COMMISSION 19: ROTATION OF THE EARTH (ROTATION DE LA TERRE)

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INTRODUCTION

During the period, there have been several major events which have effected the scope and interest of Commission 19. The most significant of these has been the dissolution of the BIH and IPMS and their replacement by the International Earth Rotation Service (IERS). The correlation of higher frequency fluctuations in the Earth's rotation rate with changes in the Earth's Atmospheric Angular Momentum is also significant. Many investigators now seem to believe that the "decade variations" in the Earth's rotation rate are caused by torques between the core and mantle caused by the uneven motions at the core-mantle boundary. These events and discoveries have made this an exciting period. It seems that the future holds more in the way of discovery due to the utilization of the more accurate and precise Earth rotation data coming from the modern observing techniques.

REPORTS FROM INTERNATIONAL SERVICES

Report from the Bureau International de l'Heure

This report covers the work on Earth rotation and related reference frames. The activities on atomic time are reported to IAU Commission 31.

The activities over the reporting period have been characterized by

- the complete introduction of the results from VLBI, Lunar and Satellite Laser Ranging (LLR, SLR) in the combined Earth rotation time series,

- the implementation of a new algorithm for the BIH Terrestrial System (BTS), in cooperation with the French Institut Geographique National (IGN),

- the study of VLBI celestial reference frames, in cooperation with the Bureau des Longitudes (BDL).

Earth Rotation

The Earth Rotation Parameters (ERP: coordinates of the pole and universal time) have been continuously computed and disseminated. As in the previous years, the three main series of evaluations have been as follows:

- A scientific solution, performed yearly on the basis of long homogeneous series made available by the associated analysis centres, in conjunction with the realisation of the BIH systems. The evolution of the relative weights of the different methods of observation and the resultant precision of the series of ERP at 5-day intervals are shown in Figure 1. The polhody over 1984-1986 is plotted on Figure 2.

The data introduced in the solution had been provided by the following institutes.

VLBI: National Geodetic Survey (NGS), Goddard Space Flight Center (GSFC), and Jet Propulsion Laboratory (JPL),

CERI (Connected Element Radio Interferometry): U. S. Naval Observatory (USNO),

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LLR: JPL,

SLR: Center for Space Research (CSR), Deutsches Geodaetishes Forschungs-institut, Abteil I (DGFII), Delft Technical University (DUT), Smithsonian Astrophysical Observatory (SAO).

Doppler: Defense Mapping Agency (DMA)

Optical astrometry: BIH, from latitude and universal time observations of 90 stations. A solution based on the IAU 1980 Theory of Nutation has been recomputed from 1978 onwards.

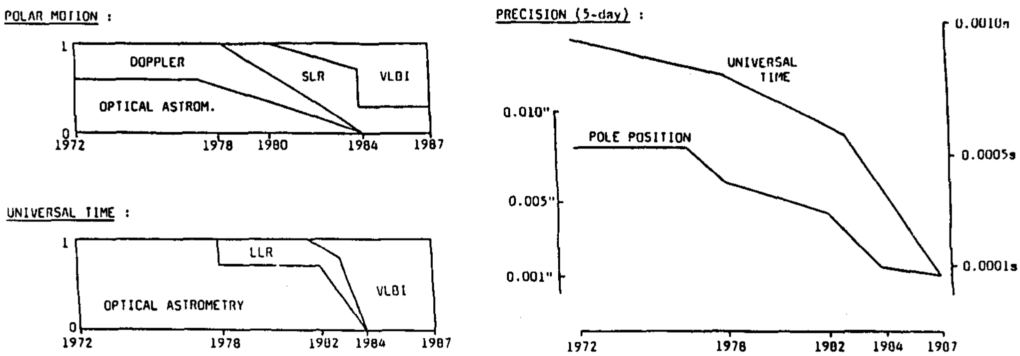

Figure 1 - Contribution of the different observing techniques to the BIH Earth rotation series and precision of the combined solution, 1972-1987.

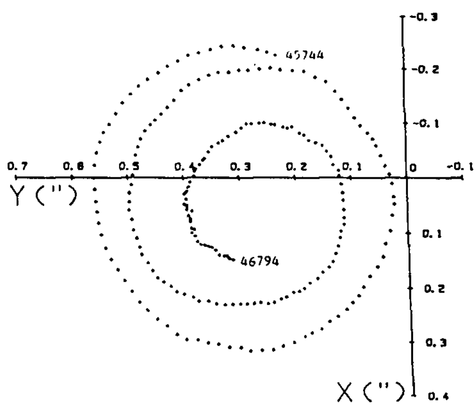

Figure 2 - Path of the pole from 1984 Feb. 14 to 1986 Dec. 30 (MJD 45744 - 46794).

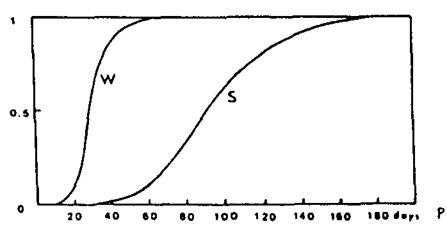

Figure 3 - Characteristics of the filters used for the BIH monthly operational solution (Circular D), 1984-1987.
S : pole coordinates, 1984-1985
W : pole coordinates, 1986-1987
universal time, 1984-1987

- An operational solution performed monthly, based on data of all techniques available with a 1-2 month delay, and on preliminary evaluations of their link to the BIH system. This solution is made available under the form of raw and smoothed values. The degrees of smoothing used over 1984-1987 are given in Figure 3. The rms agreement of this solution with the smoothing of the scientific solution with the same filtering characteritics has been 0.003" for the pole coordinates and 0.0006s for UT1, while the maximum differences have been respectively 0.010" and 0.0020s.

