31. TIME (L'HEURE)

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INTRODUCTION

The work of IAU Commission 31 members is contained mainly in the reports contributed by members and listed below. Unfortunately because of limitations in space, journal references to the work could not be listed. Readers interested in any of the topics mentioned in the reports are urged to contact those who have submitted that particular report for further information.

During the period from 1984 to 1987 the membership list of Commission 31 was revised to reflect new addresses and telephone numbers. Those listed as members previous to this period who were no longer concerned with Commission matters were deleted from membership. Members were also asked to submit their recommendations for future research in the area of time. The result of this poll was the formation of two working groups.

The first group, formed with D. Allen as chairman, is entitled "The Use of Millisecond Pulsars and Timing of Pulsars". The second is entitled "Time Transfer with Modern Techniques" with H. Fliegel serving as chairman. Both of these groups will present their findings and recommendations to the 1988 Baltimore General Assembly. In the period covered by this report the Commission sponsored IAU Symposium 128 at Coolfont, West Virginia (USA) entitled "The Earth's Rotation and Reference Frames for Geodesy and Geodynamics". The papers presented at this meeting are contained in the Symposium proceedings published by D. Reidel and edited by Wilkins and Babcock.

Many members of the Commission took an active part in the success of Project MERIT which resulted in the creation of the International Earth Rotation Service which began operation on 1 January 1988 providing information on UT1-UTC as well as the motion of the pole of rotation. During this period the responsibility for the formation of the UTC time scale was transferred from the Bureau International de l'Heure to the Bureau International des Poids et Mesures. The importance of the proper implementation of the theory of relativity to timekeeping remained an issue for research and discussion. Important developments in the transfer of precise time also took place in this period. These are mainly concerned with the development of the Global Positioning System, but other space techniques were also shown to be useful in the area of time transfer. These topics as well as many more important developments are contained in the individual observatory and laboratory reports which follow. Because of the severe space limitation for this report, the reader is urged to consult these reports for more detailed information.

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BUREAU INTERNATIONAL DE L'HEURE
(BUREAU INTERNATIONAL DES POIDS ET MESURES), FRANCE
(Reported by B. Guinot)

Formation of TAI and UTC

The transfer of BIH activities on atomic time took place in April, 1985. A team of five persons, staff members of BIPM, is in charge of TAI. The BIH has continued to produce TAI and UTC under the form of corrections to the master clocks of timekeeping laboratories, given at 10-day intervals. These corrections are disseminated monthly by Circular D and the General Electric Mark 3 system.

The first step consists in establishing a free atomic time scale EAL with stable, but not necessarily accurate, clocks. The number of clocks processed by the BIH stability algorithm has reached 173 in 1986, among which are 6 primary clocks (at NRC and PTB) and about 10 hydrogen masers. Some of the latter rival the best primary clocks for the long term stability (τ = 2 months) and have no apparent frequency drift. The frequency of EAL is estimated from the calibrations performed by 10 frequency standards located in Canada, Fed. Rep. of Germany, Japan, USA, and USSR.

The relationship between TAI and EAL includes a frequency offset which is modified by steps of 2×10^{-14} in order to maintain the accuracy of the TAI frequency. However, this steering has not been applied since February 29, 1984. Since that date TAI runs as a free time scale, its frequency remaining nevertheless in agreement with the data of the best primary standards, within a few units of 10^{-14}.

Development of the Time Links

In March 1987, 38 laboratories or national consortiums of laboratories participated in the establishment of TAI and UTC. Twenty of them operated GPS time receivers. In addition, four countries are soon expected to join the TAI club, Argentina, India, Israel, South Africa.

In 1986, the responsibility for establishing the schedules for simultaneous tracking of GPS satellites has been transferred from NBS to BIH/BIPM. The principles orginated by NBS, according to which each area of the world should be linked to a maximum of other areas, have been kept. However, with the increase in the number of areas and the future deployment of the GPS system, a different organization of the common views might keep the number of daily tracks at a reasonable level, while increasing the accuracy. One could have a small network of highly accurate long distance links complemented by regional links. To investigate this possibility, the BIH has undertaken several studies: improvement of the models for ionospheric refraction by using dual frequency observations of other systems; improvement of the models of orbits; and experiments in cooperation with other laboratories on ultra-accurate, short-distance links.

