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On the contribution of the Geodetic Institute Potsdam to the International Latitude Service

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On the contribution of the Geodetic Institute Potsdam to the International Latitude Service

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Abstract. The history of the study of Polar Motion began with the derivation of the equations for the rotation of a rigid body by Euler published in 1758. This was followed by further theoretical contributions made by Lagrange (1788) and Poinsoot (1834). To confirm the existence of the polar motion of the Earth in terms of a variation of latitude, intensive efforts were undertaken at several observatories toward the end of the 19th century. During the 7th General Conference of the European Arc Measurement in Rome in October 1883, Fergola had already suggested to investigate the problem. The latitude variation was detected by Küstner at the Berlin Observatory in 1888. Following this, during the Annual Conference of the Permanent Commission of the "Internationale Erdmessung" in Salzburg in September 1888, Foerster proposed to consider the variation of latitude more systematically by a Special Commission. Activities began quickly, and after considerable effort the International Latitude Service (ILS) started in September 1899. The paper reviews, in which way the Geodetic Institute Potsdam contributed to the foundation of the ILS and took part in its activities through the work of Helmert, Albrecht, Wanach and Mahnkopf. Based on international scientific cooperation, the results were the rectangular coordinates of the Polar Motion from 1890.0 to 1922.7 at 0.1 year intervals, in particular those derived from the latitude observations at independent stations from 1890.0 to 1899.8, and those derived from the latitude observations at the ILS stations from 1899.9 to 1922.7

Key words: ILS (International Latitude Service), foundation, organization, contribution, Geodetic Institute Potsdam (Helmert, Albrecht, Wanach, Mahnkopf), latitude stations

1 On the history of the study of polar motion

1758 Leonhard Euler (1707-1783), a Swiss mathematician, derived and published the classical equations for the rotation of a rigid body (Euler, 1758).

1788 Joseph Lagrange (1736-1813), an Italian-French mathematician, presented the equations of motion of a rotating body including Euler's equations for a freely rotating body (Lagrange, 1788).

1834 Louis Poinsoot (1777-1859), a French mathematician, used a purely geometrical method for studying the motion of the rotational axis of a freely rotating body. Geometrically, the axis of rotation describes two cones, namely a body cone around the axis of maximum moment of inertia and a space cone around the axis of angular momentum fixed in space (Poinsoot, 1834, 1851).

1844 Christian Peters (1806-1880), a German astronomer, studied the latitude variation using observations of the zenith distance of the Pole Star from March 1842 to April 1843 at the Pulkovo Observatory. He predicted that the period of a polar motion of the Earth would be about 304 days. Here, the polar motion should manifest itself as a periodic variation of the latitude of the observatories (Peters, 1844).

1844 Friedrich Wilhelm Bessel (1784-1846), a German astronomer, found a variation in latitude observations made from 1842 to 1844 at the Königsberg Observatory. As reason for it, he thought of variations in the Earth's body (Bessel, 1844).

1873 M. O. Nyrén, a Swedish astronomer, compared the results of latitude observations of Pulkovo with those of Greenwich, Naples (Napoli) and Washington (Nyrén, 1873).

1876 William Thomson (1824-1907), an English physicist, pointed out, that the motion of the pole might be more complicated than generally believed because of possible redistributions of masses in and on the Earth (Thomson, 1876).

2 On the history of organizing the International Latitude Service

1861 The Prussian General Johann Jacob Baeyer (1794-1885) submitted to the Prussian War Ministry a document entitled "On the size and figure of the Earth: a memorandum on the establishment of a Central European arc measurement" (Baeyer, 1861).

April 1862 Inaugural Conference of the Central European Arc Measurement (Mitteleuropäische Gradmessung) in Berlin (Baeyer, 1862; Protokoll, 1882)

Oct. 1864 1st General Conference of the Central European Arc Measurement in Berlin. Topics: Organizational structure and research program. Resolutions: Permanent Commission for the scientific leadership having an annual conference, Central Bureau as executive organ, General Conferences at three-yearly intervals (Foerster, 1865)

April 1, 1866 The Central Bureau of the Central European Arc Measurement was established under General J. J. Baeyer as President in Berlin.

Sept./Oct. 1867 2nd General Conference of the European Arc Measurement (Europäische Gradmessung) in Berlin (Bericht, 1868)

Jan. 1, 1870 The Royal Prussian Geodetic Institute, which included the duties of the Central Bureau, was established under its first director General J. J. Baeyer in Berlin (Baeyer, 1872).

Oct. 1883 7th General Conference of the European Arc Measurement in Rome: Emmanuele Fergola (1830-1915), an Italian astronomer, suggested to investigate the problem of the variation of the Earth's axis using simultaneous latitude observations at two observatories on the same parallel from several such combinations (Jahresbericht Preussen, 1884).

1884 Friedrich Robert Helmert (1843-1917), a German geodesist, believed that a secular drift of the pole could be caused by postglacial rebound (Helmert, 1884, Vol. II, p. 446). For some information on the biography of Helmert, see the Appendix.

Jan. 1, 1886 F. R. Helmert became Baeyer's successor as director of the Royal Prussian Geodetic Institute and of the Central Bureau (Helmert, 1913).

June 3, 1886 The site for the Royal Prussian Geodetic Institute was selected on the Telegrafenberg of Potsdam.

1889-1892 The main building of the Royal Prussian Geodetic Institute was built.

April 1892 Inauguration of the Royal Prussian Geodetic Institute on the Telegrafenberg of Potsdam

1892/1893 A geodetic-astronomical observatory including pavilions for latitude and time observations and a tower for angle measurements (now Helmert Tower) was built.

Table 1. Coordinates of the latitude stations at Berlin, Potsdam, Prague, Strasbourg and Honolulu and observers

Station	Latitude	Longitude	Observer
Berlin	+ 52° 30' 17"	- 13° 24'	Adolf Marcuse (in 1889/91)
Potsdam	+ 52° 22' 56"	- 13° 04'	Max Schnauder
Prague	+ 50° 05' 16"	- 14° 25'	L. Weinek and G. Gruss
Strasbourg	+ 48° 35' 00"	- 7° 46'	E. Becker and H. Kobold
Honolulu	+ 21° 16' 25"	+ 157° 50'	Adolf Marcuse (in 1891/92)

1889 Beginning of permanent latitude observations at the Institute (until 1923; then again from Oct. 1957 to 1991).

Sept. 1892 The Time Service started to work at the Institute (until 1991).

Oct./Nov. 1886 8th General Conference of the "Internationale Erdmessung" (Association Internationale de Géodésie), known since 1932 as the International Association of Geodesy, in Berlin: A convention including an annual endowment of the Permanent Commission with 16000 Mark was accepted. The scientific program was enlarged (Uebereinkunft, 1886; Helmert, 1887).

1888 Friedrich Küstner (1856-1936), a German astronomer, detected a variation in latitude observations made from April 2, 1884 to May 28, 1885 at the Berlin Observatory (Küstner, 1888).

Sept. 1888 Annual Conference of the Permanent Commission of the "Internationale Erdmessung" in Salzburg (Helmert, 1889):

The German astronomer Wilhelm Foerster (1832-1921) proposed to appoint a Special Commission for dealing with the variability of the Earth's axis.

The Special Commission, to which Foerster, Helmert, the Dutch astronomer Hendricus van de Sande Bakhuyzen (1838-1923), the French astronomer François Tisserand (1845-1896) and the Austrian astronomer Edmund Weiss (1837-1917) belonged, submitted three recommendations at the following session of the Permanent Commission. They were adopted and read:

- (1) The question is an important and urgent problem of the "Internationale Erdmessung";
- (2) The Bureau obtains grants (up to 4000 Marks) to prepare corresponding latitude determinations at four or more stations located on the same parallel and to study the suitable method of observation and the suitable type of instrument including making the instruments of the same kind;
- (3) In the next session, it should be reported on the results of the preparation and the spending money.

1889 The observatories Berlin, Potsdam, Prague and Strasbourg started their cooperation to observe latitude variations (Jahresbericht, 1889). Table 1 gives the coordinates of the observing sites and the observers. Also included is Honolulu (see below).

Oct. 1889 9th General Conference of the "Internationale Erdmessung" in Paris (Helmert, 1890; Albrecht, 1890):

Helmert reported on the cooperation of several observatories with the objective of studying small motions of the Earth's axis, in particular

- Latitude observations using Horrebow-Talcott's method at the Observatory of Berlin and at the Astrophysical Observatory of Potsdam starting on January 1, 1889
- Latitude observations at the Observatories of Prague and Strasbourg
- Analysis of the observations under the direction of Theodor Albrecht (1843-1915), head of the Astronomical Section at the Royal Geodetic Institute; for some information on the biography of Albrecht, see the Appendix.

