Journal of Geodesy (2005) 78: 558–568
DOI 10.1007/s00190-004-0423-0

Journal of Geodesy

The International Association of Geodesy 1862 to 1922: from a regional project to an international organization

W. Torge

Institut für Erdmessung, Universität Hannover, Schneiderberg 50, 30167 Hannover, Germany; e-mail: torge@ife.uni-hannover.de;
Tel: +49-511-762-2794; Fax: +49-511-762-4006

Received: 1 December 2003 / Accepted: 6 October 2004 / Published Online: 25 March 2005

Abstract. Geodesy, by definition, requires international collaboration on a global scale. An organized cooperation started in 1862, and has become today's International Association of Geodesy (IAG). The roots of modern geodesy in the 18th century, with arc measurements in several parts of the world, and national geodetic surveys in France and Great Britain, are explained. The manifold local enterprises in central Europe, which happened in the first half of the 19th century, are described in some detail as they prepare the foundation for the following regional project. Simultaneously, Gauss, Bessel and others developed a more sophisticated definition of the Earth's figure, which includes the effect of the gravity field. In 1861, the retired Prussian general J.J. Baeyer took up earlier ideas from Schumacher, Gauss, Struve and others, to propose a Central European Arc Measurement in order to study the figure of the Earth in that region. This led to a scientific organization, which soon extended from Central Europe to the whole continent and later to the globe, and changed its name in 1886 to 'Internationale Erdmessung' (International Geodetic Association). The scientific programme also widened remarkably from more local studies based on geometric data to regional and global investigations, with gravity measurements as an important source of information. The Central Bureau of the Internationale Erdmessung was hosted at the Prussian Geodetic Institute in Potsdam, and with Baeyer as Director, developed as an efficient tool of the Association. The scientific research extended and deepened after 1886, when F.R. Helmert became Director of the Central Bureau. A stronger international participation then took place, while the influence of the German states reduced. Of great practical importance were questions of standardization and reference systems, but first attempts to interpret gravity field variations and to monitor geodynamic phenomena by geodetic methods indicated future tendencies. With the First World War and the expiry of the last international convention in 1916, the international cooperation within the frame of the Association practically came to an end, which ended the first epoch of the Association. Nevertheless, due to the strong commitment of two scientists from neutral countries, the International Latitude Service continued to observe polar motion and to deliver the data to the Berlin Central Bureau for evaluation. After the First World War, geodesy became one of the founding members of the International Union for Geodesy and Geophysics (IUGG), and formed one of its Sections (respectively Associations). It has been officially named the International Association of Geodesy (IAG) since 1932.

Key words: Arc measurements – Baeyer – Helmert – Figure of the Earth – History of geodesy – International Association of Geodesy

1 The origin of modern geodesy and first international cooperation: 18th century

The beginning of modern geodesy may be reckoned from the 17th century, when physics and astronomy postulated an oblate figure of the Earth (Perrier 1939; Bialas 1982; Torge 2001). Based on the theory of hydrostatic equilibrium, the flattening of a rotating Earth was calculated, with values ranging between 1/230 (I. Newton 1687: 'Philosophiae Naturalis Principia Mathematica') and 1/576 (C. Huygens 1690: 'Discours de la Cause de la Pesanteur'). This was a great challenge for geodesists: to prove the polar flattening by *geometric* methods and to determine the actual value of the flattening, which then would represent a boundary value for physical Earth models. It started the period of arc measurements at different latitudes, whereby latitude arc measurements prevailed in practice. Here, the length of a part of a meridian is determined by triangulation, a method which had been successfully introduced by the Dutchman Snellius at the beginning of the 17th century, and which was employed for nearly 300 years. By measuring the corresponding difference of the latitudes using well-known astronomical procedures, the Earth's curvature at that latitude could be calculated.

