# 31. TIME (L'HEURE)

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## INTRODUCTION

This report will try to review briefly the work achieved from 1982 to 1984 in different "subjects to be considered by Commission 31 Time" as adopted in Grenoble 1976. It contains also information provided by Commission members, for which hearty thanks are to be given. The limitation of space required the abbrevation of some institution reports.

## MERIT

At IAU Symposium No 82 on "Time and the Earth's Rotation", organized by Commission 19 and 31 at Cadiz, Spain, May 1978 the Project MERIT was initiated. MERIT is a special programme of international collaboration to Monitor Earth-Rotation and Intercompare the Techniques of observation and analysis.

The project includes after an initial short campaign of observation (during 1980) the main campaign of observation from 1983 September 1 to 1984 October 31, the period of data analysis, and a review phase during which the results are to be discussed. It has been proposed that at IAU General Assembly 1985 a review of the scientific results should be presented which will provide the scientific background for the IAU/IUGG recommendations concerning future Earth orientation services.

A great number of observatories with different techniques (Astrometry, Doppler, SLR, LLR, VLBI, CERI) took part in the Project MERIT. The results enable better knowledge on the behaviour of Earth's rotation and consequently also of UT.

## FUNDAMENTALS

At the IAU Symposium No 109 on "Astrometric Techniques" in Gainsville, Jan. 1984, there was a strong feeling among participants that the exact definitions of some of the entities which define (astronomical) space-time are in need of attention. The majority of these entities was conceived at a time when the precisions and accuracies which we can achieve at present were not even dreamed of, and most of these depend intimately on the kinematics of the Earth, whose recently uncovered complexities may make it desirable to redefine some of the current concepts (H.K. Eichhorn).

For all astronomers discussions on general concepts of reference systems are significant. Guinot has proposed quasi-ideal theory-independent reference frames for both space and time. As a result of the discussions in Gainsville it has been decided to create a Working Group on the "Fundamental Concepts of Astronomical Space-Time and their Realization".

Last year consultations took place between interested organisations (BIH, CIPM, IAU, IUGG, URSI, CCIR, BIH Directing Board) on the transfer of the activities concerning TAI from BIH to the BIPM. For this decision it is to be taken into consideration that TAI is based

solely on physical measurements independent of astronomy, that TAI and UTC are of general interest as a basis for numerous technical and public applications and that therefore it is natural to entrust the intergovernmental organization in charge of the metrology of basic physical quantities, CGPM and its bodies (CIPM, BIPM) with TAI and UTC.

OBSERVATION OF UT AND ET ON A ROUTINE BASIS

Astronomical observations for UTO-UTC have been continued on a routine basis in participating observatories to BIH. The BIH has continued the regular computations of UT1 on the basis of a solution by optical astrometry, from the observations of 88 stations in 22 countries. Moreover, provisional raw and smoothed values of UT1-UTC are computed from the combination of the optical astrometry solution with the VLBI results obtained by the U.S. National Geodetic Survey and partly with the CERI results obtained by the U.S. Naval Observatory.

In order to increase the precision and the accuracy of optical astrometric observations in some observatories efforts have been made for the automatization of observation and for other improvements of the instruments (e.g. Chinese observatories, Mizusawa, San Fernando, Potsdam). USNO has completed a new 20 cm PZT and has installed it on the original site of PZT1.

Results on ET2 - TAI were obtained by the Hydrographic Department of Japan (JHD) for the epoch 1981.5, 1982.5, and 1983.5 as 30.60, 30.71, and 30.68 s respectively with the mean error of $\pm$0.04 s by use of the occultation timing data observed by JHD. The services of the International Lunar Occultation Center at JHD have been continued since 1981. Total data reported from 34 countries amount to 43,000.

CLOCKS, T-F STANDARDS AND TIME SCALES

In the last few years an increasing number of observatories with industrial cesium clocks have participated in the formation of TAI (33 laboratories in July-August 1984, operating 140 clocks), but laboratories with primary standards contributing to TAI have not increased. In some laboratories investigations on frequency standards have been made and new primary frequency standards have been constructed.

Highly accurate primary clocks (NRC, PTB) seem to be especially qualified for establishing TAI because of their accuracy and their long term stability. Most of the individual time scales based on sets of industrial c sium clocks show a seasonal variation with respect to the primary clocks of NRC and PTB. This effect seems to be produced partly by the LORAN-C time comparison, partly by environmental effects on the industrial clocks.