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- An advanced solution performed weekly, based on SLR for the pole coordinate and on optical astrometry, SLR, LLR, and since 1987, on VLBI for universal time. The maximum differences with the operational solution have been 0.01" on the pole coordinates and 0.004s on universal time. This solution was complemented by a weekly prediction issued by USNO and by a monthly prediction issued by BIH. The typical accuracy of these predictions has been 0.005" (pole) and 0.002s (UT) for a time lag of 10 days and 0.015" (pole) and 0.010s (UT) for a time lag of 40 days.

Terrestrial System

The maintenance of a terrestrial system of reference has always been an important activity of the BIH, since the series of the pole coordinates and universal time are referred to this system. The BIH system was defined in 1968 by the adoption of astronomical coordinates for a network of 68 optical instruments contributing to the monitoring of the Earth's rotation. The initial realization was concerned only with the directions of the axes: the tie to the CIO and the definition of the origin of longitudes. These directions were maintained by a stability algorithm applied to the yearly determinations of the astronomical station coordinates. Starting with 1973, the series obtained by the space geodesy and interferometric techniques were progressively introduced in the maintainance of the direction of the axes of the BIH System.

Thanks to a cooperation with the French Institut Geographique National (IGN), starting with 1984, the BIH System has been realized through a set of coordinates of sites where space geodesy stations are operated. This follows a proposal of B. Guinot (1981), "Comments on the terrestrial pole of reference, the origin of longitudes, and on the definition of UT1," Proc. 56th IAU Coll., Reidel Publ. Co. The implementation is based on a study by C. Boucher and M. Feissel (1984) "Realization of the BIH Terrestrial System," Proc. Internat. Symp. on Space Techniques for Geodynamics, J. Somogyi (ed.), Sopron, Hungary.

In its 1986 issue, the BTS is realized by the cartesian coordinates of 51 sites belonging to six of the main tectonic plates: Pacific (4), North America (23), South America (4), Eurasia (16), Africa (2), and India/Austalia (2). It is adjusted from 301 station coordinates determinations in seven networks (three VLBI, one LLR, two SLR, one Doppler), using the local ties collected by IGN. The transformation parameters which relate the seven individual systems to the BTS are evaluated in the same process. The stability of the BTS in this new realization is estimated to a few centimeters in the origin, 0.002ppm in the scale and 0.004" in the orientation.

Extragalactic Celestial Frames For Earth Rotation

During the last ten years, three groups (JPL, GSFC, and NGS) have published catalogues of precise positions of extragalactic radio sources derived from Very Long Baseline Interferometry (VLBI) observations. The catalogues provide the celestial reference frames for the series of Earth Rotation Parameters derived from the observations. It has been found that the various reference frames have their directions of axes consistent within 0.003". This is a remarkable agreement considering the diversity of observing stategies and data analysis.

The rotation angles estimated statistically with the common radio sources between catalogues have uncertainties in the range of 0.0001" to 0.0005". This range is confirmed by the stability of the estimation when the number of radio sources is changed. Consequently, the maintainance of a celestial reference system by means of VLBI coordinates of radio sources could be ensured within 0.001" by a no-rotation condition applied to the ensemble of source coordinates.

Participation In The MERIT Program

The BIH acted as the coordinator of MERIT project, during and after the main observing campaign, in 1983/1984. The different tasks accomplished in this framework were as follows.

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- Collection of the precise description and geodetic ties of the sites involved in the measurement of the Earth's rotation; at IGN a Directory of MERIT Sites (DOMES) is kept up to date. Collection of the Sets of Station Coordinates (SSC) defining the terrestrial frame for each series of ERP.

- Collection of the series of ERP obtained during and after the campaign by the participating computing centres; maintainance of a data bank for storing the collected data, dissemination of copies on request.

- Issuing of results from, and information on, the campaign, in the MERIT Monthly Circular, distributed to 180 addresses. Publication of the results obtained by the Operational and Analysis Centres for Earth rotation and the related reference frames (20 Centres from 8 countries).

Other Studies

- Determination of the Earth orientation from optical astrometry: during a stay at BIH, Dr. Li Zheng-xin from Shanghai Observatory computed the ERP over 1962-1981 from optical astrometry observations; the solution is referred to the IAU 1976 System of Constants and to the IAU 1980 Theory of Nutation.

- Atmospheric excitation of irregularities in the Earth's rotation: the seasonal and higher frequency oscillations in duration of the day under the action of atmospheric currents have been studied on the basis of series of universal time and series of Angular Momentum of the Atmosphere. The "50 days" oscillations have been shown to be permanently active with unstable pseudo periods, and peak-to-peak variations from 0.2 to 0.6ms in the duration of the day. to comply with a request of the SSG 5.98 of IAG, "Atmospheric excitation of the Earth's rotation", data bank of Atmospheric Angular Momentum has been established. The associated documentation appears in the Annual Report, part. D.

