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Mean Solar Time on the Meridian of Greenwich

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SUMMARY

The object of this expository article is to review certain aspects of the definitions of, and terminology for, mean solar time on the meridian of Greenwich, and to explain the effects on astronomy of adopting the recommendations recently endorsed by the General Assembly of the International Astronomical Union.

I INTRODUCTION

The author has been interested, for over 40 years, in the background of the change from noon to midnight in the beginning of the astronomical day, which was implemented on 1925 January 1. The recently-adopted Resolution (Grenoble 1976) of Commissions 4 and 31 of the International Astronomical Union, which relates to the nomenclature for 'mean solar time on the meridian of Greenwich', provides the opportunity of giving an account of that change and of considering the connection and possible similarities between these decisions. The account is necessarily written from a personal point of view – one associated, in particular, with Greenwich. But, although obvious longitudinal differences exist, the basic principles are independent of longitude and the pre-1884 (**1**) nationalistic rivalries are presumably long forgotten. The emphasis is firmly on the astronomical aspects, but some reference to civil usage is essential. Documentary records have been used as far as possible; many of the hearsay accounts of the 1925 change and of the individual arguments, both on the main issue and on nomenclature, that were then put forward, have regretfully been omitted.

Only the main principles are here considered; practical details (such as equinox corrections and star positions) are generally ignored; and many historical developments have been summarized.

In the present context, in which philosophical considerations are not relevant, 'time' is considered to have its ordinary meaning of a smooth-flowing, monotonically-increasing, coordinate. In 1906 (**2**) Simon Newcomb wrote 'The main purpose of a measure of time is to define with precision the moment of a phenomenon.' Astronomically that is still true; a 'measure of time' is a numerical expression, in some appropriate units, that specifies the instant to which it refers. A 'time-scale' is a correspondence set up between the instants of specific, identifiable, events and the measures of time that specify them. The time-scales used in practical (**3**) astronomy (such as, for example, apparent solar time) specify the measures of time (e.g. 0^h or 12^h) corresponding to the instants at which natural events (e.g. the meridian

transits of the Sun) are observed; they may thus be described as 'observational time-scales' (4). On the other hand the time-scales defined by clocks (whether depending on atomic transitions or the oscillations of a pendulum) specify the instants at which the clocks indicate the measures of time, or, more strictly, of time-interval; they have been described as 'integrated time-scales' (4), though it would be less confusing if they were called, simply, 'clock-times'. The two forms of time-scale are fundamentally different; both are essential for modern astronomy and it would seem important to ensure that no unnecessary confusion between them is introduced (5).

2 MEAN SOLAR TIME AS A TIME-SCALE

After many refinements mean solar time is derived from the natural time-scale of apparent solar time which was used, from ancient times until relatively recently, for both astronomical and civil purposes. Apparent time (the word solar is often omitted) was, until 1925, simply the hour angle of the Sun, measured in conventional units of hours, minutes and seconds, westwards from the meridian. With the addition of the date, which can be determined independently by observations of the positions of the Moon and planets, apparent time satisfies Newcomb's main requirement for a time-scale (6). Maskelyne chose to use apparent time as the time-argument of *The Nautical Almanac and Astronomical Ephemeris* (the NA) in 1767; even as late as 1830, when the Society was formally invited by the Admiralty to recommend revisions, there was some opposition (7) to the proposal that apparent time should be replaced by mean time. However, the Committee appointed by the Society took the view '. . . that the latter [mean solar time] is the most convenient, not only for every purpose of Astronomy, but also (from the best information they have been able to obtain) for all the purposes of Navigation; . . . the Committee recommend the abolition of the use of *apparent* time in all the computations of the Nautical Almanac; excepting only . . . '. The main reason for that view, and for the recommendation, was the increasing availability of man-made time-keepers that could not be adjusted to maintain non-uniform apparent time. Mean (solar) time was used in the NA from 1834.

At that date mean solar time was still defined, descriptively, as the hour angle of the mean sun, 'a fictitious body moving uniformly along the equator at such a rate that, in the long run, it is as much ahead of the true Sun as behind it.' From that definition expressions were derived for the 'equation of time', the interval of mean time to be applied to the hour angle of the Sun to give the unobservable hour angle of the mean sun, i.e. mean time (8). Mean solar time, as so defined, was amply adequate to serve as a time-scale for all purposes. There was no practical long-term alternative to the diurnal rotation of the Earth as the defining unit, it met all the local civil requirements, it was far more accurate than the best available clocks, and it was more generally convenient than sidereal time.

Although the time-argument of the NA was (and is) that appropriate to the meridian of the Royal Observatory at Greenwich, astronomical observations were (and are) made relative to the local frame of reference; the difference between the local apparent or mean time and the time-argument of the

NA was simply the difference in longitude. The increasing use of Greenwich Mean Time (GMT) for civil purposes within the United Kingdom led, in 1880, to the Definition of Time Act making it the legal time throughout the country. The International Meridian Conference of 1884 in Washington established the Greenwich meridian as the initial meridian for longitude and a 'universal day for all purposes for which it may be found convenient . . .', the 'universal day is to be a mean solar day; is to begin for all the world at the moment of mean midnight of the initial meridian . . .'. These decisions referred primarily to civil usage, but encouraged the already widespread usage of GMT as the time-argument for astronomical and nautical ephemerides. However, the astronomical day was considered to begin at mean noon, the instant at which the hour angle of the mean sun was zero; thus the universal day, as proposed, began 12^h earlier than the Greenwich astronomical day. The Washington conference expressed 'the hope that, as soon as practicable, the astronomical and nautical days will be arranged everywhere to begin at mean midnight' (**9**), and various proposals were later made to this effect (**10**).

It was, however, to be 40 years before such a change was made and, in the interval, a small but significant change took place in the definition of mean time. In 1895 Newcomb published his tables of the motion of the Sun, in which he gave an expression, with numerical coefficients, for the 'right ascension of the fictitious mean sun'; from the NA for 1901 onwards mean time has been defined rigorously in terms of this expression, and the equation of time deduced from it. Thereafter mean time has been obtained, both in practice and in principle, from observations of the transits of stars. With the recognition, in 1950, of the variability of the speed of rotation of the Earth and the need for the dynamical time-scale of Ephemeris Time, mean solar time can no longer be regarded as a measure of the motion of a 'mean sun'. But it is still a precise measure of the rotation of the Earth, and its significance and usefulness as a time-scale are in no way diminished.