Since its introduction on 1972, January 1 the UTC system has gained widespread acceptance as the reference time scale throughout the world not only for practical and scientific application but also as the basis of legal time.

TIME SYNCHRONIZATION AND DISSEMINATION

Different methods have been used for the comparison of time scales: TV, LORAN-C,portable clocks, satellite techniques, VLBI. These methods differ in accuracy and precision, coverage, operational convenience, cost, and availability. Therefore no single system can satisfy all requirements. The necessary accuracy of world-wide

time synchronization now is in the 10 to 1 ns level, in the next decade nano-second accuracy or better is required also for intercontinental time synchronization and comparison.

Most of the regular time comparisons between the laboratories contributing to the TAI were carried out by LORAN-C. For seven months in 1982 measurements NRC-OP and NRC-PTB via satellite Symphonie were used for the atlantic time link between North America and Europe. In 1983 GPS time comparisons using GPS time receivers have been introduced in some laboratories (NBS, USNO, OP/BIH, VSL, PTB, TUG, TAO and laboratories in Australia). The GPS time comparison permitted the start of an active participation of laboratories in Japan and PR China in the establishment of TAI.

Many experiments of time transfer or time synchronization via satellites have been made in last few years. New experiments are planned for the near future. One-way and two-way techniques are used, each of them offering certain advantages. For the one-way method simple equipment can be used but the accuracy is lower than for the two-way technique.

In 1982 the planned LASSO experiment with an estimated accuracy of time synchronization of 1 ns or better failed because of the loss of the carrier rocket. A new LASSO experiment is planned for June 1986.

For the purpose of calibrating propagation time and instrument delay when requested (e.g. LORAN-C, TV), the comparison of time scale by using portable atomic clocks is the most precise operational method over short and long distances. Commercial cesium clocks can give accuracies of about 10 ns.

RELATIVITY

In the field of time scales, time dissemination, and time synchronisation relativistic effects are of importance. The state-of-the-art navigation and communication systems, the nano-second accuracies of clocks need relativistic corrections. Rate changes because of the velocity of satellite- and aircraft transported clocks and of the gravitational potential must be taken into account.

REFERENCES

Because of the limitation of space only a list of major references concerning the work of the commission is given. Complete references to the reports of BIH, observatories and laboratories can be furnished separately on request.

1) Proc. of the 14th (15th) Annual Precise Time and Time Interval (PTTI) Planning Meeting 1982 (1983)

2) Advance Program of the 16th Annual PTTI Meeting 1984

3) BIH Annual Reports 1981, 1982, 1983

4) CCIR, XVth Plenary Assembly, 1982, Recommandations and Reports, Vol. VII, Standard Frequencies and Time Signals

5) BIPM, Comptes Rendus 17$^{e}$ Conférence Générale des Poids et Mesures, 1983

6) Documents on Commission A -"Electromagnetic Metrology", XXI URSI General Assembly, Florence 1984 (to be published)

7) Papers on the IAU Symposium 109, Astrometric Techniques, Gainsville, USA, Jan. 1984

## Report of the Director of the Bureau International de l'Heure

The BIH is organized in two sections: (a) Time, (b) Rotation of the Earth, respectively under the scientific responsibility of B. Guinot and M. Feissel.

The following report will cover the activities on atomic time and some administrative and operational matters common to both sections. The BIH activities on the Rotation of the Earth and related problems are presented to Commission 19.

### ATOMIC TIME SCALES

(a) Time comparisons and participating laboratories.

The International Atomic Time (TAI) and the Coordinated Universal Time (UTC) are reference time scales. But they can also be regarded as a worldwide system of coordination of clocks: to this respect, the time comparisons of remote clocks are crucial.

During the last three years, the major event was the implementation of the time comparisons by the Global Positioning System, GPS. The operational link established between NBS and USNO in June 1981 demonstrated that the accuracy of 10 ns on daily averages was realized, as announced by Allan and others. In 1983/84, many other laboratories acquired GPS time receivers (10 laboratories equipped in Nov. 1984) and, for the first time, the network of permanent and precise time comparisons extended to Far East and Australian laboratories. On July-August 1984, over 140 clocks, which entered in the TAI computations, 78 are directly linked by GPS. Most of the remaining clocks are linked to a GPS-equipped laboratory by common reception of the same LORAN-C station and thus benefit from the GPS advantages.

