Polar Motion: Historical and Scientific Problems
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History of the International Polar Motion Service/International Latitude Service

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Abstract. The history of the International Latitude Service and the International Polar Motion Service is described, with an emphasis on the evolution of the international cooperation for monitoring the Earth's rotation. Also given is a brief description of the history of the Japanese geodetic and astronomical activities, as well as the future prospects.

1. Introduction

In 1895, the International Association of Geodesy (IAG) decided to set up the International Latitude Service (ILS) to investigate the polar motion in a more systematic way than ever before, on the basis of international cooperation. The Central Bureau was set at the Geodetic Institute of Potsdam, and F. Helmert took office as the Director. ILS started its regular operation in the fall of 1899. Even though this international cooperation was begun under the name of "latitude service," it clearly targeted monitoring and investigating polar motion. In those days, due to technical limitations, the latitude variation was the only phenomenon observable with enough precision for the study of polar motion. Nowadays, however, we know that polar motion is a manifestation of the Earth's variable rotation composed of three different perturbations, namely, polar motion, precession/nutation, and variation in the rotational speed.

In 1919, the International Council of Scientific Unions (ICSU) was established. As its member unions, the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG) were also established, the IAG was included in IUGG as a member association. Both IAU and IAG set up the commission of latitude variation in the respective Unions, and H. Kimura, the Director of the International Latitude Observatory of Mizusawa (ILOM), Japan, was elected the President of the respective commissions. At the first General Assemblies of IAU and IUGG held in 1922 at Rome, the ILS in the new framework of ICSU was started and the Central Bureau was set up at ILOM, with H. Kimura designated the Director. In addition Standard Times, which had till then been determined independently in the respective countries, were unified to Universal Time (UT) via radio signal transmissions, and international coordination for that was started by the Bureau International de l'Heure (BIH) established in 1919.

From the 1930s instruments for time (UT0) observations have been gradually developed. Especially in the 1950s the precision of UT0 measurement (induced both by variation of the rotational speed and longitude variation due to polar motion) was remarkably improved. This enabled one to simultaneously monitor the three aspects of the Earth's variable rotation using both time and latitude observations, and hence the necessity to reorganize ILS was strongly recognized. In fact, in 1955 the Service International Rapid (SIR) was set up for BIH to speed up the determination of UT. Thus the IAU and IUGG decided to replace the ILS in 1962 with the IPMS, in which not only ILS stations but also a number of stations operating instruments for time and latitude observations were incorporated.

In view of these instrumental developments and the widening scientific scope, the name of Commission 19 of the IAU was changed to "Rotation of the Earth" in 1967 from "Latitude Variation" as it was originally named in 1922 at the first General Assembly of the IAU. In this period, the two international services, namely IPMS and BIH, were simultaneously operational utilizing almost the same observational data. Thus, there arose a problem of duplication of the functions of IPMS and BIH.

On the other hand, progress in research on the Earth's rotation in those days was rather slow due to precision/accuracy limitations of the optical astrometry instruments that were the major tools for observations. Although gradual instrumental improvements were being made, angular measurements by optical observations at the bottom of the atmosphere could not achieve drastic precision improvement.

More than two orders of magnitude improvement in observational precision/accuracy was achieved by space geodetic techniques that had been developed from late 1960s. In particular, the investment of the National Aeronautics and Space Administration (NASA) in the NASA/CDP (Crustal Dynamics Project) started in late 1970s and played a leading role in dramatic improvement of precision/accuracy, as well as temporal resolutions in the determination of the Earth's variable rotation. In fact, the advent of space geodesy brought about a paradigm change in the scientific disciplines centered on Earth rotation study. This led to the establishment of the International Earth Rotation Service (IERS) in 1988, by reorganizing the IPMS and BIH. The most outstanding characteristic of the IERS is that it adopted only the space geodetic techniques having achieved cm/mm accuracy at its start: satellite laser ranging (SLR), lunar laser ranging (LLR), and very long baseline (radio) interferometry (VLBI). Later the global positioning system (GPS) was also included in the IERS.

Eventually, the research field of Earth's rotation evolved into an interdisciplinary field now called "geodynamics," and plays a major role in "Earth system sciences." In addition, precise positioning of radio sources at the cosmic distances observed by VLBI replaced the IAU celestial reference frame, which had been defined by positions and motions of optical sources in our Galaxy. Another outstanding achievement in IERS activities is the realization of comprehensive treatment of geophysical data and modeling to understand the evolution of the Earth system as a whole.