Jointly with the NBS, the BIPM has measured the GPS receiver and antenna delays of laboratories in Europe and the USA by carrying a GPS receiver taken as a reference. Biases up to 100 ns have been found. It is intended to pursue these calibrations. Most of the GPS time comparisons used in establishing TAI are processed by the BIH. The agreement with computations made by other countries is normally within a few nanoseconds. The Loran-C time comparisons have been entirely reorganized in order to link the laboratories by simultaneous tracking of the same station. Daily measurements are then used in a similar way as GPS data. A substantial improvement has been obtained, but the comparison with GPS has confirmed a seasonal variation in the Loran-C time comparisons which may reach several tenths of a microsecond. To illustrate the performances of the time comparison methods, we have considered the scattering of the ten-day averages of the TAI-TA (lab), after removing a trend by using a high-pass filter with cut-off frequency of 60 days^{-1}. The quadratic mean of the residuals, for the years 1985 and 1986 ranges

for GPS, from 8 to 17 ns (average = 12 ns),
for Loran-C, from 31 to 54 ns (average = 44 ns).

Other Studies

(a) Tests on real data have shown that the linear production of the clocks rates is optimum with the rhythm used in the BIH algorithm. But with the advent of more precise time comparisons, new studies of the predictions are needed and have been undertaken. A major difficulty remains in the existence of seasonal variations of the clock rates, the period involved being a large fraction of the life of the clocks.

(b) An improved atomic time scale for pulsar studies has been established and made available. Since 1977 its maximum departure from TAI has been 9 μs.

(c) The definition of TAI in general relativity has been considered. The relationship between TAI and the time-like argument of dynamical theories has been discussed by Seidelmann and Guinot.

(d) A detailed study of the non-rotating orgin and its application to the definition of UT1 has been completed in cooperation with Paris Observatory.

SHANGHAI OBSERVATORY, SHAANXI ASTRONOMICAL OBSERVATORY
BEIJING ASTRONOMICAL OBSERVATORY, BEIJING INSTITUTE OF RADIO METROLOGY AND MEASUREMENT, NATIONAL INSTITUTE OF METROLOGY, INSTITUTE OF GEOPHYSICS, CHINA.
(Reported by Y. R. Miao)

There are 6 institutes which are engaged in time service in China. They are: Shanghai Observatory; Shaanxi Astronomical Ovservatory; Beijing Astronomical Observatory; Beijing Institute of Radio Metrology and Measurement; National Institute of Metrology; Institute of Geodesy and Geophysics.

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Shanghai Observatory's major purpose in time research activities is to serve the VLBI system at Shanghai Observatory and the Chinese VLBI network which is being developed. The Hydrogen masers which have been used at Shanghai Observatory were improved again in 1986. The frequency stability for periods of several hours is 5×10^{-15}. A transportable Hydrogen maser which has been developed at Shanghai Observatory for the Chinese VLBI network was successful in early 1987. Time comparisions using the Japanese GMS satellete ranging signals between Shanghai Observatory and RRL are being made routinely. The precision of the time comparision is about ±15ns. During recent years, Shanghai Observatory's atomic time scale which is established by using 3 HP commercial Cesium clocks has reached much better performance.

In reference frame reseach, Shanghai Observatory has discussed the definition, application, research, and transformations of the solar system barycenter and Earth-centered frames in detail, and obtained some good results in satellite laser ranging processing.

Shaanxi Astronomical Observatory has two stations for transmission of time signals, a short-wave transmitting station (BPM), and a long-wave transmitting station (BPL). An intensive investigation with ground-wave propagation of long-wave signals was made in recent years. The synchronization precision within a 2000-km range for the complex condition of propagation path has been able to reach ±0.5 μs. The synchronization precision using the TV signal of the Russian Screen Satellite is ±3 μs which has been achieved within China. Meanwhile, time synchronization research through a Chinese satellite is also being made to obtain higher precision. In addition to keeping the local atomic time scale, Shaanxi Astronomical Observatory is responsible for the Joint Atomic Time System which is composed of the HP commercial Cesium clocks of five institutes mentioned above except the National Institute of Metrology. By using ionosphere D-Layer data observed for 6 years, Shaanxi Astronomical Observatory has determined the ionospheric parameters and the pattern of activities for ionosphere and radio wave absorption, etc. With these investigations, the timing precision for the sky-wave of long-wave signals has been able to reach the order of 10^{-12}.