The following table shows the improvement of the worldwide coordination of time.

| | July-Aug. 1981 | July-Aug. 1984 |
|---|---|---|
| Nr of clocks participating in TAI | 105 | 140 |
| Nr of Laboratories for which UTC-UTC(lab) is published in BIH Circular D | 33 | 38 |
| Nr of Laboratories the clocks of which enter in TAI computations | 26 | 33 |
| Nr of Laboratories for which TAI-TA(lab) is published in BIH Circular D | 8 | 10 |

However some difficulties remain.

The potential accuracy of 10 ns by GPS can be realized by the common view mode, which is well organized by NBS. But this requires also that the delays are correctly handled. In practice, discrepancies of the order of 100 ns can be observed due to the lack of precise definition of UTC(lab), to misunderstandings concerning the cable delays, to the lack of precise measurements of the differential delays between GPS receivers. That shows:

- the possible need of upgrading the time equipment of laboratories in order to make it compatible with a few ns-seconds accuracy,
- the importance to continue clock transportation,
- the interest of a portable GPS calibration system (planned by USNO),
- the need of a good coordination concerning the adopted delays.

Concerning the last item, the BIH has begun to collect informations on the adopted delays. The BIH also suggested that the GPS coordination be a topic for a future meeting of the Consultative Committee for the Definition of the Second, to be held in 1985.

In the current work the BIH uses either its own evaluations of the UTC(i)-UTC(j) from the GPS common views, either evaluations from other laboratories. In this domain also a coordination is desirable in order to avoid duplication of work.

Studies of the statistical properties of the GPS time comparisons have been made, especially thanks to the loan to BIH of GPS time receivers by NBS and by Stanford Telecommunications Inc. (these instruments being operated in cooperation with the LPTF at the Paris Observatory).

(b) Computation of TAI and UTC.

No changes have been made in the BIH algorithms. The free running time scale EAL is derived from all the clocks. Then the second of EAL is compared to the realization of the second by the primary standards and a steering process is used to derive TAI from EAL, implying frequency steps of $0.2 \times 10^{-13}$ when needed.

The primary clocks PTB CS1, NRC Cs V and VI-A, -B, -C, are used both as clocks with an input in EAL, and as frequency standards for the steering. The frequency standards functioning in a discontinuous mode, NBS-5 and RRL Cs1 are used for the steering only.

The long term stability of the participating clocks still continues to improve, as shown by the percentage of clocks reaching the (unchanged) maximum weight accepted by the BIH algorithm: 35 % over January - August 1984, instead of 28 % over January - August 1981.

A number of studies on the time scale algorithms has been performed, but did not enter in the practice of the TAI computations. The possibility of modeling annual frequency variations of the clocks is being considered and will be tested when a sufficient amount of past data obtained by the GPS will be availabe.

The alignement of BIH results with the GPS data and the clock transportation in 1983 was attempted, as explained in a note "Use of GPS time comparisons for establishing TAI in 1983 and related problems", which is available on request.

The operation of the UTC system raised no special problems.

DATA PROCESSING AND DISSEMINATION OF RESULTS

Much effort was devoted to the simplification of the current work of both BIH sections. With the help of USNO, the General Electric Mark III system is used intensively. A set of mini-computers has been installed in the BIH offices at Paris Observatory; they are used for automated data transfers, local computations, and as terminals on several computation centers or systems. The edition of Circular D and of most of the pages of the BIH Annual Report has been fully automated.

The main series, Circular D and BIH Annual Report are sent to about 750 addresses. Circular D and other BIH results are available through the GE Mark III System.

BIH ORGANIZATION

In 1985, the Time section of BIH will be moved from the Paris Observatory to the Bureau International des Poids et Mesures (BIPM) in the outskirts of Paris. Computing facilities are being installed at BIPM, and arrangements are being made so that this move will affect neither the contributors to the BIH work, nor the users of its results. The Section of the Rotation of the Earth remains at the Paris Observatory where it receives an increased support.

ACKNOWLEDGEMENTS

There are so many participants to the BIH work, who not only contribute data, but help the service by constructive exchange of ideas, by sending visiting scientists, that it is not possible to thank individually each of them. However, we would like to mention some organizations to which we are especielly indebted for their help.

. USNO for loan of equipment, the administration of the GE Mark III catalog, the distribution in USA of BIH publication.
. NBS for loan of a GPS receiver and for the coordination of GPS common views.
. Stanford Telecommunications Inc., for the loan of a GPS receiver.

