by means of recent absolute and quasi-absolute observations, and application of these systematic corrections to the FK4 positions and proper motions;

(5) Elimination of the E-terms of aberration from FK5 mean positions, because they will be included in the reduction to the apparent places;

(6) In the computation of apparent places of FK5 stars the new theory of nutation and the relativistic effects will be introduced;

(7) Conversion to the new Standard Epoch and Equinox J 2000.0, and from tropical to Julian centuries as the unit of time interval;

(8) Determination of individual corrections to the positions and proper motions of FK4 stars and their application;

(9) Addition of new fundamental stars with extention to magnitude $\sim$9.0.

Steps (1)-(7) could be completed by 1984. In the discussion Fricke pointed out that the faint stars will be taken from existing well-observed series, and that some radio sources would also be included.

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

20 August 1979

Joint meeting with Commissions 19 and 31

UNIVERSAL TIME AND DYNAMICAL TIME

G.A. Wilkins read the following draft resolution proposed by D.H. Sadler who was unable to attend: "Commission 4 requests that neither the name Universal Time nor its designation UT be used to denote the time-scale of Co-ordinated Universal Time, and that the General Secretary of the Union arrange for the content of the Resolution to be communicated to the appropriate international organizations". Sadler put forward this resolution since he considered that by adopting Resolution No. 1 at the last General Assembly, Commissions 4 and 31 had unnecessarily perpetuated confusion and complication. The aim of the proposed resolution was to preserve the original meaning of Universal Time and to avoid the ambiguity that arises when the same name would be used for several kinds of Universal Time. Wilkins strongly supported Sadler's proposal. G.M.R. Winkler claimed that the matter had been fully discussed at three previous General Assemblies and that he had not heard any new argument. He proposed that the meeting should not further discuss this problem, and the meeting agreed.

W. Fricke explained the change in the expression of UT1 in terms of Greenwich mean sidereal time (GMST), in accordance with Recommendation 3(c) of the Joint Report as adopted at the last General Assembly (Trans. IAU XVIB, p. 59):

1. In order that the equinox of the FK5 corresponds as closely as possible to the dynamical equinox, a correction E to the right ascensions of the FK4 and a correction $\dot{E}$ to the centennial proper motions of the FK4 will be introduced giving the change from the FK4 equinox to the FK5 equinox

$$E(T) = E_{1950} + \dot{E}\ (T - 19.50),$$

where T is measured in centuries, and where from the current work on the FK5 the following preliminary numerical values are available

$$E_{1950} = +\ 0\overset{s}{.}040,$$
$$\dot{E} = +\ 0\overset{s}{.}086 \text{ per century.}$$

A distinction between tropical and Julian centuries is of no importance in this case. These preliminary values have been employed in Para. (b) of the proposed Resolution. Final numerical values which will not differ from the preliminary ones by more than 10 milliseconds will be reported by the end of 1980.

2. The change of the positions and proper motions of the fundamental stars described by E and $\dot{E}$ affects the determination of sidereal time. However, the change does not affect the determination of UT1, if the relationship between sidereal time and UT1 is redefined. Furthermore, it should be noted that the 1976 change in precession does not affect the apparent right ascensions, since such change modifies the proper motions correspondingly.

3. UT1 is currently defined as 12^h + the Greenwich hour angle of a point on the equator whose right ascension, measured from the mean equinox of date, is:

$$R_u = 18^h 38^m 45\overset{s}{.}836 + 8\,640\,184\overset{s}{.}542\ T_u + 0\overset{s}{.}0929\ T_u^2,$$

which becomes now

$$R_u = 18^h 38^m 45\overset{s}{.}833 + 8\,640\,184\overset{s}{.}628\ T_u + 0\overset{s}{.}0929\ T_u^2.$$

The old expression for R_u is identical with that given by Newcomb (Astron.Pap.Amer. Eph. 6, p. 9, 1895) for the right ascension of the fictitious mean sun. It is now recognized that this expression for R_u, while intended to represent the motion of the fictitious mean sun, is not rigorously related to the position and motion of the Sun. Newcomb, unaware of the variable rotational speed of the Earth, considered that T was measured in mean solar time. Hence, the mean sun differs from R_u by 0.002738 ΔT, where ΔT = ET - UT1.

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

4. A small and partly unpredictable discontinuity in UT1 may occur with the introduction of the FK5 and the 1979 Theory of Nutation. This could possibly be removed by a correction to station longitudes.

After some discussion about the definitive values of E and $\dot{E}$ the Resolution was adopted. See Resolution 3.

A. Orte stated that the clarification of the UT concept and related conventions to study the Earth's rotation is a priority task. This is necessary mainly in view of the advent of new powerful techniques for measuring the duration of a day. Limitations of the present UT are in accuracy, in precision, and in the stability of the system of reference. Moreover, today's definition contains ambiguities concerning the meridian and the pole of reference. Hence explicit operational conventions are required. Orte suggested the initiation of studies for a new definition, freezing the present conventions and terminology in the meantime.

The President gave the information to the members of Commission 4 that the Project MERIT had been already discussed in Commissions 19 and 31, and asked for a vote together with the members of Commissions 19 and 31. The Resolution was adopted unanimously. See Resolution 4.

B. Guinot made some comments on his recent paper (Proc. IAU Symp. No. 82, p. 7, 1979) to advocate the use of a non-rotating reference system, taking the origin at the departure point. UT1 could then be simply defined as proportional to the hour angle of the origin, and hence could be used not only to locate angularly the Earth relative to celestial objects but also to investigate the irregularity in the Earth's rotation through the relationship with sidereal time. He therefore regretted that without changing anything in the practical definition of UT1 from sidereal time, the IAU had not given, in addition, a clear statement on the principles underlying this definition. Such a statement could have put an end to the confusion arising from the historical background of solar time.

P.K. Seidelmann described the background to his proposal on the designation of dynamical time-scales defined at the last General Assembly. To differentiate between the relativistic coordinate time referred to the barycentre of the solar system and the proper time referred to the Earth, descriptive adjectives are required. Many possibilities have been considered and the simplest would be "coordinate" and "proper", but "coordinate" is subject to confusion with "coordinated" of UTC and "proper" does not specify for what it is proper time. Therefore, using the adjectives "barycentric" and "terrestrial", the designations "Barycentric Dynamical Time" (TDB) and "Terrestrial Dynamical Time" (TDT) have been proposed. Alternative designations, such as "TB" and "TT", were suggested in the discussion but the proposed designations were favoured by the majority. See Resolution 5. It was understood that, when it is unnecessary to differentiate between a coordinate and proper time-scales, the general term Dynamical Time (TD) may be used; for instance, when the accuracy is lower than 0.1 second. Several people questioned the wisdom of introducing new names for coordinate and proper times when the primary reason for doing so seems to be solely to enable almanac offices to state that Proper Time equals Dynamical Time plus some tabular corrections to be determined after the publication of the ephemerides. It was suggested that besides being confusing, it is improper to define a dynamical coordinate time and a dynamical proper time without specifying the metric.