3 THE CHANGE IN THE BEGINNING OF THE DAY – A. THE SOCIETY'S PART

In May 1917 the Hydrographer of the Navy (Rear-Admiral J.F.Parry) wrote to the Astronomer Royal (F.W.Dyson) proposing the setting up of a conference to consider 'the system of time-keeping at sea which is now adopted in the French Navy'. At the invitation of the Admiralty, the Conference on Time-keeping at Sea was duly held on 1917 June 21, with further meetings on June 22, 26 and July 3; the Chairman was the Hydrographer and, in addition to the Astronomer Royal, there were present senior representatives of the Board of Trade, the General Post Office, the War Office, the Eastern Telegraph Company, the Ordnance Survey (C.F.Close), the Royal Society (A.Schuster), the Royal Astronomical Society (H.H.Turner), the Royal Geographical Society (A.R.Hinks) and of the French Navy (including a 'wireless' expert). The Superintendent of the Nautical Almanac (P.H.Cowell) was not invited.

The main subject for discussion was 'ship-time', as distinct from the chronometer-time used for navigation. It was reported that confusion was arising through the custom, in the Royal Navy, of setting ships' clocks to 12^h at apparent noon each day, particularly in the timing of 'wireless' messages (**11**). On the recommendation of the Bureau des Longitudes the French Navy had extended to the sea the system of Time Zones (in which times differed by an integral number of hours from that appropriate to the prime meridian) already in use on land. There was little difficulty in arriving at the two recommendations that:

(a) the system of time-zones should be extended to general use at sea;

(b) the most convenient time to adopt for the recording 'of all messages, whether wireless, cable, or land line, throughout the world would be Greenwich Time . . . '.

Although not mentioned in the record of the meeting it seems to have been generally understood that the French intended to change the beginning of the astronomical (and thus the navigational) day from noon to midnight as from 1920. After general (**12**), not technical, discussion it was agreed:

'That from the point of view of the seaman it would be of considerable advantage if a day commencing at 0 hours midnight were subsituted for the astronomical day commencing at 0 hours noon in all nautical publications, and that the Royal Astronomical Society should be asked to ascertain the views of astronomers as to such an alteration, including possibly the general substitution of the civil for the nautical day.'

An official request, 'I am commanded by the Lords Commissioners of the Admiralty . . . to acquaint you that they will be glad if the Royal Astronomical Society would ascertain the views of astronomers generally on the proposal . . . would be glad to be advised whether it would be practicable to introduce this change into the nautical almanacs without excessive confusion: and as to what other documents will require to be similarly altered.' was addressed to the Secretaries of the Society on 1917 December 15, following a preliminary enquiry on October 9. H.H.Turner had previously reported the recommendations of the Conference to the Council, and the question had been raised, in an informal manner, by a letter to *The Observatory* magazine from Dyson and Turner dated July 19. The general trend of the views expressed and received, in response to that letter, favoured a change subject to three desiderata:

(a) the change, if made, should be made simultaneously in the different Almanacs;

(b) the year 1925 is the earliest date at which such a change could conveniently be introduced;

(c) there should be no alteration in the system of reckoning by Julian days which would begin, as heretofore, at Greenwich noon.

There were some dissenting views based on two grounds: that the danger of confusion was substantial; and that the 'considerable advantage to seamen' had not been established. The second point was not clarified by a 'Memorandum on Time-Keeping at Sea' by the Marine Department of the Board of Trade (**13**). To quote: 'There seems to be no reason whatever for the continued

use of an Astronomical Day when its use only serves to produce a complication in publications which should be as simple as possible; . . . The calculation of the Ephemeris for the Civil date would abolish the necessity of adjusting the Civil date to the Astronomical and if, in addition, zone time is adopted the corrected elements for all problems in Nautical Astronomy given in Civil time could be taken out of the Abridged Nautical Almanac [ANA] by inspection, without any calculation on the part of the navigator.' It is not surprising that the strongest objections were expressed by those most experienced in position determination (who could assess such statements at their true value).

A Committee, appointed by the Council, met on 1918 February 13 primarily to consider the changes that would be required in the NA (**14**); it consisted of P.H.Cowell, F.W.Dyson and A.S.Eddington with A.C.D. Crommelin (Secretary of the Society). As might be expected it reported that 'the necessary alterations in the Astronomical Ephemerides are not very numerous and could readily be made if the change is considered desirable.' On the basis of that report the Secretaries prepared a printed letter requesting the expression of 'the opinions of Astronomical Societies, Superintendents of Almanacs, Directors of Observatories, and other representative Astronomers in the allied and neutral countries as to the desirability of the proposed change.' The letter contains the statements: 'it appears that the change would be of considerable advantage to seamen' and 'this change will be introduced into the *Extrait à l'usage des Marins* of the *Connaissance des Temps* for 1920'. It contained a detailed list of the changes that would be required in the NA. Dated 1918 March 18 this letter was given as wide a circulation as the war-time circumstances permitted.

On 1918 May 1 Crommelin wrote to the Admiralty asking for further information, explaining that many astronomers had expressed doubts as to the wisdom of the change and whether it would help seamen. 'Further evidence was required to assist reconciling the views of those astronomers who at present dislike the change.' The reply, dated 1918 June 8, was not very helpful. To quote: 'The advantage . . . by the statement that seamen are interested in every measure that shall promote uniformity in the manner in which time is kept at sea, and shall assist in removing the anomalies of existing usages'. There follows a number of non-astronomical points (communications in terms of the civil day, the Tide Tables are to be changed . . .) and the following comment attributed to the Director of Navigation: 'It is contrary to common sense to have two time systems differing by 12^h. As an example an officer takes a sight at 0600 on April 1 and yet has to look out his elements in the Nautical Almanac under the date of March 31; this may very easily lead to error and probably does' (**15**). The final reason given for the change was that the French had already announced its adoption, and the British seamen would certainly purchase the French almanac in preference to the British, with a serious loss of revenue! In summary '. . . already agreed by the French; and from a seaman's standpoint the advantages of such a change cannot be combatted by any arguments in favour of the present arrangement'.

The replies to the circular letter varied enormously in form and authority, as well as in opinion: a few lines on a postcard from, for example, Kasan (Dubiago) and Cordoba (Perrine) observatories to a long, detailed and technical discussion from San Fernando (Observatorio de Marina). There was a representative statement from the American Astronomical Society. Crommelin analysed 17 replies and reported that nine (including the American Astronomical Society and the US Naval Observatory) were definitely in favour of the change whereas three (San Fernando, the Ordnance Survey and the Royal Geographical Society) were definitely against. The remainder tended to be in favour. It was assumed that the French, from whom no reply was received, were also in favour. H.F.Newall at Cambridge was strongly opposed to the change, but was not included in the count; neither were the Royal Observatory nor the Nautical Almanac Office. There is evidence, from the replies, that astronomers as a whole could see little or no positive advantage in the change but were prepared to accept any confusion that might arise for the benefit of the seaman.

