COMMISSION 31: TIME (L'HEURE)

Report of Meetings, 19, 21, 24 and 26 August 1970

ACTING PRESIDENT: G. M. R. Winkler.
SECRETARY: C. J. A. Penny.

First Session

The session was opened by the Vice-President, *G. M. R. Winkler*, who had been asked to preside in the absence of the President, *F. Zagar*.

The President appointed Miss Penny, RGO, as Secretary.

The proposed names for officers of the Commission, as well as of new members, were approved by the members.

The President proposed that in the future the Director of the Bureau International de l'Heure (BIH) should be an ex officio member of the Organizing Committee. This was agreed.

The *President* reported that the following names had been proposed as consulting members: G. Becker and A. R. Robbins. They were approved by the members.

The *President* expressed regret that J. P. Blaser had resigned from the Commission.

The Draft Report was approved.

The Director of the BIH, B. Guinot, reported on matters of general interest and of an administrative character. The BIH is one of the permanent services of the Federation of Astronomical and Geophysical Services (FAGS), it is sponsored by the IAU, UGGI and URSI; the parent union is the IAU. The Directing Board presently includes H. M. Smith (IAU) as Chairman, F. Zagar (IAU), W. Markowitz (UGGI), B. Decaux (URSI, CCIR), P. Giacomo (CIPM), and B. Guinot, Director of the BIH.

A minor change of statutes had been made to make it clear that the BIH is only concerned with the scientific problems of time and not adopted legal times.

UT1 and the co-ordinates of the pole are now computed by the simultaneous use of time and latitude observations obtained from 76 instruments and are published in Circular D. Some improvements have been made such as weighting the observations and publication of the raw data as well as the smoothed data for every five days. Work has commenced on reduction of the observations prior to 1964 in order to obtain a homogeneous set of data.

Research centred on two main topics:

The best use to be made of the polar motion determinations deduced from the U. S. Navy Doppler satellite observations by the Dahlgren Polar Monitoring Service and the systematic differences between these results and the IPMS and the BIH results; and secondly, how to keep the reference system, '1968 BIH System', in the long term.

Computation of an international atomic time scale was considerably improved at the end of 1968 when international time comparisons became possible with the use of Loran-C. AT (BIH) is now uniform to about 1×10^{-13} over several years. It is now possible to maintain clocks in agreement with UTC, defined by an exact relationship with AT (BIH) to ± 1 microsecond. The Director of the BIH thanked the U.S. Naval Observatory and the U.S. Coast Guard for loans of equipment and for visits with travelling clocks and also the Paris Observatory and other French organizations for support.

The Director sought views on the need to continue publishing all the observed values of UTO and of the latitudes and their residuals from the BIH solution.

The Director expressed concern about the financial position of the BIH which receives an annual grant of 6000 U.S. $ from FAGS, but the real expenses of the computing service alone are more than 100000 U.S. $, and the difference in the income and expenditure is borne entirely by the Paris

Observatory. The BIH could not continue its work without some other financial support.

The following discussion on the report of the Director of the BIH took place:

In reply to a question from *J. Bonanomi*, the Director said that most of the BIH expenditure is due to salaries and that the costs of the determination of UT and AT are approximately equal.

In reply to a question from *I. Shapiro*, B. Guinot said that he was looking into the differences in the polar coordinates obtained by the three different organizations. He noted that the drift of the mean pole obtained by the IPMS was different from that of the BIH.

After some discussion on the need to publish information on erroneous time signal emissions *W. Markowitz* moved that the BIH should publish a list of agencies responsible for the various services; this was seconded by *H. Enslin* and approved by the members.

H. Enslin proposed that the material in the Annual Report of the BIH should be reduced by publishing figures at $\frac{1}{20}$ yr intervals only. B. Guinot said that it would be necessary to consider also the advice of Commission 19 on this matter. In reply to *R. G. Hall*, B. Guinot said that all observations were available at the BIH on magnetic tape. It was agreed by a small number of members to recommend that the Annual Report of the BIH be condensed.