21 August 1979

ADOPTION OF FURTHER RESOLUTIONS

The President announced that the Commission had been requested to cosponsor the Resolution on the space astrometry project initiated by Commission 24. C.A. Murray, President of Commission 24, then explained the background to the Resolution. The meeting agreed unanimously to support the Resolution. See Resolutions adopted at the General Assembly.

The President asked the Commission to support the proposal for the Colloquium on Reference Systems for Earth Dynamics to be held in 1980 in Poland. The meeting agreed unanimously. See Resolution 6.

The President asked the Commission to consider a resolution which had been put forward following an informal discussion of the future of the lunar occultation programme. L.V. Morrison explained that, although the H.M. Nautical Almanac Office (HMNAO-RGO) had been responsible since 1943 for an international service for the prediction and reduction of lunar occultation of stars, it would be impossible for the HMNAO to continue to provide this service due to its gradual reduction of the number of staff and to the necessity of allocating staff to a new programme for satellite laser ranging. He stated that the HMNAO would be still prepared to continue the prediction service and to give all possible assistance to any organization that would take on responsibility for the collection and processing of observations. In seconding the Resolution W. Fricke thanked the HMNAO for the valuable work that had been done; in particular he pointed out that Morrison's recent analysis was highly useful for his investigation on the equinox of the FK5. The Resolution was adopted unanimously. See Resolution 7.

FUNDAMENTAL EPHEMERIDES

J. Chapront, on behalf of P. Bretagnon, M. Chapront-Touzé, and himself, described the progress made at the BdL in constructing new theories for the lunar problems and planetary motions. (i) A modern solution for the Earth's motion, taking into account the second-order perturbations, has been proposed and its comparison with an internal numerical integration has shown agreement within 0"01 in longitude and 0"005 for the other osculating elements. (ii) Starting with a solution for the lunar main problem, a variational method has been retained to compute the planetary perturbations of the Moon. Main limitations are: the first order terms with respect to the masses of planets, terms of periods less than 3500 years, and internal precision of 0"0005 for the longitude. A comparison with some of Brown's results has been made.

D. Standaert presented the theoretical background to a method for computing the planetary perturbations in the Moon's motion. An algorithm has been formulated on the basis of the Lie transform method, and is being implemented using Henrard's Semi-Analytical Lunar Ephemeris as a solution of the main problem and Bretagnon's planetary theory. The accuracy of the solution is intended to be around 0"001 for terms with periods up to 2000 years. He illustrated some preliminary results obtained for the direct perturbations due to Venus on the Moon's longitude. J.D. Mulholland congratulated to the BdL and Namur people on the success achieved in solving one of the most difficult problems in the theory of the motions of the solar system objects.

P.K. Seidelmann described the current situation with respect to the IAU (1976) System of Astronomical Constants: (i) It is not certain whether the IUGG will adopt the IAU value for the equatorial radius of the Earth or an improved value, at its General Assembly to be held in December 1979. For astronomical calculations, the difference is not significant. (ii) Based on the recent discovery of a satellite of Pluto, it appears that the adopted mass and radius of Pluto are not accurate. However, definitive values are not available at this time. (iii) The adopted set of values for the gravity field of the Moon are not completely self-consistent. The adoption of some new values for the sake of consistency would not necessarily mean the adoption of the best values, particularly in cases where the true value is quite uncertain. Since improved values are likely to be available in the next few years, no changes to the IAU (1976) System were introduced at the meeting. A suggestion

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

was made that the almanac offices may use some improved values of planetary masses in computing the new fundamental ephemerides for introduction in 1984, but they should indicate those changes clearly.

P.K. Seidelmann described the basis for the new fundamental ephemerides to be introduced in 1984. The guiding principles for the new ephemerides are: (i) the ephemerides should not be based on a single or isolated computation, (ii) all available observational data should be utilized, (iii) bases, constants and reference frame should be consistent and specified for all ephemerides, and (iv) machine readable ephemerides should be available covering extended periods of time. For this purpose, a programme of ephemerides preparation, collection of observations and comparison between ephemerides and observations has been underway. Plots of such comparisons illustrated the differences between ephemerides and their comparison with observations. In the discussion it was pointed out that the differences for the inner planets were solely the result of comparing two numerical integrations and are due to model differences and truncation errors. In response to the question of getting data on the "same system" Seidelmann stated that to the best of its ability the USNO tries to reduce data to the FK4 system.

At the conclusion of the meeting a vote of thanks to the President, V.K. Abalakin, was moved by T. Lederle and was carried with acclamation. The meeting was adjourned.

RESOLUTIONS

Resolution 1 of Commissions 4 and 16 on cartographic coordinates.

IAU Commissions 4 and 16 endorse the Report of the Joint Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites,

recommend

that the Report be used as the basis for computing the physical ephemerides of planets and satellites in the international and national ephemerides, and

request

that a small working group continues its activity in order to provide improved rotational elements.

Resolution 2 of Commissions 4, 7, 8, 19, 24 and 31 on nutation.

IAU Commissions 4, 7, 8, 19, 24 and 31 endorse the recommendations given in the Report of the Working Group on Nutation (1979 IAU Theory of Nutation), and

recommend

that they shall be used in the national and international ephemerides for the years 1984 onwards, and in all other relevant astronomical work.

Resolution 3 of Commissions 4, 19 and 31 on the expression of UT1 in terms of GMST.

In considering that it is planned to introduce the IAU (1976) System of Astronomical Constants, the 1979 IAU Theory of Nutation, and the equinox of the FK5 on

1984 January 1, it is recommended that:

(a) the relationship between mean sidereal time and UT1 be modified so that there is no change in either value or rate of UT1, due to a correction to the zero point of right ascensions of the FK4 and a correction for the motion of the zero point, to be introduced in the FK5;

(b) the new (provisional) expression for Greenwich mean sidereal time of 0^h UT1 be

$$\text{GMST of } 0^h \text{ UT1} = 6^h38^m45^s\!.833 + 8\,640\,184^s\!.628\, T_u + 0^s\!.0929\, T_u^2,$$

where T_u is the number of Julian centuries of 36525 days of Universal Time elapsed since 1900 January 0, 12^h UT1 (JD 2 415 020.0). This expression is rigorously equivalent to the following

$$\text{GMST of } 0^h \text{ UT1} = 6^h41^m50^s\!.5539 + 8\,640\,184^s\!.8138\, T_u + 0^s\!.0929\, T_u^2,$$

where T_u is measured from 2000 January 1, 12^h UT1 (JD 2 451 545.0).