After discussion, at some length, by the Council, Crommelin wrote to the Admiralty on 1918 December 21 indicating that, on the evidence of the replies received to its enquiries, it reported in favour of the change; but he also mentioned the objections that had been received, mainly by Close (Ordnance Survey) and Hinks (RGS). 'The Council consider that it is practical and desirable to introduce the change into the Nautical Almanac commencing with the year 1925.' The Admiralty replied on 1919 February 19 'the Superintendent of the Nautical Almanac had been directed to make the change in The Nautical Almanac at the Year 1925 (**15**).'

4 THE CHANGE IN THE BEGINNING OF THE DAY – B. THE ADMIRALTY'S PART

On 1919 January 17 the Superintendent of the Nautical Almanac (P.H. Cowell), in response to an enquiry from their Lordships, indicated that the change could, if agreed, be introduced into the NA commencing with the year 1925. He was so directed on 1919 January 29.

Little appears to have been done during the next year other than the publication of Admiralty *Notices to Mariners* (N to M) No. 1291 of 1919 April 9, introducing a system of time-zones in the Royal Navy. The Hydrographer (J.F.Parry) wrote to Cowell on 1919 February 5 asking his opinion on two points: on nomenclature 'I feel sure that the seamen would prefer to retain the familiar denomination of GMT'; and on the interpretation of midnight which 'must obviously begin the day' (**16**). Cowell replied on February 6 pointing out, in some detail, the dangers of retaining the same name and reiterating his view that 'midnight on February 6 means the end of February 6 and the beginning of February 7'. Parry replied on March 4 'the special matters to which I called attention do not appear vitally to affect the Seaman . . . provided that the actual arrangement carried out is clearly described in the preface'. And there the matter rested until 1920 January 14 when the newly-appointed Director of Navigation (D of N – J.E.T.Harper), in a long minute to the Hydrographer (then F.C.Learmouth), called attention to the necessity for early consideration of the changes that

would be required in navigational practice. He expressed his own views bluntly, considering that the change was 'agreed to by the Astronomers because generally it was considered by them to be an alteration desired by Seamen.' After references to the need to consult 'practical Seamen and Educational establishments both Naval and Mercantile' and to 'alterations being made which would affect definitions and formulae in every textbook on Navigation . . .', he wrote: 'it is however considered that the alteration is unnecessary and will not be popular amongst Seamen, for whose alleged benefit it was apparently designed.' Under a misapprehension regarding the status of the 'proposal' he submitted that 'the suggestion be allowed to drop, thus obviating the necessity of scrapping existing textbooks, and altering the method of instruction.' In a later minute of 1920 May 7 he modified his attitude, and his views, considerably and proposed that a conference be arranged 'with those concerned to decide how the matter is to be dealt with in so far as the instruction of officers and men in navigation and navigational text-books are concerned.' He had in mind particularly the *Admiralty Manual of Navigation*, then in an advanced state of preparation, as well as the ANA (**17**). Learmouth clarified the whole matter in a minute of 1920 May 17 and agreed that such a meeting be convened 'for as early a date as possible after due notice had been given'.

The meeting was held on 1920 June 8, under the chairmanship of Learmouth. Cowell, who could not attend, was represented by his Chief Assistant B.F.Bawtree (**18**). The Board of Trade (and thus the Merchant Navy) was represented by a Captain Fulton, but all others present were of the Royal Navy, including representatives of both operational and educational establishments. Instructor-Lieutenant W.M.Smart (**19**), who was joint author of the 1922 edition of the Manual, was present. The meeting adopted the resolution 'Greenwich Mean Time shall be considered to be the standard time of the meridian of Greenwich, commencing at midnight and reckoned throughout the 24 hours'. Of the many details, concerning changes in the ANA, in the Manual and in navigational practice, only one is particularly relevant – namely the interpretation of 'midnight'. Learmouth sent a copy of the report to Cowell on 1920 June 22 '. . . which has now been approved by the Board'.

In further correspondence (June 23 and 30, July 2 from Learmouth, June 29 from Cowell) the difference in view about midnight became even greater. Cowell wrote 'but I had written 24^h and not 0^h deliberately. The day is to begin at a midnight, but unless we are to introduce language which conflicts with common speech the midnight is the midnight of the day before'. Learmouth replied '. . . , there is no such thing as 24 hours, which only tends to confuse the issue', and, later, 'I think the term "midnight" should be taken out of the Almanac altogether, as, being the end of one day and the beginning of the next, it is now a loose word and only liable to confuse the real date.' This was done, but the underlying ambiguity persisted when considering in which direction the half-day difference between the old and the new GMT had to be applied. There is here the same problem (did noon begin or end the day?) that arose with the old 'Nautical Day' which began 24 hours before the astronomical day (**20**).

In reply to Learmouth's repeated requests that a statement explaining the changes should be included in the prefaces to the Almanacs 'giving in some instances the reason', Cowell replied 'our prefaces will notify the change in Mean Time. The reason for the change is that it has been ordered by the Lords Commissioners of the Admiralty. I do not see how I can attempt to give reasons – other peoples' reasons – I might not express them fully.' The actual statement in the preface to the NA for 1925 consists of a one-line notification of the change, as one item in a list. However, widespread publicity was given to the change in N to M No. 1030 of 1920 June 29, and Cowell was instructed to arrange for slips (with text drafted by the Hydrographer) 'to be printed or pasted, in red colour, on the outside cover of all future editions now preparing of the Nautical Almanac, abridged and complete, up to 1924 inclusive and subsequently in amended form up to 1927 inclusive.'

5 NOMENCLATURE

Until 1925 the name Greenwich Mean Time and its abbreviation GMT, (or their equivalents in other languages) were used world-wide in astronomy and related sciences for mean solar time on the meridian of Greenwich measured from noon. It was also used for civil purposes in the United Kingdom, and increasingly elsewhere, for mean time on the meridian of Greenwich, usually in two sets (am and pm) of 0^h to 12^h, from midnight. But it was generally regarded as essential that the change in the beginning of the astronomical day must be accompanied by a change of name. Thus the Society's letter of 1918 March 8 stated that 'The Preface (to the NA) would call attention to the breach of continuity, and state that, while before the change time reckoned from noon was described as Greenwich Mean Time (GMT), after the change time reckoned from midnight would be described as Greenwich Time (GT). The absence of M would serve to call attention to the change'.