The Institute of Geodesy and Geophysics joined the Joint Atomic Time System with its 3 HP commercial Cesium clocks. Using the reception of short-wave time signals, research of near-distance progagation characteristics of short-wave signals has obtained very good results.

Beijing Astronomical Observatory has been using HP commercial Cesium clocks to control a Chinese national radio broadcasting station which has a timing program for civil purposes. At present, it is planned to put time code into the time signal broadcast. Also, HP commercial Cesium clocks of Beijing Astronomical Observatory have joined the Joint Atomic Time System.

The National Institute of Metrology has also established a local atomic time scale with its HP Cesium clock. In addition, the HP commercial clocks are being used to control frame pulse and line pulse signal of TV pictures for the national central TV brodcasting station, so as to be used for the purpose of TV synchronization. The primary Cesium standards which were developed at the National Institute of Metrology have an accuracy of $3x10^{-13}$.

The Beijing Institute of Radio Metrology and Measurement is engaged in time metrology with several HP commerical Cesium clocks and two hydrogen masers which were made in China. Meanwhile, Bejing Institute of Radio Metrology and Measurement has developed crystal circuits for many years, and achieved better performance.

In China, investigations of the relationship between time definition, time coordinates, relativity, and time metrology have been made in recent years. The determination of more accurate time periods by using pulsars is also being investigated in China. We have started to use the GPS timing receiver for international time comparison. Currently VLBI, Solar-Earth investigations, and satellite geodesy as well as space techniques and earthquake prediction have begun to use more stable and accurate time and frequency standards in China.

ZENTRALINSTITUT FUER PHYSIK DER ERDE (ZIPE), POSTSDAM, DDR
(Reported by G. Hemmleb)

The time scale UTC (ZIPE) is based upon one HP Cesium clock 5061 A. UTC (ZIPE) is compared daily with UTC (ASMW) using the TV method. UTC (ASMW) is based on two atomic clocks (one since 1987.0). For time comparison against clocks of PTB, DHI, TP and AOS the TV method is also used. Furthermore, Loran-C signals from Sylt were received for time comparison. The ZIPE was included in the regular portable clock trips of SU.

Throughout 1985, 1986, and 1987 the Amt fuer Standardisierung, Messwesen und Warenpruefung (ASMW) has continued to form the independent atomic time scale TA (DDR) from the readings of 3 (two since 1987.0) commercially produced Cesium clocks of ZIPE and ASMW. Time and latitude observations with PZT 2 were continued, whereas observations with the Danjon astrolabe (OPL 10) - made from 1957.7 onwards without interruption - were discontinued since January 1986. A Photo-eletric Zenith Tube (PEZR) was constructed. Preliminary observations are planned still in 1987. The results of time observations and comparisons are communicated weekly to BIH, IPMS, and to the time service of USSR. They were published in quarterly series bulletins.

DEUTSCHE FORSCHUNGS-UND VERSUCHSANSTALT FUER LUFT-UND RAUMFAHRT (DFVLR), Oberpfaffenhofen, F.R. GERMANY
(Reported by S. Starker)

From Oct. 30 to Nov. 6, 1985 in the first German Spacelab-Mission D1 a Cesium and a Rubidium clock were flown in an orbit of 326 km height. During this experiment, called NAVEX, the onboard clocks were compared with ground clocks using a two-way method with PN-code signals at 1.5 GHz. For the data transfer spread spectrum techniques were used. The slope between onboard and ground clocks could be measured with an uncertainty of ±1.6 x 10^{-14} during 3 days. The expected relativistic effects (velocity and gravitational effect) were $\Delta f/f = (-3.3009 + 0.3538) \times 10^{-10} = 2.9471 \times 10^{-10}$. The measurement result agreed with this value within 0.1%.

In connection with this experiment 4 clock transportations were accomplished between PTB-Braunschweig and DFVLR-Munich with parallel GPS-time comparisons. The deviations between both methods were in every case smaller than 5 ns.

Before and after the D1-mission, the flight clocks at Cape Kennedy were compared with the Cesium clocks at DFVLR-Munich via GPS with a frequency uncertainty of ±1 x 10^{14} during one week.