Note: The followings are frequently used quantities which are also affected by the Resolution:

a) The interval of mean sidereal time in a mean solar day becomes

$$24^h + \frac{8\,640\,184^s\!.628 + 0^s\!.185\,8\; T_u}{36525} = 86\,636^s\!.555\,362\,8 + 0^s\!.000\,005\,087\, T_u\,,$$

while the current value is $86\,636^s\!.555\,360\,5 + 0^s\!.000\,005\,087\, T_u\,.$

b) The ratio of a sidereal day of 86400 mean sidereal seconds to this interval becomes

$$\frac{\text{mean sidereal day}}{\text{mean solar day}} = 0.997\,269\,566\,388 - 0.586 \times 10^{-10}\, T_u,$$

while the current ratio is $0.997\,269\,566\,414 - 0.586 \times 10^{-10}\, T_u.$

c) The ratio of the mean solar day to the mean sidereal day becomes

$$\frac{86\,636.555\,362\,8 + 0.000\,005\,087\, T_u}{86400} = 1.002\,737\,909\,292 + 0.589 \times 10^{-10}\, T_u,$$

while the current ratio is $1.002\,737\,909\,265 + 0.589 \times 10^{-10}\, T_u.$

d) Disregarding the inappreciable secular variations, the equivalent measures of the lengths of the days at 1900 are

1 mean sidereal day: $23^h56^m04^s\!.090\,536$ of mean solar time,
1 mean solar day : 24 03 56.555 363 of mean sidereal time,

while the current values are

1 mean sidereal day: $23^h56^m04^s\!.090\,54$ of mean solar time,
1 mean solar day : 24 03 56.555 36 of mean sidereal time.

Resolution 4 of Commissions 4, 19 and 31 on Project MERIT.

IAU Commissions 4, 19 and 31 endorse the proposal of the joint working group on the determination of the rotation of the Earth for a special period of international collaboration in the monitoring of Earth-rotation and in the intercomparison of the techniques of observation and analysis, recognize

that the responsibility for the organization of this project MERIT should be shared with the International Union of Geodesy and Geophysics, and

request

that the national and international organizations concerned give full technical and financial support to the development of the proposal and to the implementation of the project.

Resolution 5 of Commissions 4, 19 and 31 on the designation of dynamical times.

IAU Commissions 4, 19 and 31 recommend that the time-scales for dynamical theories and ephemerides adopted in 1976 at the 16th General Assembly be designated as follows:

(1) the time-scale for the equations of motion referred to the barycentre of the solar system be designated Barycentric Dynamical Time (TDB),

(2) the time-scale for apparent geocentric ephemerides be designated Terrestrial Dynamical Time (TDT).

Resolution 6 of Commission 4 on a Colloquium on Reference Systems.

IAU Commission 4 expresses its full support in favour of the proposal of the Space Research Centre of the Polish Academy of Sciences and the Smithsonian Astrophysical Observatory to convene the Second International Colloquium on Reference Systems for Earth Dynamics.

Resolution 7 of Commission 4 on processing of occultation data.

IAU Commission 4 recognizing

(a) that timings of occultations of stars by the Moon will continue to be of value in studies of the lunar motion and figure, the rotation of the Earth, and the stellar reference frame, and

(b) that it is desirable that the observations should continue to be collected and processed by one organization, and

considering

that beginning with January 1981, H.M. Nautical Almanac Office, Royal Greenwich Observatory, will no longer be able to act as the international centre for the receipt and processing of timings of occultations,

recommends

that an organization with the appropriate experience and commitment to the occultation programme be requested to take over this important work.

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

Annex 1.

REPORT OF THE IAU WORKING GROUP ON CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS OF THE PLANETS AND SATELLITES

Chairman: M.E. Davies
Members: V.K. Abalakin, R.L. Duncombe, H. Masursky, B. Morando, T.C. Owen, P.K. Seidelmann, A.T. Sinclair, G.A. Wilkins
Consultants: C.A. Cross, Y.S. Tjuflin

1. Introduction

The IAU Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites was established as a consequence of the adoption of the following resolution at the IAU General Assembly at Grenoble in 1976 (Trans. IAU XVIB, p. 144):

"Commissions 4 and 16 noting that

(a) confusion exists regarding the present rotational elements of some of the planets
(b) extensive amounts of new data from radar observations and by direct imaging from spacecraft have made cartography of the surface of the Moon, Mercury, Venus, and Mars a reality
(c) there will be an extension of these techniques to the mapping of larger satellites of Jupiter and Saturn in the near future

assert that

(a) to avoid a proliferation of inconsistent cartographic and rotational systems, there is a need to define the rotational elements of the planets and satellites on a systematic basis and to relate the new cartographic coordinates rigorously to the rotational elements

and therefore recommend that

(1) Commission 4 (Ephemerides) and Commission 16 (Physical Study of Planets and Satellites) establish a Joint Working Group to study the cartographic coordinates and rotational elements of the planets and satellites and to report recommendations thereon at the next general assembly of the IAU."

In preparing the recommendations given in this report, the Working Group adopted the guiding principles that have been previously adopted by Commission 16 at the IAU General Assembly at Brighton in 1970, namely (Trans. IAU XIVB, p. 128):

"1. The rotational pole of a planet or satellite which lies on the north side of the invariable plane shall be called north, and northern latitudes shall be designated as positive.
2. The planetographic longitude of the central meridian, as observed from a direction fixed with respect to an inertial coordinate system, shall increase with time. The range of longitudes shall extend from 0° to 360°."

The technical arguments in support of, and in opposition to, both of these principles have been reviewed; these arguments were considered at the time of the adoption in the preparation of numerous maps of both planets and satellites, and the Group considers that the advantages that are claimed for other principles are not sufficient to justify the adoption of new principles. Because of historical usage, longitudes on the Moon and Earth are measured from 0° to 180° east and west of the prime meridian. Thus these bodies are exceptions to the general rule. The Group does, however, recommend that the rotational elements and cartographic coordinate systems be specified more simply and uniformly than in the past.

The rotational elements define the direction of the axis of rotation and the rate of rotation relative to an inertial coordinate system. The values of the elements given later in this report are based where possible on recent observational determinations. These elements, especially those for the satellites, vary with time, but it is sufficiently accurate to adopt simplified models of these motions; in particular, short-period nutations are ignored.

Each cartographic coordinate system is defined by reference to the adopted axis of rotation and an arbitrarily chosen prime meridian, whose position on the surface is specified where possible by the adoption of the longitude of a suitable observable feature. For some of the planets and most of the satellites it is sufficient, at present, to assume that the reference surface is spherical, but for others it is necessary to adopt a reference spheroid, with the principal axis of inertia along the axis of rotation.

The following sections of this report describe the ways in which the rotational elements and cartographic coordinate systems are defined. The recommended values are given in a series of tables.