It is now widely accepted that perturbations of the Earth's rotation are useful indexes of the Earth system change. Because the recent rapid changes in the Earth's environments might have been induced by human activities, and because the change might be accelerated in the coming century, comprehensive research on the Earth's variable rotation is indispensable for the future of human beings. As a result of the 100-year history of research of the Earth's rotation, we are now convinced that geodynamical tools of observation, both space-borne and ground-based, will continue to provide humans with good measures of the Earth's environmental change.

In addition, the method of precise positioning, which has been the most fundamental technique for Earth rotation study, is now acquiring enough accuracy for measuring positions, motions and even distances of the objects in the whole area of our Galaxy or far beyond. It is very exciting to imagine that the scientific field originated from the study of Earth rotation more than a century ago will widen its scope to the study of galactic rotation, as well as lunar and planetary rotation.

2. Scientific Background of Japan before ILS

In describing the short history until the inauguration of the ILS, it will be worthwhile to mention here the scientific and social background of Japan. At that time, Japan was obviously a developing country at the Eastern edge of the Eurasian continent. Hence it was suspected, both from economic and scientific points of view, that Japan might not have enough resources to carry out ILS observations. In fact, a proposal was made by the Central Bureau to send observers to Japan. However, the Japanese science community decided to carry on observations by Japanese scientists. The following are brief descriptions of historical benchmarks related to geodesy and astronomy in Japan.

In 1799, a century before the first observation by ILS, Tadataka Ino started a geodetic survey in Japan for precise mapping by means of astronomical measurements at more than 1,200 points. Before starting the survey, Ino learned Western astronomy for four years from Yoshitoki Takahashi. Thus there existed a certain number of Japanese astronomers who understood Western astronomy already in the middle of 1700s. In 1872 the Japanese Government adopted the solar calendar, and in 1874 the first primary triangulation was conducted.

In October 1886, the International Association of Geodesy (IAG) was established. IAG was the international body extended from the former European Association in which France participated in 1872, USA in 1877, and England in 1884. Its original body had been set up in 1862 by the Central European countries. In response to the invitation by IAG, the Japanese government decided in 1888 to participate in the IAG and the National Geodetic Committee was organized in 1889. In the same year, the Tokyo Astronomical Observatory was founded.

In 1892, the Nobi Earthquake of magnitude 8.4 hit central Japan and killed about 7,000 inhabitants. Just after this earthquake, the government set up the Earthquake Research Committee for disaster prevention. This included research on geomagnetism, gravity, latitude observations, *etc.*, and thus the geophysical research environment of Japan were rapidly set up. In particular, the gravity survey was conducted as part of the international gravity survey proposed by Förster, and the committee also accepted the task of latitude observations and

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purchased a visual zenith telescope. The first latitude observation in Japan was made at the Tokyo Astronomical Observatory in 1895 by Kimura, who had just finished the astronomy course of the Tokyo Imperial University.

3. ILS Activities

3.1. Establishment of ILS

Proverbio in this Proceedings deals with the detailed history prior to the establishment of the ILS. Nevertheless, we will also include in this section a brief history of the pre-ILS period.

Euler's suggestion in about 1765 that the Earth may undergo free nutation of approximately ten-month period was made over 230 years ago. Since the first attempt to search for latitude variations induced by the Euler free nutation, approximately 150 years have passed. In order to commemorate the period of scientific chaos through which our predecessors created the new discipline of polar motion study, benchmark events are listed in chronological order in the following.

1765	Euler	Theory of rigid Earth polar motion of ten-month period (referred to as Euler's PM).
1841–1851	Peters, Bessel, Maxwell	Search for the Euler's PM, unsuccessfully.
1876	Kelvin, Newcomb	Report of detection of the Euler PM in Washington observations during 1862 to 1865, but unsuccessful.
1883	Fergola	Proposal to make latitude observations at two sites of different longitudes, noting that latitudes at European stations were almost uniformly decreasing.
1884	Küstner	Clear detection of periodic variation of latitude at Berlin through observations to determine the aberration constant.
1886	IAG	Establishment of IAG.
1888	Förster	Proposal to set up ILS.
1891	Küstner	Detection of latitude variations of opposite phase at Waikiki and Berlin, 180° longitude apart.
1891	Chandler	Discovery of 14-month period polar motion (referred to as Chandler PM).
1891	Newcomb	Geodynamical interpretation of the Chandler PM: elastic yielding and ocean loading.
1895	IAG, Berlin	Resolution to set up ILS on northern latitude parallel of 39°8′.
1899	ILS	Beginning of ILS operation.