Naturally, the solution to this problem required international collaboration. A driving force in this direction was the French Academy of Sciences, founded in 1666, which emphasized the importance of the problem of the Earth's figure. First attempts to calculate the flattening from measurements carried out in France along the meridian through Paris by J.D. Cassini and others (around the turn of the 18th century) failed, and the French Academy consequently initiated the well-known arc measurements in Lapland (1736–1737) and in the Spanish Vice-Kingdom of Peru (today Ecuador) (1735–1744). These enterprises required political agreement between the countries involved, but, through the participation of non-French scientists and engineers, these French expeditions obtained an international character. The Lapland expedition, led by the French Academy member Maupertuis,[1] included the Swedish astronomer Celsius. In addition to the French academicians Godin, Bouguer and La Condamine, the Spanish officers Jorge Juan and Antonio de Ulloa participated in the measurements and the evalution of the Peru expedition.

The early combination of the Lapland arc measurement with the revised Paris meridian arc then confirmed the oblate ellipsoidal Earth model, with a flattening of 1/304, which is close to the value known today (1/298.25). Further arc measurements in the 18th century delivered, by different combinations and calculation procedures, flattening values of between 1/144 and 1/352. Gravity measurements, although carried out in connection with most of the arc measurements, were not then exploited for the determination of the Earth's flattening according to Clairaut's theorem (published in 1743 in 'Théorie de la Figure de la Terre, tirée des Principes de l'Hydrostatique'). However, the common adjustment of only 19 measurements performed until 1760 would have led to a reasonable flattening value of 1/328 (Ekman and Mäkinen 1998).

With the strengthening of the European national states, and the related changes in economy, administration and military organization, the 18th century also hosted the first national geodetic surveys, organized or sponsored by the respective national governments. These surveys provided a network of geodetic control points, which then served as a basis for topographical and partly also cadastral maps, as well as for large-scale engineering projects. France was the leading nation, with a country-wide triangulation for the 'Carte géométrique de la France' (Cassini de Thury, 1733–1750). The connection between the astronomic observatories in Paris and Greenwich (1784–1787) was the beginning of the national geodetic survey of Great Britain under the direction of the Ordnance Survey, and set an example for international collaboration. It also demonstrated a fruitful cooperation between scientists and military state organizations, which were soon found in other countries. During this time, there were significant improvements in the measurement and computation techniques, characterized by the introduction of the Borda repetition circle and baseline apparatus in France, the Ramsden second theodolite in Great Britain, and mathematical developments for the calculation of triangulation networks on the ellipsoid by Legendre, Lagrange, Laplace and others.

2 Collaboration in central Europe in the 19th century: the forerunners

The political situation in central Europe was less favourable in the 19th centuary, due to the strong division into local territorial units, which was especially pronounced in Germany. On the other hand, this diversity led to a variety of different solutions for geodetic surveys, and several interesting attempts to contribute to the determination of the size and shape of the Earth. As the organized international cooperation in geodesy started in central Europe during the second half of the 19th century, we next consider the developments that led to this step (Torge 1997).

There were a number of state surveys in the last decades of the 18th century, which were based on the method of triangulation, such as the survey of Denmark (1764–1792) under the direction of Thomas Bugge, and the survey of the principality, and later kingdom, of Saxonia in Germany (1780–1811), under Friedrich Ludwig Aster. On the other hand, in the survey of the principality of Hannover (1764–1786) under Josua de Plat and Johann Ludwig Hogrewe, plane table measurements were only locally connected by short baselines, and orientated by a few astronomically derived positions. The situation was even worse in the kingdom of Prussia, which covered a large part of northern Germany. Topographical information was kept secret for military reasons, and mapping of larger areas utilized existing local information, supplemented and connected by occasional plane table surveys.

A radical change happened at the turn of the 19th century, with the extension of French influence over central Europe through the Napoleonic wars. The geodetic tradition built up by the French arc measurements and the triangulation of France, but also the establishment of a land recording system (cadastre) on the initiative of Napoleon, strongly influenced the German states. The French military surveys, which were performed between 1801 and 1813, played a special role in the states occupied by or allied with France. These surveys were based on a triangulation, and connected to the French triangulation and the recent arc measurement through the Paris meridian by Delambre and Mechain (1792–1798), which was carried out in order to define the metre as a natural unit of length.