2. Definition of Rotational Elements

The rotational elements of a planet or satellite specify the direction of the north pole and the orientation of its prime meridian as functions of time in the following manner:

The north pole is that pole of rotation which lies on the north side of the invariable plane of the solar system. The direction of the north pole is given with respect to the standard celestial equator and equinox of 1950.0, i.e., in effect with respect to the system of the fundamental catalog FK4. Variable quantities are expressed in units of ephemeris days (or Julian ephemeris centuries of 36525 days) from the standard epoch of 1950 January 1.0, ET, or JED 2433282.5; this epoch is denoted J1950 and is slightly different from the epoch 1950.0, which refers to the beginning of the Besselian year and corresponds to JED 2433282.423 357. The values will be given with respect to the new standard equator, equinox and epoch of J2000, i.e., of 2000 January 1.5 or JED 2451545.0, when the relationship between the systems of the new catalog FK5 and that of FK4 is precisely defined.

The direction of the north pole is specified by the values of its right ascension α_0 and declination δ_0, while the orientation of the prime meridian is specified by the angle W that is measured *along* the planet's equator in the positive sense with respect to the planet's north pole (i.e., in an easterly direction on the planet's surface) *from* the ascending node Q of the planet's equator on the standard equator *to* the point B where the prime meridian crosses the planet's equator (see Fig. 1). (The point Q is the node at which a point moving around the planet's equator in a positive sense would cross the standard equator from south to north; the right ascension of the point Q is $90^\circ + \alpha_0$ and the inclination of the planet's equator to the standard equator is $90^\circ - \delta_0$.) The prime meridian is assumed to rotate uniformly with the planet, and so W varies linearly with time due to this rotation. In addition, α_0, δ_0 and W may vary with time due to a precession of the axis of rotation of the planet (or satellite). If W increases with time, the planet has a *direct* (or prograde) rotation relative to the invariable plane; if W decreases with time the rotation is said to be *retrograde*.

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

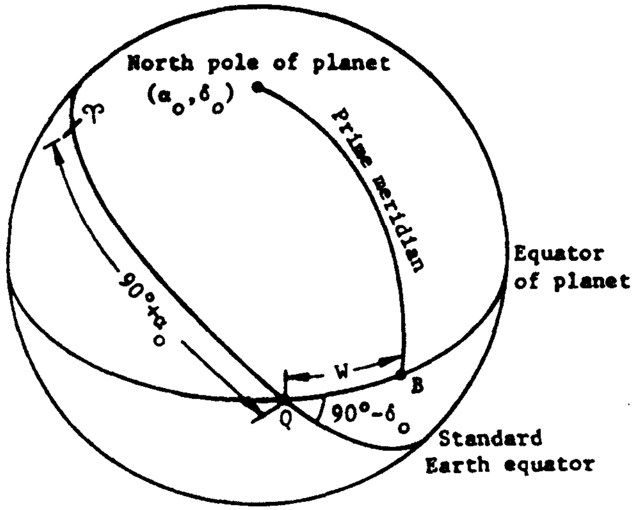

Figure 1. Reference system used to define orientation of the planet

In the absence of other information, the axis of rotation is assumed to be normal to the mean orbital plane; Mercury and most of the satellites are in this category. For many of the satellites it is assumed that the rotation rate is equal to the mean period of orbital revolution.

The angle W specifies the ephemeris position of the prime meridian, and for planets or satellites without any accurately observable fixed surface features the adopted expression for W defines the prime meridian and is not subject to correction. Where possible, however, the cartographic position of the prime meridian is defined by a suitable observable feature and so the constants in the expression $W = Wo + Wd$, where d is the interval in days from the standard epoch, are chosen so that the ephemeris position follows the motion of the cartographic position as closely as possible; in these cases the expression for W may require amendment in the future.

For the planets on which no suitable features have been observed, W has been given the value of 360° at the standard epoch (Saturn, Uranus, Neptune, Pluto); in other cases W has been chosen so that the planetographic longitude of the central point of the apparent disk as seen from the center of the Earth (i.e., the longitude of the central meridian) has an arbitrary value at some adopted epoch (Venus, Jupiter). In general, the values given here are compatible with those currently in use.

For satellites on which no suitable features have been observed, the expression for W has been chosen so that the ephemeris position of the prime meridian passes through the intersection of the satellite's equator and the plane containing the centers of the satellite, the planet, and the Sun at the time of the first superior heliocentric conjunction of the satellite and the planet after the standard epoch (Trans. IAU XVB, p. 108). An exception is the Moon, whose prime meridian passes through the mean sub-Earth direction.

Recommended values of the constants in the expressions for α_0, δ_0 and W are given for the planets in Table 1 and for the satellites in Table 2. Expressions for the Sun, Earth, and Moon are given to a similar precision as those of the other bodies of the solar system for comparative purposes only.

Table 1. Recommended Values for the Direction of the North Pole of Rotation and the Prime Meridian of the Sun and Planets (1979)

α_o, δ_o are standard equatorial coordinates of 1950.0. Approximate coordinates of the north pole of the invariable plane are $\alpha_o = 272^\circ.40$, $\delta_o = +66^\circ.99$.
T = interval in Julian ephemeris centuries (of 36525 days) from the standard epoch.
d = interval in ephemeris days from the standard epoch.
The standard epoch is 1950 January 1.0 ET, i.e., JED 2433282.5.

Sun	α_o = 286°.0			
	δ_o = 63.8			
	W = 240.9	+ 14°.18440 d		
Mercury	α_o = 280.9	− 0.033 T		
	δ_o = 61.4	− 0.005 T		
	W = 184.74	+ 6.1385025 d		(a)
Venus	α_o = 272.8			
	δ_o = 67.2			
	W = 213.63	− 1.4814205 d		
Earth	α_o = 0.0	− 0.64032 T		
	δ_o = 90.0	− 0.55669 T		
	W = 99.87	+ 360.985612 d		(b)
Mars	α_o = 317.342	− 0.108 T		
	δ_o = 52.711	− 0.061 T		
	W = 11.50	+ 350.891983 d		(c)
Jupiter	α_o = 268.00	− 0.008 T		
	δ_o = 64.50	+ 0.003 T		
	W_I = 17.7	+ 877.900 d	System I	(d)
	W_{II} = 16.8	+ 870.270 d	System II	
	W_{III} = 80.6	+ 870.536 d	System III	
Saturn	α_o = 38.50	− 0.034 T		
	δ_o = 83.31	− 0.004 T		
	W_I = 360.0	+ 841.558 d	System I	(d)
	W_{III} = 360.0	+ 822.00 d	System III	
Uranus	α_o = 256.72			
	δ_o = −15.04			
	W = 360.0	− 554.913 d		
Neptune	α_o = 294.91			
	δ_o = 40.53			
	W = 360.0	+ 468.750 d		
Pluto	α_o = 305			
	δ_o = 5			
	W = 360.0	− 56.367 d		

Note (a) The 20° meridian is defined by the crater Hun Kal.
(b) The 0° meridian is defined by the transit circle at Greenwich, England.
(c) The 0° meridian is defined by the crater Airy-0; its longitude in the system of the *American Ephemeris*, 1968 to present, (de Vaucouleurs' NA3), was 358°.4 ± 0°.3 (m.e.) on 1909 January 15.5 UT.
(d) System I refers to the atmospheric equatorial rotation.
System III refers to rotation derived from radio emissions.
System II refers to atmospheric rotation north of the south component of the north equatorial belt, and south of the north component of the south equatorial belt.