In 1895, recognizing the importance of polar motion research, provoked by the works by Chandler (1891) and Newcomb (1891), the IAG at its XIth General Assembly held in Berlin decided to set up ILS. In 1896, at the Permanent

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Commission of the IAG, 17 candidate combinations of stations on 10 latitude parallels (including southern lines) were discussed, and the 39°8′ line of the northern parallel was finally selected.

This network was composed of Mizusawa (Japan, Ministry of Education, Science and Culture), Tschardjui (USSR, Military Topographic Department of Russian General Staff Office), Cagliari (Italy, Italian Circular Measure Committee), Gaithersburg (USA East Coast, US Coast and Geodetic Survey), Cincinnati (Central USA, Cincinnati Observatory) and Ukiah (USA East Coast, US Coast and Geodetic Survey). The telescope used by the ILS was the visual zenith telescope (VZT), which measures astronomical latitude with reference to the plumb line adjusted by the Talcott levels mounted on the telescope.

The stations of Mizusawa, Carloforte, Gaithersburg, and Ukiah were equipped with Wanschaff Zenith Telescopes of 108mm aperture and 130cm focal length, while the Tschardjui and Cincinnati stations had telescopes with 68mm aperture and 87cm focal length. The method of observation is called the Horrebow-Talcott method, which at that time achieved the highest precision in latitude observations. Refraction pairs (2 pairs in each group, 60 degree zenith distance) were also included in the observing program.

In Table 1, locations, periods of observation, mean latitudes, and dates of first observations are listed. Mean latitudes in the table are given in the Conventional International Origin (CIO), which will be explained in detail in a following section.

Table 1. ILS Stations

Stations	Longitude	Period of Obs.	Mean Φ 39°8'+	First Obs.
Mizusawa	141°08′E	1899–1984	3.″602	Dec. 16, 1899
Tschardjui	63°29′E	1899–1909	10.″703	Sep. 10, 1899
	63°35′E (New site)	1909–1919	10.″978	Jul. 28, 1909
Kitab	66°53′E	1935–1984	1.″850	Jan. 27, 1939
Carloforte	8°19′E	1899–1984 (interruption: 1944–1945)	8.″941	Oct. 24, 1899
Gaithersburg	77°12′W	1899–1914 1932–1984 (interruption: 1915–1931)	13.″202	Oct. 2, 1899
Cincinnati	84°25′W	1899–1915	19.″354	Sep. 1, 1899
Ukiah	123°13′W	1899–1984	12.″096	Oct. 11, 1899

3.2. The Equation to Derive Polar Motion from Observed Latitude Variations

As stated in "Resultate des Internationalen Breitendienstes, Band I", the major objective of the ILS was to clarify true polar motion by comprehensive means. The observed latitudes of the ILS stations can be geometrically related to the

Figure 1. H. Kimura, Japanese leader in polar motion studies.

two-dimensional coordinates (x, y) of the instantaneous position of the north pole. On the other hand, latitude variations are computed through complicated reduction procedures, such as instrumental corrections, refraction corrections, and above all star place computations based on the numerical values of the astronomical constants. Observed latitudes are corrected for these known and predictable phenomena, so that the final values of latitudes may be composed only of unpredicted polar motion. If the adopted astronomical constants are exact, this is true, and the equation of condition has to have only two unknown parameters (x, y).

Preliminary computation of polar coordinates by the Central Bureau at Potsdam showed that large residuals remained in the observational series of the station of Mizusawa, and therefore a lower weight was assigned. The Central Bureau sent a letter to the Japanese Geodetic Committee and requested to inspect the telescope, as well as the observational procedures of Mizusawa. After careful inspections, it was concluded that there had been no problems.

Kimura (Fig. 1) considered that the observations must have been describing something unknown but real. He finally came to the conclusion that addition of one more unknown parameter, which is independent of station longitudes, is necessary to correctly interpret the observations. This unknown is now called the Z-term (Kimura, 1902). The new solution of the polar coordinates using the equation of condition including the Z-term showed remarkable improvement in polar motion results, and the residuals of the observing stations were also improved. Although the cause of the Z-term remained unknown at that time, the Central Bureau decided to adopt Kimura's formula from its first volume of the official ILS report. Kimura was awarded the Gold Medal of the Royal Astronomical Society in 1910.