Much informal discussion (most of which is no longer on record) took place between astronomers as to the name, and GT appears to have emerged only closely ahead of Greenwich Civil Time (GCT) which was apparently favoured by Cowell, even though it would erroneously imply Summer Time when that was in force. But, in 1918 November, the Council accepted the view that GCT would be the better name. On 1920 February 23 Learmouth wrote to Cowell 'Nothing further has yet been settled since our Conference (**21**) respecting the nomenclature as to Greenwich time or any change in the Abridged Nautical Almanac; as you are aware the proposition to describe the time as GCT was not approved.' Much later, on 1935 June 20 (**22**), there is a reference in a Hydrographic Department file to an Admiralty minute, by a member of the Board, of 1919 December 17 which was stated to furnish 'the reason for their Lordships' decision to retain the term GMT.' Smart, who was well informed though not directly involved, has often asserted that the term GCT was turned down at the highest level because the abbreviation was used for Gunnery Control Tower (**23**). It is clear that, by the time of the meeting on 1920 June 8, all that was necessary was a decision to put into practical effect the Board's decision in principle. Board approval of the report of that meeting constitutes definite confirmation of the Admiralty

decision to the continuation of the name Greenwich Mean Time. It was immediately implemented by the publication of N to M No. 1030 on June 29. Even so, as late as 1922 January, Cowell questioned whether formal approval had been given, almost certainly as a consequence of discussions with the directors of other national ephemerides – almost all of whom adopted GCT or its other language equivalents. He was informed, by the Assistant Hydrographer on January 18 that a decision 'that the letters GMT are to be retained for the new reckoning' had been given by the Board.

Whatever the reasons were (and Parry's views in his letter of 1919 February 5 are relevant) the decision overrode astronomical opinion. The Society and, through the Society, astronomers in general were consulted about the change which primarily affected the practice of navigation; but astronomers were not consulted about nomenclature, the decision on which has caused endless dissension and, more than 50 years later, still has serious repercussions on astronomy.

6 THE EFFECTS OF THE CHANGE – A. TECHNICAL

Nautically, there must have been considerable advantage in having the civil and astronomical dates and times in coincidence, particularly in the field of communications. Navigationally, any advantage is limited by the fact that astronomical data must be tabulated for a specified meridian, e.g. that of Greenwich. A minor advantage is that all the usual sights (at morning twilight, noon and evening twilight) would be taken on the same local astronomical day.

However, the symmetry of having 0^h corresponding to meridian passage of the mean sun gave a small advantage in sight reduction, both in the calculation of hour angles and in interpretation, to the pre-change system (**24**). The extent of the advantage depends on the forms of tabulation and calculation and, with the present forms of GHA almanacs and sight-reduction tables, is now negligible. An unforeseen advantage of the change emerged in that the quantity E ($= 12^h$ – the equation of time), required to convert mean time into the hour angle of the Sun, could be tabulated without the need to specify its sign. E, so defined, together with the analogous quantity R (for the stars) was introduced into the ANA for 1929; possibly because of inadequate prior consultation (**25**) and notice, the change (which was certainly a considerable simplification) was at first resented by the Merchant Navy. The E-form of tabulation was used in the ANA until 1952, and is still used in Japan.

Over five years were available to prepare for the change which had almost no retrospective content. Although many existing textbooks could not be changed, some new editions (including the *Admiralty Manual of Navigation*) and printed pro-formas were produced; warning notices were printed on the almanacs. There is little record of actual error arising, but it is inconceivable that a mistake of 12^h in an hour angle would not be detected; the most likely undetected error would arise from taking out the equation of time and the Sun's declination from the ANA for a time 12^h in error – leading to a maximum error in position of about 12 miles. The equivalent error for star

observations would lead to a position-error of about 30 miles and would, presumably, be detected. It can confidently be assumed that, navigationally, any confusion was small and short-lived.

Astronomically there was little, if any, advantage in bringing the local civil and astronomical days into coincidence. However, all the usual observations (other than daylight transits of the Sun, Moon, planets and bright stars) throughout an observing period, which previously were made on the same day, subsequently were spread over two days – a nuisance, especially to surveyors and amateur astronomers. The International Astronomical Union thought it desirable to provide for the continuation of the old time-scale (under the name of Greenwich Mean Astronomical Time) for some classes of observation. But it may be assumed that astronomers and surveyors were not seriously affected by any change required in the reduction of their observations.

Unlike navigators, many astronomers are concerned with observations, tables and discussions made in the past; these cannot be changed. Also the much smaller demand for textbooks makes new editions uneconomic. There is, in general, no immediate check on the recorded date and time of observation; errors (which occur for other reasons as well) have to be corrected later on the basis of probable cause. There is no reliable information on the number of recording errors, but they did occur; and they have caused subsequent investigators considerable work (**26**). However, the most serious confusion undoubtedly occurred in the ephemeris offices, where the two time-systems were in use simultaneously. Many errors were made in HM Nautical Almanac Office during the years 1930–1940 though, as far as is known, none gave rise to erroneous published data. Four time-systems had to be used: mean time measured from noon, used for the heliocentric ephemerides until 1940, in most tables and for most theoretical expressions; mean time measured from midnight for all current geocentric ephemerides, for some theory and tables; Brown's half-day count used in his lunar tables; the Julian Date. It is easy to say that such errors were inexcusable and should have been avoided by, say, using the Julian Date (which is, fortunately, uniquely unambiguous) throughout; this would have been impracticable, since all copies of all tables, and all calculations, would have had to be annotated by hand. Systematic calculations were, of course, relatively simple to plan; but it cannot be foreseen that, 10 or 20 years later, a new member of the staff will extract data for a non-systematic investigation from those calculations without appreciating the necessity for the greatest care. Most errors arose in this way, many by applying the half-day difference in the wrong direction (**27**) – by no means an unreasonable error, especially for the argument of a correcting term with small amplitude. The essential fact is that errors did arise, even though the danger was foreseen and specific efforts made to counteract it.

The decision (see Section 7) to continue the same name of Greenwich Mean Time (GMT) for the time-system differing by 12^h from that to which it previously referred may well have contributed to the confusion, and the resulting errors, in the recording of observations, but it made little contribution to the confusion inside HM Nautical Almanac Office. Nor, as far as can

be ascertained, did it affect navigation significantly – mainly because the two time-systems were never in use simultaneously.

7 THE EFFECTS OF THE CHANGE – B. NOMENCLATURE

The Admiralty decision to retain the name Greenwich Mean Time (GMT), in the NA as well as the ANA, for mean solar time on the meridian of Greenwich measured from midnight caused (and still causes) much concern in astronomy, with the fear of widespread misunderstanding. It is now irrelevant to analyse how justified the original fear was, but it is doubtful if the successive discussions and recommendations of the International Astronomical Union (IAU) led to less confusion than would have been caused by accepting the change. The matter was discussed, at great length, at the General Assemblies of 1925 (Cambridge), 1928 (Leiden), 1935 (Paris), 1938 (Stockholm), 1948 (Zürich), 1952 (Rome) and, after a long interval, 1976 (Grenoble).