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

Table 2. Recommended Values for the Direction of the North Pole of Rotation and the Prime Meridian of the Satellites (1979)

α_o, δ_o, T and d have the same meanings as in Table 1.

Earth: Moon

$$\alpha_o = 270^\circ - 3^\circ\!.878 \sin E1 - 0^\circ\!.120 \sin E2 + 0.070 \sin E3 - 0.017 \sin E4$$

$$\delta_o = 66.534 + 1.543 \cos E1 + 0.024 \cos E2 - 0.028 \cos E3 + 0.007 \cos E4$$

$$W = 244.375 + 13.17635831\,d + 3.558 \sin E1 - 0^\circ\!.120 \sin E2 + 0.121 \sin E2 - 0.064 \sin E3 + 0.016 \sin E4 + 0.025 \sin E5$$

where

$$E1 = 12^\circ\!.112 - 0^\circ\!.052992\,d, \quad E2 = 24^\circ\!.224 - 0^\circ\!.105984\,d$$

$$E3 = 227.645 + 13.012000\,d, \quad E4 = 261.105 + 13.340716\,d$$

$$E5 = 358.00 + 0.985600\,d$$

Mars: Phobos

$$\alpha_o = 317^\circ\!.329 + 1^\circ\!.674 \sin M1$$

$$\delta_o = 52.717 + 1.014 \cos M1$$

$$W = 270.202 + 1128.844483\,d - 3^\circ\!.310 \sin M2 - 1^\circ\!.332 \sin M1$$

Deimos

$$\alpha_o = 316.307 + 3.051 \sin M3$$

$$\delta_o = 53.367 - 1.821 \cos M3$$

$$W = 70.832 + 285.161807\,d - 2.448 \sin M3$$

where

$$M1 = 201^\circ\!.605 - 0^\circ\!.435427\,T, \quad M2 = 93^\circ\!.440 + 1128^\circ\!.409143\,T$$

$$M3 = 23.054 - 0.018143\,T$$

Jupiter: Amalthea

$$\alpha_o = 268^\circ\!.0$$

$$\delta_o = 64.5$$

$$W = 50.2 + 722^\circ\!.6303746\,d$$

Io

$$\alpha_o = 268.002 - 0.0085\,T + 0^\circ\!.094 \sin J1 + 0^\circ\!.024 \sin J2$$

$$\delta_o = 64.504 + 0.0033\,T + 0.040 \cos J1 + 0.011 \cos J2$$

$$W = 262.7 + 203.4889538\,d - 0.085 \sin J1 - 0.022 \sin J2$$

Europa

$$\alpha_o = 268.029 - 0.0085\,T + 1.086 \sin J2 + 0.060 \sin J3 + 0.015 \sin J4 + 0.009 \sin J5$$

$$\delta_o = 64.516 + 0.0033\,T + 0.468 \cos J2 + 0.026 \cos J3 + 0.007 \cos J4 + 0.002 \cos J5$$

$$W = 156.9 + 101.3747235\,d - 0.980 \sin J2 - 0.054 \sin J3 - 0.014 \sin J4 - 0.008 \sin J5$$

Ganymede

$$\alpha_o = 268.149 - 0.0085\,T - 0.037 \sin J2 + 0.431 \sin J3 + 0.091 \sin J4$$

$$\delta_o = 64.574 + 0.0033\,T - 0.016 \cos J2 + 0.186 \cos J3 + 0.039 \cos J4$$

$$W = 195.8 + 50.3176081\,d + 0.033 \sin J2 - 0.389 \sin J3 - 0.082 \sin J4$$

Callisto

$$\alpha_o = 268.678 - 0.0085\,T - 0.068 \sin J3 + 0.590 \sin J4 + 0.010 \sin J6$$

$$\delta_o = 64.830 + 0.0033\,T - 0.029 \cos J3 + 0.254 \cos J4 - 0.004 \cos J6$$

$$W = 158.0 + 21.5710715\,d + 0.061 \sin J3 - 0.533 \sin J4 - 0.009 \sin J6$$

where

$$J1 = 19^\circ\!.2 + 4850^\circ\!.7\,T, \quad J2 = 120^\circ\!.8 + 1191^\circ\!.3\,T, \quad J3 = 349^\circ\!.5 + 262^\circ\!.1\,T$$

$$J4 = 198.3 + 64.3\,T, \quad J5 = 241.6 + 2382.6\,T, \quad J6 = 317.7 + 6070.0\,T$$

Table 2. (continued)

Saturn:	Mimas	α_0	$= 38^\circ.5 + 13^\circ.1 \sin S1$
		δ_0	$= 83.3 - 1.5 \cos S1$
		W	$= 207.6 + 381.9952887\,d - 13^\circ.0 \sin S1$
	Enceladus	α_0	$= 38.5$
		δ_0	$= 83.3$
		W	$= 301.8 + 262.7315302\,d$
	Tethys	α_0	$= 38.5 + 9.4 \sin S2$
		δ_0	$= 83.3 - 1.1 \cos S2$
		W	$= 33.7 + 190.6981682\,d - 9.3 \sin S2$
	Dione	α_0	$= 38.5$
		δ_0	$= 83.3$
		W	$= 121.6 + 131.5347179\,d$
	Rhea	α_0	$= 38.2 + 3.0 \sin S3$
		δ_0	$= 83.3 - 0.4 \cos S3$
		W	$= 14.1 + 79.6900944\,d - 3.0 \sin S3$
	Titan	α_0	$= 34.3 + 2.6 \sin S4$
		δ_0	$= 83.7 - 0.3 \cos S4$
		W	$= 79.1 + 22.5769734\,d - 2.6 \sin S4$
	Hyperion	α_0	$= 33.4 + 4.9 \sin S5 + 2.7 \sin S4$
		δ_0	$= 83.8 - 0.6 \cos S5 - 0.3 \cos S4$
		W	$= 336.0 + 16.9199489\,d - 4.9 \sin S5 - 2^\circ.7 \sin S4$
	Iapetus	α_0	$= 320^\circ.2 - 3^\circ.9\,T$, $\delta_0 = 75.4 - 1.1\,T$) rocky or $\alpha_0 = 289^\circ.3$, $\delta_0 = 78.7$) icy
		δ_0	$= 75.4 - 1.1\,T$ (rocky) or $= 78.7$ (icy)
		W	$= 275.5 + 4.5379589\,d$

where $S1 = 68^\circ.6 - 36504^\circ.9\,T$, $S2 = 314^\circ.5 - 7226^\circ.0\,T$, $S3 = 134^\circ.9 - 1017^\circ.7\,T$