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

The time signal transmissions of the Deutsches Hydrographisches Institut (DHI) were terminated on October 13, 1985, and the high-precision time comparisons on December 31, 1985. The Cesium clocks were switched off on January 3, 1986. One of the clocks (HP 5061 Ser. No. 11050, Opt. 004) was given to Wettzell where it contributes to TA1; the other clock is in operation in Munich for research work on GPS.

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

The Time Service of the Cagliari Observatory is based on 2 commercial cesium standard and 2 quartz clocks. During the period 1984-1987 the local reference time scale has been compared continuously by 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 1-3x10^{-13} The results of time and frequency comparisons are published in the Monthly Bulletin of Cagliari Astronomical Observatory and in Circular D of the BIH.

Particular techniques for time dissemination and synchronization were investigated. The Time Service actively participated in the MERIT Campaign and is participating in the new LASSO enterprise.

ISTITUTO ELETTROTECNICO NAZIONALE, ITALY
(Reported By P. G. Galliano)

Since May 1985, Istituto Elettrotecnico Nazionale (IEN) has been using GPS satellite reception to relate UTC (IEN) to the international time scales. Nevertheless, the reception of two Loran-C stations of the Mediterranean Sea Chain has been continued.

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Thanks to the daily synchronization link by means of television measurements, an investigation of the long-term behavior of the commercial Cesium standards kept at IEN and in the ISPT Time and Frequency Laboratory in Rome, with reference to the enviromental conditions was carried out in 1986/1987. The results were presented at the First Time and Frequency European Forum held in Besancon, France in March 1987.

Regarding time transfer techniques, the IEN performed the following experiments:

1. A two way time synchronization experiment between the IEN and the Shaanxi Observatory time scales via Sirio 1 geostationary satellete. The experiment lasted two weeks in May/June 1984 and the precision of the time comparisons was 30 ns (one sigma). In the same period, the time scales of other Chinese observatories (Peking, Shanghai, and Wuhan) were also compared by different synchronization techniques with that of the Shanghai Observatory. A paper dealing with this work was published.
2. A two way time synchronization experiment via the Sirio 1 satellite using Mitrex modems, developed by Prof. Hartl of the Stuttgart University, to evaluate the capabilities of PRN codes and using at one site an Earth station equipped with a small antenna. This experiment lasting one week in March, 1985, was performed by IEN with Politecnico of Turin in Italy, the Shannxi and Beijng Astronomical Observtories in China, and, in a one way mode, the Technische Universitaet of Graz in Austria. The standard deviation of the measurements was of the order of 300 ps.

Finally I wish to point out that a general review of the activity of the IEN Time and Frequency laboratory can be found in the paper presented at the Eighteenth PTTI in 1986.

INTERNATIONAL LATITUDE OBSERVATORY OF MIZUSAWA, JAPAN
(Reported by C. Kakuta)

1. SPACE TECHNIQUES

Time variations of relative positions of celestial radio sources were investigated to estimate errors of group delay observations for geodesy and geophysics with a very long baseline interferometer. It was found that systematic errors exist between the second and third catalogues. There is no time variation exceeding 30 milli-arc-seconds between mean observation epoch 1975 and 1981.

The system-level experiments on the Japan-U.S. joint VLBI project were conducted in January and February, 1984 Over five hundred observations were successfully performed in the experiments. The correlation processing was made by both the K-3 processor at Kashima and the Mark-III processor at Haystack. The two baseline-lengths between Kashima and Mojave obtained in the two experiments showed excellent repeatability. The precision of the baseline length was higher than 0.02 m in root mean square. Observations of plate motions and regional crustal deformations using space technologies, Doppler observation of Navy Navigation Satellite, Satellite Laser Ranging (SLR), and VLBI were reviewed.

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Descriptions were given for the astronomical, geophysical, and geometrical models and formulae adopted in KAPRI, a program for computing the theoretical delay and delay-rate of geodetic VLBI observations and their partial derivatives with respect to physical parameters of interest. In KAPRI more sophisticated therories were adopted for the tidal and relativistic effects. A program was developed for converting an HP1000 based Mark-III database archive to a file on MELCOM COSMO 900II. The program enables us to use VLBI observation data for various calculations and analyses on MELCOM COSMO 900II.

2. POLAR MOTION AND THE ROTATION OF THE EARTH

During the main campaign of Project MERIT (a program of international cooperation to monitor Earth rotation and intercompare the techniques of analysis and observation) from September 1983 through October 1984, the Central Bureau of the International Polar Motion Service (IPMS) at the International Latitude Observatory of Mizusawa (ILOM) acted as an analysis center for the optical astrometry technique.