Report from the International Polar Motion Service

It will be useful to start this report with the description of recent movement in Japanese astronomical community to set up a new national organization for astronomical research. This necessarily implies the reorganization of the Tokyo Astronomical Observatory (TAO) and the International Latitude Observatory of Mizusawa (ILOM), which has played a leading role in Japan for the international cooperation to monitor the Earth's rotation.

It has been agreed that the geodynamical activities, which have been conducted at the ILOM, be taken over by the Earth Rotation Branch of the new organization which will be inaugurated in 1988 fiscal year. The headquarters will be located at the same place as the present TAO, and the Earth Rotation Branch will also be at the same place as the present ILOM.

History of the ILOM

The ILOM was founded in 1899 as one on the six stations of the International Latitude Service (ILS) organized by the International Association of Geodesy (IAG). As its name indicates, the main objective of the ILOM is to continuously monitor polar motion by observing latitude variations, in collaboration with other international latitude stations. The ILOM acted as the Central Bureau of the ILS during 1922.7 - 1934.0, and also has been the Central Bureau of the IPMS since 1962.

For these ninety years, the ILOM has strived to adapt itself to the developments of science and technology relating to Earth rotation study. From the observational viewpoint, it has developed new techniques of observation, introducing the state-of-the-art techniques.

In spite of the limitation due to the prescribed objectives of the ILOM, research activities have been extended focussing on geodynamical fields, and instrumentation efforts have been stressed to construct an integrated system of geodynamical observations, composed not only of astronomical instruments but also of geophysical instruments.

In accordance with recent drastic improvement of observational accuracies of both astronomical and geophysical instruments, the ILOM has made every effort to introduce the most modern techniques, such as a very long baseline interferometer (VLBI), a super-conducting gravity meter, and a transportable absolute gravimeter.

Conclusions of the Geodetic Council of Japan for the Reorganization of the ILOM

In July 1985, the review committee, set up by the Geodetic Council of Japan, finalized a report on the reorganization of the ILOM. This report was endorsed by the Geodetic Council of Japan.

Points of the report are as follows:

1) Although the ILOM has played an important role in the ILS and the succeeding IPMS activities, it has recently become clear that the present organizational structure of the ILOM as a branch under Ministry's jurisdiction is not suitable to meet the following requirements, which have been brought about by the recent development in science and technology:

a) The name and the objectives of the ILOM, which are now obsolete, need overall review.
b) In order to further promote research activities related to the Earth's rotation in Japan, it becomes necessary to form an organization, in which current scientific requirements could be effectively fulfilled.
c) In order to introduce new high-precision measurement techniques, it becomes necessary to establish a management system, through which the equipments could be brought into effective nationwide use.
d) In order to consolidate cooperative research activities for the scientists of various fields relevant to the Earth's rotation, establishment of a central organization is required.
e) Establishment of the system for the common use of observational data and softwares, as well as observational facilities and equipments, is required.
f) Establishment of a national center for international cooperation in observations and research has been required.

2) The report concluded that in order to meet the above requirements, it would be appropriate to implement such reorganization, in conjunction with other institution(s) which is relevant to the Earth rotation research.

Recent Agreement Between the TAO and the ILOM

In 1987, the TAO and ILOM agreed to jointly establish a new national organization for astronomy in the fiscal year of 1988. The board of council for establishing the new national organization for astronomical research, set up by the Ministry of Education, Science and Culture, accepted the fundamental conception of the new organization elaborated by the TAO and the ILOM. The new organization will be composed of six scientific branches, and the present ILOM takes part as the Earth Rotation Branch and part of the Theoretical Astronomy Branch. The Earth Rotation Branch is planned to consist of five departments, which covers wide fields of geodynamics.

VLBI for the Earth Rotation Study and Astrometry (VERA) As A Tool to Participate in the New International Earth Rotation Service

In 1985, a Japanese scientist group covering positional astronomy, geodesy and geodynamics proposed to build a Japanese VLBI system for Earth rotation study and astrometry. This system, called VERA, is to be composed of two antennas spanning 2300 km. One antenna with 35 m diameter will be built near Mizusawa, and the other with 15 diameter on one of the South-Western Islands.

VERA will be dedicated to regular monitoring of the Earth's rotation in the international networks.

There are four big projects, which Japanese astronomers desire to realize in the new organization. They are:

1) Japanese National Large Telescope (JNLT) Project, to build a 7.5 m diameter optical telescope on Mt. Maunakea in Hawaii.
2) VLBI for the Earth Rotation Study and Astrometry (VERA).
3 Radio Heliograph.
4) Solar Cycle Telescope.

Role of the ILOM in the IERS

The present ILOM, or the Earth Rotation Branch in the new national organization for astronomical research, will participate in the IERS with the following roles.

a) The network center of VLBI IRIS-P network, in collaboration with the Radio Research Laboratory (RRL) in Japan.

b) A VLBI analysis center, in collaboration with relevant Japanese institutes, namely, the RRL, TAO, Japan Hydrographic Department (JHD), and Geographical Survey Institute (GSI).

c) A computing center of atmospheric excitation functions, in collaboration with the Japan Meteorological Agency (JMA).