$S4 = 57.4 - 53.5\,T$, $S5 = 22.6 - 239.2\,T$

Uranus:	Miranda	α_0	$= 256^\circ.7$
		δ_0	$= -15.0$
		W	$= 59.2 - 254^\circ.5968883\,d$
	Ariel	α_0	$= 256.7$
		δ_0	$= -15.0$
		W	$= 47.3 - 142.8356047\,d$
	Umbriel	α_0	$= 256.7$
		δ_0	$= -15.0$
		W	$= 146.4 - 86.8688136\,d$
	Titania	α_0	$= 256.7$
		δ_0	$= -15.0$
		W	$= 202.0 - 41.3513623\,d$
	Oberon	α_0	$= 256.7$
		δ_0	$= -15.0$
		W	$= 3.2 - 26.7394375\,d$
Neptune:	Triton	α_0	$= 294.89 - 20.087 \sin N$
		δ_0	$= 36.93 + 15.264 \cos N$
		W	$= 132.3 - 61.2575147\,d + 10^\circ.521 \sin N$

where $N = 158^\circ.3402 + 61^\circ.9803\,T$

Pluto:	Charon	α_0	$= 305^\circ$
		δ_0	$= 5$
		W	$= -$

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

3. Definition of Cartographic Coordinate Systems

Both planetocentric and planetographic systems of coordinates are used in the study of the planets and satellites. These systems are based on the same fundamental reference axis but differ, as explained below, in the definitions of latitude and longitude. Planetocentric coordinates are used for general purposes and are based on a right-handed system of axes, whereas planetographic coordinates are used for cartographic purposes and depend on the adoption of additional parameter to define a reference surface, usually a spheroid, that approximates an equipotential surface of the planet.

For these systems, the fundamental reference z-axis is the mean axis of rotation and the planetary equator is the plane that is normal to this axis and passes through the center of mass of the planet. The x-axis is defined by the intersection of the equatorial plane with the plane of the prime meridian, whose position is defined in an arbitrary manner. The y-axis of planetocentric rectangular coordinates is defined so as to form a right-handed system.

Latitude is measured north and south of the equator; north latitudes are designated as positive. The planeto*centric* latitude (ϕ) of a point is the angle between the equatorial plane and the line connecting the point to the center of mass. The planeto*graphic* latitude (ϕ') of a point on the reference surface is the angle between the equatorial plane and the normal to the reference surface at the point.

Longitude is measured around the equatorial plane from the prime meridian from 0° to 360°. Planeto*centric* longitudes (λ) are measured positively to the east, whereas planeto*graphic* longitudes (λ') are measured in the direction opposite to the rotation, i.e., positively to the west in the case of direct rotation. Planetocentric longitudes are measured from the ephemeris position of the prime meridian as defined by the adopted longitude of some clearly observable surface feature. These two positions may normally be assumed to coincide but it is conceivable that errors in the rotational elements may be such that the cartographic position may drift away from the ephemeris position by a small amount ΔW, where ΔW is measured positively to the east of the ephemeris position.

Planetocentric *radius* (R) is measured from the center of mass to the point concerned. In the planetographic system the position of a point (P) not on the reference surface is specified by the planetographic longitude and latitude of the point (P') on the surface at which the normal passes through P and by the *height* (h) of P above P'.

The reference surfaces for most of the planets are spheroids for which the radius of the equator (A) is larger than the polar semiaxis (C). For some planets and most satellites the reference surface is a sphere ($A = C$), and the planetocentric and planetographic latitudes are then numerically the same. The polar axis of each reference surface is assumed to be the mean axis of rotation as defined by the adopted rotational elements since the accuracy of measurements is, at present, such that a motion of the axis of rotation with respect to the axis of figure cannot be observed.

The recommended values of the parameters for the reference surfaces for planets and satellites are given in Table 3. Radii for irregular-shaped satellites are given in Table 4.

It should be noted that east longitude on the Sun, Earth, and Moon is commonly considered to be in the positive direction.

Table 3. Recommended Reference Spheroids for Mapping the Planets and Major Satellites (1979)

Planet	Satellite	Equatorial Radius (km)	Flattening
Mercury		2439	0
Venus		6052	0
Earth		6378.140	0.00335281
	Moon	1738	0
Mars		3393.4	0.0051865
Jupiter		71398	0.0648088
	Io	1819	0
	Europa	1563	0
	Ganymede	2637	0
	Callisto	2424	0
Saturn		60000	0.1076209
	Mimas	200	0
	Enceladus	275	0
	Tethys	520	0
	Dione	500	0
	Rhea	800	0
	Titan	2900	0
	Hyperion	112	0
	Iapetus	725	0
Uranus		25400	0.0165
	Ariel	400	0
	Umbriel	275	0
	Titania	500	0
	Oberon	450	0
	Miranda	150	0
Neptune		24300	0.0259
	Triton	1600	0
Pluto		1500	0
	Charon	600	0

Note: The equatorial radii for Mercury, Venus, Moon, and Mars are used in current mapping programs, and those for Jupiter and Saturn are used in sequencing and analyzing data from current flight missions. The values for Mars and Pluto differ from those recommended by the IAU in 1976 (Trans. IAU XVIB, p. 60). The reference spheroid for Mars (3393.4 km radius) has been used in all mapping programs since 1973, although the IAU 1976 radius (3397.2 km) is probably a better value. In 1976 Pluto's satellite, Charon, had not been discovered.

Table 4. Recommended Reference Shapse for Mapping Irregular Satellites (1979)

Planet	Satellite	Equatorial Radius, A (km)	Equatorial Radius, B (km)	Polar Radius, C (km)
Mars	Phobos	13.5	10.7	9.6
	Deimos	7.5	6.0	5.5
Jupiter	Amalthea	140	105	80

Annex 2.

SUMMARY REPORT

of

THE IAU WORKING GROUP ON NUTATION

(1979 IAU THEORY OF NUTATION)

1. The president of IAU Commission 4, V.K. Abalakin, established the Working Group on Nutation in response to the request made at IAU Symposium No. 78 on *Nutation and the Earth's Rotation* held in Kiev in May 1977. The final membership of the Working Group comprise the authors of this report.

2. The theory of nutation, currently adopted by the IAU, is that of Woolard and has the following characteristics:

(a) It is based on a rigid model of the Earth with dynamical symmetry ($A = B$).
(b) The "constant of nutation" is an empirical value and is not consistent with other adopted astronomical constants.
(c) Eulerian motion and forced nearly diurnal polar motion are not included in the current theory of nutation, but are assumed to be part of polar motion.
(d) The pole of reference is the instantaneous celestial rotation pole.