The *President* urged Commission 31 to consider the scope of its activities. The Commissions of URSI, CCDS, and the IAU are, in many cases, attended by the same people, but the discussions are held in very different climates. Commission 31 should ensure that its views are made known to the Directing Board of the BIH.

The Chairman of CCIR IWP VII/I, H. M. Smith, explained that problems arose from the need for two time systems: UT based on the rotation of the Earth and a uniform atomic time scale based on the second. The control of radio time signals is the responsibility of the CCIR, and at Boulder, 1968, a Working Party had been set up to look into the problem of improving the system for radio time signals which would better suit the needs of users of both UT and AT. The Working Party had proposed that the signals should be emitted without offset, but that there should be steps of 1 second to keep the signals in general agreement with UT and that this system should commence on 1.1.72. The Working Party sought the views of Commission 31 on details of implementation.

During discussion on these points it was noted that if the 1 second steps were made on fixed dates then the signals could diverge from UT by up to 0.7 second. *W. Markowitz* said that he did not believe that a ship navigating by celestial means needed greater accuracy than one second. The *President* postponed discussion on this point until the joint discussion with Commission 4.

A. A. Mikhailov said that a correction is something that must be added so that he proposed:

Time signal + correction = UT

H. M. Smith thought that since $\Delta T = \mathrm{ET} - \mathrm{UT}$ there would also be great advantage in an analogous convention.

The meeting adjourned.

Second Session

At the request of the President, *J. Terrien* reported on the CCDS Meeting of 18–19 June, 1970. He commenced by reporting that the CCDS had expressed great appreciation of the work of B. Guinot as Director of the BIH. He then went on to explain the organization of which the CCDS is a part. The Conférence Générale des Poids et Mesures is a Governmental organization of which the CIPM is the executive body. The Bureau International des Poids et Mesures (BIPM) is a scientific laboratory of which he is the Director, nominated by the CIPM. The CCDS is one of seven consultative committees whose membership is decided by the CIPM. In 1967, when the second was defined in terms of an atomic transition, the CCDS had restricted themselves to defining the interval of time. Since then several international organizations had pressed the CIPM to define a scale of atomic time.

In reporting informally on the draft recommendations, J. Terrien stressed that the CCDS had still to report to the CIPM. He added that although the IAU had no power to change the recommendations he would note any views expressed by Commission 31 and report them at the October meeting of the CIPM.

CCDS recommendation S1 (1970) stressed the need for the adoption of an atomic time scale.

Recommendation S2 (1970) reads as follows:

'Le Comité Consultatif pour la Définition de la Seconde propose de définir le Temps Atomique International (TAI) comme suit:

Le Temps Atomique International est la coordonnée de repérage temporal établie par le Bureau International de l'Heure sur base des indications d'horloges atomiques fonctionnant dans divers établissements conformément à la definition de la seconde, unité de temps du Système International d'Unités.'

Recommendation S3 (1970) which is concerned with the practical realization of the atomic time scale states that the duration of the interval unit must be as close as possible to the duration of the second of the SI at a fixed point on the Earth at sea level, that the scale must be as uniform as possible and that the scale unit would only be intentionally altered if it differed significantly from the duration of the second.

J. Terrien reported that the majority of members of the CCDS were in agreement that the BIH should continue to form the atomic time scale, but FAGS had already asked for financial support for the work from adhering governments.

The *President* opened the discussion by remarking that it was essential to know what was meant by the fixed point and suggested that the pole might be suitable. *G. Becker* said that it was not necessary to refer to a fixed point, that any point on an equipotential surface was as good as another. *The President* agreed that he would expect the same rates but he wondered if time would vary from one equipotential point to another. *J. Terrien* said the definition had been phrased for practical reasons and could very easily be changed.