Brief Description of VLBI IRIS-P Network

IRIS-P network became operational in April 1987. Before that, we had only one IRIS VLBI network called IRIS-A, which is composed of four regular stations (one in FRG and three POLARIS stations in USA) and several stations participating intermittently. The objectives of IRIS-P are: a) to provide Earth rotation results independently of IRIS-A for cross-check, b) to make precise time synchronization between Kashima in Japan and Richmond in USA, and b) to get experiences to design and operate Japanese VLBI system VERA.

The network center at the ILOM is responsible for smooth operation of IRIS-P, in collaboration with the VLBI coordinating center at the NGS and the correlation center at the United States Naval Observatory (USNO).

Estimation and Dissemination of the Smoothed Daily EOP's

Since September 1983, the Central Bureau of the IPMS has regularly provided optimally smoothed EOP's from optical astrometry observations using the method of Bayesian information criterion. Hyperparameters, which define smoothness of polar motion and UT1, are selected so as to minimize a Bayesian information criterion. This leads to the estimation of optimum EOP's. By the adoption of this method, precisions of the EOP's from optical astrometry were remarkably improved. Nominal rms errors of the estimates are about +/- 0.003" for polar motion and +/-0.0002 s for UT1. Systematic errors in polar motion, however, are comparatively large in comparison with the results of VLBI and SLR. On the contrary, UT1 or LOD of optical astrometry has shown very close agreement with that of VLBI and SLR.

The IPMS smoothed daily EOP's have been published in the Monthly Notes of the IPMS. A whole set of the EOP series starting from 1962 was distributed on magnetic tape basis to several institutions and agencies.

Computation and Software Services

Services to compute apparent places of stars has been provided on request. Software to compute corrections of star positions and proper motions was provided by the Central Bureau to several stations on request. Also, software to evaluate the effects of ocean-tide loading developed by the ILOM has been supplied to several institutes through the Central Bureau.

Computation of the Atmospheric Excitation Functions

As one of the three computing centers under the Special Study Group 5.98 of the IAG, "Atmospheric Excitation of the Earth's Rotation", the Central Bureau has regularly reported the atmospheric excitation functions based on the data provided by the Japan Meteorological Agency, to the chairman of the SSG 5.98.

Dissemination of Data

In response to the requests of individuals, institutions and agencies relevant to Earth rotation research, various kinds of data accumulated in the IPMS data files were disseminated.

Collection of Data Related to Earth Rotation Investigation

The EOP's estimated from both astronomical observations and geophysical data have been collected and stored in the IPMS data files.

Summary

Especially from 1980 when the short campaign of Project MERIT was initiated, development in observational and analysis techniques was quite drastic in Earth rotation research. Important scientific findings have been obtained during this short period. This was never achieved by classical optical astrometry data, which have been accumulated for about century from the beginning of the ILS.

By virture of centimeter precision and accuracy achieved by VLBI and laser ranging, scientific values of the IERS data are incomparably larger than the past data. This means that scientific aspects of the IERS activities will become more important, compared to the activities of the BIH and IPMS, which are going to be replaced by the IERS.

Most essential for the IERS is to extend current observational networks, so that they may cover the whole surface of the Earth uniformly. It is especially important for the VLBI community to establish several independent networks, each of which covers a region of the Earth's surface and is linked up with one another, so that the ensemble of the regional networks cover the whole surface of the Earth. Each of the regional network will act as an independent unit.

Cost of the new-technique facilities, however, are rather high, compared with classical instruments. Hence it may not be easy for such instruments. In addition to efforts of individual groups, international support will be very important to realize the instrumentation plans of various countries.

Report from the new International Earth Rotation Service

In accordance with resolution B2 of the IAU General Assembly at Delhi a Provisional Directing Board for the new International Earth Rotation Service (IERS) was set up with the following membership: C. D. Boucher, W. E. Carter, R. Coates, J. O. Dickey, M. Feissel, R. W. King, D. D. McCarthy, I. I. Mueller, (Vice-Chairman), P. E. C. Paquet, G. A. Wilkins (Chairman), Y. S. Yatskiv, S. - H. Ye, and K. Yokoyama. The Board held three meetings in conjunction with other conferences, as follows: at Austin, Texas, on 1986 April 29 and 30; at Coolfont, West Virginia, on 1986 October 21; and at Pasadena, California, 1987 March 20 and 21. At each meeting the Board received and discussed reports on the progress of the current activities within and related to the continuation of the MERIT/COTES programmes. The main task of the Board was, however, to prepare recommendations on the terms of reference, structure and composition of the new service.

The reports and recommendations of the MERIT and COTES Working Groups were published by the IAU in Highlights of Astronomy (7, 771-788), by the International Association of Geodesy in Bulletin Geodesique (60, 85-100), and in other publications. A letter with supplementary information about the proposed Service was sent out on behalf of the Board to all organisations that were known to be capable of participating in it. By the time of the third meeting the Board had received offers of participation from eight countries which were prepared to operate one or more technical centres, a further four countries were prepared to provide observational data, and three others indicated their intentions of setting up new stations which would contribute to the Service.

The Board discussed the submissions and decided on its recommendations which were accepted by the Executive Committee of the IAU at its meeting in 1987 September and by Councils of the IAG and of the IUGG at the General Assembly of the IUGG at Vancouver, D. C., in 1987 August. The structure and composition will be as follows:

1. The Central Bureau will be provided jointly by the Observatoire de Paris, the Institut Geographique National and the Bureau des Longitudes of France, and will be supported by two sub-bureaux.