3. The current theoretical developments and the observational data of various types indicate the following problems with the currently adopted theory of nutation:

(a) The determinations of UT1 and polar motion using optical observations of stars, Doppler or laser range tracking of satellites, laser ranges to the Moon, and radio interferometric measurements are sufficiently accurate that their usefulness can be degraded by use of the present theory of nutation in the data reduction process.
(b) The Earth is not a rigid body and the effects of the non-rigid body can be observationally significant.
(c) As pointed out by Jeffreys and Atkinson, the currently adopted axis of rotation rotates relative to an Earth-fixed coordinate system with a quasi-diurnal period. For accurate observation reduction, this rotation cannot be ignored and a resolution was passed at the Sixteenth General Assembly of the IAU in 1976 in Grenoble to adopt a different pole of reference.
(d) Observational data indicate that, with the current theory of nutation and a redefined pole of reference, a body-fixed coordinate system would still rotate with respect to the reference pole; therefore, the theory of nutation should be revised.

4. The goal of this report is the adoption of a set of nutation coefficients so as to provide a working standard for determination of UT1 and polar motion, the reduction of optical observations of stars, Doppler or laser range tracking of satellites, laser ranges to the Moon, radio interferometric measurements and other high precision requirements. This report should not be considered as the selection or endorsement of a particular Earth model.

5. Therefore, the proposed solution incorporates the following changes:

(a) A non-rigid model of the Earth with axial symmetry ($A = B$) is used.
(b) The constants are consistent with the IAU (1976) System of Astronomical Constants and are in agreement with available observational data of various types.
(c) The reference pole is selected so that there are no diurnal or quasi-diurnal motions of this pole with respect to either a space-fixed or Earth-fixed coordinate system. The phenomenon of diurnal variation of latitude, otherwise

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

known as forced diurnal polar motion, is included implicitly in the new nutation theory. The new nutation theory thus includes all externally-forced motions of the Earth's rotation axis; no geophysical or free motions are included.

6. *Resolution*:

We request that the following draft resolution be submitted to Commissions 4, 8, 19 and 31, with the view of its being adopted at the Seventeenth General Assembly of the IAU. "The IAU endorses the recommendations given in the Report of the Working Group on Nutation and recommends that they shall be used in the national and international ephemerides for the years 1984 onwards, and in all other relevant astronomical work."

7. *Recommendation*:

Whereas, the complete theory of the general nutational motion of the Earth about its center of mass may be described by the sum of two components, astronomical nutation, commonly referred to as nutation, which is motion with respect to a space-fixed coordinate system, and polar motion, which is motion with respect to a body-fixed coordinate system, it is recommended that:

(a) Astronomical nutation be computed for the "Celestial Ephemeris Pole" using a non-rigid model of the Earth such that there are no nearly diurnal motions of this celestial pole with respect to either space-fixed or body-fixed coordinates which can be calculated from torques external to the Earth and its atmosphere.

(b) The numerical values given in Table 1 of the complete report be used for computing astronomical nutation of the Celestial Ephemeris Pole.

P.K. Seidelmann, Chairman
V.K. Abalakin, H. Kinoshita, J. Kovalevsky, C.A. Murray,
M.L. Smith, R.O. Vicente, J.G. Williams, Ya.S. Yatskiv.

(The complete Report will be published in *Celestial Mechanics*.)

Table 1. Nutation in Longitude and Obliquity referred to Ecliptic of Date

Epoch: J2000.0 (JED 2451545.0), T in Julian centuries, Unit: 0."0001

No.	Period (days)	Argument multiple of l	l'	F	D	Ω	Longitude coefficient of sine argument		Obliquity coefficient of cosine argument	
1	6798.4	0	0	0	0	+1	-172058	-174.2T	+92044	+8.9T
2	3399.2	0	0	0	0	+2	+2063	+0.2T	-895	+0.5T
3	1305.5	-2	0	+2	0	+1	+46	0.0T	-24	0.0T
4	1095.2	+2	0	-2	0	0	+11	0.0T	0	0.0T
5	1615.7	-2	0	+2	0	+2	-3	0.0T	+1	0.0T
6	3232.9	+1	-1	0	-1	0	-3	0.0T	0	0.0T
7	6786.3	0	-2	+2	-2	+1	-2	0.0T	+1	0.0T
8	943.2	+2	0	-2	0	+1	+1	0.0T	0	0.0T

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

Table 1. (continuation)

No.	Period (days)	l	l'	F	D	Ω	Longitude coefficient of sine argument		Obliquity coefficient of cosine argument	
9	182.6	0	0	+2	-2	+2	-13152	-1.5*T*	+5719	-3.1*T*
10	365.3	0	+1	0	0	0	+1411	-3.4*T*	+49	-0.1*T*
11	121.7	0	+1	+2	-2	+2	-515	+1.2*T*	+224	-0.6*T*
12	365.2	0	-1	+2	-2	+2	+217	-0.5*T*	-95	+0.3*T*
13	177.8	0	0	+2	-2	+1	+129	+0.1*T*	-70	0.0*T*
14	205.9	+2	0	0	-2	0	+48	0.0*T*	0	0.0*T*
15	173.3	0	0	+2	-2	0	-22	0.0*T*	0	0.0*T*
16	182.6	0	+2	0	0	0	+17	-0.1*T*	0	0.0*T*
17	386.0	0	+1	0	0	+1	-15	0.0*T*	+8	0.0*T*
18	91.3	0	+2	+2	-2	+2	-15	+0.1*T*	+7	0.0*T*
19	346.6	0	-1	0	0	+1	-12	0.0*T*	+6	0.0*T*
20	199.8	-2	0	0	+2	+1	-5	0.0*T*	+3	0.0*T*
21	346.6	0	-1	+2	-2	+1	-5	0.0*T*	+3	0.0*T*
22	212.3	+2	0	0	-2	+1	+4	0.0*T*	-2	0.0*T*
23	119.6	0	+1	+2	-2	+1	+4	0.0*T*	-2	0.0*T*
24	411.8	+1	0	0	-1	0	-4	0.0*T*	0	0.0*T*
25	131.7	+2	+1	0	-2	0	+1	0.0*T*	0	0.0*T*
26	169.0	0	0	-2	+2	+1	+1	0.0*T*	0	0.0*T*
27	329.8	0	+1	-2	+2	0	-1	0.0*T*	0	0.0*T*
28	409.2	0	+1	0	0	+2	+1	0.0*T*	0	0.0*T*
29	388.3	-1	0	0	+1	+1	+1	0.0*T*	0	0.0*T*
30	117.5	0	+1	+2	-2	0	-1	0.0*T*	0	0.0*T*
31	13.7	0	0	+2	0	+2	-2260	-0.2*T*	+972	-0.5*T*
32	27.5	+1	0	0	0	0	+709	+0.1*T*	-7	0.0*T*
33	13.6	0	0	+2	0	+1	-384	-0.4*T*	+199	0.0*T*
34	9.1	+1	0	+2	0	+2	-299	0.0*T*	+128	-0.1*T*
35	31.8	+1	0	0	-2	0	-157	0.0*T*	-1	0.0*T*
36	27.1	-1	0	+2	0	+2	+123	0.0*T*	-53	0.0*T*
37	14.8	0	0	0	+2	0	+63	0.0*T*	-2	0.0*T*
38	27.7	+1	0	0	0	+1	+63	+0.1*T*	-33	0.0*T*
39	27.4	-1	0	0	0	+1	-58	-0.1*T*	+32	0.0*T*
40	9.6	-1	0	+2	+2	+2	-59	0.0*T*	+25	0.0*T*
41	9.1	+1	0	+2	0	+1	-51	0.0*T*	+26	0.0*T*
42	7.1	0	0	+2	+2	+2	-38	0.0*T*	+16	0.0*T*
43	13.8	+2	0	0	0	0	+29	0.0*T*	-1	0.0*T*
44	23.9	+1	0	+2	-2	+2	+29	0.0*T*	-12	0.0*T*
45	6.9	+2	0	+2	0	+2	-31	0.0*T*	+13	0.0*T*
46	13.6	0	0	+2	0	0	+26	0.0*T*	-1	0.0*T*
47	27.0	-1	0	+2	0	+1	+21	0.0*T*	-10	0.0*T*
48	32.0	-1	0	0	+2	+1	+15	0.0*T*	-8	0.0*T*
49	31.7	+1	0	0	-2	+1	-13	0.0*T*	+7	0.0*T*
50	9.5	-1	0	+2	+2	+1	-10	0.0*T*	+5	0.0*T*
51	34.8	+1	+1	0	-2	0	-7	0.0*T*	0	0.0*T*
52	13.2	0	+1	+2	0	+2	+7	0.0*T*	-3	0.0*T*
53	14.2	0	-1	+2	0	+2	-7	0.0*T*	+3	0.0*T*
54	5.6	+1	0	+2	+2	+2	-8	0.0*T*	+3	0.0*T*
55	9.6	+1	0	0	+2	0	+6	0.0*T*	0	0.0*T*
56	12.8	+2	0	+2	-2	+2	+6	0.0*T*	-3	0.0*T*
57	14.8	0	0	0	+2	+1	-6	0.0*T*	+3	0.0*T*
58	7.1	0	0	+2	+2	+1	-7	0.0*T*	+3	0.0*T*