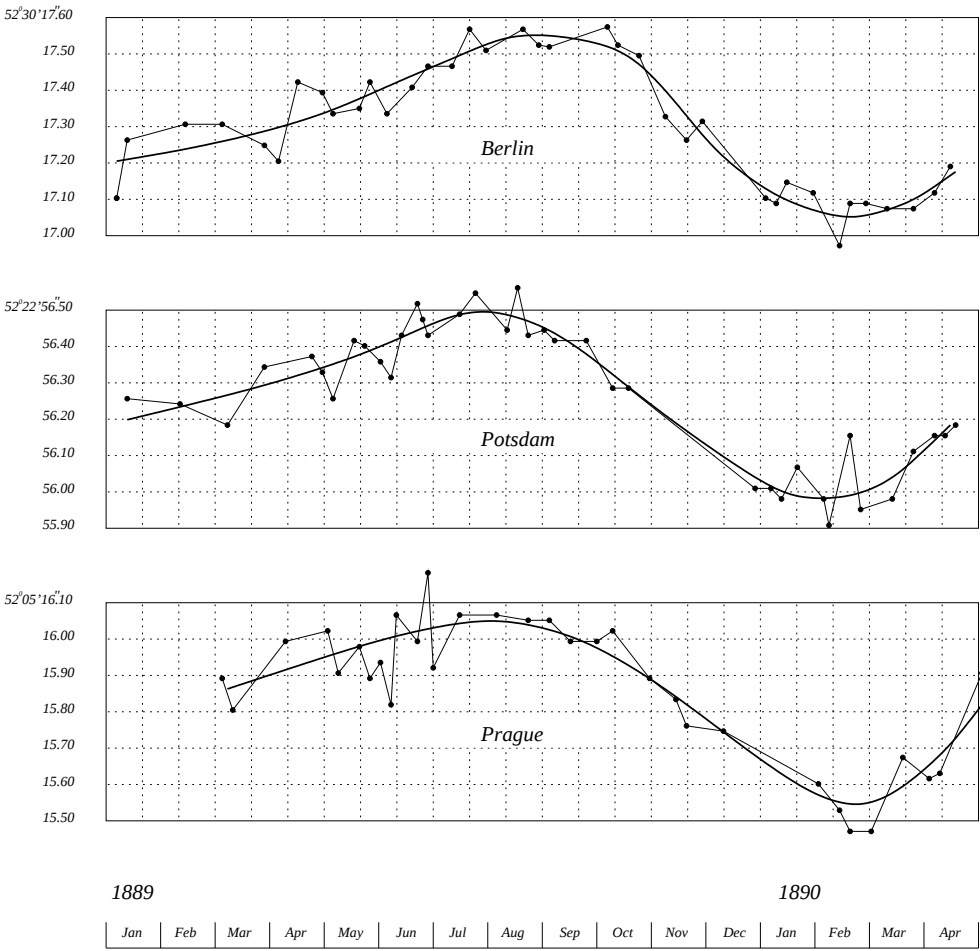


Figure 1. Latitude variations observed at Berlin, Potsdam and Prague from January 1889 to April 1890 (from Albrecht, 1891). The mean values are denoted by filled circles. For the number of the observed star pairs and the number of the days of observation, see the original figure

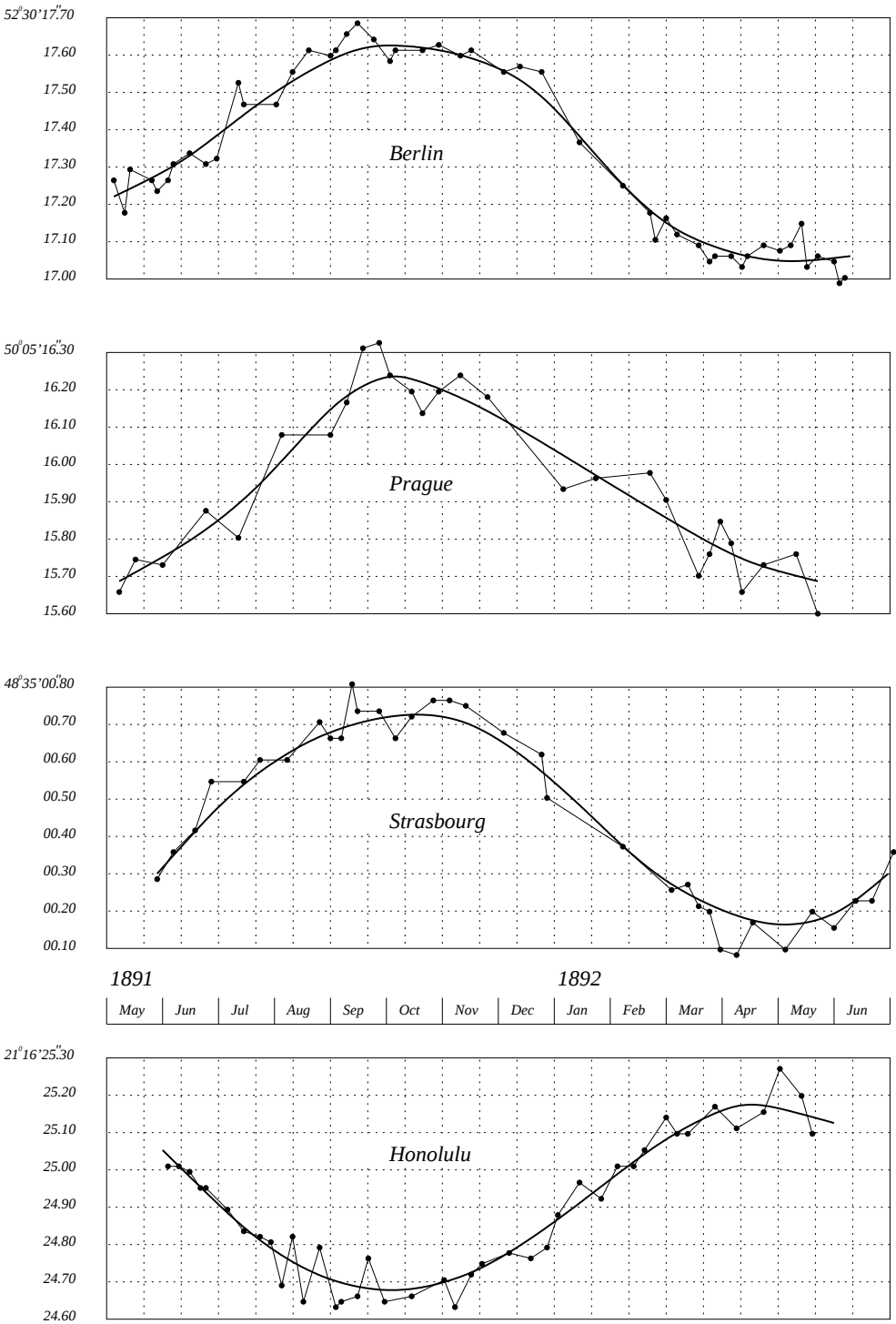


Figure 2. Comparison of the simultaneous latitude variations observed at Berlin, Prague, Strasbourg and Honolulu from May 1891 to June 1892 (from Albrecht, 1892). The mean values are denoted by filled circles. For the number of the observed star pairs and the number of the days of observation, see the original figure

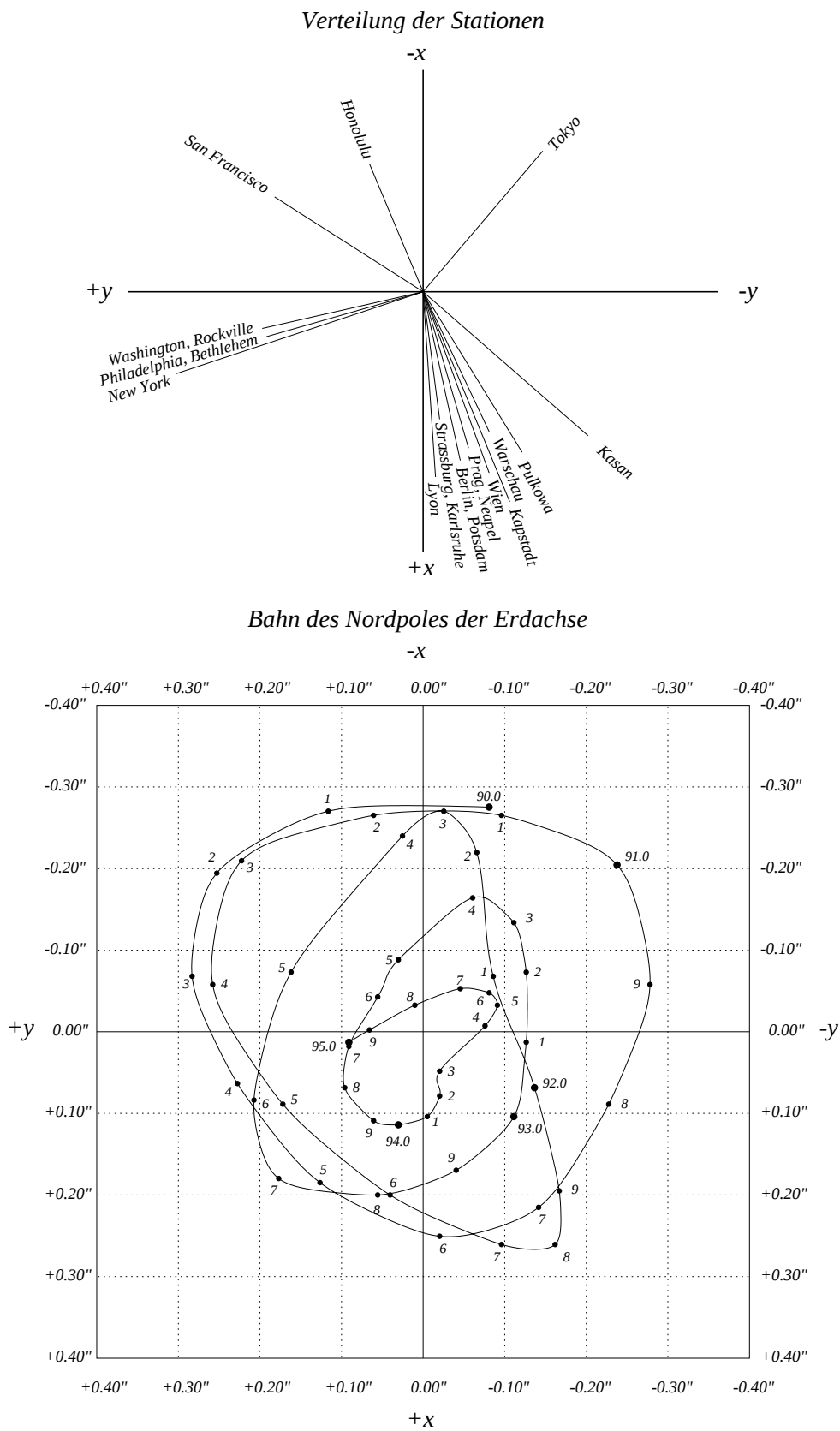


Figure 3. Polar motion from 1890.0 to 1895.0 derived from latitude observations at 20 independent stations (from Albrecht, 1898). Top: Distribution of the stations. Bottom: Motion of the northern pole of the Earth's axis. The values at 0.1 year intervals are denoted by filled circles. The positive x-axis points towards the Greenwich meridian, the positive y-axis towards 90°W longitude