Seventy years after the discovery of Kimura's Z-term, a physical interpretation was made by Wako (1970), an astronomer of ILOM. In short, Kimura's Z-term was due to the inadequacy of the nutation model used to calculate the ILS star places. The adopted nutation table was based on the rigid Earth model. However, the real Earth is composed of an elastic mantle, liquid core, oceans, *etc.*, and therefore the nutation of the real Earth is remarkably different from

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the rigid Earth nutation. The largest component of this discrepancy appeared as an annual variation of about 0".02 (60cm) amplitude in the Z-term. Although the precision of a single observation by the VZT was about 0".1 (3m), by taking average, such a small annual variation could be detected. Later various nutation theories have been developed based on realistic Earth models (*cf.* Jeffreys and Vicente, 1957; Wahr, 1981). When Wahr's nutation model is used for the star place computation, the annual variation in the Z-term disappears (Kinoshita *et al.*, 1979).

Thus only three years after the beginning of ILS operations, a valuable discovery which foresaw one of the major scientific themes of the present-day geodynamics was made. Nowadays, space geodetic techniques are providing Earth orientation parameters at millimeter level precision. In order to achieve such precision, more and more elaborate models have been developed for eliminating predictable phenomena from the observed quantities, and accurate observations are contributing to improving the models.

3.3. Observing Programs of ILS

As shown in Table 2, the observing program of the ILS was revised seven times. Especially in 1955 revision was made to observe three groups (6 hours) every night. This made it possible to clarify the physical origin of the annual latitude variation in the Z-term. It is essential to design the most appropriate observing program meeting scientific objectives.

Table 2. Observation Program of ILS

Program	Period of obs.	No. of Groups	No. of Star Pairs
1	1899–1905	2	8
2	1906–1911	2	8
3	1912–1922.7	2	8
4	1922.7–1934	2	8
5	1935–1954	2	6
6	1955–1966	3	6
7	1967–1984	3	6

3.4. Southern Latitude Stations

Here we give a brief description of the southern latitude stations. Readers may refer in detail to "ILS Results Vol. VII and VIII."

In the late 1920s, the ILS network was at a critical juncture. Among six ILS stations, Cincinnati was already closed. Tschardjui interrupted observations in 1919 due to soft ground of the site, until it restarted operation at the new site, 300km east of the former station on November 14, 1930. Furthermore on August 21, 1932 the Gaithersburg station restarted operation after its long interruption. In order to strengthen ILS activities, at the IAU General Assembly held at Leiden in 1928, a resolution was passed to set up the southern ILS, taking advantage of the two existing astronomical observatories on the same latitude parallel with the longitude difference of about 180°: Adelaide in Australia and

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La Plata in Argentine. In addition, Kimura attempted to set up a station near the equator, and observations were begun at Batavia in Indonesia in 1931, with the cooperation of Holland. However, since Batavia was the only station on the same latitude parallel, it was difficult to precisely determine errors of star positions and motions.

3.5. Definition of the Conventional International Origin (CIO)

CIO was defined as a set of numerical values of the mean latitudes of the five ILS stations as follows (IAU Transaction, 1967, Vol. XIIIB, P.111).

Mizusawa	$+39°8'$	$3''.602$
Kitab		$1''.850$
Carloforte		$8''.941$
Gaithersburg		$13''.202$
Ukiah		$12''.096$

Thus the instantaneous coordinates of the north pole were defined to be calculated referring to the origin defined by the above mean latitudes. Until the CIO was officially adopted, the successive ILS Central Bureaus used to adopt the mean latitudes averaged over the observational period concerned. In those days, the necessity to fix the origin of the polar coordinates was recognized, in consideration of the possible secular motion of the pole. The first use of CIO in the official ILS report was made in "Resultati del Servizio Internazionale, Vol. X" published in 1970, where a detailed description concerning derivation of CIO values is given. Mean latitudes of Cincinnati and Tschardjui in the CIO system, which were originally not given in CIO, were computed in "Results of ILS in a Homogeneous System" (1980) for the recalculation of the past ILS observations. They are given in Table 1.

3.6. Reduction of the Past ILS Observations

In 1961, a resolution concerning the recomputation of past ILS observations in a uniform system was adopted at the XIth IAU General Assembly in Berkeley. It was submitted by IUGG and proposed by Commission 19 (Resolution No. 3, (7)(a), IAU Trans. XIB, 1961, P 87.). Later, in 1970, at the IAU General Assembly in Brighton Commission 19 adopted the resolution and requested the Scientific Council of IPMS to establish a small working group to re-reduce the northern ILS VZT observations on a homogeneous basis (Resolution 4, IAU Trans. XIVB, 1970, p. 152). Members of the working group were S. Yumi (Chair), E.P. Fedorov, E. Fichera, B. Guinot, G. Hall, Wm. Markowitz, P. Melchior and R.O. Vicente. With the support of various worldwide institutes and funds, the work of homogeneous re-reduction was made at IPMS/CB.