In Germany, the first half of the 19th century was characterized by triangulations carried out in most

[1] It should be mentioned that in 1741 Maupertuis was appointed as President of the Academy of Sciences in Berlin by Frederic II the Great, King of Prussia, which is another example of the international character of science in those times of absolute monarchies.

German states as the basis for mapping. The persons in charge of these operations were either scientists (mainly astronomers and mathematicians) or military officers with scientific interest and skills. As a consequence, there were also several attempts to use these state surveys for the determination of the figure of the Earth. A first outstanding result was the triangulation of Bavaria starting in 1808, which followed the French military survey. It is connected with the name of Johann Georg von Soldner, who introduced new methods of calculation. By using new survey instrumentation developed by the Bavarian workshop of Reichenbach, the accuracy of the results was significantly increased. This was a prerequisite for the purpose of the survey, namely the production of large-scale cadastral maps, which should also provide the basis for topographical mapping. In north-western Germany, a military triangulation was carried out by the Prussian colonel Karl Ludwig von Lecoq (1796–1805), in a period when Prussia had withdrawn from the coalition against France. South of this area, a triangulation of Thuringia started in 1803, under the direction of the astronomer Franz Xaver von Zach. This survey was to be extended to an arc measurement in central Germany, but was interrupted by revival of the war between Prussia and France.

At the end of the Napoleonic wars, Prussia reorganized its mapping organizations and concentrated them on the general staff (see e.g. Torge 2002). Its chief, Friedrich Carl Ferdinand Freiherr von Müffling, immediately organized a first-order triangulation that started from the French military surveys along the Rhine River and ran over Berlin to Silesia (1817–1828), with later extension to eastern Prussia and connections to the Russian triangulation chains along its western boundary. Those surveys had started in 1816 under the direction of the astronomer Friedrich Georg Wilhelm Struve and the general Karl Ivanovic von Tenner, and were intended to also serve as a meridian arc of great length. Von Müffling had already participated in the earlier triangulation in north-western Germany and in Thuringia, and was highly interested in establishing a longitude arc measurement between the Paris meridian arc (for this purpose he contacted Delambre in 1815, when he was governor of Paris, which was occupied by allied troops) and the existing or developing triangulation networks in Germany, as a contribution to the determination of the figure of the Earth. Although this project failed, the systematic organization of the Prussian state survey under von Müffling and his interest in geodetic problems was the school for Johann Jacob Baeyer, who later became the founder of the ‘Central European Arc Measurement’ as a scientific organization. He performed topographic and trigonometric measurements under von Müffling, assisted in calculating the ‘Müffling ellipsoid’ as the reference surface for the calculations, and entered the general staff in 1821, where he began a rapid career progression (described below).

An outstanding enterprise of this period was the arc measurement of the kingdom of Hannover, carried out by Carl Friedrich Gauss (1821–1824). It was initiated by the Danish astronomer Heinrich Christian Schumacher, who was in charge of a new triangulation of Denmark, and who suggested to Professor Gauss in Göttingen the extension of the triangulation southwards as part of a central European arc measurement. The reconnaissance, measurement and calculation of the arc between Altona (the seat of Schumacher’s astronomical observatory) and Göttingen were undertaken personally by Gauss, where he introduced the method of least-squares (LS) adjustment. The arc measurement was connected to the Dutch triangulation, and hence to the French meridian arc in the west, to the triangulations of Müffling, and to the state of Hessen (organized by Christian Ludwig Gerling, a student of Gauss) in the south. A further extension south failed because the results of the triangulation of Bavaria were not made available, and large-scale geodetic control in Italy did not yet exist. However, the vision of Gauss was already that “… perhaps it is not an unrealizable prospect, that one day all the astronomical observatories of Europe could be connected together by trigonometric means …” (Gauss 1828).

From the theoretical point of view, the first decades of the 19th century were also of great importance for geodesy, because Gauss, Bessel and others refined the definition of the figure of the Earth by taking the gravity field into account. There was now a clear distinction between the physical surface of the Earth described by the topography, the equilibrium surface of constant gravity potential coinciding with the surface of the oceans (later called the geoid), and the ellipsoid as a mathematically simple reference surface.