Table 2. Coordinates of latitude stations, observers and periods

Station	Latitude	Longitude	Observer	Period
Tokyo	+ 35°39' 16"	- 139°45'	H. Kimura; K. Hirayama	1895.6 ... 1897.7; 1898.7 ... 1899.4
Kasan	+ 55°47' 23"	- 49°07'	A. M. Kowalski; I. P. Kornuch-Trotzki and M. A. Gratschew	1892.4 ... 1893.5; 1893.6 ... 1895.0; 1895.1 ... 1897.4; 1897.6 ... 1899.8
Pulkovo (Pulkowa)	+ 59°46' 18"	- 30°19'	B. Wanach; S. K. Kostinsky; M. O. Nyrén; A. Pedaschenko	1890.4 ... 1891.4; 1891.6 ... 1895.9; 1892.1 ... 1894.3; 1896.2 ... 1899.9
Warsaw (Warschau)	+ 52°13' 05"	- 21°02'	Ehrenfeucht	1897.4 ... 1898.8
Cape Town (Kapstadt)	- 33°56' 03"	- 18°29'	David Gill; W. H. Finlay	1892.2 ... 1894.2
Vienna (Wien)	+ 48°12' 40"	- 16°22'	Robert D. von Sterneck & O. Krifka	1892.9 ... 1894.0
Prague	+ 50°05' 16"	- 14°25'	L. Weinek & G. Gruss; R. Spitaler & Robert Lieblein; Egon von Oppolzer	1889.2 ... 1892.4; 1895.2 ... 1897.9; 1898.2 ... 1899.8; 1898.3 ... 1899.6
Naples (Neapel)	+ 40°51' 45"	- 14°15'	E. Fergola	1893.4 ... 1894.5
Berlin	+ 52°30' 17"	- 13°24'	A. Marcuse; H. Battermann	1889.0 ... 1891.1; 1891.1 ... 1893.0
Potsdam	+ 52°22' 56"	- 13°04'	M. Schnauder & O. Hecker	1889.0 ... 1890.3; 1894.0 ... 1899.9
Karlsruhe	+ 49°00' 29"	- 8°24'	F. Rispenpart	1892.8 ... 1896.5
Strasbourg	+ 48°35' 00"	- 7°46'	E. Becker & H. Kobold	1891.4 ... 1898.7
Lyons (Lyon)	+ 45°41' 41"	- 4°47'	F. Gonnessiat	1893.3 ... 1899.5
New York	+ 40°48' 27"	+ 73°58'	J. K. Rees, Jacoby, H. S. Davis	1893.4 ... 1894.5; 1894.5 ... 1899.9
Philadelphia	+ 39°58' 02"	+ 75°10'	C. L. Doolittle	1896.8 ... 1898.6; 1898.7 ... 1899.7
Bethlehem	+ 40°36' 23"	+ 75°23'	C. L. Doolittle	1890.0 ... 1890.9; 1892.8 ... 1895.6
Washington	+ 38°55' 14"	+ 77°03'	George A. Hill	1894.3 ... 1899.8
Rockville	+ 39°05' 10"	+ 77°10'	Edwin Smith	1891.5 ... 1892.5
San Francisco	+ 37°47' 28"	+ 122°26'	George Davidson	1891.4 ... 1892.6
Honolulu	+ 21°16' 25"	+ 157°50'	A. Marcuse; E. Preston	1891.5 ... 1892.4; 1891.5 ... 1892.5
Taschkent	+ 41°19' 38"	- 69°18'	D. D. Gedeonow	1895.5 ... 1896.7 (see Figure 5)

Albrecht reported on the activity of the Central Bureau concerning the variability of the position of the Earth's axis.

Sept. 1890 Annual Conference of the Permanent Commission of the "Internationale Erdmessung" in Freiburg in Br. (Helmert, 1891a; Albrecht, 1891)

Helmert reported that there is a variation of latitude derived from observations from January 1889 to April 1890 at Berlin, Potsdam and Prague with a magnitude of about 0.5" and that other scientists will submit the results of latitude observations at their observatories to the Central Bureau.

Albrecht reported on the results obtained from the latitude observations at Berlin, Potsdam and Prague from January 1889 to April 1890; see Fig. 1. Note that the data processing of the Potsdam observations was made by Andreas Galle (1858-1943); for details, see Polhöhe (1898).

The Special Commission was newly appointed and included the following members: Bakhuyzen, Foerster, Helmert, Tisserand as before, and the Italian General Annibale Ferrero (1840-1902), President of the Italian Geodetic Commission, and the Swiss astronomer Adolph Hirsch (1830-1901), permanent secretary of the "Internationale Erdmessung", as new members.

After vehement discussion of the problem of latitude variations in the Special Commission, a resolution was adopted which comprised eight points, of which the following were important:

- It is necessary to continue the latitude observations at Berlin (or Potsdam), Prague and, if possible, Strasbourg;
- arrangements should be made by the Bureau of the Permanent Commission for a scientific expedition to the Sandwich (Hawaiian) Islands located nearly opposite to Berlin concerning the northern pole of the Earth's axis to observe the latitude variation there simultaneously to Central Europe.

1891/92 Adolf Marcuse (1860-1930), a German astronomer, carried out latitude observations at Honolulu from June 1891 to May 1892; for the coordinates of the station, see Table 1.

Oct. 1891 Annual Conference of the Permanent Commission of the "Internationale Erdmessung" in Florence (Helmert, 1892)

Helmert reported that an expedition to Honolulu under Foerster's leadership was prepared and that the German astronomer Adolf Marcuse, a scientist at the Berlin Observatory, began to observe on June 1, 1891.

Foerster proposed that a Special Commission should submit a plan on a service of latitude observations at stations located suitably over the Earth at the next General Conference. For this, a Special Commission was appointed with Foerster, Helmert, Bakhuyzen and Tisserand.

1891 Helmert (1891b) published a paper on the explanation of the observed variations in latitude. Here, he studied a polar motion with a 12-months period (caused by meteorological processes) and a polar motion with a 10-months period (Euler's period).

1891/92 Seth Carlo Chandler (1846-1913), a private American astronomer, found periodic latitude variations arising from two superposed constituents. Here, the first has a period of about 427 days and the second an annual period. In this studies, all observations from 1840 to 1891 have been used (Chandler, 1891 and 1892).

Sept./Oct.1892 10th General Conference of the "Internationale Erdmessung" in Brussels (Albrecht, 1892, 1893a, b; Helmert 1893; Marcuse, 1893)

Helmert reported on new results in studying the latitude variation using the observations at Berlin, Prague, Strasbourg and Honolulu from May 1891 to June 1892; see Fig. 2. Albrecht submitted the results of the latitude observations made by Marcuse at Honolulu. Marcuse personally reported on his expedition to Honolulu.

After longer discussion of a plan submitted by the Special Commission, the proposal was adopted. From this, the following points should be noted:

- (1) From the latitude observations made at Berlin, Potsdam, Strasbourg, Prague and Honolulu over three years and, later, simultaneously at Berlin, Honolulu and Washington and also at Pulkovo using another method, it is confirmed that significant periodic variations of the rotation axis within the interior of the Earth's body exist.
- (2) The Permanent Commission should continue its efforts concerning the problem of determining quickly and precisely corrections to latitude, longitude and azimuth observations for studies of the Erdmessung as fast and precise as possible, i. e., to refer the values to the mean position of the Earth's axis.
- (3) The Central Bureau of the Erdmessung in the Geodetic Institute Potsdam continues to organize the observations and to derive and publish the results.
- (4) The Permanent Commission should organize for the following years the precise observation method, the efficient distribution of work and the availability of the results for scientific and practical use.
- (5) Finally, all steps should result in establishing and maintaining some observation stations on the same parallel at different longitudes. For this, the Permanent Commission should submit a special project to the governments of the corresponding states. If possible, there should be four stations. For example, the stations could be in Sicily, Japan, California and Virginia.

1892 Simon Newcomb (1835-1909), an American astronomer, explained the surprisingly long period of the polar motion (Chandler period) by the elasticity of the Earth in terms of lengthening the theoretical 304-day-period (Euler period) by at least 100 days. Besides, he found that there is an effect of some 30 days due to the ocean pole tide (Newcomb, 1892).

Sept. 1893 Annual Conference of the Permanent Commission of the "Internationale Erdmessung" in Geneva (Helmert, 1894)

Helmert suggested to make available the precise motion of the Earth's axis for every year separately.

Foerster proposed a complete service to improve the homogeneity of the results. To this, the Special Commission appointed in Florence in 1891 should be reactivated.

In a letter, the Italian astronomer Giovanni Schiaparelli (1835-1910) supported Foerster's idea of establishing special observing sites on the same parallel to monitor the phenomenon. After reading the letter, Ferrero proposed that a Special Commission consisting of only a few members should present the plan at the next General Conference.

Foerster disagreed with Helmert, who favoured the existing practice of voluntary cooperation of the observatories for scientific and economical reasons. After a controversial discussion, Hirsch's proposal for the settlement of the dispute that a Special Commission further investigates the problem was accepted. Schiaparelli, Tisserand and Foerster were elected to be the members.

Sept. 1894 Annual Conference of the Permanent Commission of the "Internationale Erdmessung" in Innsbruck (Albrecht, 1895; Helmert, 1895; Marcuse, 1895a, b)

Albrecht submitted a report about the study of latitude variation. Especially, he showed the results obtained from the latitude observations made at 15 stations including 11 observing sites with observations from 1889 to 1894. Since, in his opinion, continuing observations would be carried out only at very few observatories, he suggested to organize an international latitude service.