According to the agreement of the working group, the Melchior-Dejaiffe (1969) catalog (compiled in the FK4 system), and the IAU 1964 System of Astronomical Constants (with the rigid Earth nutation table) were adopted as the celestial reference frame, and CIO was adopted as the terrestrial reference frame.

The total numbers of observed pairs and nights are over 770 thousand and 66 thousand, respectively. The results were distributed to the worldwide institutes recorded on magnetic tapes.

We show monthly mean latitudes and Orlov mean latitudes of five ILS stations in Figure 3.6..

3.7. ILS Publications

Table 3 gives a list of official publications of the ILS results published by the successive Central Bureaus.

Table 3. Official Reports of ILS

Period of Obs.	Central Bureau (Director)	Publications, Authors
1899–1901	Potsdam (F. Helmert)	Resultate des Internationalen Breitendienstes, Band I, 1903, Th. Albrecht
1902–1904	Potsdam (F. Helmert)	*ibid.*, Band II, 1906, Th. Albrecht & B. Wanach
1899–1905	Potsdam (F. Helmert)	*ibid.*, Band III, 1909, Th. Albrecht & B. Wanach
1906–1908	Potsdam (F. Helmert)	*ibid.*, Band IV, 1911, Th. Albrecht & B. Wanach
1909–1919	Potsdam (F. Helmert)	*ibid.*, Band V, 1916, B. Wanach
1912–1922.7	Potsdam (F. Helmert)	Ergebnisse des Internationalen Breitendienstes von 1912 bis 1922.7, 1932, B. Wanach & H. Mahnkopf
1922.7–1930	Mizusawa (H. Kimura)	Results of the International Latitude Service from 1922.7 to 1930, Vol. VII, H. Kimura
1922.7–1934	Mizusawa (H. Kimura)	*ibid.* from 1922.7 to 1934, Vol. VIII, H. Kimura
1935–1940	Napoli (L. Carnera)	Resultati del Servizio Internazionale delle Latitudini dal 1935.0 al 1941.0, Vol. IX, 1957, L. Carnera
1941.06–1948.98	Napoli (L. Carnera)	*ibid.* dal 1941.06 al 1948.98 , Vol. X, 1970, T. Nicolini & E. Fichera
1949.0–1962.0	Turin (G. Cecchini)	Results of the International Latitude service from 1949.0 to 1962.0, Vol. XI, 1973, G. Cecchini
1962–1966	Mizusawa (S. Yumi)	Results of the International Latitude Service, Vol. XII, 1978, S. Yumi & K. Yokoyama
1899.0–1979.0	Mizusawa (S. Yumi)	Results of the International Latitude Service in a Homogeneous System, 1980, S. Yumi & K. Yokoyama