G. Becker noted that the definitions clarified the origin and the scale unit, but did not say how to designate the scale values or the origin; he wondered if dates should be given according to the Gregorian calendar. *W. Markowitz* thought it better to use the Julian date. The *President* said the question of date should be discussed at the joint meeting with Commission 4; the question of a better definition of the origin had been discussed by the Organizing Committee and they had decided that nothing could be gained by trying to improve on the present one. *B. Guinot* said the origin was fixed by reference to the Earth itself and could not be defined more precisely and *N. Stoyko* confirmed that UT was not known to great accuracy.

G. Becker proposed that the next step should be to interest the CIPM in legal time scales. *H. Enslin* endorsed this and said it was important that all countries adopt the new system simultaneously and that it was fully publicized in all countries. The *President* remarked that adjustments to time signals had already been made without difficulty and that publication of information was an internal problem for countries; however he agreed that there would be an increasing need for better communications.

The *President* said that the Commission should review the scope of its activities and interests, for example, representation of the IAU on the CCDS was of increasing importance.

The *President* thanked J. Terrien and wished to join in the complimentary remarks to the BIH, who had done a marvellous job with very little funds. The Commission formally expressed its gratitude to the BIH.

P. L. Bender emphasized the importance of an international atomic time scale in new fields of astronomy, for example, lunar laser ranging, timing pulsars, etc., which already utilized the full accuracy of the atomic time scale.

The *President* reported that unfortunately the IAU had received no official communication from the CCIR of the recommendations and resolutions made at New Delhi. *D. H. Sadler* expressed amazement since a CCIR resolution stated specifically that the IAU should be informed. After further discussion *H. M. Smith* said that although the Commission could not comment on documents which had not been received he would like views on the six points he had raised in an earlier meeting.

The *President* proposed that the discussion on reaction to the CCIR's recommendations be dropped and that the Commission proceed to hold a free discussion giving their own views and this

was agreed. The President then read out a draft of the resolution on time signal emissions which had been prepared by the Organizing Committee. After clarification of a few points the meeting adjourned.

Third Session

The *President* reopened discussion on the draft Resolution by remarking on the need to reach an acceptable compromise. The following points were made:

that the difference given should be UTC-UT1 and not UTC-UT2,

that the maximum tolerance had been increased from $0^s.5$ to $0^s.7$ because it would be impossible to keep to a tolerance of $0^s.5$, with 1^s steps on fixed dates and the requirement to give advance notice,

that all time signal emissions *must* include the information necessary to obtain UT1 to at least $0^s.1$.

At the request of *D. H. Sadler*, the President agreed to put to the vote the sentiment expressed in the final paragraph that Commission 31 considered the document as the optimum solution. This was agreed unanimously. The amended Resolution was agreed nem. con.

H. M. Smith proposed the following statement:

"Commission 31 received with interest an informal report by the Director of the BIPM on the proceedings of the meetings of the CCDS (Paris 1970), and noted with satisfaction that the CCDS endorsed the atomic scale of time proposed by the IAU (Prague 1967) and currently operated by the BIH.

Commission 31 would welcome the appointment of a representative nominated by the CIPM as a member of the Directing Board of the BIH."

After translation into French by B. Guinot this was agreed unanimously.

The *President* reported that Commissions 7 and 19 had asked that a representative of Commission 31 be appointed for discussions on the formation of a Working Group with COSPAR on lunar laser ranging. He proposed that Dr Guinot be the representative and this was agreed.

W. Markowitz reported that from 1820 to date there were only two periods, about 1870 and 1910, when the rate of rotation of the Earth would have required more than a single 1 second step a year to be made in time signals if the proposed rules had been in operation, and that in no case would more than two such steps have been needed.

W. Markowitz reported on the use of Loran-C for synchronization of clocks at various laboratories for satellite tracking, and for lunar laser ranging. An experiment with Loran-C conducted at Marquette University indicated that the frequency of electromagnetic radiation is not affected by mass.

B. Guinot presented a slide illustrating the difference TUC (OP)-TUC (USNO) obtained via Loran-C and with portable clocks for a period of fourteen months and noted the remarkable agreement between these two methods.