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press

Table 1. (continuation)

No.	Period (days)	Argument multiple of *l*	*l'*	*F*	*D*	Ω	Longitude coefficient of sine argument		Obliquity coefficient of cosine argument	
59	23.9	+1	0	+2	−2	+1	+6	0.0*T*	−3	0.0*T*
60	14.7	0	0	0	−2	+1	−5	0.0*T*	+3	0.0*T*
61	29.8	+1	−1	0	0	0	+5	0.0*T*	0	0.0*T*
62	6.8	+2	0	+2	0	+1	−5	0.0*T*	+3	0.0*T*
63	15.4	0	+1	0	−2	0	−4	0.0*T*	0	0.0*T*
64	26.9	+1	0	−2	0	0	+4	0.0*T*	0	0.0*T*
65	29.5	0	0	0	+1	0	−4	0.0*T*	0	0.0*T*
66	25.6	+1	+1	0	0	0	−3	0.0*T*	0	0.0*T*
67	9.1	+1	0	+2	0	0	+3	0.0*T*	0	0.0*T*
68	9.4	+1	−1	+2	0	+2	−3	0.0*T*	+1	0.0*T*
69	9.8	−1	−1	+2	+2	+2	−3	0.0*T*	+1	0.0*T*
70	13.8	−2	0	0	0	+1	−2	0.0*T*	+1	0.0*T*
71	5.5	+3	0	+2	0	+2	−3	0.0*T*	+1	0.0*T*
72	7.2	0	−1	+2	+2	+2	−3	0.0*T*	+1	0.0*T*
73	8.9	+1	+1	+2	0	+2	+2	0.0*T*	−1	0.0*T*
74	32.6	−1	0	+2	−2	+1	−2	0.0*T*	+1	0.0*T*
75	13.8	+2	0	0	0	+1	+2	0.0*T*	−1	0.0*T*
76	27.8	+1	0	0	0	+2	−2	0.0*T*	+1	0.0*T*
77	9.2	+3	0	0	0	0	+2	0.0*T*	0	0.0*T*
78	9.3	0	0	+2	+1	+2	+2	0.0*T*	−1	0.0*T*
79	27.3	−1	0	0	0	+2	+1	0.0*T*	−1	0.0*T*
80	10.1	+1	0	0	−4	0	−1	0.0*T*	0	0.0*T*
81	14.6	−2	0	+2	+2	+2	+1	0.0*T*	−1	0.0*T*
82	5.8	−1	0	+2	+4	+2	−2	0.0*T*	+1	0.0*T*
83	15.9	+2	0	0	−4	0	−1	0.0*T*	0	0.0*T*
84	22.5	+1	+1	+2	−2	+2	+1	0.0*T*	−1	0.0*T*
85	5.6	+1	0	+2	+2	+1	−1	0.0*T*	+1	0.0*T*
86	7.3	−2	0	+2	+4	+2	−1	0.0*T*	+1	0.0*T*
87	9.1	−1	0	+4	0	+2	+1	0.0*T*	0	0.0*T*
88	29.3	+1	−1	0	−2	0	+1	0.0*T*	0	0.0*T*
89	12.8	+2	0	+2	−2	+1	+1	0.0*T*	−1	0.0*T*
90	4.7	+2	0	+2	+2	+2	−1	0.0*T*	0	0.0*T*
91	9.6	+1	0	0	+2	+1	−1	0.0*T*	0	0.0*T*
92	12.7	0	0	+4	−2	+2	+1	0.0*T*	0	0.0*T*
93	8.8	+3	0	+2	−2	+2	+1	0.0*T*	0	0.0*T*
94	23.8	+1	0	+2	−2	0	−1	0.0*T*	0	0.0*T*
95	13.1	0	+1	+2	0	+1	+1	0.0*T*	0	0.0*T*
96	35.0	−1	−1	0	+2	+1	+1	0.0*T*	0	0.0*T*
97	13.6	0	0	−2	0	+1	−1	0.0*T*	0	0.0*T*
98	25.4	0	0	+2	−1	+2	−1	0.0*T*	0	0.0*T*
99	14.2	0	+1	0	+2	0	−1	0.0*T*	0	0.0*T*
100	9.5	+1	0	−2	−2	0	−1	0.0*T*	0	0.0*T*
101	14.2	0	−1	+2	0	+1	−1	0.0*T*	0	0.0*T*
102	34.7	+1	+1	0	−2	+1	−1	0.0*T*	0	0.0*T*
103	32.8	+1	0	−2	+2	0	−1	0.0*T*	0	0.0*T*
104	7.1	+2	0	0	+2	0	+1	0.0*T*	0	0.0*T*
105	4.8	0	0	+2	+4	+2	−1	0.0*T*	0	0.0*T*
106	27.3	0	+1	0	+1	0	+1	0.0*T*	0	0.0*T*

$\sin \varepsilon_{2000} = 0.397\,777\,16$

https://doi.org/10.1017/S0251107X00003527 Published online by Cambridge University Press