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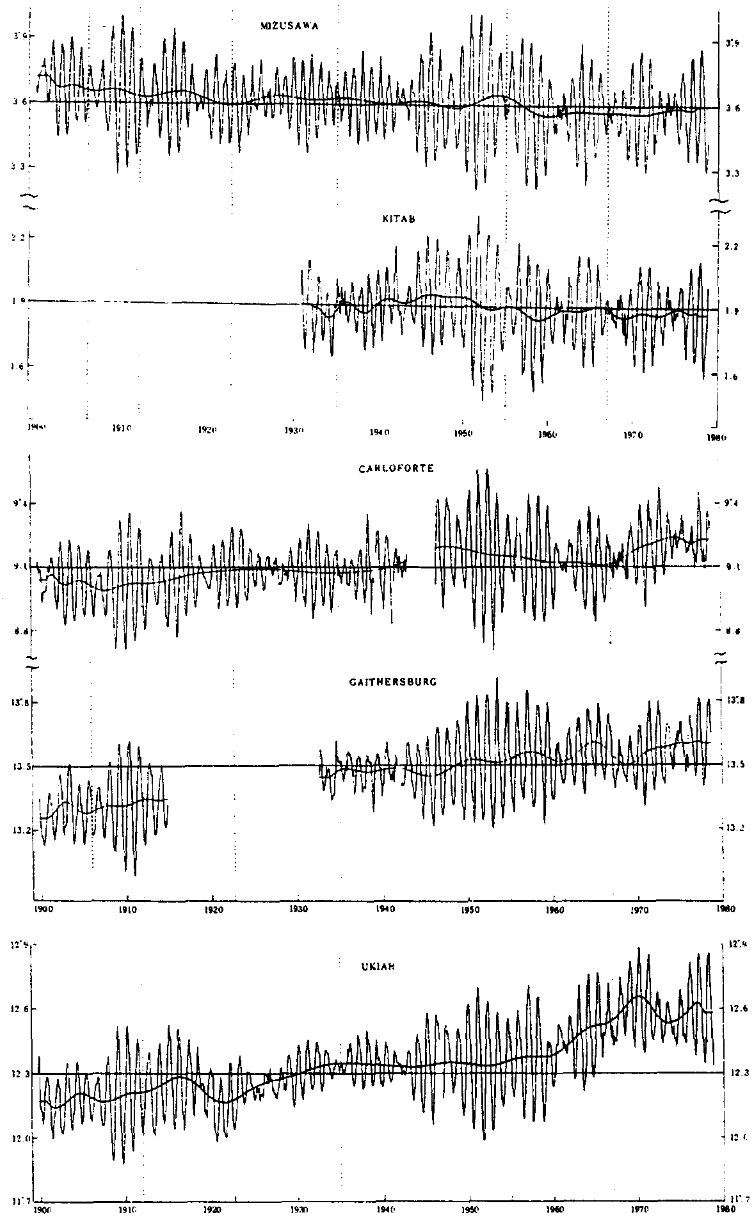

Figure 2. Monthly mean latitudes and Orlov mean latitudes of the ILS stations (Yumi and Yokoyama, 1980).

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4. International Polar Motion Service (IPMS)

4.1. Reorganization of ILS: To the Foundation of IPMS

Already in the early 1950s, a number of independent stations were carrying out latitude and time observations using various instruments. Hence the necessity for establishing a new organization was widely recognized. At the IAU General Assembly at Dublin in 1955 (IAU Trans., Vol. IX, 1955), discussions were held to improve the quality of polar coordinates from various viewpoints, such as more effective use of the photographic zenith tube (PZT), Danjon astrolabe, and other newly developed instruments, and need of a rapid service for prompt determination of polar motion for use in the determination of time.

The IAU General Assembly held at Moscow in 1958 was an epoch-making meeting for the Earth rotation community. The first line of the first paragraph of the commission report stated "The period of this report is notable for a considerable expansion in and change of the latitude work" (President E.P. Fedorov). It also reported that the number of instruments already reached 22 zenith telescopes (including large ones), 10 PZTs, 10 Danjon Astrolabes, and 2 others. SIR was also established in accordance with the recommendation of the ninth IAU General Assembly.

Further, a resolution was passed at this meeting to organize the symposium on the future of ILS. This symposium was organized by IAG as "l'Avenir du Service International des Latitudes," Helsinki, July 26–August 7, 1960 (Bulletin Géodésique, pp. 4–97, No. 59, March 1, 1961). The resolutions concerning the reorganization of ILS passed by this symposium were submitted to the XIIth IAU General Assembly by IUGG (IAU Trans. Vol. XIB, p. 87, 1961).

Resolution No. 3 (extract) states:

The International Union of Geodesy and Geophysics recommends

(2) that the northern ILS stations should continue in operation with the present instruments, ...

(3) that the ILS be reorganized into an International Polar Motion Service utilizing both time and latitude observations made at both independent and ILS stations,

(4) that a small number of working group be created initially to establish a definite plan for the organization of international co-operation in the study of polar motion and then to direct the work in the future. The group should submit to the IAU recommendations concerning the future location of the Central Bureau of the ILS (to become IPMS), ...

The objectives and organizational structure of IPMS was defined at this meeting as follows:

Objectives of the service: IPMS is a scientific organization attached to the Federation of Astronomical and Geophysical Services (FAGS) and is in charge of the following works:

(a) advance study of all the problems related to the motion of the pole,

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(b) collect the astronomical observations which can be utilized for the determination of this motion,

(c) analyze and synthesize them,

(d) calculate the coordinates of the pole,

(e) distribute the data required,

(f) publish the initial data and obtained results.

The Scientific Council of IPMS: to be composed of a representative of FAGS, and 5 members: 2 representatives of from IAU and 2 representatives of IUGG and the director of the Central Bureau. B. Guinot (President of the Commission 19) and E.P. Fedorov represented the IAU, and Wm. Markowitz and P. Melchior represented IUGG.