H. M. Smith showed a similar slide giving comparisons between UTC (RGO) and several international laboratories.

H. M. Smith took the chair whilst *G. M. R. Winkler* reported on portable clocks and the problems of time synchronization. Two series of portable clock trips, of greater than $2\frac{1}{4}$ days duration, had been analyzed, the first with cesium standards, model 5060 A, showed a mean closure error of $+0.1 \pm 1.1$ μsec and the second with standards, model 5061, showed a mean closure error of -0.5 ± 1.5 μsec. *G. M. R. Winkler* presented a slide showing the variations in frequency of typical cesium standards over periods up to 100 days; whilst some did not improve, the frequency of the best clock was determinable to 3×10^{-14} within 40 d.

On time synchronization *G. M. R. Winkler* said that for purposes of economy time signals were superposed on navigational and communication systems. Of the different systems in use HF radio time signals gave global distribution to 1 msec, portable clocks to 0.5 μsec, VLF-OMEGA 1–3 μsec by relative phase tracking and LORAN-C 0.5 μsec in the northern hemisphere (except in the western United States). Communication satellites, such as Telstar and Relay gave time to 0.1 μsec, the navigational satellite, Transit, gave 10 μsec, the experimental satellite GEOS gave 5–10 μsec. Exotic systems such as very long baseline interferometry (VLBI) gave 1 nsec and TV gave 10 nsec locally

and 1 μsec regionally. He also reported on the work of *M. Lefebvre* (ONERA) who had achieved an accuracy of 10 μsec using TRANSIT. TV had been used very successfully in Prague and Potsdam and in the U.S.

H. M. Smith thanked G. M. R. Winkler for his review of methods of precision time comparison and the United States Naval Observatory for their comprehensive service with travelling clocks.

J. Bonanomi reported a portable clock experiment lasting 5–7 d with closure errors of 0.2 ± 1 μsec or better.

The meeting adjourned.

Fourth Session

The President opened the session.

E. Proverbio discussed radio wave propagation. HF and VLF signals are still used for time synchronization and this calls for a knowledge of the velocity of radio propagation to obtain travel times. A great deal of work has been done on the effects of diurnal and seasonal variations. Anomalies due to solar disturbances were also mentioned.

The *President* confirmed that VLF signals are still useful for world-wide synchronization and mentioned two ways of determining path delays: one is to develop a theoretical model ionosphere and produce tables giving path delays for different heights; a second is to measure phase differences between a number of synchronized transmitters at the same site with differing frequencies and produce an empirical model by assuming the path delay from the transmitters to the receiving station to be a function of distance and the phase differences.

R. G. Hall reported on a meeting of IAU Working Group No. 1 on Numerical Data which he had attended and which was enquiring into the feasibility of setting up a data storage centre. Commission 31 was already catered for with the BIH and BIPM, but it had been suggested that the BIH might transfer some of its data to the centre. A matter of direct concern to Commission 31 was the recommendation that all stars be referred to by the Durchmusterung BD number where possible.

B. Guinot reported on the meeting of representatives of Commissions 4, 7, 9, 17, 19 and 31 which had agreed to send representatives from each of these Commissions to the COSPAR Working Group on lunar laser ranging experiments.

The *President* said that there is a need for a precision of from 10–100 μsec for space tracking. In theory it is possible to use a spacecraft as a fixed point for radio tracking and to derive also information on x, y and UT1; but in practice it is better to obtain these data by conventional means and use them to improve the tracking. For missions which will take place during the changeover of the UTC scale the President advised anticipating the new scale.

The *President* made some comments on Loran-C measurements. The phase values reported by the USNO were unsmoothed. Attempts were being made in Washington to measure the sky wave transmissions on two chains at one station. On cycle identification the *President* described difficulties that were encountered and said that it was of paramount importance to use the standard bandwidth of ± 20 kcs.