The Special Commission submitted no unanimous proposal for organizing a separate international observation service. But Foerster explained again its need. On Ferrero's initiative, three decisions were adopted by the Permanent Commission:

- (1) The studies should be transmitted to an international organization.
- (2) The Special Commission should submit a plan for this organization and its cost within two to three months.
- (3) According to the plan, the Permanent Commission will present its proposals at the next General Conference.

Also, it should be noted that the following papers were distributed among the members:

- The motion of the north pole of the Earth's axis derived from latitude measurements in 1891-1894 by Marcuse (1895a), and
- Comparison of the two observation series made simultaneously and side by side at Honolulu in 1891-1892 for determining the latitude variation by Marcuse (1895b). The first series was observed by Marcuse, and the second series by E. Preston from the U. S. Coast and Geodetic Survey.

Sept./Oct. 1895 11th General Conference of the "Internationale Erdmessung" in Berlin (Albrecht, 1896a; Helmert, 1896; Marcuse 1896)

The following reports were presented: Review of the results by Helmert as director of the Central Bureau and special reports by Albrecht (1896) and Marcuse (1896).

Albrecht again urged to establish an international latitude service. Here, the following conditions should be noted:

- (1) to choose the observing sites on the same parallel in latitude and on suitable longitudes;
- (2) to equip the sites with instruments of the same type and to use a reliable observation method;
- (3) to avoid carefully all causes that could influence the results systematically.

Marcuse submitted his report on the photographic method of determining the latitude and the first results obtained with the photographic zenith telescope.

The contractual base of the "Internationale Erdmessung" was renewed. Here, Foerster supported the renewal strongly; for it, see Protokolle (1895) and Foerster (1895a, b).

The new convention decided that the annual budget will increase of 16000 Marks to 60000 Marks. By this, the financial side concerning a latitude observation service was guaranteed: 44000 Marks for investment, 34000 Marks for carrying out the observations and 10000 Marks for reduction of the observations and

publication of the results.

According to the plan by Foerster, the scientific side consisted in an observation service including four observing sites on the same parallel of $37^{\circ}05'$ in northern latitude. The board of the Astronomical Society agreed to this in August 1893. Moreover, the head of the American surveying and the head of the Japanese surveying showed interest to cooperate.

At the last session of the Permanent Commission (on October 12, 1895), a new Special Commission with Helmert, Schiaparelli, Tisserand and Foerster as its members was appointed with the task to work out a detailed program of the latitude service including the cost, i. e., founded on fact, the decision was made to organize the International Latitude Service (ILS).

1895 Intensive preparations for the planned International Latitude Service were started. Especially, Albrecht with the support of the astronomer Oscar Hecker (1864-1938) carefully investigated the best combination of four observing sites on the same parallel in latitude (Albrecht, 1897b). It should be noted that the Italian astronomer G. Celoria and the Japanese seismologist Fusakichi Omori contributed valuable information to this problem. For the observation method, latitude observations with photographic and visual zenith telescopes were carried out by the astronomers Max Schnauder (1860-1939) and Hecker at the Potsdam Geodetic Observatory; see Schnauder and Hecker (1897).

1896 Albrecht (1896b) published a paper on deriving the motion of the north pole during 1890-1895 based on the latitude observations at 13 independent stations.

Oct. 1896 Annual Conference of the Permanent Commission of the "Internationale Erdmessung" in Lausanne (Albrecht, 1897a, b, c; Helmert, 1897; Marcuse, 1897a, b; Schnauder and Hecker, 1897)

Meanwhile, Helmert supported Foerster's plan, i.e., Fergola's plan in a modified form.

Albrecht presented the following three papers:

- (1) Report about the status in studying the latitude variation including the polar motion from 1890.0 to 1896.4 derived from latitude observations at 13 stations;
- (2) On the choice of the stations for the International Latitude Service;
- (3) Comparison of the optical and photographic observation methods for determining the latitude variation.

In addition, a report about the results obtained from observations with photographic and visual zenith telescopes by Schnauder and Hecker was submitted. Here, it was not recommended to make use of the photographic modification of the Horrebow-Talcott's method. Also, there were reports by Marcuse on the choice of the stations for the International Latitude Service and on the photographic method for determining the latitude.

The following problems were discussed by the members: Observation method and choice of the four stations. According to Foerster's proposal, a third comparison of parallel observations using optical and photographic methods should be made to find the best method. For the choice of the stations, a letter wrote by Helmert on June 20, 1896 was subject of the discussion.

Figure 3 shows the polar motion from 1890.0 to 1895.0 as derived from latitude observations at 20 independent stations by Albrecht (1898). For the coordinates of the observing sites, the observers and the periods of observation, see Table 2. It should be noted that the astronomer Bernhard Wanach (1867-1928) took part in the data processing. Some biographical information on him can be found in the Appendix.

Oct. 1898 12th General Conference of the "Internationale Erdmessung" in Stuttgart (Albrecht, 1899; Helmert and Albrecht, 1899a; Wanach, Helmert and Foerster, 1899)

Helmert and Albrecht submitted the report about the preparations for the International Latitude Service. A report about a new series of latitude measurements made with the photographic zenith telescope in 1897 was

Table 3. Coordinates of the International Latitude Service stations and the initial observers

Station	Latitude	Longitude	Observer
Mizusawa (Japan)	+ 39°08' 04"	- 141°08'	H. Kimura and T. Nakano
Tschardjui (Russia)	+ 39°08' 11"	- 63°29'	Ossipoff; Medzwietsky
Carloforte (Italy)	+ 39°08' 09"	- 8°19'	G. Ciscato and G. Bianchi
Gaithersburg (USA)	+ 39°08' 13"	+ 77°12'	E. Smith; H. S. Davis
Cincinnati (USA)	+ 39°08' 19"	+ 84°25'	J. G. Porter
Ukiah (USA)	+ 39°08' 12"	+ 123°13'	F. Schlesinger

given by Wanach, Helmert and Foerster. The comparison of the photographic measurements to the visual observations showed no superiority of either method.

Eight proposals were prepared by the so-called Latitude Commission (six members, including Bakhuyzen and Foerster). The delegates of the General Conference adopted the proposals with proposal (6) modified:

- (1) The international study of the latitude variations will begin under the direction of the Central Bureau and under the control of the presidium of the "Internationale Erdmessung" in 1899.
- (2) According to the program of the director of the Central Bureau, six observing sites should exist, four directly financed by the "Internationale Erdmessung" and two, namely Tschardjui (Russia) and Cincinnati (USA), obtaining a grant by it.
- (3) The cost will be according to the agreement of 1896.
- (4) The observations will be for five years. At the end of the period, during a General Conference, a decision will be reached about the continuation of the observations and concerning modifications.
- (5) According to the report on the preparation of the International Latitude Service by Helmert and Albrecht, the observations will be made using the Horrebow-Talcott's method.
- (6) The optical method will be used for the five years only.
- (7) Latitude observations at individual observing sites should be continued or initiated, where any instrument and method may be used.
- (8) The Central Bureau will organize the project including the equipment and instructions for the observing sites.

The decision on the observing sites should be made later after considering the individual conditions. However, it was outlined that the parallel of 39°08' in northern latitude suggested by Albrecht in 1896 instead of the parallel of 37°05' in northern latitude suggested by Foerster in 1895 would be chosen.

Therefore, after an effort of 10 years, it was decided to set up the International Latitude Service.

3 Start of the International Latitude Service from 1899

1899 The International Latitude Service (ILS) started as the first permanent worldwide scientific cooperation.

The Central Bureau of the ILS charged with the programs and data reductions was installed at the Geodetic Institute of Potsdam under the responsibility of Albrecht.

Specially for the International Latitude Service stations, the visual zenith telescope (VZT) was made by

Table 4. Coordinates of the International Latitude Stations on the southern hemisphere and observers

Station	Latitude	Longitude	Observer
Bayswater (Western Australia)	- 31°55' 14"	- 115°55'	Curt Hessen (from Berlin)
Oncativo (Argentina)	- 31°55' 10"	+ 63°42'	Luigi Carnera (from Trieste) and J. Aguilar