Thus IPMS officially started its activities in 1962.

4.2. IPMS Activities

The Central Bureau (CB) was set up at ILOM of Japan, and T. Hattori of ILOM was appointed the Director. T. Hattori, however, passed away about two months after the appointment, and then S. Yumi took office in August 1963 until 1980, and K. Yokoyama succeeded S. Yumi until the end of IPMS at the end of 1987.

Since 1962, all stations have regularly reported latitude observations to IPMS/CB, and since 1967 time observations too. The maximum numbers of the participating countries and stations were 26 and 75, respectively. Utilizing these data, IPMS/CB has published the *Annual Report* (AR) from 1962 to 1978 and the *Monthly Notes* (MN) from 1962 No. 1 to 1987 No. 12, regularly. The Earth Orientation Parameters (EOPs) given in AR and/or MN are as follows.

Table 4. IPMS Publications

Period	Published EOPs	Data	Time Resolution	Remarks
1962–1973	PM, Z	L	1/12 & 1/20 yr	
1974–1977	PM, Z, τ	L & T	1/12 & 1/20 yr	UT1 not published
1978–	PM, UT1, Z, τ	L & T	1/12 & 1/20 yr	1978 IPMS System
1983–	PM, UT1, lod	L & T	24 hour	1984 IPMS System

Note: PM (polar motion), lod (length of day), Z and τ (the nutation dependent terms in latitude and time observations).

In computing the daily EOPs, Z and τ (Yokoyama, 1976) were not estimated. As all predictable phenomena were reduced from the reported data using MERIT Standards (*cf.* Melbourne, 1981), it was unnecessary to include the nutation dependent terms in the equation of condition, when we took account of the precision of optical astrometry techniques.

In 1978, IPMS/CB established "1978 IPMS System" of EOPs and made a thorough recomputation of EOPs from 1962. In 1983, it began to publish daily EOPs (1984 IPMS System) based on ABIC (Akaike's Bayesian Information

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Criterion). A general description of the method is given in Manabe *et al.* (1982). We show in Figure 3, comparison of daily UT1 in "1984 IPMS System" with the results of VLBI. This seems to show that classical optical instruments might have detected rapid variations of the Earth's rotation with more fidelity than had been unfairly misunderstood. Although we believe that the IPMS method to derive optimal high time-resolution EOPs made use of the maximum potential of the optical astrometry observations, the 1980s was already the period of space techniques that optical astrometry could not cope with in every aspect.

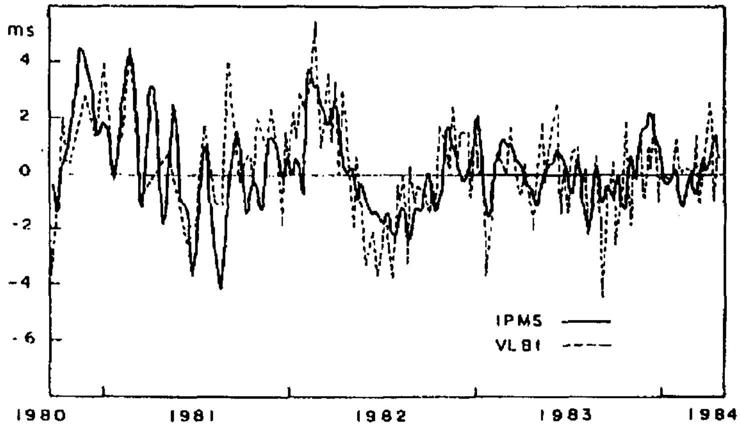

Figure 3. Comparison of UT1 between IMPS optical astrometry and VLBI with respect to BIH UT1 (Yokoyama, 1984).

4.3. From IPMS to IERS

Wilkins in this Proceedings describes the movement to establish the present IERS through MERIT/COTES from 1978. Also a brief description of the scientific and organizational backgrounds surrounding the Earth rotation community is given in the introduction of this paper. Eventually, optical astrometry techniques phased out of international cooperation, and space techniques took over the role for monitoring the Earth's rotation. Thus at the end of 1987, IPMS was closed, having finished its historical role, and IERS started at the beginning of 1988.