B. Guinot
Director

## Reports of Observatories and Laboratories

A. BELGIUM. OBSERVATOIRE ROYAL DE BELGIQUE, UCCLE/BRUSSELS (ORB)
(Reported by P. Paquet)

The astronomical observations for the determination of UT are discontinued since January 1979.

The Doppler tracking station integrated into the DMAHTC Polar Monitoring Service has continued permanent operation. For the time scaling of the Doppler tracking network the satellite time marks are recorded during all passes. The standard deviation is of the order of 10 microseconds.

The Belgian time service is still provided with 2 HP 5061 A Cesium Standards, a visual Loran-C receiver operating on Sylt, and a TV receiver used for daily time comparisons between the Observatories of Brussels and Paris.

According the method used to realize the time synchronisation: Transit satellites, Loran-C or TV signals the precision is respectively 10, 0.20, 0.05 microseconds. In 1984 a receiver for time signals synchronisation via the GPS system has been ordered. Delivery is expected in late 1985.

B. BRAZIL. OBSERVATORIO NACIONAL, RIO DE JANEIRO (ONRJ)
(Reported by P. Mourilhe Silva)

Time keeping for legal time transmissions in UTC and all other national applications of Time and Frequency, is achieved with two HP 5061 A commercial Cesium Standards, (one standard tube and one high performance tube). Two Rubidium Standards TRACOR 304D and HP 5065 A are also kept at Rio de Janeiro installations of the Time Service. A third Rubidium, HP 5065 A is at a new station in Brazilia.

By line-10 TV method and clock transportation, the Cesiums and Rubidiums of other institutions are intercompared.

For global synchronization, some clock trips were made to Rio de Janeiro by USCG, ONBA and PTB.

The Time Service was qualified by INMETRO (National Institute of Metrology, Standardization and Industrial Quality), as the National Primary Laboratory for Time and Frequency measurements and basic researches.

The time reference was supplied during the last experiments of VLBI, from December 1983 to February 1984, between Itapetinga Radio Observatory (INPE) and foreign Observatories. For the future time transfer by this way is foreseen.

C. FEDERAL REPUBLIC OF GERMANY, DEUTSCHES HYDROGRAPHISCHES INSTITUT, HAMBURG (DHI)
(Reported by H. Enslin)

Observations of UTO - UTC with the PZT - made from 1957.7 onwards without interruptions worth to be mentioned - have been continued; the results have been communicated weekly to the BIH and the IPMS.

The time-scale UTC(DHI) has been produced by a HP 5061 A Cesium Standard combined with a micro-stepper. It has been compared regularly with the time-scales of other institutions via Loran-C and TV. The DHI was included yearly in portable clock trips of the USNO. Time-signals have been transmitted regularly on 4 frequencies (2 MF, 2 HF).

D. FEDERAL REPUBLIC OF GERMANY. PHYSIKALISCH-TECHNISCHE BUNDESANSTALT, BRAUNSCHWEIG (PTB)
(Reported by K. Dorenwendt)

The PTB primary Cesium beam standard CS1 has been operated continuously generating the time scales UTC(PTB) and TA(PTB).

After two and a half year of duration the two-way time transfer between PTB, OP (France) and NRC (Canada) via the Symphonie satellite had to be stopped in August 1982. It could be shown that the primary standards at PTB and NRC agreed in frequency within the claimed uncertainties of $5.10^{-14}$. A comparison of the time transfer across the Atlantic via Loran-C and via the Symphonie satellite revealed seasonal variations of the order of 1 µs in the Loran-C link.

From February to December 1982 one-way time transfer via the test satellite OTS-2 were executed between different timing institutes in Europe. Since July 1983 the satellite system GPS has been used for intercontinental time comparisons with an uncertainty of the order of 10 ns.

In June 1983 experiments with a pseudo-random phase noise (phase modulation $\pm$ 10°) on the frequency of the transmitter DCF77 have been started. First results showed that an attribution of the transmitted second markers to a period of the carrier can thus be achieved.

An experimental Cesium beam standard using atoms with an average velocity of 400 m/s was put into operation in 1982. The apparatus allowed to determine the phase gradient in a Ramsey resonator and the resulting uncertainty contribution to the frequency of a primary standard. The influence of field inhomogeneities on the frequency of Cesium beam standard will be investigated next. The work on three new primary standards is continued.