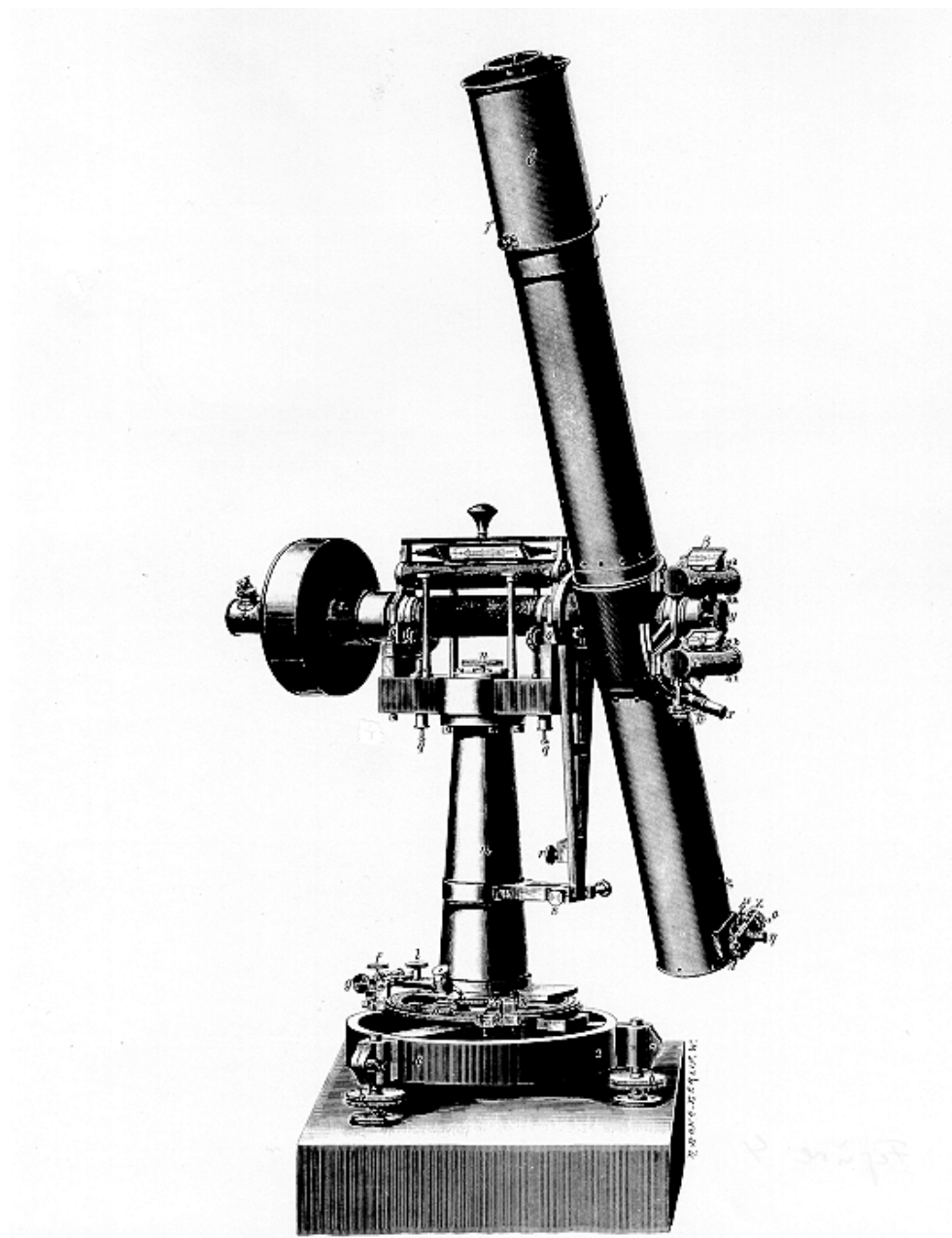


Figure 4. Visual zenith telescope as made by Wanschaff for Mizusawa (Japan), Carloforte (Italy), Gaithersburg (USA), and Ukiah (USA); aperture of the objective 108 mm, focal length 130 cm, 104-fold enlargement (from Helmert, 1900)

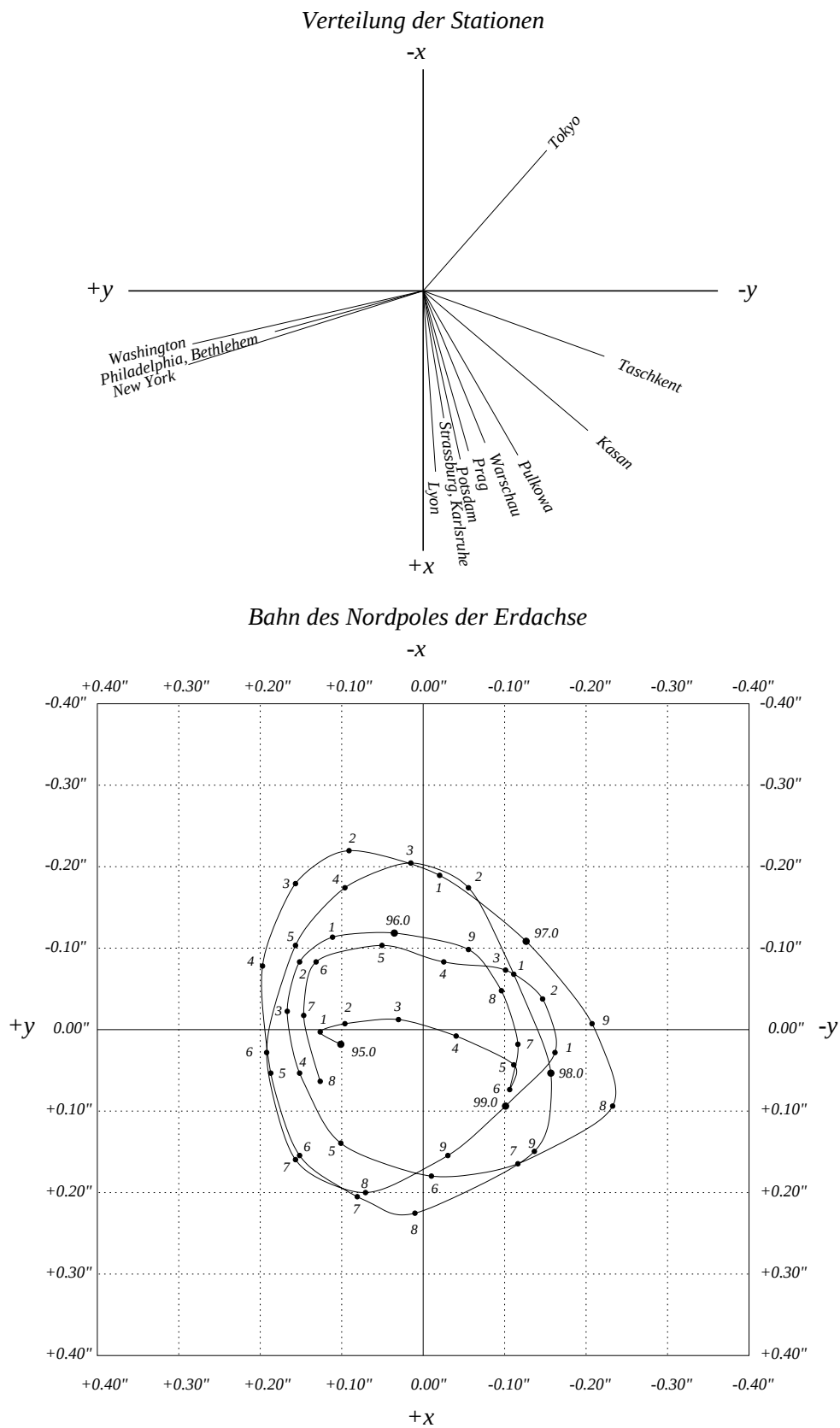


Figure 5. Polar motion from 1895.0 to 1899.8 derived from latitude observations at 14 independent stations (from Albrecht, 1900a, b). Top: Distribution of the stations. Bottom: Motion of the northern pole of the Earth's axis. The values at 0.1 year intervals are denoted by filled circles. The positive x-axis points towards the Greenwich meridian, the positive y-axis towards 90° W longitude.

16 CRAIGIE STREET,
CAMBRIDGE, MASS. June 24, 1902

Prof. Dr. Th. Albrecht,

Geodätisches Institut,

Dear sir: -

I have mailed you a copy of A. J. 522, in which I have presented some evidence, which appears to have some plausibility, of a term with a period of about thirteen months in the latitude-variation. It will of course need verification by observation in the future before it can be accepted; but as the matter appears to me now we shall probably be compelled to resort to some such term to represent the observations since 1890. I may add that Nyren's prime vertical observations 1875-82 harmonize well with such a hypothesis, indicating a slightly longer period, say about 394 days. Also his vertical circle series 1882-91, on Polaris, accords with its existence.

Since I presume you have by this time at hand the results of the International latitude series for the year 1901, I shall be curious to learn whether they also appear to bear out the same idea. I should be extremely obliged and gratified if you could give me some information with regard to those results, in advance of your Report. Of course I will make no use of them in publication before the appearance of your Report, and only desire them to confidentially satisfy my curiosity on the points involved, whether the hypothesis is reasonably amenable to them. You will notice that I have given on p. 147, in the table, the coordinates for 1901.

Very sincerely yours,

S. C. Chandler

Figure 6. A letter to Albrecht written by Chandler on June 24, 1902, concerning a term with a period of about thirteen months in the latitude variation connected with the request for getting the results of the ILS for the year 1901 before their publication

Julius Wanschaff in Berlin, optical parts by Carl Zeiss in Jena and levels by Carl Reichel in Berlin. For an illustration of the instrument, see Fig. 4.

For the stations of Tschardjui (Russia) and Cincinatti (USA), the visual zenith telescopes made by Wanschaff having an aperture of the objective of 68 mm and 81 mm, respectively, a focal length of 87 cm and 100 cm, respectively, and 100-fold enlargement, were available.

To have uniformity in observing, Albrecht submitted the instructions for the use of the zenith telescope at the International Latitude Stations including its description (Albrecht, 1899).

From the beginning at the Central Bureau, Wanach was responsible for the reduction of the latitude observations of the International Latitude Service.

1899 To inform the scientific community, Helmert and Albrecht (1899b) published a paper on the International Latitude Service in the journal *Astronomische Nachrichten*. It included details on the history from the beginning to the foundation of the service and of its organization.

During a visit at the Geodetic Institute Potsdam, the Japanese astronomer Hisashi Kimura compiled the observing program with the visual zenith telescope of the International Latitude Stations. The version concerning the brightness of the star pairs was revised by Albrecht and Wanach. Thus, if a pair was not bright enough to be observed, a change was made. The observing program was used from September 1899 to December 1905. It included 12 groups each comprising 8 star pairs, in particular 6 latitude pairs (zenith distance to 24°) and, according to Helmert's proposal, 2 refraction pairs (zenith distance of about 60°).

Sept.1899 The latitude observations at the International Latitude Stations started. The coordinates of the stations and the initial observers are given in Table 3.