Long arguments, and the deliberations of a Special Committee, produced no agreed recommendation in 1925; MTG or MGT were suggested for the old (noon) time-scale, and Greenwich Civil Time (GCT) or Universal Time (UT) (**28**) for the new (midnight) time-scale. Lengthy discussions in 1928 resulted in the following statement (quoted in part only):

'The terms Greenwich Civil Time (GCT), Weltzeit (WZ) and Universal Time (UT) denote time measured from Greenwich Mean Midnight, and are not ambiguous. The name Greenwich Mean Time (GMT) for dates before 1925 January 1 refers to time counted from Greenwich Mean Noon, but as used after that date (**29**) in British publications it refers to time counted from midnight. Astronomers are advised not to use the letters GMT in any sense for the present'.

In 1935 a resolution proposed by Belgium, that the IAU should persuade Great Britain not to use GMT, was not adopted. Instead the relevant Commissions 3 (Notations) and 4 (Ephemerides), considering a proposal by the United Kingdom that the number of terms be reduced, recommended:

'Que l'on adopte pour l'usage international: Universal Time (UT), Temps Universel (TU) ou Weltzeit (WZ) pour le Temps Moyen de Greenwich (GMT) compté a partir de minuit. Que à l'avenir Greenwich Civil Time (GCT) ne soit plus employé'.

This resolution heralded the gradual replacement, in the national ephemerides, of GCT by UT; but, largely because L.J.Comrie (then Superintendent of the Nautical Almanac) was President of Commission 4, it did not specially condemn the continued use of GMT in British publications. However, both in 1935 and in 1938 (when, with Comrie still President, no formal resolution was adopted) the long discussions indicated deep disquiet at the continued use of GMT; it was only the categorical statements that GMT must, by direction of the Admiralty, be used in the NA that prevented a strongly worded recommendation that it be replaced by UT.

At Zürich in 1948 the General Assembly adopted the following resolution on the recommendation of Commission 4, which had been requested by the Executive Committee to clarify the 1928 resolution:

'La Commission recommande que la désignation "Temps Universel" (Universal Time; Weltzeit) soit seule utilisée par les astronomes pour désigner le temps solaire moyen, compté à partir de minuit du méridien de Greenwich. Elle exprime le voeu que cette désignation remplace aussitôt que possible les autres expressions encore employées.'

The Superintendent of the Nautical Almanac (then D.H.Sadler) had earlier explained that, although the use of GMT in the NA was still obligatory, 'other projected changes include the gradual introduction of UT as an alternative terminology to GMT.' But, during the discussion, both he and G.M.Clemence (Director of the US Nautical Almanac Office) 'stated that there were considerable difficulties in the introduction of the terminology UT into the navigational almanacs'; it should be noted that the resolution was restricted to the use by astronomers.

In their Reports to Commission 4 for the eighth General Assembly (Rome, 1952) Clemence stated:

'Beginning with 1953 the designation Greenwich Civil Time will be dropped and the designation Universal Time will be exclusively used (in the American Ephemeris). . . . The designation Universal Time will not, however, be introduced in purely navigational publications.', and Sadler wrote:

'In conformity with the (1948) resolution . . . all references to Greenwich Mean Time (GMT) in the Almanac (the NA) have been replaced, as from 1952, by 'Universal Time (UT) or Greenwich Mean Time (GMT)'; the use of GMT will be discontinued in the Almanac in a few years time. GMT continues to be used in purely navigational publications'.

Both these undertakings were carried out and, as far as the writer knows, the designation Greenwich Mean Time (GMT) has not been used, officially, in astronomy since 1960. However, it continues to be used in the British and American editions of *The Nautical Almanac*, which since 1960 has been a purely navigational publication, and of *The Air Almanac*; it is also used for navigational purposes in other connections. In addition it is in general, widespread, use as the legal standard time in the United Kingdom, for civil purposes, for communications (it is, for example, the official designation for the transmission times of radio time-signals), and for such publications as international rail and air timetables. There appears to have been no difficulty arising from these uses of GMT until the change, introduced on 1972 January 1, in the time-system now designated as Coordinated Universal Time (UTC). In fact the terminology for mean time on the meridian of Greenwich appears not again to have been the subject of a formal IAU resolution until 1976.

8 COORDINATED UNIVERSAL TIME (UTC)

At the 1955 (Dublin) General Assembly of the IAU a resolution by Commission 31 (Time) was adopted calling upon le Bureau International de L'Heure (BIH) to arrange for the calculation and publication of the quantities to be applied to the observed UT to allow for the effects of polar motion and the annual fluctuation in the rotation of the Earth. As a result of informal

discussions between BIH and the former (H.Spencer Jones) and current (Wm Markowitz) Presidents of Commission 31, the following terminology was adopted and used from 1956 January 1:

'UT0 is Universal Time as formerly computed;

UT1 is UT0 corrected for observed polar motion;

UT2 is UT0 corrected for observed polar motion and for extrapolated seasonal variation in the speed of rotation of the Earth.'

The adoption of this terminology was reported to Commission 31 at the 1958 (Moscow) General Assembly (**30**), but (although generally accepted) it appears never to have received formal approval by the IAU; it was not reported to Commission 4, and was clearly intended for specialist use in the time-services.

Thereafter, radio time-signals were disseminated on the basis of UT2, this being the time-scale that could be most accurately extrapolated by clocks. In 1959 August it was agreed to coordinate the time and frequency transmissions of the United Kingdom and the United States; other countries participated later, and eventually the coordination was taken over by the BIH. Originally the time-signals were generated by quartz-crystal oscillators with a frequency, controlled to be constant with respect to the caesium transition, such that they were nearly in accord with UT2 as deduced from the observed UT0. By (annual) selection of frequency and (monthly) step adjustments of 50 ms, it was stated that 'the time pulses will remain within 50 ms of UT2, as recommended by the CCIR' (**31**). The name Coordinated Universal Time (UTC) appears to have been established in the early 1960s in conjunction with CCIR. With various modifications (such as increasing the step adjustments, and thus the maximum difference from UT2, to 100 ms), this cooperative effort was operated until 1972 January 1, when it was replaced by a time-system linked precisely to International Atomic Time (TAI) from which it differs by an exact number of seconds. Since then all major time-services and time-signals, and all the corresponding national time-systems, have been based on the new form of UTC; the name has been retained unchanged, although the step adjustments are now 1s and the permitted departure from UT1 is now $\pm 0{\cdot}9$s, a ten-fold increase (**32**).