1a. A rapid service for earth-rotation parameters to be provided by the National Earth Orientation Service (NEOS) of the USA (formed jointly by the US Naval Observatory and the National Geodetic Survey);

1b. A service for atmospheric angular-momentum data, including forecast values. The AAM sub-bureau will receive and combine data from several meteorological centres for use in the prediction and study of earth rotation parameters. It is expected that many organisations in other countries will provide data and results on reference systems, as well as on earth-rotation, for use and dissemination by the Central Bureau.

2. The Coordinating Centre for VLBI will be provided by the National Geodetic Survey (NGS) of the USA, and there will be three Network Centres: NGS for the IRIS-Atlantic network; the Jet Propulsion Laboratory (JPL), USA, for the TEMPO Deep Space Network; and the International Latitude Observatory of Mizusawa (ILOM), Japan, for the IRIS-Pacific network. Each centre will be responsible for the initial data analysis for its network, as well as for scheduling the observations at each of the radio-telescopes of the network. The Shanghai Observatory (SHO), China, the Forschungsgruppe Satellitengeoda/sie (FGS), Germany, and the three network centres will also carry out long-term analyses of the VLBI data.

3. The Coordinating Centre for SLR will be provided by the Center for Space Research (CSR) at the University of Texas at Austin, USA, and it will be supported by a Quick-look Operational Centre at the Delft University of Technology (DUT) in The Netherlands, and by Data Collection Centres provided by FGS and SHO; CSR will itself also carry out these functions. Full-rate data analysis centres are to be provided by CSR, FGS, and SHO, and it is expected that the Japanese Hydrographic Department (JHD), the University of Padova-Telespazio group (HPSN), ITALY, the Royal Greenwich Observatory (RGO), UK, and the Zentral Institut fur Physik der Erde (ZIPE), GDR, will also provide the results of their analysis of full-rate SLR data. The Intercosmos network will also contribute observational data and results to the Service. Almost all of the stations in the current global network of observing stations will provide data for the Service.

4. The Coordinating Centre for LLR will be provided by CERGA, France. It will be supported by JPL and the Astronomy Department of the University of Texas at Austin (UTEX), which will act as both Quick-look Operational Centres and as Data Analysis Centres; CERGA will also carry out these functions and SHO will act as a Data Analysis Centre. It is expected that at least three stations (Grasse, Hawaii, and Mcdonald) will provide observational data; it is hoped that Orroral will also soon contribute again from its key position in the southern hemisphere; Wettzell is expected to commence LLR observations in 1989.

All data and results submitted to the Service will be made available for general use. The recognised organisations in the Service will receive priority in their distribution. Charges may be made to cover the costs of supply of data. The Service will archive results on earth rotation and reference systems, but will not archive the observational data, although it is hoped that other organizations will do so.

The Directing Board for the new Service, which will come into operation on 1988 January 1, will consist of six members nominated by the Executive Committees of the IAU and IUGG/IAG, the Central Bureau (Paris Obs.) and the three Coordinating Centres (NGS, CSR and CERGA), respectively. The Federation of Astronomical and Geophysical Services (FAGS) is to be asked to provide financial support (comparable to that now given to BIH and IPMS) for those activities that cannot be met by the host organisations. The Board will report annually to FAGS and to each General Assembly of the IAU and IUGG/IAG.

The members of the Board are: W. E. Carter (VLBI), M. Feissel (Central Bureau), B. E. Schutz (SLR), C. Veillet (LLR), G. A. Wilkins (IAU), and K. Yokoyama (IUGG). A preliminary meeting of the Board was held in Vancouver on 1987 August 17. IA reviewed progress and agreed on actions to be taken. In particular, it was agreed that the Central Bureau (at the Paris Observatory) should issue the following series of IERS publications:

Monthly Circular (similar to BIH Circular D)
Annual Report (similar to BIH Annual Report)
Special Circulars and Technical Reports.

The Rapid Service Sub-Bureau (at the U S Naval Observatory) should issue:

Weekly Circular (with quick-look results and predictions)
Monthly Circular (with predictions for 3 months).

In general, the new Service will follow the procedures developed during and since the MERIT Main Campaign of 1983/4, and it is hoped that the transition will not cause any inconvenience to users of the services. A set of IERS Standards for using in the processing of the observational data is being prepared to replace the current MERIT Standards. During the past two years there have been further improvements in the observational results from the three principal techniques used in the service (mainly VLBI, SLR and LLR), although there is not yet a full set of LLR stations in regular operation. Forecast values, as well as synoptic values, of the angular momentum of the atmosphere are now provided by meteorological centres for use in the prediction of the short-term variations of UT1 with respect to UTC. Particular attention has been given to the development of new conventional terrestrial and celestial reference systems for use by the Service, which will determine and publish estimates of the relationships between these new systems and the various reference systems now in current use.

REPORTS BY OBSERVING TECHNIQUES

Report from VLBI

The IRIS-A Network, formed by observatories in the United States, the Federal Republic of Germany and Sweden, represents the state-of-the-art Earth Orientation Monitoring System. At 5-day intervals the X and Y components of Polar Motion and the nutations in obliquity and longitude are determined with an accuracy of 1 to 2 mas, and UT1 is determined with an accuracy of 0.05 to 0.10 milliseconds. At daily intervals, UT1 values accurate to 0.10 milliseconds are produced. The IRIS-A observations have also been used to develop a northern hemisphere Celestial Reference Frame with a precision of a fraction of a mas, and a Terrestrial Reference Frame accurate to a few centimeters. The IRIS-A results are distributed monthly by bulletin, and are available in a more timely manner by direct access to computer files maintained at the National Geodetic Survey, the network center.