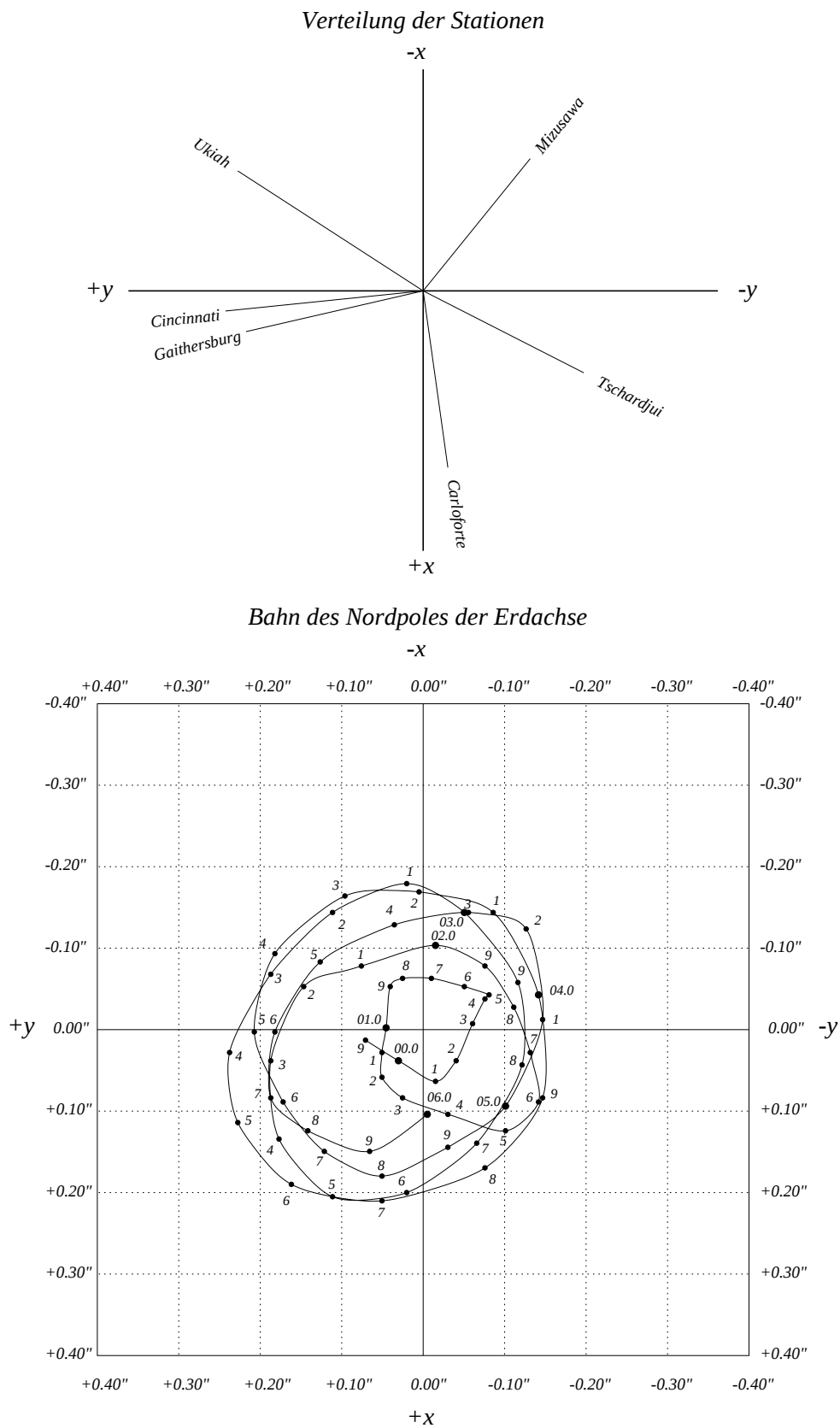


Figure 7. Polar motion from 1899.9 to 1906.0 derived from the latitude observations at the International Latitude stations (from Albrecht and Wanach, 1909). Top: Distribution of the stations. Bottom: Motion of the northern pole of the Earth's axis. The values at 0.1 year intervals are denoted by filled circles. The positive x-axis points towards the Greenwich meridian, the positive y-axis towards 90°W longitude

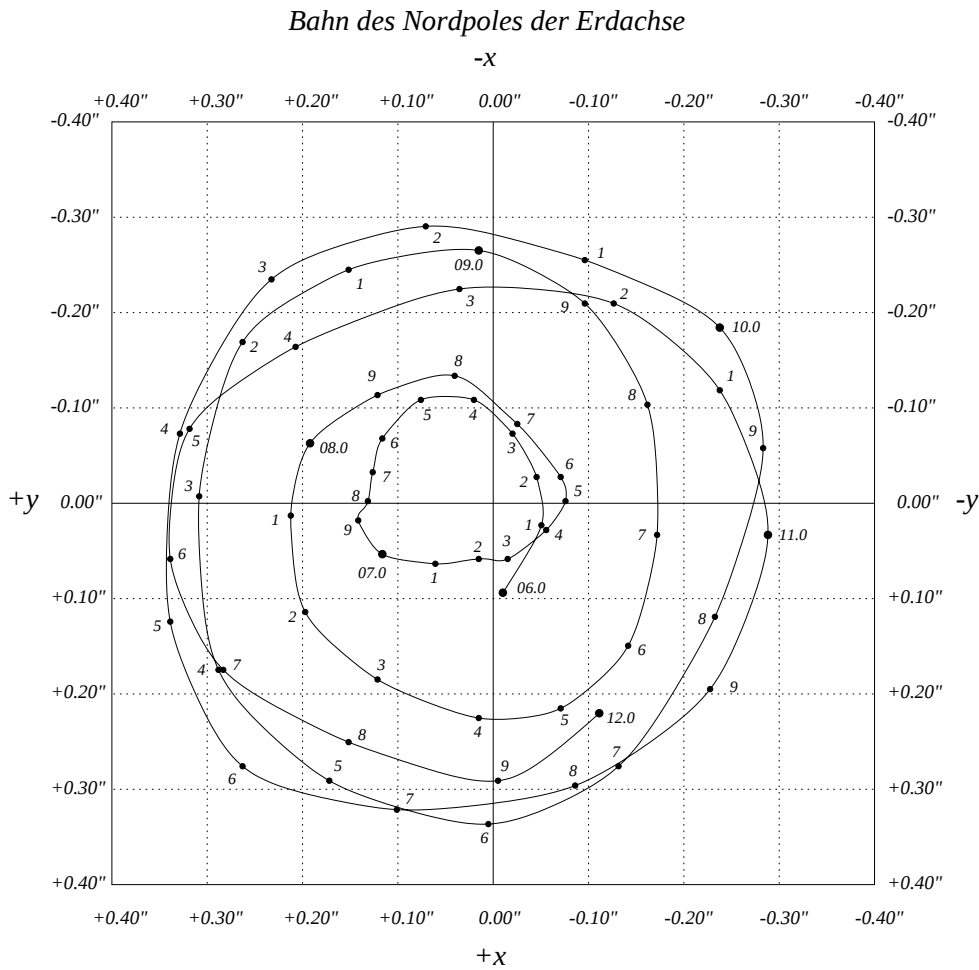


Figure 8. Polar motion from 1906.0 to 1912.0 derived from the latitude observations at the International Latitude stations (from Wanach, 1916): Motion of the northern pole of the Earth's axis. The values at 0.1 year intervals are denoted by filled circles. The positive x-axis points towards the Greenwich meridian, the positive y-axis towards 90°W longitude. For the distribution of the stations, see Fig. 7

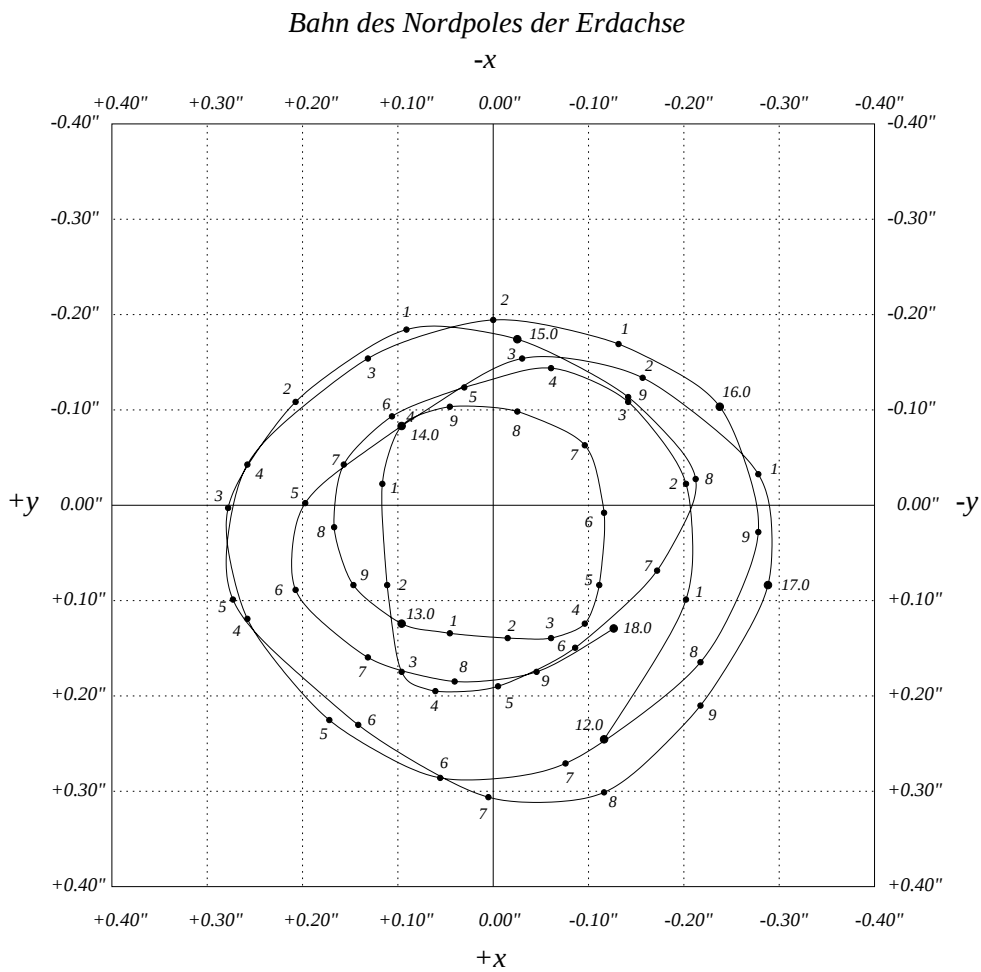


Figure 9. Polar motion from 1912.0 to 1918.0 derived from the latitude observations at the International Latitude stations (from Wanach and Mahnkopf, 1932): Motion of the northern pole of the Earth's axis. The values at 0.1 year intervals are denoted by filled circles. The positive x-axis points towards the Greenwich meridian, the positive y-axis towards 90° W longitude. For the distribution of the stations, see Fig. 7