Prior to the main campaign, the ILOM in collaboration with the Tokyo Astronomical Observatory (TAO) and the Japan Hydrographic Department (JHD) developed software to compute star positions based on the new system of astronomical constants. The method developed by the Japanese group was adopted as the standard method and given in the MERIT Standards compiled by the MERIT group. The computer programs were distributed to all countries where optical astrometry techniques were in operation.

Since the beginning of the main campaign, the Central Bureau of the IPMS (ILOM) has published daily smoothed Earth orientation parameters. This method developed at the ILOM proved to be a very efficient and reliable method to analyze the optical astrometry data through the comparison of the results with those of the new techniques.

At the IAG/IAU Symposium No. 128 held at West Virginia, USA, the results of the daily smoothed EOPs based on a revised method of computation were presented. This method made it possible to estimate the station coordinates simultaneously with the EOPs. As a result of comparison with the VLBI results, agreement is known to be very close. Recomputation of the EOPs based on the past observations will bring about results more reliable than any other past series of EOPs determined using optical astrometry.

The Central Bureau of the IPMS started computation of the atmospheric excitation functions of the Earth's rotation from September 1984, using the data computed at the Japan Meteorological Agency (JMA). JMA's data as one of the three data sources, will contribute very much to understanding atmospheric effects on Earth rotation. The ILOM will continue this work in the coming new International Earth Rotation Service (IERS). The global analysis data of the JMA and the computing method of the effective Atmospheric Angular Momentum (AAM) functions were explained in the Annual Report of the BIH.

In accordance with the establishment of the IERS, the IPMS, as well as the Bureau International de l'Heure (BIH), will be closed. The ILOM is preparing to act as analysis center for the

VLBI technique in the IERS. As the coordinator of optical astrometry in Project MERIT, K. Yokoyama, the Director of the IPMS, has made various activity reports.

The ILOM, in order to continue Earth rotation activities using the techniques which fulfill precision requirements of the IERS, is planning to build a Japanese VLBI system, VERA (VLBI for the Earth Rotation Study and Astrometry). VERA will be composed of two antennas spanning about 2300 km and a correlator of multistation capability. The diameters of the antennas are 35 m and 15 m.

A catalog of PZT stars was compiled by Sato et al. The catalog includes all the stars used in PZT observations at the ILOM (Mizusawa) and the United States Naval Observatory Washington, D.C. since 1959 and 1915, respectively. The stars of proposed programs for the International Latitude Service (ILS) chain of PZT's on the line of 39 8'N latitude were also included. This catalog would give a standard for the recalculations of past observations by the ILS instruments. A unified catalog of Washington and Mizusawa PZT stars was constructed by using re-compiled and re-reduced data from 1954 to 1983. The reduction is made based on the MERIT Standards. Computations of the right ascension and declination corrections, as well as their proper motions were based on the least squares chain method. Internal precisions of the right ascensions and declinations at the mean epochs of observations were 0.6 ms and 0".008, respectively, for the best determined stars. Those of proper motions were 0.08 ms/year and 0".001/year, respectively.

Estimations for the effects of the nutation errors on the determination of the Earth orientation parameters and the corrections to stellar positions in source catalogs, which were determined internally by the chain method using the observed latitude and UT0-UTC, were made. Internal corrections were found to be related to the adopted nutation series. It was required that every station re-reduce all the past observations in the new system and re-estimate internal corrections based on observed data.

Li's expression for the gravitational deflection of light in the case of astrolabe observations was corrected by deriving a rigorous and simpler expression based on elementary methods. The derived corrections are to be added to group values of time and latitude.

The Mizuaswa PZT (Photographic Zenith Tube) was moved from its semi-basement location (the second PZT observation room) to a location 6.65 m above ground level (the third PZT observation room) in order to avoid the effects of temperature variation near the ground during observations. The PZT base was constructed on a stable layer of silt 14.8 m in depth. Larger tremors were expected for the tall base than lower ones. Comparison of measured micro-seisms confirmed that the amplitude of horizontal displacement of the new tall base for PZT 2 is even smaller than the rest of the bases, which are used for astronomical observations at the ILOM with the old VZT, automatic astrolabe and the semi-basement type observing house.