Originally UTC 'will remain within 50 ms of UT2', so that the maximum difference between UTC (as generally available) and UT1 was about 0·085s. Even though this was later increased, when the step adjustments were 100 ms, the difference was small enough to be negligible for all except those who require UT1 to full accuracy, which is only possible by applying the *post facto* observational corrections published by the BIH. UTC was used without any difficulty or confusion (and in most applications without any realization of its structure) for both navigation (in the sense of GMT) and civil purposes; and it provided precise measures of frequency and time-interval, albeit with some little complication.

As from 1972 January 1 the conceptual difference could no more be ignored than the increased departure from UT1. The necessity to apply the correction DUT1 (incorporated in coded form in the primary time-signals) to UTC to give UT1 to its previous accuracy also emphasises the difference in

purpose. UTC is now, first and foremost, an atomic time-scale intended to provide directly precise measures of frequency and time-interval; it is only secondarily, almost incidentally, a measure of time and an approximation to UT1.

9 CONFLICT IN INTERPRETATION OF GMT

Apart from the increased effort (by no means inconsiderable) to users of UT1, a conflict of interpretation arose after 1971 between the two usages of GMT, the difference between which could no longer be ignored: GMT, defined as mean solar time on the meridian of Greenwich (strictly UT1, but to navigational accuracy the distinction between UT0, UT1 and UT2 is not significant), as used as the time-argument of the navigational ephemerides; and GMT, the statutory legal time in the United Kingdom (and the basis of standard times in other countries), which is *de facto* UTC. Both usages are so well established, and so embedded in nomenclature and practice, that any change in nomenclature can only be achieved gradually, as was done in the astronomical ephemerides from 1952 to 1960, by using dual notations over a period of years.

Since GMT is no longer in use in astronomy proper, the practical problem is primarily the concern of navigators; and, as far as can be ascertained, navigational users of GMT would much prefer to retain it in the sense of UT1 (**33**). In spite of the obvious danger of confusion there is no evidence that any navigator requiring UT1 more accurately than given by UTC has used UTC without applying the DUT1 correction; but there is evidence (**34**) that navigators, using ephemerides with GMT or UT as arguments, have applied the DUT1 correction to UTC when the precision of their observations does not warrant it. As with the 1925 change, it is the change itself and not the nomenclature that is the main cause of difficulty; it is somewhat ironic that the 1972 change in UTC (**35**) largely vitiated the 1925 change in GMT which was made specifically to bring the astronomical day into accord with the civil day!

In preparation for the General Assembly of the IAU in 1976 (Grenoble), Commissions 4 (Ephemerides) and 31 (Time) discussed by correspondence, as part of a general review of nomenclature for time-scales, how best this conflict could be resolved. A draft resolution (by D.H.Sadler), in favour of the *status quo* by recognizing the dual usage of GMT, did not receive adequate support, and was withdrawn in favour of a carefully-drafted compromise resolution by the President of Commission 31 (H.Enslin) dated 1975 August 14; in this the hope was expressed 'that GMT will be gradually replaced by the appropriate designations'. In the interests of achieving general agreement, the General Assembly of the International Association of Institutes of Navigation (IAIN), meeting in 1975 October, communicated its support for this resolution to the IAU. However, shortly before the Grenoble meeting an amended version (by B.Guinot, the Director of the BIH) was circulated to members of Commission 31 (**36**). It is this version, further amended during the meeting, which was adopted (**37**) at a joint meeting of Commissions 4 and 31, under the chairmanship of Dr Enslin, on 1976 August 30.

'Commissions 4 and 31

Considering the desirability of a clarification of the use of Greenwich Mean Time (GMT) and Universal Time (UT):

Notice (a) that GMT and UT are used in the sense of UTC for Statutory, communications, civil use and other purposes in which maximum precision of timing is integer seconds;

(b) that GMT and UT continue to be used in the sense of UT1 as the independent argument of almanacs for astronomical navigation and surveying (**38**);

Recognize that UT may be used in the place of UT0, UT1, UT2 and UTC in cases where the distinction between them is not needed;

Urge that GMT be replaced by the appropriate designations, and

Recommend that the unambiguous notations UT0, UT1, UT2 and UTC be used in all scientific publications whenever it is necessary to distinguish between them.'

As GMT is no longer used in astronomy, the word 'urge' (**39**), with its implication of exhortation and urgency, suggests a greater concern than might be expected. Moreover, neither of the appropriate designations is likely to find ready acceptance: UT1 (Universal Time One or UT One) is nameless and the significance of the 'one' irrelevant to the navigator; UTC (Coordinated Universal Time) is an awkward and meaningless term that has outgrown its original derivation. It would have been much easier for navigators to have accepted a change to UT, as is at present in widespread use as a generic term for UT0, UT1 and UT2; in possible anticipation of such a change *The Nautical Almanac*, from the edition for 1976, contains the statement: 'The name universal time (UT) is now often used instead of the name Greenwich Mean Time. The time-scale used in this almanac is denoted by UT1, while the scale of the time signals is denoted by UTC.' Civil users will be encouraged by the resolution to use UT instead of the 'appropriate designation' UTC.

10 UNIVERSAL TIME

The resolution indicates that notice has been taken of the present dual usages of GMT and UT for civil and navigational purposes, but neither notices nor refers to the long-established, widespread use in astronomy of UT as a general term for mean solar time on the meridian of Greenwich, as recommended in the 1948 IAU resolution. UT is so used throughout the international and national ephemerides, in the *Explanatory Supplement* to the AE (and similar manuals) and in numerous textbooks; UT0, UT1 and UT2 are only used in the specialized explanations concerning time-determinations. There is no corresponding terminology for sidereal time, and the fundamental tabulations give corresponding values of ST and UT without qualification.

Correction for polar motion (maximum about 0·035s) is essentially a local correction to be classed and treated (in spite of its general origin) with the other local, instrumental and personal corrections that must be applied to

the observed time-determinations. The empirical correction for seasonal variation in the speed of rotation of the Earth (maximum also about 0·035s) has now only limited use for interpolation and extrapolation (its original purpose), since TAI provides the short-term uniformity for which UT2 was introduced. Both UT0 and UT2 are of interest only to the specialists of the time-services, and there would seem no longer to be a general requirement for their separate identities.