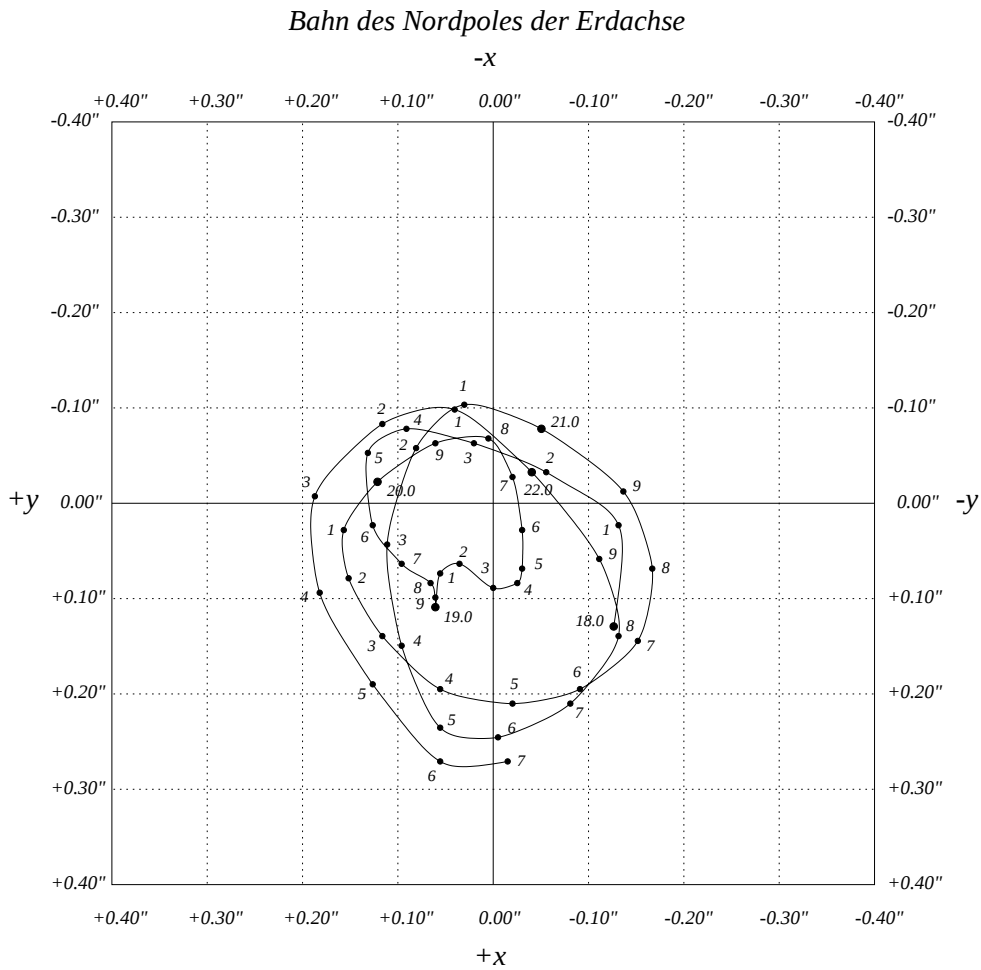


Figure 10. Polar motion from 1918.0 to 1922.7 derived from the latitude observations at the International Latitude stations (from Wanach and Mahnkopf, 1932): Motion of the northern pole of the Earth's axis. The values at 0.1 year intervals are denoted by filled circles. The positive x-axis points towards the Greenwich meridian, the positive y-axis towards 90° W longitude. For the distribution of the stations, see Fig. 7

1900 The results of the independent stations participating in the latitude observations from 1895.0 to 1899.8 were published by Albrecht; for the illustration of the polar motion for this interval, see Fig. 5. Table 2 lists the coordinates of the observing sites, the observers and the periods of the observation.

Sept./Oct. 1900 13th General Conference of the "Internationale Erdmessung" in Paris (Albrecht, 1901a; Helmert, 1901)

The delegates were informed that all six observing sites had begun to observe: Cincinnati (USA) on Sept. 1, 1899, Tschardjui (Russia) on Sept. 10, 1899, Gaithersburg (USA) on Oct. 2, 1899, Ukiah (USA) on Oct. 11, 1899, Carloforte (Italy) on Oct. 24, 1899, and Mizusawa (Japan) on Dec. 16, 1899.

For the first time, Albrecht could inform about the latitude observations made at the six International Latitude Stations. His report included a summary of the results from September 1899 to May 1900.

1901 The preliminary results of the International Latitude Service and of four independent stations (Tokyo, Kasan, Leiden, and Philadelphia) participating in the latitude observations from 1899.8 to 1901.0 were published by Albrecht. As in the previous papers, the fundamental formula of the latitude variation due to polar motion in the form $\Delta\phi_j = \phi_j - \phi_{0j} = x \cos \lambda_j + y \sin \lambda_j$ was used for calculating the polar coordinates at 0.1 year intervals, where ϕ_j is the observed latitude at the j-th station, ϕ_{0j} the adopted mean latitude of the j-th station, λ_j the west longitude of the j-th station, and x, y the rectangular coordinates of the instantaneous pole referred to the origin defined by the mean position of the pole; see Albrecht (1901b). However, it was found that the course of the polar motion for the different stations could not be expressed by this formula with sufficient accuracy.

1902 Kimura suggested that, for deriving the polar coordinates, the equation $\Delta\phi_j = \phi_j - \phi_{0j} = x \cos \lambda_j + y \sin \lambda_j + z$ should be used, where z is an annual term that is independent of the components of the polar motion and of the longitude of the stations (Kimura, 1902). After that, the Central Bureau of the ILS adopted the formula that includes the z-term. By this, the errors originating in the catalogue and other unknown factors were considered.

June 1902 Chandler studied a term with a period of about thirteen months in the latitude variation with the objects to better quantify this term, as can be seen in Fig. 6.

1903 The results of the International Latitude Service from Sept. 1899 to Jan. 1902 (Vol. I) were published (Albrecht, 1903).

Aug. 1903 14th General Conference of the "Internationale Erdmessung" in Copenhagen. Albrecht reported on the ILS (Albrecht, 1905). He suggested to carry out latitude observations on the southern hemisphere to investigate the existence of the z-term of the whole globe.

It was arranged that observations should be made on the same parallel of $-31^{\circ}55'$ in southern latitude at the stations of Bayswater (near Perth, Western Australia) and Oncativo (Argentina).

The following zenith telescopes made by Wanschaff were used: For Bayswater, the visual zenith telescope of the Geodetic Institute Potsdam already used to observe at Potsdam and Honolulu (having an aperture of the objective of 68 mm, a focal length of 87 cm, and 100-fold enlargement) and, for Oncativo, the zenith telescope of the "Internationale Erdmessung" originally used for photographic purposes and reconstructed for visual observations (having an aperture of the objective of 108 mm, a focal length of 130 cm, and 104-fold enlargement).

Jan. 6, 1906 The latitude observations at the International Latitude Station of Bayswater started (until the middle of 1908).

May 5, 1906 The latitude observations at the International Latitude Station of Oncativo started (until the middle of 1911).

For the coordinates of the stations and the observers, see Table 4.

Jan. 1906 The observing program modified for the influence of precession by Wanach was performed from January 1906 to December 1911. Giving up the 24 refraction pairs, it had 30 new latitude pairs.

Sept. 1906 15th General Conference of the "Internationale Erdmessung" in Budapest. Albrecht (1908) reported about the ILS on the northern hemisphere for the period 1903-1905 and on the southern hemisphere for the period from 1906.

1906 The results of the International Latitude Service from Jan. 1902 to Jan. 1905 (Vol. II) were published (Albrecht and Wanach, 1906).

1909 The preliminary results of the ILS on the southern parallel from 1906.4 to 1908.4 were published by Albrecht (1909). The z-term on the northern and southern hemispheres differed only by several hundredths of an arc second (").

The results of the International Latitude Service from Sept. 1899 to Jan. 1906 (Vol. III) were published (Albrecht and Wanach, 1909); see Fig. 7.

July 23, 1909 The latitude observations began at the new observing site of Tschardjui with the longitude of $-63^{\circ}35'$.

Sept. 1909 16th General Conference of the "Internationale Erdmessung" in London and Cambridge. Albrecht (1910) reported about the ILS on the northern and southern hemispheres for the period 1906-1909.

1911 The results of the International Latitude Service at six stations of the northern parallel and at two stations of the southern parallel from 1906 to 1908 (Vol. IV) were published (Albrecht and Wanach, 1911).

Jan. 1912 The observing program was again modified and carried out from January 1912 to September 1922. It had 16 new pairs.

Sept. 1912 17th General Conference of the "Internationale Erdmessung" in Hamburg. Albrecht (1913a, b) reported about the ILS on the northern and southern hemispheres for the period 1909-1912.

1915 After Albrecht's death, Wanach became head of the International Latitude Service (until 1922).

Jan. 1915 For economical reasons, the latitude observations were ended at Gaithersburg.

Jan. 1916 For economical reasons, the latitude observations were ended at Cincinnati.

1916 The results of the International Latitude Service from 1909 to 1911, jointly from 1906.0 to 1912.0, and jointly from 1899 to 1912 using another method (Vol. V) were published (Wanach, 1916); see Fig. 8.

May 1919 Because of political disorders, the latitude observations were ended at Tschardjui.

1927 A new latitude station was established at Kitab (Uzbekistan) on the latitude $+39^{\circ}08'40''$ and the longitude $-66^{\circ}53'$ (Wanach, 1928).