5. Summary: Toward the Next Century

On July 1, 1988, ILOM under the jurisdiction of the Ministry of Education, Science, Sports and Culture (MESSC) finished its historical role and was reorganized as the Earth Rotation Division of the National Astronomical Observatory of Japan (NAOJ). From the early 1980s, ILOM started planning to construct a VLBI system mainly for geodynamical research. Later in the framework of

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NAOJ, the Earth Rotation Division has been making full efforts to extend its research field including galactic astrometry and planetary sciences, by means of precision positioning techniques which have continuously been the primary technique for Earth rotation study.

In December 1999, the budget was allocated to NAOJ for the construction of VERA (VLBI Exploration for Radio Astrometry), which is the VLBI network to be composed of four stations in Japan, originally designed by the Mizusawa group. This year, however, construction of three stations (Mizusawa, Chichi-jima and Kagoshima) was approved. VERA is dedicated to galactic dynamics and geodynamics, both based on high-precision positioning implemented by the phase referencing relative VLBI technique using specially designed dual-beam radio telescopes.

Further, the lunar group of Mizusawa has been developing the techniques for precise positioning of the radio transmitters to be located both on the surface of the Moon and on board the lunar orbiter, as a mission in the Japanese SELENE (SELenological and Engineering Expedition) Project to be launched in 2004. In this project too, VLBI techniques will play an essential role in measurements.

The Mizusawa group has made remarkable contributions to the international cooperation for Earth rotation study. But because it could not have a dedicated observational tool for these years, its contribution has been diminishing. However, with the new projects like VERA and SELENE, we hope to return to international cooperation, and also to develop new scientific disciplines making full use of precise positioning techniques which we have been elaborating.

What we have done during the past one hundred years must be measured by what we will create for human beings in the coming century.

Acknowledgments. The authors who have been involved in the works of IPMS/CB would like to express their profound reverence to all the individuals and national/international organizations who have contributed to ILS and IPMS activities.

The Earth Rotation Division of NAOJ celebrated the centennial anniversary of latitude observations on October 23, 1999. For this occasion, we published a memorial book to which Drs. B.F. Chao, D.D. McCarthy, E. Proverbio, and Ya. Yatskiv, who have at least once stayed at Mizusawa, kindly contributed. Although the book is written in Japanese, we are happy to make announcement that a few tens of copies are available for distribution on request.

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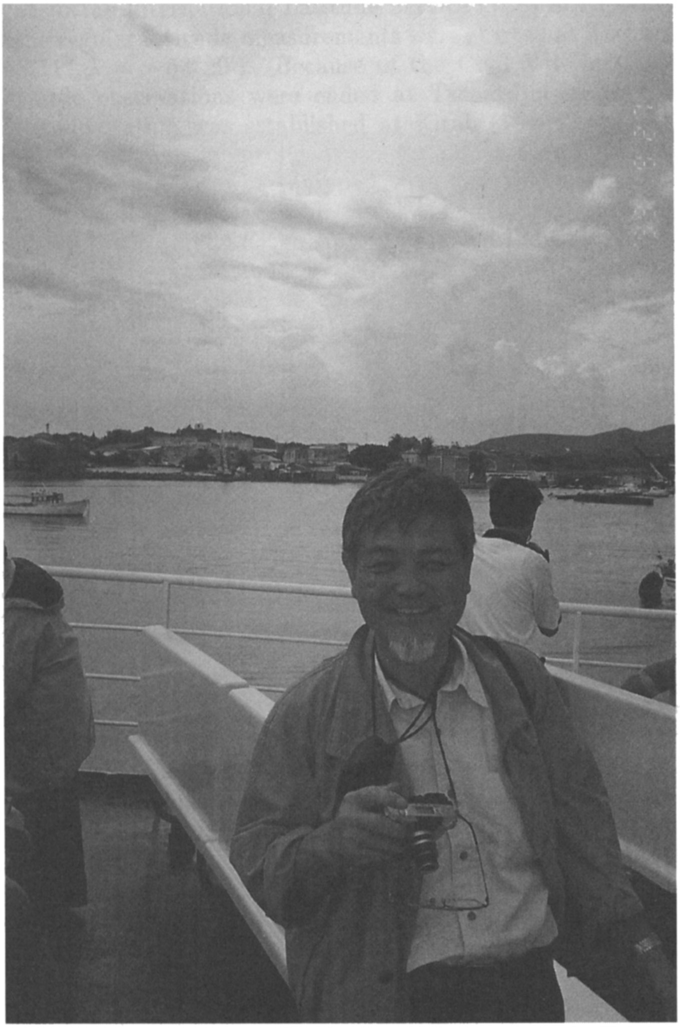

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