E. GERMAN DEMOCRATIC REPUBLIC. ZENTRALINSTITUT FÜR PHYSIK DER ERDE, POTSDAM (ZIPE)
(Reported by G. Hemmleb)

Regular time and latitude determinations are being continued with one astrolabe Danjon and one PZT. The results are being transmitted to the international centres BIH and IPMS and published in two-monthly booklets.

Special efforts were made to obtain a large number of observations during the MERIT Main Campaign. Beginning with 1984 January 1 all observations were reduced using the MERIT Standards. Also the observations during the period from 1983 September through December were re-reduced using the MERIT Standards.

The efficiency of the PZT 2, which is working since 1980, was estimated using the observation results from 1981. The results confirm that the PZT 2 is expecially suited for precise time and latitude determinations in geodynamic observatories.

The investigations for the development of a Photoelectric Zenith Tube (PEZR) were continued.

An independent time scale TA(DDR) is computed by the Amt für Standardisierung, Meßwesen und Warenprüfung (ASMW) using the data of 4 cesium standards of ASMW and ZIPE. Time scale UTC(ZIPE) is based on 1 HP cesium clock 5061 A. This scale is compared daily with UTC(ASMW) using TV method. UTC(ASMW) on its part is based on 3 atomic clocks (1 Ebauches B 5000 and 2 Oscilloquarz 3200).

For time comparisons with time services BIH, TP, PTB, and AOS the TV method is used. Receptions of LORAN-C station Sylt and phase tracking of VLF transmitters were also carried out.

F. ITALY. ASTRONOMICAL OBSERVATORY, CAGLIARI (CAO)
(Reported by E. Proverbio)

The Time Service of the Cagliari Observatory is based on 2 commercial cesium standards and 2 quarz clocks. During the period 1981-1984 the reference local time scale has been continuously compared by mean VLF and Loran-C techniques. The UTC (CAO) scale was also compared via television pulses with IEN (Turin) and ISPT (Rome).

The accuracy of the UTC(CAO) scale versus UTC is about $1\text{-}3\times10^{-13}$. The result of time and frequency comparisons are published in the Monthly Bulletin of Cagliari Astronomical Observatory and in Circular D of the BIH.

Relativistic effects on physical time scales has been studied and particular techniques for time dissemination & synchronisation were investigated.

G. JAPAN. TOKYO ASTRONOMICAL OBSERVATORY (TAO)
(Reported for all Japanese establishments by Sh. Aoki)

Astronomical observations for time and latitude have been made regularly with the PZT. From the beginning of 1984, astronomical observations have been referred to the new system of IAU astronomical constants.

UTC(TAO) has been kept with a Master Clock, selected out of 5 HP cesium clocks, controlled with a phase-microstepper.

Domestic time comparisons of UTC clocks have been continued by a cesium portable clock of TAO regularly twice a year against the ILOM, NRLM, RRL, and GSI (Geodetic Survey Institute), and KGO (Kanozan Geodetic Observatory). Also TAO clocks have been linked with TV-signals. Clock comparison between the TAO and the USNO with a flying clock of the USNO has been made regularly once a year with an accuracy of 0.1 micro-seconds by courtesy of the USNO.

The receptions of Loran-C signals from the Okinawa slave station (Northwest Pacific Loran-C chain) was commenced on 1 September 1983. The measurements of Loran-C from the Iwo-Jima Master Station (9970-M) and from the Okinawa Station (9970-Y) with Loran-C receiver (Austron 2000C) have been continued with an accuracy of the order of 0.1 micro-seconds.

From 1 April 1983, the TAO has started formal receptions of the Global Positioning System (GPS) timing signals with a GPS receiver (STI Model TTS 502) and has continued regular time comparisons among the TAO and six laboratories: OP, PTB, TUG, USNO, VSL, and NBS with an accuracy of the order of a few 10 nano-seconds.

The results of time comparison via the GPS and the Loran-C time transfer are transmitted every week by the General Electric (GE) Mark III system. By these means, the TAO clocks and the Asian clocks, which had been hitherto excluded from contribution to the International Atomic Time scale (TAI), have effectively participated in TAI from the beginning of 1984.