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near Southeast Asia. Local variations for periods of several years in longitude and latitude might be attributed to thermal expansion in the fluid core near the core-mantle boundary.

Relative variations of UT1-TAI in Mizusawa and Washington were found to show a secular variation associated with a periodic variation during the period of 4 years. One branch of the secular variation shows a similar direction as the plate motion. Decreases in the relative variations of UT1-TAI, in Mizusawa and Washington, were studied from the point of a global motion of the ocean and the El Nino events.

HYDROGRAPHIC DEPARTMENT OF JAPAN
(Reported by Kubo)

For the purpose of monitoring the relation between dynamical time reduced from the orbital longitude of the Moon TDT_M and TAI, the observation of occulations of stars by the Moon have been continued at the head office of the Hydrographic Department of Japan (JHD) in Toyko and three branch Observatories, Sirahama, Simosato, and Bisei. About 900 timing data including 600 photoelectric data were obtained each year. TDT_M-TAI obtained from the occulation observations for the epochs 1984.5 and 1986.5 were 32.98s, 32.93s and 32.78s, respectively, with mean errors of 0.04s. Details are published in Data Report of Hydrographic Observations, Series of Astronomy and Geodesy as well as in the Japanese Ephemeris.

The services of the International Lunar Occultation Center have been continued since 1981. The number of data reported to the Center in the years 1984 to 1986 amounts to 31,370.

Satellite Laser Ranging (SLR) observations have been carried out at Simosato Hydrographic Observatory since March, 1982. The mean ranging precision of the SLR system is about 9 cm. Total return signals obtained from Lageos, Starlette and Beacon-C satellites in the years 1984 to 1986 amount to 725,000. Since August 1986, ranging to the Japanese geodetic satellite Ajisai also has been done with 139,000 return signals in 1986. A transportable SLR system is under construction at JHD, the completion being expected at the end of October, 1987.

TOKYO ASTRONOMICAL OBSERVATORY, JAPAN
(Reported By S. Aoki)

Astronomical observations for time and latitude have been made regularly with the PZT, using the star system (α_{85}, δ_{85}) since January 1, 1985. PZT plates have been measured with an automated-measurement system equipped with a linear CCD since January 1, 1985.

UTC(TAO) has been kept with a master clock, selected out of five HP Cesium clocks, controlled with a phase-microstepper. Three of five Cesium clocks, have been in operation in a shielded room, which has been intended to reduce the effect of eletromagnetic waves on the Cesium clocks, and to keep the appropriate

A Tsubokawa type astrolabe has been developed at the ILOM. To investigate effects of the meteorological enviroment around observational sites upon anomolous refractions for astrometry at the ILOM, measurements of horizontal and vertical profiles of temperature were made during periods before and after thinning out trees around the observational site. Results showed that an inhomogeneous distribution of the environments in the site mainly produces inhomogeneous distributions of temperature, particularly for stable nights, due to a radiative effect of the enviroment. Refraction corrections for VZT observation have been made traditionally by using the mean values of temperature and pressure during the observations of a pair of stars. Because temperature and pressure variations exist during the observations of a pair of stars it is necessary to employ the temperature and pressure measured during the observation of a pair of stars to eliminate refraction error completely in VZT observations.

Refraction effects currently remain on the order of 0."01 in the VZT and astrolabe observations. In order to make such errors as small as possible we must not only improve the meteorological measurements but also keep the meteorological enviroment, such as the roughness height homogeneous in all directions around the observing room. Even the new techniques such as VLBI and laser ranging have errors which originate from the meteorological environment near the observing sites.

Onodera investigated the southern oscillation, one of large-scale atomospheric phenomena, in relation to variations of the rate of the Earth's rotation. The results showed that the variation of the former appears by 2-3 years in advance of the variation of the latter. This fact suggested that there is some correlation between the two variations.

Fluctuations of the Earth's rotation with periods shorter than about 2 years were analyzed using the data compiled or obtained at the BIH, the IPMS, the IRIS (International Radio Interferometeric Surveying), and the CSR (Center for Space Research).- The IPMS optical astrometry data show close agreement with the AAM (Atmospheric Angular Momentum) data which include the effects of both the zonal wind and the migration of the air mass (pressure term) for periods between two years and forty days. Relatively high spectral power density is observed at periods around 35 days, 24 days, and in the period range of 21 to 16 days in the astronomically observed UT1 by the CSR and the IRIS. Thus, the short period fluctuations of the Earth's rotation can be explained fairly well by the atmospheric excitations for the periods between two years and sixteen days.