Since April 1987 a second network, the IRIS-P network, consisting of observatories in Japan and the United States had conducted monthly observing sessions to determine earth orientation. The International Latitude observatory at Mizusawa (ILOM) serves as the IRIS-P network center. As the network matures in the next few years, it will provide the redundancy needed to insure the continuity of the VLBI- based Earth Orientation Service, and contribute to the global distribution of the Terrestrial Reference Frame.

Joint VLBI projects were conducted in January and February, 1984. Over five hundred observations were successfully performed in the two experiments. The correlation processing was made by both K-3 processor at Kashima and 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 0.02m in root mean square (Takahashi et al., 1985). Observations of plate motions and regional crustal deformations obtained using space technologies of Doppler observations of Navy Navigation Satellite, Satellite Laser Ranging (SLR) and VLBI were reviewed (Fujishita, 1985).

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 theories were adopted for the tidal and relativistic effects (Manabe et al., 1984).

A program was developed for converting a 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 (Ishikawa, 1985).

A third network, referred to as the IRIS-S network, has conducted two short observing campaigns during January and February 1986 and 1987. In this network the IRIS-A observatories are teamed with the Hartebeesthoek Observatory, South Africa, to produce earth orientation values.

Report from Laser Ranging

The last three years have been 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 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 G/M Earth of 398 600.44 +/-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 in an improved lunar ephemeris; preparations are now under way for a new joint lunar and planetary ephemeris at JPL.

Report from Satellite Laser Ranging

During the period from 1984-1987, Satellite Laser Ranging (SLR) continued regular contributions to earth rotation that began with the short MERIT campaign in 1980. At the conclusion of the Main MERIT Campaign in October, 1984, SLR data had been collected at over 30 sites and the Operational Center had provided weekly solutions of x, y and LOD based on quick-look data. Full-rate data were used by the Designated Analysis Centers in the USA, the FRG and the GDR. Contributions were also provided by Associate Analysis Centers located in France, Italy, Japan, PRC, UK, and USSR. Comparison of results showed agreement between the SLR analyses and the VLBI technique at the 2 marc sec level for x and y.

Since the Main MERIT Campaign, SLR has continued to provide contributions to Earth rotation through both rapid (weekly) determinations and annual analyses. The rapid service began providing three-day determinations of x, y and UT1 on a preliminary basis in 1985, and regular distributions began in mid-1986.

Because of the global nature of SLR and the high precision of many of the contributing SLR systems (1-5 cm), the effects of global tectonic motion have been readily apparent. Furthermore, the influence of unmodeled plate motion was shown to produce a secular drift in the pole position at the rate of about 1 marc sec/yr. Consequently, the definitions of the reference systems have become increasingly important. In some of the analyses, plate motion models have been adopted, whereas other analyses have simultaneously determined plate motion parameters.

SLR will continue its contributions in the International Earth Rotation Service. It is expected that improved measurement precision and geographic distribution of SLR systems, as well as improvements in the data analysis techniques, will take place in the next four years.

Report from Optical Astrometry

1) Organizational Structure

During the main campaign of Project MERIT, the Central Bureau of the international Polar Motion Service at the International Latitude Observatory of Mizusawa in Japan, and Bureau International de l'Heure at the Paris Observatory acted as operational and designated analysis centers. Also the Shanghai Observatory was an associate analysis center.

2) Stations and Instruments

The total number of stations and instruments, which participated in the main campaign are 62 and 85, respectively. Among them, 63 instruments of 52 stations provided time data, and 62 instruments of 49 stations provided latitude data.

3) Statistics of Observation

On the average, one star was observed every 2.0 minutes for time, and every 1.6 minutes for latitude. The best instrument showed precisions in 2-hour session observation, +/- 0.0049 s for time and +/- 0.059" for latitude.

4) Earth Orientation Parameters (EOP'S) and their Precisions

Two designated analysis centers, namely BIH and IPMS, provided optical astrometry EOP's. BIH series of EOP's are 5-day raw values with formal errors of +/- 0.007" - +/- 0.016" in Polar Motion, and +/- 0.00075 - +/- 0.00125 in UT1. IPMS Series of EOP's are smoothed daily values with formal errors of +/- 0.003" in Polar Motion, and +/- 0.00025 in UT1.

5) Comparison with the EOP's of New Techniques

Systematic differences of optical astrometry EOP's with respect to VLBI and SLR results are: about 0.01" and 0.00035 in both annual and semi-annual components of UT1.

6) Terrestrial Reference Systems

Both BIH and IPMS devised their own methods to estimate the variations of the station coordinates of all participating stations together with the EOP's. These methods obviously improved the EOP's.

7) Situations After the Main Campaign

After the Main Campaign, many optical astrometry stations closed operation. Hence the optical astrometry network is now far from homogeneous in station distribution. A working group was set up in the Commission 19, chaired by Dr. Ye of Shanghai Observatory, to consider the future of optical astrometry.