The phrases 'where the distinction between them is not needed' and 'whenever it is necessary to distinguish between them' are subjective, and will be interpreted according to interest. Civil users cannot be expected to appreciate the difference between UTC and UT1 and, if they change from GMT, as urged to do by the resolution, will undoubtedly use the simpler UT 'in the sense of UTC for Statutory, communications, civil use and other purposes' in spite of the fact, unknown to them, that a distinction is needed. The difference between UTC and UT1, which may be 20 times the maximum differences of UT0 and UT2 from UT1, is large enough to be significant in the time-signals (giving an accuracy of about 0·1s) given by talking clocks and in radio and TV programmes; these are much used by amateur astronomers and others. The conceptual difference between the observed Earth-rotational time-scale UT and the 'atomic-clock' time-scale of UTC will not, of course, be appreciated.

The effect on astronomy of adherence to the resolution, which was given a general endorsement by the General Assembly on 1976 September 2 recommending that 'astronomers give effect' to it, will be the replacement of the designation UT in all astronomical, surveying and navigational publications (both ephemeral and permanent) by UT1 or a phrase such as 'UT0, UT1 or UT2 as appropriate'. Astronomers who have used, for mean solar time on the meridian of Greenwich, the designation Greenwich Mean Time (GMT) for hundreds of years and Universal Time (UT) for 40 or more years are under an obligation to the IAU now to use the unnamed UT1; whereas civil users may, and undoubtedly will, use UT to designate a time-scale that differs significantly, both in concept and practice, from mean solar time.

However, UT must continue to be used 'in the sense of UT0, UT1 or UT2,' in ephemerides and associated publications for many years, even if a decision to change has already been made; and its use in the sense of UTC is both unnecessary and inapt.

II CONCLUDING REMARKS

The disadvantages of the resolution for both astronomers and navigators, as indicated in the preceding sections, are considerable; there appear to be no compensating advantages and none was put forward by the proposer of the resolution – or have emerged in subsequent correspondence. As with the 1925 change in GMT and the 1972 change in UTC, any advantages lie with other users. In the circulated proposal of the resolution, Dr Guinot added the comment 'I very much disagree with the proposal that UT should imply UT1 because, in practice, UT implies UTC which is the only time-scale which is

easily available. For instance, when UT is given in the schedules of air-lines, it means UTC, because the watches of the passengers as well as the clocks of the airports are set on UTC + an integer number of hours.' This argument is reminiscent of some of those used in 1918; and it would seem to indicate that, as implied in the resolution, UT was already in use in the sense of UTC for civil purposes, although such use certainly did not have IAU approval. The most powerful argument for the resolution, however, stems from the recommendation of the Conférence Général des Poids et Mesures (CGPM) that the time-scale UTC be adopted as the basis of legal time in its adhering countries; it would thus replace GMT which, because of the change in the derivation of UTC in 1972, is ambiguous. It is understood that appropriate legislative steps have been, or are being, taken in France, Holland, Spain, Switzerland and the Federal Republic of Germany (**40**) to achieve this. Dr Guinot informs me that, in France, mention is made in the new law of the use of UT, although the legal time is defined on the basis of UTC. Clearly, considerable advantage is to be gained by allowing the simpler form of UT for civil use, for which the time-difference from UTC is of no practical importance. There was also the consideration that the permitted use of UT, instead of UTC, would influence the International Telecommunication Union to change its present usage of GMT in the Radio Regulations. The initiative for this usage of UT seems to arise from an explanatory note to a 1974 recommendation of the Consultative Committee for the Definition of the Second (CCDS) (**41**) to the effect that 'Except where confusion might arise the designation Universal Time (Coordinated), UTC, may conveniently be abbreviated to Universal Time (UT)'; clearly, the vigorous objections to this note from some astronomers, based on the considerations given above, did not carry adequate weight (**42**).

Much of the discussion, both by correspondence and at the meeting, was concerned with the choice of the word 'urge' in respect of the continued usage of GMT. Comments such as 'GMT should be dropped as an anachronism of uncertain definition and no value'; 'GMT should be allowed to retire without attempts to sustain it', can hardly be regarded as constructive; but the substantial criticism was that GMT has (due to the redefinition of UTC) now two distinct meanings, leading to possible confusion. Surprisingly, reference was also made to the 1925 change, and to the long conflict (see Section 7) over nomenclature; apparently time is not the great healer! It is, again, ironic that the ambiguity, which in the meaning of GMT is regarded as so undesirable as to warrant its discontinuation, should be introduced in the meaning of UT.

Another interesting point, not apparently mentioned, is that whereas most time-zones can retain their designations (e.g. Central European Time) unchanged, Greenwich Mean Time is no longer permitted to be used for the standard time appropriate to the zero meridian of Greenwich!

In the 1925 change the non-astronomical advantages of bringing the astronomical day into accord with the civil day were significant, even if not substantial, and the astronomical disadvantage was not great; in the 1972 and 1976 changes the astronomical disadvantages are considerable, and it

would seem that they could easily have been avoided without any detriment to any non-astronomical advantages.

Coordinated Universal Time, as UTC is at present defined, is a 'terminological inexactitude': UTC is not a 'coordinate' time-scale and it is certainly not 'universal'; relativistically it is 'proper' to the surface of the Earth and corrections are in fact applied to make it so (43). Although 'coordinated' by the BIH (as are the final values of UT1 and many other quantities) the use of this unnecessary word should be avoided in the context. The 1972 change, unlike that of 1925 which was simply a change of origin (44), involved changes in both concept and purpose and, in retrospect, should certainly have been accompanied by a change of name. Such a change would seem to be even more desirable when UTC is being adopted as the basis for legal time in most countries. A name such as International Time (IT) or Temps International (TI) – and there are many other suitable names from which to choose – would be descriptive, unique and quite unambiguous; there would be no confusion with mean solar time on the meridian of Greenwich and with its existing names of Universal Time and Greenwich Mean Time.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the interest and assistance of Rear-Admiral G.S.Ritchie who, as Hydrographer of the Navy in 1970, made available to me all the files and documents in the Hydrographic Department relevant to the 1925 change. I am also most grateful to the present Hydrographer, Rear-Admiral D.W.Haslam for valuable comments on the later drafts of sections 3, 4 and 5 which were first drafted in 1970. Dr H.Enslin, of the Deutsches Hydrographisches Institut, has been most helpful and cooperative; he has made available to me the comments he received, as President of Commission 31, during the two years of discussion on this subject; he has let me see his personal account of the proceedings of the relevant meetings in Grenoble; and he has sent me copies of several of the draft legislative documents that will give legal status to UTC. I am indeed most grateful to him. Dr B.Guinot, director of the BIH, has been helpful in our frank exchange of views and in supplying me with information as to the legislative procedures in France.

Dr G.A.Wilkins has kindly read the final manuscript; and I owe to him many improvements in content and presentation.