A comparison was made between variations of strain, which are observed at the Esashi Earth Tides Station and UT2-TAI, published by BIH, residuals of UTO-UTC and latitude of the PZT and Danjon Astrolabe at Mizuaswa since June 1979. Kakuta and K-S. Sato obtained a good correlation between variations of the Earth's rotational speed and UTO-UTC of the Miszusawa PZT with the east-west component of strain.

Residuals of astronomical observations of longitude and latitude in Asia might be related with the secular variations of the z-component of the internal geomagnetic field in the 1970's temperature and humidity. Domestic time comparison of UTC clocks has been continued by using a Cesium portable clock of TAO twice a year with those of ILOM, NRLM, RRL, GSI,(Geodetic Survey Institute) and KGO (Kanozan Geodetic Observatory). TAO clocks have also been linked with TV-signals.

For international time comparisons, the receptions of Loran-C signals from the Iwo Jima Master station (9970-M) and Okinawa station (9970-Y) have been continued. By means of the reception of GPS timing signals the TAO has continued time comparisons among the TAO and six institutes: NBS, NPL, OP, PTB, RRL, and USNO with an accuracy of the order of a few tens of nanoseconds.- Clock comparison between the TAO and the USNO with a flying clock of the USNO has been performed regularly once a year by courtesy of the USNO.

JET PROPULSION LABORATORY, USA
(Reported by J.O. Dickey)

The Jet Propulsion Laboratory has been actively involved in the following areas key to IAU Commission 31:

* the development of constants, models, and ephemerides to be used as standards by the community and by the MERIT analysis centers;
* reference frame studies: 1) determination of the JPL Radio Frame; 2) the determination of the Dynamical Reference Frame of the Lunar/Planetary Ephemerides; 3) determination of ties between the various reference systems; and 4) development of the concept of the dynamical equinox as a reference point for the modern ephemerides and the unification of coordinate systems;
* acquistion, reduction analysis of VLBI data;
* intercomparisons of Earth rotation results from the various techniques;
* combination of data types via a Kalman filter;
* analysis of the scientific implications of these measurements.

During both the Main MERIT and the continuing campaign, Earth rotation and polar motion studies have demonstrated the unprecedented accuracy (~5 cm) achieved by modern space geodetic techniques, permitting us to determine tectonic plate motion at various stations and observatories located on separate plates; these results are in general agreement with those of Minster and Jordan. In fact, the combination of data sets from several sites and different techniques demands the inclusion of tectonics; omission of such considerations would result in a combined series that would be systematically corrupted and degraded.

High-quality estimates of the atmospheric excitation of Earth rotation and polar motion, provided by the routine analyses of global weather data for operational weather forecasting, together with the modern Earth orientation measurements have allowed new insight into atmospheric and non-atmospheric excitation of Earth rotation and polar motion variations. We have shown that changes in the Length of Day (LOD) at seasonal and higher frequencies are dominated by the exchange of angular momentum between the atmosphere and the solid Earth. The correlation is significant at the 99% level indicating that atmospheric angular momentum (AAM) analysis and forecast fields may be useful in providing near-real time estimates and prediction of Earth rotation changes. Our studies using the forecasts of AAM from large numerical models of the major forecast centers indicate that these models can forecast the AAM better than the currently used statistical predictors (done in collaboration with Rosen, Salstein (AER), Miller and McCalla (NMC)). The dominance of the atmosphere in short-period variations and the simple power law spectrum of the AAM made possible the development of a Kalman filter for smoothing and predicting Earth orientation. We have established the existence of rapid polar motion; by comparison with AAM data, we found that it is produced at least in part by atmospheric pressure changes. The atmospheric excitation of the Chandler wobble was investigated using both modern polar motion determinations and meteorological estimates of atmospheric forcing; some correlation was found, but the nature of the Chandler wobble forcing remains unclear. The relationship between the Southern Oscillation and the Length of Day (LOD) was established; the observed correlation at lead times of 2.6 years was used to derive a statistical predictor of the Southern Oscillation Index based on the LOD.