The *President* gave his sincere thanks to the very excellent co-operation that the USNO had received from a number of laboratories and mentioned in particular BIH, PTB, DHI, RGO and RRL (Japan).

The *President* asked Commission 31 to consider what interest it had in regard to very long base line interferometry. *W. Markowitz* reported only a resolution of Commission 19 which noted the advantages of VLBI for measurements of the rotation of the Earth.

Finally the *President* acknowledged with pleasure the interest of the members and closed the meeting.

RESOLUTION ADOPTED BY COMMISSION 31

Commission 31 *makes the following recommendations*:

1. That the frequency offset of UTC be made zero, effective 0^h, 1 January 1972.

https://doi.org/10.1017/S0251107X0002023X Published online by Cambridge University Press

2. That *step adjustments* shall be exactly 1^s. When a step adjustment is made it shall be at 0^h on the first day of a month with preference for 1 January or 1 July. These step adjustments will be decided upon and announced as early as possible by the BIH.

3. The maximum difference UT1–UTC will be less than $0^s.7$ unless there are exceptional variations in the rotation of the Earth.

4. *Special adjustment*. The BIH will also announce a unique fraction of a second adjustment to be made at 0^h 1 January 1972, so that UTC and the International Atomic Time Scale (IAT, in French TAI) will differ by an integral number of seconds.

5. The *emission times* of time signals from co-ordinated stations shall be kept as close to UTC (BIH) as feasible with a maximum tolerance of 1 ms.

6. *Nomenclature*

6.1. Clocks in common use will indicate the minutes, seconds and fractions of UTC (French: TUC).

6.2. The terms 'G.M.T.' and 'Z' are accepted as the general equivalents of UTC in navigation and communications.

7. The term ΔUT is defined by: $\Delta\text{UT} = \text{UT1}-\text{UTC}$. Extrapolated and final values of ΔUT will be issued by astronomical observatories and the BIH, and will be given the widest possible distribution.

8. All standard time signal emissions must include information which will enable a user to obtain UT1 with a precision of at least $0^s.1$.

9. *Designation of the epoch of steps in UTC*

9.1. If UTC is to be advanced, then second 00 will follow $23^h\ 59^m\ 58^s$ of the previous day.

9.2. If UTC is to be retarded, then the second of the previous day $23^h\ 59^m\ 58^s$ will be followed by the next second $0^h\ 00^m\ 00^s$ of the first day of the month.

9.3. The stepped second will be commonly referred to as a "leap" second (in French: intercalaire).

9.4. The time of an event given in the old scale, before the leap second, will be given as a date in the previous month, exceeding 24^h if necessary. The time of an event given in the scale after the step will be given as a date in the new month, with a negative time, if necessary.

Note: Commission 31, taking into account the conflicting requirements of the various users of UTC, including the large number of those requiring immediate knowledge of hour angle, considers that the above represents the optimum solution.

JOINT MEETING OF COMMISSIONS 4 AND 31, ON TIME SCALES, 25 AUGUST 1970

CHAIRMAN: G. A. Wilkins.
SECRETARIES: C. J. A. Penny and A. T. Sinclair.

UNIVERSAL TIME

G. A. Wilkins drew the attention of members of Commission 31 to the resolution of D. H. Sadler (see pp. 60-63) which had been approved at the previous meeting of Commission 4. This resolution requested that adequate means should be provided for making the difference UT1–UTC available to a precision of $0^s.1$ before UTC is permitted to depart from UT1 by more than about $0^s.1$. W. Markowitz asked why a precision of $0^s.1$ was necessary since he doubted whether it was possible to determine positions to the corresponding accuracy of about 100 m. In reply, R. L. Duncombe said that observational errors by navigators were unavoidable, but the time errors should be kept below the level where they would contribute to the result. R. F. Haupt said that the almanacs were designed to allow the determination of positions to 0.1 min of arc, and for this a precision in time of 0.25 sec was required.

The meeting then discussed Resolution No. 1 of Commission 31 (see p. 123). R. L. Duncombe