8) Rereduction of Past Optical Astrometry Observations

One of the serious error sources in optical astrometry technique is catalog errors. In consideration of the progress of Hipparcos Project, it will be extremely significant to rereduce past observations based on star catalog obtained by Hipparcos. Every station is requested to prepare machine readable data of the past records of observations.

REPORTS CONCERNING DIFFERENT AREAS OF RESEARCH

Reference Systems for Earth Rotation: Concepts, Definition, Realization

The definition and properties of the "non-rotating origin", (NRO) as introduced by Guinot (1979), have been investigated as well as the implementation of the corresponding conceptual definitions of the "stellar angle" (representing strictly the sideral rotation of the Earth) and of UT1. A θ/UT1 relation has thus been proposed as a primary conventional definition of UT1 with no appreciable step of UT1 and d(UT1)dt when the model of the pole trajectory is improved. The use of the NRO has also been shown to simplify the transformation between the terrestrial and celestial reference systems: Capitaine and Guinot (1986), Capitaine, Guinot and Souchay (1986).

The conceptual and conventional definitions of the Celestial Pole have been investigated and clarified: Capitaine, Williams, and Seidelmann (1986), Captaine (1986).

The relations between the Celestial Ephemeris Pole and several axes considered in the Earth tides have been investigated: Sevilla and Camacho (1986).

Trigonometric series to calculate the instantaneous vector of the Earth's motion with respect to the barycenter of the Solar System were derived in (Vondrak and Ron, 1986). These series, needed to calculate annual aberration, are based on Bretagnon's theory of planetary motions.

Time variations of relative positions of celestial radio sources were investigated to estimate errors on group delay observations for geodesy and geophysics with a very long baseline interferometer. It was found that systematic errors exist between the second and the third catalogues. There is no time variation exceeding 30 milli-arc-second between mean observation epoch 1975 and 1981 (Fujishita 1984B).

Practical realization of the celestial reference frame used for the reduction of the PZT results at Ondrejov was substantically improved by Ron and Vondrak, (1985).

A catalog of PZT stars was compiled by Sato et al. (1984). The calalog includes all the stars used by PZT observations at the ILOM (Mizusawa) and the United States Naval Observatory (USNO), Washington, D. C. since 1959, respectively. The stars of proposed programs for the International Latitude Service (ILS) chain by 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 and will be suitable for the initial observations by the ILS instruments.

A unified catalog of Washington and Mizusawa PZT stars was constructed by using recompiled and reduced data spanning 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 0.6ms and 0.008, respectively, for the best determined stars. Those of proper motions were 0.08ms/year and 0.001/years, respectively (Menabe et al., 1984).

New catalogue of declinations of latitude stars has been compiled at Kazan Observatory. Catalogue contains 2845 star declinations with mean error 0.072 arcsec (Urasina I.). It was used for reduction of 19 years of latitude observations (41.044.019). Set of coordinates of SLR stations was derived by using Kiev Geodynamics Program Complex (41.045.032., and Proc. IAU Sym. 128).

Determination of Earth Rotation Parameters

The operation of the PZT of the Deutsches Hydrographisches Institut (DHI) was discontinued on 1 July 1986. The observational data from 1962.0 to 1986.5 (new IAU constants, PZT catalogue of 1982) are available on magnetic tape in the usual BIH/IPMS format.

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 time, UT0-UTC, and latitude of the PZT and Danjon Astrolabe at Mizusawa since June 1979. Kakuta and Sato (1985) obtained a good correlation between variations of the Earth's rotational speed and UT0-UTC of the Mizusawa 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 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 (Kakuta, 1985).

Relative variations of UT1-TAI, Mizusawa to Washington are 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 (Kakuta et al., 1986).

Decreases in the relative variations of UT1-TAI, Mizusawa to Washington were studied from the point of a global motion of the ocean, the El Nino events (Kakuta, 1986).

The Hydrographic Department of Japan (JHD) has been carrying out Satellite Laser Ranging (SLR) observation at Simosato Hydrographic Observatory since 1982. The mean ranging precision is about 9 cm. The numbers of return signals obtained in the years 1984 to 1986 are 483,000 of 744 passes for Lageos, 102,000 of 318 passes for Starlette and 140,000 of 361 passes for Beacon-C. Since August, 1986, the ranging to the Japanese geodetic satellite Ajisai also has been made with 139, 000 return signals of 169 passes in 1986.

A transportable SLR system is under construction at JHD, the completion being expected at the end of October, 1987.

The Royal Observatory of Belgium had maintained the activities of the Tranet Station on a daily basis. Data were provided for the monitoring of the Polar Motion and generation of precise ephemeris extensively used for the determination of the Terrestrial Reference Systems. The station will be maintained in operation till the closure of the Tranet Network.

Accuracy of Earth-rotation parameters in different frequency bands as determined by different techniques of observation was estimated by Vondrak (1984b and 1986). It was found *that the difference in accuracy of different techniques are present mainly in the highest* frequency band while all the techniques studied are nearly equivalent in the lowest frequencies.

New reduction of latitude observation at Pulkovo from 1904 to 1986 was made for studying secular polar motion (V. Sakharov, L. Kostina) and nonpolar variation (L. Kostina and N. Persianinova). Authors showed some arguments on the reality of secular polar motion. Six years of latitude and time observations carried out by Soviet Observatories from 1978 to 1984 have been rereduced using new system of constants and original software. The work resulted in new determination of ERP and Station Coordinates (D. Belotserovskij, A. Korsun, et al.).