H. JAPAN. INTERNATIONAL LATITUDE OBSERVATORY OF MIZUSAWA (ILOM)

1. Observational Activities: Time and latitude observations have been made with the PZT No. 2 and Danjon astrolabe. The fully automated electronic astrolabe has been subjected to a preliminary observation since July 1983 and will join to a regular observation after the MERIT main campaign. UTC(ILOM) has been maintained with a selected HP cesium clock out of four.

Loran-C signals from Iwo-Jima and Hokkaido stations and Omega signals from Hawaii have been received for the clock comparison. The comparison by TV has been made against clocks in NRLM, RRL, and TAO. Loran-C signals from the secondary station Hokkaido has been received at ILOM since April 1982. Delay times of the receiving systems and propagation times of the Loran-C signals were investigated to examine a consistency between these two Loran-C data and also the portable clock data. Horiai et al. (1983) have pointed out the discrepancy in these and institutes located around Tokyo area. The portable clock of USNO visited ILOM in November 1983 and showed a discrepancy of around 4 μs between portable clock data and the Loran-C data. An experiment is planned by ILOM to determine the propagation time of Loran-C signals over land this year and forth.

2. Astronomical Reference Frame: Yokoyama (1983, 1984) presented a full description of the method for reducing the optical astrometry observations at each station, as well as at the international centers, in accordance with the adoption of the FK5 system and the IAU (1976) System of Astronomical Constants for 1984 Jan. 1 onwards. Yokoyama and Tanikawa (1983) completed a standard FORTRAN program for computing apparent places of stars based on the new astronomical constants and circulated the program to all countries where optical

astrometry instruments are in operation.

3. Reference Frame: Fujii and Murakami (1982) derived the corrections of the PZT star places of Mizusawa using the data of the Mizusawa new PZT, and compared their results with those of the Tokyo PZT observations and the NPZT 74 based on an improvement of the Tokyo PZT Catalogue (Fujii, 1981).

4. Astronomical Instrumentation: A fully automated pendulum astrolabe (Automatic Electronic Astrolabe) was designed, constructed, and tested at the ILOM. The telescope is controlled by the mini-computer which is installed at 170-meter distance, and is drived by seven pulse (stepping) motors. Star-image motions along both azimuth and altitude directions are photoelectrically detected by ETD (Elektronic Transit Detector). ETD output signals are used for tracking, guiding, and correction for observed time. An instrumental accuracy is expected to be about 0.001. The automatic astrolabe can be used for observations of two different almucantars with two astrolabes. This gives a way for a precise determination of the star place and EOP simultaneously.

5. Reduction Method: A new method for the reduction of PZT observations was proposed (Manabe and Kitago, 1981). In this method, the UTO-UTC and latitude for individual stars, and the plate parameters are simultaneously estimated by solving a non-linear least-squares problem. Linearized equations of observation are solved to give approximate but explicit expressions of the estimates and their dispersions in terms of the measured coordinates. It was shown that the scale value is determined mainly from the diurnal motion. The method is applied to the data of the Mizusawa PZT.

An algorithm has been developed at the IPMS to provide a frequent series of the Earth orientation parameters (EOP). Vondrak's method was generalized for calculating smoothed EOP, directly from individual values of observed time and/or latitude. Statistically optimum smoothing factors can be determined with the aid of the procedure in which a Bayesian information criterion is minimized. This method was applied to the astrometric observations which have been accumulated at the IPMS, and the estimated EOP for every 0.5 days was compared with the EOP from the new techniques such as VLBI, LLR and SLR. Agreement was generally close with one another, and this means that observations with optical astrometry could reveal short periodic or irregular variations of the Earth's rotational speed, whose amplitude is a few milliseconds of time (Manabe et al, 1982).

I. JAPAN. HYDROGRAPHIC DEPARTMENT OF JAPAN (JHD)

For the purpose of establishing the relation between ET2 and TAI the observations of occultations of stars by the Moon have been continued at the head office in Tokyo and branch observatories. Around 1000 timing data including 550 photoelectric data have been obtained every year.

Results on ET2-TAI based on the data obtained above for the epoch 1981.5, 1982.5 and 1983.5 were: 30.60, 30.71 and 30.68 s respectively with the mean error of $\pm$ 0.04 s. Details are published in Data Report of Hydrographic Observations, Series of Astronomy and Geodesy and Japanese Ephemeris.

The services of the International Lunar Occultation Center have been continued since 1981. Total data reported from 34 countries amount to 43,000.