1928 After Wanach's death, Heinrich Mahnkopf (1892-1932) was head of the Astronomical Section of the Geodetic Institute of Potsdam; the Appendix gives some information on the biography of Mahnkopf.

1932 The results of the International Latitude Service from 1912.0 to 1922.7 were published (Wanach and Mahnkopf, 1932); see Figs 9 and 10. For temporal variations of the value of pitch of the micrometer screw (see Przybyllok, 1915), the values of one revolution were steadily adopted only within the observation duration of a group combination in deriving the results.

Note that Albrecht and, later, Wanach published the preliminary results of the International Latitude Service in the journal *Astronomische Nachrichten* about every year; for it, see Lerbs et al. (1968). Then, as stated above, the volumes of the results derived for the longer intervals were published.

4 Concluding remark

Finally, it should be said that many co-workers at the Geodetic Institute Potsdam and, in particular, the scientists Gustav Förster (1873-1932), Albrecht von Flotow (1873-1927), Wilhelm Schweydar (1877-1959), Hans Boltz (1883-1947), and Erich Przybyllok (1880-1954, a scientist at the Institute in 1910 and 1914-1921) helped in processing the latitude observations and in compiling the individual volumes of the International Latitude Service. During this interval, the permanent latitude observations at the Geodetic Institute Potsdam were carried out and processed by Schnauder and Hecker.

Acknowledgement. This paper was presented at IAU Colloquium 178, "Polar motion: Historical and Scientific Problems", in Cagliari, Sardinia, Italy, from 23-30 September 1999. Thanks to Dr Detlef Wolf for his linguistic advice that helped to improve the quality of this paper.

Appendix

Friedrich Robert Helmert (1843-1917) Prof. Dr. phil., Dr. Ing. e. h.



<i>July 31, 1843</i>	Born in Freiberg, Saxony (Sachsen)
<i>1859-1863</i>	Study of geodesy at the Polytechnic College of Dresden
<i>July 1863</i>	Graduation with a silver medal and a travel grant
<i>1863-1866</i>	Assistant at the Saxon Arc Measurement in Dresden (until Oct. 1866)
<i>1866-1868</i>	Study of mathematics, physics and astronomy at the University of Leipzig
<i>May 12, 1868</i>	Received his Dr. phil. degree with a thesis on rational surveying from the University of Leipzig
<i>Feb. 1, 1869</i>	Observer at the Observatory of Hamburg (until August 1870)
<i>Oct. 1, 1870</i>	Teacher at the Technical College of Aachen (until April 15, 1887)

<i>Dec. 21, 1872</i>	Professor at the Technical College of Aachen
<i>Jan. 1, 1886</i>	Provisional director of the Royal Prussian Geodetic Institute in Berlin (from April 1892 on the Telegrafenberg of Potsdam)
<i>Oct. 1886</i>	Director of the Central Bureau of the Internationale Erdmessung
<i>April 15, 1887</i>	Professor for mathematical geodesy at the University of Berlin
<i>April 22, 1887</i>	Director of the Royal Prussian Geodetic Institute in Berlin (1892 in Potsdam)
<i>Aug. 30, 1893</i>	Award of title Geheimer Regierungsrat
<i>Jan. 31, 1900</i>	Member of the Royal Prussian Academy of Sciences in Berlin
<i>Dec. 20, 1902</i>	Honorary Doctoral Degree (Dr. Ing. e. h.) of the Technical College of Aachen
<i>Jan. 27, 1912</i>	Award of title Geheimer Oberregierungsrat
<i>Sept. 14, 1912</i>	Great Gold Medal for Science on the jubilee of the Internationale Erdmessung
<i>June 15, 1917</i>	Died in Potsdam

Helmert's reputation is reflected by many honourable awards, memberships and positions received at home and abroad. Thus, he became a member or honorary member of 11 Academies, 12 scientific societies and 2 federations.

Research fields: Theory of errors; adjustment using least-squares method; methods of the adjustment of networks; theory of geometrical and trigonometric levelling; studies on the geoid; absolute and relative gravity measurements; reductions of gravity accelerations; constitution of the Earth's crust; isostasy and mass distribution of the Earth; dimensions of the Earth and the Earth's ellipsoid.

Helmert published about 200 papers. Important publications are: a monograph on adjustment using the least-squares method (1872 and 1907); a monograph on mathematical and physical theories of the higher geodesy ("Die mathematischen und physikalischen Theorien der höheren Geodäsie") issued in two volumes (1880, 1884 and 1962); paper on deflections of the vertical including instructions for deriving the figure of the geoid (1886); paper on gravity in high mountains (1890); European longitude arc measurements on the parallel of 52° in northern latitude from Greenwich to Warsaw including new methods of the adjustment of networks (1893); contributions to the theory of the reversion pendulum (1898); contributions to gravity and mass distribution of the Earth including isostasy (1908, 1910, 1912, 1914); running of gravity at sea-level including the derivation of a difference between the two main equatorial moments of inertia (1915). More than 50 reports were presented by him at the conferences of the "Internationale Erdmessung". These include: Deflections of the vertical; measurements of gravity; triangulations; triangle measurements.

Carl Theodor Albrecht (1843-1915) Prof. Dr. phil., Dr.-Ing. h. c.



Aug. 30, 1843 Born in Dresden

1860 Study of geodesy at the Polytechnic College of Dresden; Graduation in course for teacher of mathematics and natural sciences

1865-1868 Study of mathematics, physics and astronomy at the University of Berlin

May 1, 1866 Assistant at the Central Bureau of the European Arc Measurement in Berlin

1868-1869 Study of astronomy at the University of Leipzig

1869 Received his Dr. phil. degree with a thesis on the determination of longitude differences using electric telegraphs from the University of Leipzig

Jan. 1, 1870 Scientist at the Prussian Geodetic Institute in Berlin (from April 1892 on the Telegrafenberg of Potsdam)

1873 Head of the Astronomical Section

1875 Professor

1895 Head of the International Latitude Service

1898 Award of title Geheimer Regierungsrat

1904 Corresponding Member of the Russian Geographical Society

1905 Associate of the Royal Astronomical Society

1907 Foreign Member of the Accademia dei Lincei

- 1910 Corresponding Member of the Academy of the Sciences in Paris
- 1913 Honorary Doctoral Degree (Dr.-Ing. h. c.) of the Technical College of Stuttgart
- Aug. 31, 1915 Died in Potsdam

Research fields: Studies of the intensity of gravity; longitude determinations using electromagnetic and wireless telegraphs; latitude and azimuth determinations; latitude variations.

Albrecht published more than 100 papers including publications on: Catalogue of 39 polar stars for longitude determinations (1873); results of 51 longitude determinations, including the stations of Paris, Warsaw, Bucharest, Pulkovo, Greenwich and Horta, Azores; adjustments of the longitude network (1879 and 1905); results of latitude and azimuth determinations; instructions for latitude and azimuth measurements (1876 and 1883); instructions for longitude measurements (1877); instructions for the use of the zenith telescope at the International Latitude Stations (1899 and 1902); 20 reports concerning the latitude variation and longitude, latitude and azimuth measurements presented at the conferences of the "Internationale Erdmessung"; logarithmic-trigonometrical tables (1883, 1884, 1890, 1894); ILS results in four volumes as single or joint author. His famous book "Formeln und Hilfstafeln für geographische Ortsbestimmungen" originally appeared 1873 and in new editions in 1879, 1894, 1908 and 1967.

Bernhard Karl Wanach (1867-1928) Prof. Dr. phil. h. c.



- June 11, 1867 Born in Mesothien, Kurland
- 1886-1889 Study of astronomy at Dorpat, Estonia
- 1889 Graduation in astronomy with a thesis on the rate of the normal clock of the Dorpat Observatory
- 1890-1891 Appointment as special astronomer at the Pulkovo Observatory, where he observed time series of the latitude
- 1892 Scientific assistant at the Observatory of Königsberg, Prussia
- 1893-1897 Scientific employee at the Observatory of Strasbourg, Alsace
- 1897 Scientific employee of the time service at the Prussian Geodetic Institute in Potsdam
- Oct. 1902 Scientific employee and observer (permanent scientist)

1906	Professor
1915	Head of the International Latitude Service (until 1922)
1922	Head of the Astronomical Section
1927	Honorary Doctoral Degree (Dr. phil. h. c.) of the University at Königsberg
April 2, 1928	Died in Potsdam

Research fields: Time service; clock-technique including the design of a compensation pendulum; radio time signals including the design of receivers and transmitters; comparison of clocks using time signals; longitude and latitude determinations; latitude variations; test of diverse geodetic-astronomical instruments and of precision levels.

Wanach published about 70 papers including publications on: The influence of arrangement in temperature layers on different pendulums (1904); practical problems concerning the time service (1912); theoretical considerations on the polar motion and the path of the inertia pole (1916 and 1919); testing of precision levels (1926); contribution to the question of the continental displacement (1926); progressive change of the position of the Earth's axis (1927); ILS results in five volumes as single or joint author.

Heinrich Mahnkopf (1892-1932) Prof. Dr. phil. habil.



May 29, 1892	Born in Oldenrode-Düderode/Harz
1912-1913	Study of mathematics, physics, and geodesy at the College of Hannover
1913-1916	Study of astronomy, mathematics, physics, and geophysics at the University of Göttingen
Dec. 1917	Received his Dr. phil. degree with a thesis on the relations of comets from the University of Göttingen
1918	Scientific employee at the German Sea Observatory (Deutsche Seewarte) in Hamburg
1926	Scientific employee and observer (permanent scientist) at the Prussian Geodetic Institute of Potsdam
1928	Head of the Astronomical Section
1929	Award of <i>venia legendi</i> (Habilitation) at the College of Berlin

Dec. 20, 1932 Died in Hannover

Publications: ILS results between 1912.0-1922.7 (Wanach and Mahnkopf, 1932); studies on capacitive contacts (1929); on the influence of the lateral refraction to the accuracy of time determinations (1929).

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