Turning to longer period fluctuations in Earth rotation, torques are probably largely due to dynamic pressure forces associated with core motions acting on topographic undulations of the core mantle boundary and the equatorial budge. Estimates of such torques are becoming available from a combination of core motion models from geomagnetism and core mantle boundary maps from seismic tomography. Our geodetic torques estimates will provide a strong constraint on the models and assumptions used (done in collaboration with R. Hide, Met Office (UK)) and strongly favor the inclusion of the D" layer in the mantle and point to bumps on the core-mantle boundary of about 1/2 km. The magnitude of these undulations is in agreement with the findings from nutation studies. Corrections at the 2 milliarcsecond level required for the annual term of the Standard IAU Nutation Model as inferred by the analysis of both the IRIS and the JPL Deep Space Network VLBI data are in agreement with those of Herring et al. at CfA. Analyses of seventeen years of lunar laser ranging (LLR) data allowed calculation of corrections to the IAU accepted values of the 18.6-year nutation terms and the precession; results indicate agreement with optical astrometry.

The last three years have seen an improvement in LLR data quality and the development of a Lunar Laser Ranging Network. Recent equipment and software improvements at the stations have resulted in 3-5 cm ranges (the previous data prior to 1984 had ranges of more than 10 cm accuracy); data are currently being acquired from three stations: CERGA (France), Maui (Hawaii-USA) and McDonald (Texas-USA). An analysis of the seventeen year LLR data set yields a value for GM_{EARTH} of 398 600.443 ±0.006 km^3/s^2 in the geocentric system comparable to LAGEOS (the LLR result agrees with the LAGEOS result within one standard deviation of the error estimate). The increased accuracy of LLR should result

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in an improved lunar ephemeris; preparations are now underway for a new joint lunar and planetary ephemeris at JPL.

Reference frame studies have included the determination of the JPL Radio Frame, the Dynamical Reference Frame of the Lunar/Planetary Ephemerides, ties between the various reference systems, and the development of the concept of the dynamical equinox and the unification of coordinate systems. Ties between VLBI and optical frames have been established via the observations of radio stars (in collaboration with our French colleagues); a link has been determined between the VLBI and the Ephemeris frame through the use of differential VLBI. Very Large Array measurements of Jupiter, Saturn, Uranus and Neptune provide both a tie between the outer planet ephemerides and the radio frame and a means of improving the ephemerides themselves.

U.S. NAVAL OBSERVATORY (USA)
(Reported by W.J. Klepczynski)

Optical observations for time were made with Photographic Zenith Tubes in Washington, D.C. (PZT7, 65cm) and at the Naval Observatory Time Service Alternate Station (NOTAS) in Richmond, near Miami, Florida (PZT6, 20cm). Observations with PZT2 (20cm) were discontinued in Richmond on June 24, 1987. Daily radio observations with the Connected Element Interferometer located in Green Bank, West Virginia were obtained throughout the period. Measurements were made of three 35-km baseline vectors to determine Earth orientation parameters. The Richmond POLARIS Observatory, located at NOTAS participated in the VLBI Observations of the International Radio Interferometric Survey (IRIS).

The Washington Mark IIIA VLBI Correlator was dedicated at the U.S. Naval Observatory on August 25, 1986 in a ceremony attended by representatives of the four sponsoring agencies (National Geodetic Survey, National Aeronautics and Space Administration, Naval Research Laboratory and U.S. Naval Observatory).- After several months, the Washington Mark IIIA VLBI Correlator expanded from a 3-station, 3-baseline correlator to a 5-station, 8-baseline facility. The addition of the final two baselines to make a 5-station, 10-baseline correlator is in progress.

The primary reference time system, designated UTC(USNO,MC), is now derived from the hydrogen maser based master clock. Two Smithsonian Astrophysical Observatory VLG 11 Hydrogen Maser Frequency Standards are phase-locked together and are steered to UTC(USNO,MEAN) by adjustments to the frequency synthesizer of the lead hydrogen maser. Steering of the master clock system is done in steps no larger than 7 parts in 10 to the 15th (0.6 ns/day).

Evaluation of the Hewlett-Packard Mercury Ion Frequency Standards (MIFS), delivered in July 1986 and May 1987, for long-term performance has begun. The difference between the MIFS's and the Hydrogen maser based master clock is being studied for use in extrapolating UTC(BIH)-UTC(USNO). Preliminary analysis indicates that the MIFS agrees with UTC(BIH) in frequency to better than a part in 10 to the 14th.