K. SPAIN. INSTITUTO Y OBSERVATORIO DE MARINA DE SAN FERNANDO CADIZ (IOM)
(Reported by A. orte and J. Benavente)

Series of observations with the Danjon Astrolabe for the determination of UTO and polar coordinates have continued up to May 10, 1983. At this date, the instrument has been disassembled in order to proceed to its modernization by incorporating the "full pupil" feature. Some difficulties with micrometer movement system have impeded resuming the series of observations.

Timekeeping activities, based upon the operation of six Cs beam atomic clocks have continued along the present term; to improve the environmental operating conditions of the clocks, thermal control chamber, capable for three or four standards, has been specified and ordered. Solid state, electronically controlled cooling, will provide a high degree of higrometric and thermal stability. This chamber is to be fully operative in the last quarter of 1984.

San Fernando has been included in USNO flying clock trips for global synchronization.

Operation of the mobilde t/f laboratory was continued to satisfy national needs, and four calibration and synchronization trips have been achieved. Link with INTA/NASA space station at Robledo de Chavela (Loran C) includes now a GPS timing receiver at Robledo along with periodical comparisons with our time scale by means of clock transport.

Funds have been appropiated for the purchase of a GPS receiver to be operated at San Fernando, hopefully by mid 1985.

L. U.K. ROYAL GREENWICH OBSERVATORY, (RGO)
(Reported by J. Pilkington)

During this period the RGO has been obliged to reduce both the number of staff employed and its expenditure on equipment and operations. The effects have been felt particularly strongly in the fields covered by Commissions 19 and 31 although, since the satellite laser ranging facility at RGO commenced regular operation in 1983 October, the RGO has been contributing more accurate data than ever before to the international programmes for the determination of Earth-orientation parameters. It has, however, been necessary to stop observations with the Herstmonceux PZT, and unless additional sources of funding can be found the work of the atomic-time service will soon be directed almost exclusively towards meeting the requirements of the RGO's observational programme.

Throughout 1982, 1983 and 1984 the RGO has continued to form the independent atomic timescale TA(RGO) from the readings of up to eight commercially-produced cesium-beam clocks on site. Two of these, models HP 5060A which were purchased before 1968, are no longer in service and several of the others are known to be working at a level of predictability substantially below the best that may be achieved by such clocks. Although TA(RGO) has often been explicitly based on the readings of only two clocks from the ensemble, the process of clock evaluation requires that several more clocks must be kept in undisturbed operation and so limits the opportunities for diagnostic investigation.

The Time Service has also continued to publish results obtained by using the related UTC(RGO) scale as a reference in monitoring four Loran-C and two VLF signals. These results have provided the main link between the clocks and timescales of RGO and those of other establishments; they are used by the BIH in the formation of TAI and they contribute to the accuracy and effectiveness with which the systems being monitored may be used elsewhere for position-fixing or as sources of precise time and frequency.

M. USA. U.S. NAVEL OBSERVATORY, (USNO)
(Reported by D.D. McCarthy)

Optical observations were made with Photographic Zenith Tubes (PZT's) in Washington., D.C. and at the Time Service Substation in Richmond, near Miami, Florida. Two PZT's were operated at each site: a 20 cm (PTZ3) and a 65 cm (PZT7) in Washington, and two 20 cm instruments (PZT2 and PZT6) in Richmond. A new 20 cm PZT at Washington (PZT8) has been completed and is being installed on the original site of PZT1. Stars previously identified as supplemental stars have been added to the regular observing programs at Washington and Richmond, and at the Richmond Substation, several photographic plate and filter arrangements were tested in order to find a low-cost combination which would yield satisfactory PZT observations. The Kodak "M" plate plus a light yellow filter was adopted for routine use.

A new radio antenna was constructed for the Green Bank connected Element Interferometer (CEI). Located in Monterville, West Virginia, it is 14 meters in diameter, and forms one end of the new 1-3 baseline.

Radio observations were obtained daily with the CEI throughout the period. Measurements were made of two 35-km-baseline vectors, to determine Earth orientation parameters.

A new atmospheric model and new source coordinates were adapted in the CEI reduction on 1 January 1984. An improved estimate of UTO based only on the variations of the East-West components of the 1-4 baseline was made available to users.

Plans are underway to install a VLBI Mark III Correlator at the Naval Observatory. This is a joint effort with Naval Research Laboratory (NRL), the National Geodetic Survey (NGS) and the National Aeronautics and Space Administration (NASA).