Theoretical Studies of the Earth

At the University of Louvain Neuve, new theoretical nutation series have been computed by adding the inelasticity of the mantle to the Earth model adopted by IAU. It has been pointed out that mantle inelasticity increases the discrepancy between the observations and the theory. In the same group, recent researches show that an additional pressure effect at the core mantle boundary and a change of the flattening of the core could be responsible of the lag between theory and observations (Dehanv, 1987).

The rotational and tidal deformation of tri-axial elastic Earth was theoretically studied by Vondrak (1984a). It was found that the principal axes of inertia exhibit big complicated motions with respect to the mean Tisserand axes; the most pronounced motions are diurnal and they attain nearly 400 arcsec in case of equatorial axes.

The response of visco-elastic tri-axial Earth with fluid core and equilibrim oceans to atmoshperic excitation was theoretically studied by Vondrak (1987).

Motion of the deformable Earth were investigated from the point of view of a frequency-dependence of Q. Roles of statistical models were clarified to estimate parameters of the Chandler wobble and admittances of solid and ocean tides (Ooe, 1985). Then importance of Kalman filtering was pointed out in order to separate system noises and observational errors in the polar motion (Kaneko, 1985).

Polar motion for an elastic Earth Model using a canonical theory (Sevilla and Romero (1986). Variation of the inertia tensor for deformable models were studied by Camacho et al. (1986a). Global and core inertia tensor components for a classical Earth model were studied by Camacho et al.(1986).

Interpretations of the Earth's Rotation Irregularities

Long-period behaviour of polar motion between 1900.0 was studied by Vondrak (1985). The secular motion of the pole was confirmed and the stability of annual term shown in contrast to large changes of Chandler wobble both in amplitude and phase. The latter problem was further studied in a greater detail by Vondrak (1987b), where the polar motion data beak to 1860 were used. The strong correlation between the amplitude and frequency of Chandler wobble was found.

Earth rotation and Earth tides

Tidal effects and Q of the solar system were studied. Specially, tidal Q of Mars were computed by using a recent value of the secular acceleration of Phobos. Q of the solid earth also was investigated using results given by the Earth tides and the Chandler wobble. Q of the lower mantle of the Earth turned out to be almost consistent with tidal Q of other terrestrial planets and satellites (Ooe, 1986).

Complementary studies of the tidal waves of UT1 confirm that the fortnightly wave M is altered and leads therefore to derived values of the Love number K which vary with time: Capitaine and Guinot (1986).

Dr. P. Brosche: Reconnaissance studies of the role of oceanic effects in the Earth rotation (with J. Sundermann, Hamburg). Search for such effects in VLBI-observations (with J. Campbell, Bonn) are so far not successful, but success may be ante portas because experiments with 1^h or 2^h resolution became available just now. Updating of reviews on the tidal friction process.

Data analysis was conducted to identify a near 50-day peak in the Solar Activity. Its possible relation with similar fluctuation in ERP and AAM has still to be identified (Djurovic and Paquet, 1987).

Crustal movement and the Earth's rotation

The variation of the seismic activity is well represented by that of the earthquake energy release. It was found that the refraction points in the pole path coincide with the active periods of earthquakes and the direction of refraction in the path was related with that of the excitation function estimated from the earth quakes in the most ackre region (Onodera, 1984).

Atmospheric and oceanic motion and excitations of the Earth's rotation

Onodera (1984) investigated the southern oscillation, one of large-scale atmospheric phenomena, in relation to variation 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 the latter. This fact suggested that there is some correlation between the two variations.

Fluctuations of the Earth's rotation with the period shorter than about 2 years are analyzed by using the data compiled or obtained at the BIH, the IPMS, the IRIS (International Radio Interferometric 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) in the period range biennial-40 days. Relatively high spectral power density is observed at the periods of 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 period range between biennial and 16 days (Hara and Yokoyama, 1985).

S. Molodenskij studied dynamical theory of polar tide (Physics of the Earth, Vol. 6, P. 3-18, 1985 in Russian) and M//Nutation (in book Tide, Nutation and Internal Structure of the Earth, Moscow, 1984,213 pp.). Many new results on the investigations of ERP and tides have been reported at Second Orlov Conference in Poltava, 1986 (Proc. will be published in Kiev, 1988). V. Sakharov and L. Kostina studied Chandler Wobble for the period of 1846-1974 (Soviet Astronomy, Vol. 61, N. 6, 1984). A. Korsun studied the nature of nonpolar latitude variation (39.044.001), tidal effect (38.044.013), and correlation of secular latitude variations of Ukiah and Gaithersberg stations with Greenland ice melting (together with N. Sidorenkov). Correlations of -0.69 and -0.54 were found respectively. N. Sidorenkov proposed new interpretation of atmoshperic exitation of Polar Motion (Proc. IAG Symp. in Prague, 1986).

Longer period fluctuations in Earth rotation, the so-called "Decade Variations" can almost certainly be attributed to torques between the core and mantle. Core-mantle 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 availabe from a combination of core motion models from geomagnetism and core mantle boundary maps from seismic tomography. Geodetic torque estimates provide a strong constraint on the models and assumptions used 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.