NOTES AND REFERENCES

(1) See the report of the International Meridian Conference, Washington, in 1884. An account is given by H.M.Smith in 'Greenwich Time and the Prime Meridian', *Vistas Astr.*, **20**, 219, 1976.
(2) Newcomb, S., 1906. *A compendium of spherical astronomy*, p. 114.
(3) The requirements of dynamical astronomy, in which time is the independent variable of the equations of motion, are not here considered. They are provided for by Ephemeris Time.
(4) Sadler, D.H., 1968. Presidential address, *Q. Jl R. astr. Soc.*, **9**, 281.
(5) There is a specious argument that the only difference, in principle, between a time-scale based on the rotation of the Earth and one based on an atomic transition is that the frequencies differ by a factor of about 10^{15}. This fails to recognize that, whereas each revolution of the Earth is identifiable, individual atomic transitions are not; thus the one is truly a measure of time, the other of time-interval.

(6) Its non-uniformity causes no difficulty for that purpose; in fact, the maximum error of linear interpolation between observations at daily intervals is only 0·1s, less than the limiting precision of pendulum clocks until the twentieth century.

(7) Sir James South, then President, argued that mean solar time was alien to astronomical thinking and suitable only for 'culinary philosophy'.

(8) The sign of the equation of time was changed in the NA from 1931 onwards (causing considerable confusion) so that it could be applied to the known mean time to give apparent time.

(9) Newcomb, S., 1903. *Reminiscences of an astronomer*, p. 227, says that the resolution was made 'almost without debate, certainly without adequate consideration'.

(10) See *History of the Royal Astronomical Society*, 1820–1920, p. 225, and also the references in note (1).

(11) By this time the practice of dating the day – the Nautical Day – according to the *previous* noon had apparently been discontinued.

(12) There is no indication that the effect on astronomical navigation was considered.

(13) Undated, but early in 1918 by its context.

(14) The changes required in *The Nautical Almanac, abridged for the use of seamen* (the ANA) were apparently not considered. In his article on Time in *Encyclopædia Britannica*, 14th edn, 1929, p. 224, Eddington roundly condemned the Admiralty as 'the most prominent offender' in introducing the change without authority.

(15) Unfortunately, whatever system is used, the local date of morning twilight will in some longitudes differ from the Greenwich date! These letters were published in full in *Mon. Not. R. astr. Soc.*, **78**, 544 and **79**, 318.

(16) The Society's view on this point is stated in the circular letter of 1918 March 8: 'Midnight would, throughout the *Almanac*, be taken to mean the midnight at the end of the day (this is in accord with common usage)'.

(17) Previously, only changes in the NA appear to have been considered.

(18) However, the specimen pages indicating the proposed changes in the ANA were designed personally by Cowell.

(19) Secretary of the Society, 1930–1937; President, 1949–1951.

(20) None of the letters, or documents (the Society's letter of 1918 March 18, N to M No. 1030 of 1920 June 29, or the red slips pasted on the editions of the NA) specified *unambiguously* the relationship between the old and the new GMT.

(21) This is possibly a reference to the Conference on 1917 June 21.

(22) Arising from the then Superintendent's (L.J.Comrie) request for fuller information and precise references preparatory to the IAU General Assembly in Paris. But the actual minute of 1919 December 17 cannot now be traced and was not, apparently, available then.

(23) A similar statement, probably stemming from the same source, is given in Russel, Dugan & Stewart's *Astronomy*, 1945 edn, p. 27.

(24) It was this point that formed part of the technical opposition to the change.

(25) The Society was not consulted!

(26) The danger of misinterpreting old observations still exists.

(27) How many astronomers can say, with certainty, whether 24^h GMT on 1924 December 31 is noon on December 31 or on January 1?

(28) In conformity with the 'universal day' established at the 1884 conference.

(29) Ambiguous. In publications before 1925, GMT was measured from noon for all dates both before and after 1925 January 1; but in publications after 1925, GMT was measured from midnight only for dates after 1925.

(30) *Trans. int. astr. Un.*, X, 489, 1960.

(31) The International Radio Consultative Committee (CCIR), a Committee of the International Telecommunications Union (ITU), is responsible for coordinating radio time-signals.

(32) As originally proposed by the CCIR the maximum departure was to be $\pm 0{\cdot}5$s – with steps of 1s! When the impossibility of achieving this was pointed out, the limit was changed to $\pm 0{\cdot}7$s. Even so, with remarkable flexibility in the interpretation of its own resolutions, the departure was allowed to reach 0·81s on 1973 January 1! The present limit, proposed by the IAU in 1973, is more realistic.

(33) The Navigational Symposium held in Washington on 1975 April 16–17 recommended 'that the terminology Greenwich Mean Time be continued in its present sense in the practice of navigation and be maintained as the independent argument of the navigational tables and almanacs'.

(34) For example, A.M.Sinzi in a report to the IAU, reprinted in *Int. hydrog. Rev.* (**L1**, p. 150, 1974), said that six out of 26 who knew of DUT1 actually applied it, while 30 out of 79 were unaware of the difference between UTC and UT1; none needed to apply the correction.

(35) The reasons for the change were non-astronomical and some (for example, the provision of a collision-avoidance system for aircraft) now appear somewhat specious. Astronomical and navigational opposition was not pressed and, as for the 1925 change, had little weight in comparison with other interests.

(36) Dated 1976 July 22 and circulated on July 28. Members of Commission 4, not present at the joint meeting (which clashed with another meeting which some members attended), were unaware of it, even after its adoption.

(37) The official record of the vote is: 21 in favour; nine against; seven abstentions. A request (by D.H.Sadler and G.A.Wilkins) that the resolution should be confirmed, or not, by referendum among all members of Commissions 4 and 31 was rejected (not unreasonably) on procedural grounds.

(38) GMT is not so used for surveying in the UK or the USA.

(39) The (1976) President of Commission 4 (R.L.Duncombe) has stated, in a circular letter of 1977 April 11, 'I think the resolution merely urges ultimate replacement of GMT . . .'; but, clearly, the actual wording is specific and must be accepted.

(40) And probably several other countries; but not in the UK.

(41) The CCDS reports to the International Committee and thus, eventually, to CGPM.

(42) Such objections were made during the discussion of the resolution, but it was stated that there was a need for the use of UT in those cases where it is not possible to decide upon whether UT0, UT1, UT2 or UTC is referred to. It is not possible to give details of the discussions and the formal report of the meeting, to appear in the *Transactions* of the IAU, is necessarily very short.

(43) See, e.g., Winkler, G.M.R. & Van Flandern, T.C., 1977. *Astr. J.*, **82**, 84.

(44) At the 1973 (Sydney) General Assembly, Commissions 4 and 31 recommended, that a discontinuity, or change of origin, of 32s be introduced into International Atomic Time (TAI) – without a change of name! The resolution was withdrawn in 1976.