VLBI time transfer experiments have been carried out in this period with VSL and Onnsala using the NRL antenna at Maryland Point. Studies of the use of the Global Positioning System (GPS) for time transfer indicate that remote scale information is possible to obtain with an accuracy better than 50 nanoseconds.

Two Smithsonian Astrophysical Observatory (SAO) Hydrogen masers were installed in 1983.

Until June, 1984 two cesium reference clocks were maintained to within 50 nanoseconds of UTC(USNO, MEAN). Since June, one of the cesium reference clocks was replaced by a hydrogen maser reference clock, and new computer algorithms to steer the maser to a preliminary estimate of UTC(USNO, MEAN) were developed.

The Data Acquisition and Control System (IBM Series 1 and HP 1000) collected data from approximately 70 cesium clocks about 20 of which define UTC(USNO, MEAN).

Seven cesium clocks contributed to the time scale at Richmond, Florida. This time scale was synchronized with USNO (MC) to within 150 nanoseconds.

All available modern techniques have been uncorporated into the USNO algorithm to determine polar motion and Universal Time. The accuracy of these estimates is $\pm$ 0.005 in polar motion and $\pm$0.0014 in UTI-UTC.

The services available on the General Electric Mark II Computer Network have been expanded. Many Time Service publications and data obtained from systems such as the Global Positioning System and Loran-C are exchanged on the RC28 Catalog, which is composed of laboratories and observations concerned with timing matters.

Regular publications of astronomical time and polar motion information continued in the weekly Earth Orientation Bulletin, Time service Announcement Series 7. Predictions of polar motion and UT1-UTC were continued and published in this bulletin. The predictions were also disseminated through the GE Mark III and the Time Service Automatic Data Service (ADS), accessible by telephone through the HP 1000 at Time Service headquarters.

Timing information continued to be recorded from eleven VLF stations (U.S. Navy, OMEGA and GBR), eleven LORAN-C chains, television stations, five GPS satellites, and six transit satellites.

Investigations were carried out on past values of the length of day, the nature of the variations of the length of day, possible use of a super conducting gravimeter for the determination of Earth orientation parameters.

N. USSR.
(Reported by N. Blinov)

Astronomical determination of the Universal Time was carried out at 13, and since August, 1984 at 14 time services with photoelectric passage instruments (12), visual passage instruments (2), Danjon prismatic astrolabes (4) and photographic zenith tubes (2).

For reductions of passage instrument observations the merged catalogue of the USSR time services (CTS) was used. For reductions of photographic zenith tube and prismatic astrolabe observations, catalogues were used which were improved by original observations. Right ascensions are being calculated since January 1, 1984 in the new FK-5 system using the new IAU reduction constants and the new computational methods. Older observations (September 1983 - January 1, 1984) were re-reduced in the new system.

The results of the astronomical determinations of time were telexed weekly to the International Time Bureau (ITB) and sent by post to the InternationalarPole Motion Service.

The Universal Time was calculated at the Main Metrological Centre (MMC) of the State Service of Time and Frequency (SSTF USSR)

by joint reduction of the results of astronomical observations made by all the time services of the USSR as well as by 10 time services of Czechoslovakia, Poland, GDR, Romania, Mongolia, and Yugoslavia taking part in the operation of the SSTF USSR.

The total number of astronomical determinations of time available for the joint reduction during a calendar year amounted to about 6000. For urgent (preliminary) calculations of the Universal Time, preliminary values of the co-ordinates of the pole were used which were telexed weekly from the ITB to the SSTF USSR. Preliminary values of the Universal Time and of the co-ordinates of the pole were published weekly in the A series of the SSTF bulletins. Accurate values of the Universal Time calculated using the final values of the co-ordinates of the pole according to the ITB data were published monthly in A series bulletins and in the three-month bulletins of the E series (Universal Time) along with accurate values of the co-ordinates of the pole and with the results of astronomical determinations of time.

The national scales of the atomic and co-ordinated time of the USSR were based on the State Primary Standard of Time and Frequency consisting of a metrologic cesium reper, hydrogen storages of the dimensions of time and frequency units, hydrogen, cesium, and rubidium clocks - storages of time scales.

To intercompare the scales of time services, to compare them with State Standards and with the ITB scale, different canals of communication were used: TV, meteor canals, receiving signals of LW and SLW bands, as well as transportation of a movable clock.

G. HEMMLEB

President of the Commission