The subsequent Bessel–Baeyer period of the Prussian state survey finally prepared the organized international cooperation in that region (Dick 1994, 1996). It was triggered by the Russian proposal of 1829 to connect the triangulation in the Baltic States (Wilhelm Struve) with the Prussian triangulation chains established by Müffling and his successors. Friedrich Wilhelm Bessel, astronomer in Königsberg, Eastern Prussia, strongly promoted this proposal and widened it to a proper arc measurement intended to connect the Russian triangulation with the manifold state surveys and arc measurements in central and western Europe. From the Prussian general staff, the experienced major Baeyer was detached from this project (1831–1836), which by improved methods of observation and evaluation set new standards for geodetic work. After this, Baeyer was rapidly promoted and finally led the trigonometric department of the general staff (1843–1857).

Under his direction, improved triangulation chains were spread out over Prussia, with proper connections to the neighbouring countries. For various reasons (among them the colliding opinions on the mapping of the country, whereby Baeyer 1851 unsuccessfully proposed to produce a large-scale map as a basis for civil and military purposes, and the appointment of a younger officer, Helmuth von Moltke, as chief of the general staff), general Baeyer retired from the general staff in 1857, at the age of 63. He then concentrated on scientific work on refraction, and continued his engagement in the determination of the figure of the Earth through discussions with neighbouring countries, and initiated new measurements supported by the general staff. These years arguably prepared him for his second 'career' as the founder and organizer of an international geodetic project.

3 Foundation and consolidation — the 'Baeyer' period: 1862–1886

During his collaboration with Müffling, Struve and Bessel, Johann Jacob Baeyer (1794–1885) (Fig. 1) had recognized the importance of large-scale astrogeodetic systems for the determination of the figure of the Earth. After his retirement he concentrated on this problem, influenced also by his appointment as Prussian representative to the longitude arc measurements at 52° latitude, which was proposed by Wilhelm Struve, then director of the Dorpat astronomical observatory (Buschmann 1994).

In April 1861, Baeyer presented a 'Proposal for a Central European Arc Measurement' ('Entwurf zu einer mitteleuropäischen Gradmessung'; Fig. 2) to the Prussian Minister of War, and justified this project by a comprehensive memorial on the size and figure of the Earth, which he dedicated to the memory of Alexander von Humboldt (Baeyer 1861). After being commanded to the trigonometric bureau of the general staff in Berlin in 1823, Baeyer had been introduced to Alexander von Humboldt. This famous naturalist acknowledged the geodetic abilities of Baeyer, and even proposed his participation in the planned expedition to central Russia and Siberia. Although this cooperation did not come off, Humboldt continued to observe Baeyer's career. In a letter directed to the King of Prussia in 1837, Humboldt characterized Baeyer as one of the most experienced officers who could be found in any army. In 1854, he prepared a positive evaluation of Baeyer's rather radical (but not successful) proposal of 1851, to reorganize the surveying activities in Prussia on a higher level and to centralize them. When Baeyer's return to the practical military service (as chief of a brigade) was planned in 1856, Humboldt argued "the King of Prussia owned sufficient officers for commanding a brigade, but only one Baeyer".

The objective of Baeyer's 1861 project was the determination of anomalies in the Earth's curvature (i.e. deflections of the vertical, and thus the relative structure of the geoid) in central Europe, to be achieved by collecting and combining existing data and performing new measurements, taking high quality standards into account (Torge 1994). Baeyer clearly described the scientific problem to be tackled, which was not only to determine the deviations of the Earth's figure (namely the geoid) from the ellipsoidal model, but also to interpret these anomalies by the structure and composition of the outer layers of the Earth. In other words: the thus-far discussed pure geometric problem of determining the parameters of an ellipsoid from arc measurements was extended to a more general problem of natural sciences, which required intensified interdisciplinary cooperation; the future science discipline 'physics of the solid Earth' became visible.

Fig. 1. Johann Jacob Baeyer (1794–1885), founder of the 'Mitteleuropäische Gradmessung' and President of the Central Bureau (1864–1885). Courtesy GFZ Potsdam

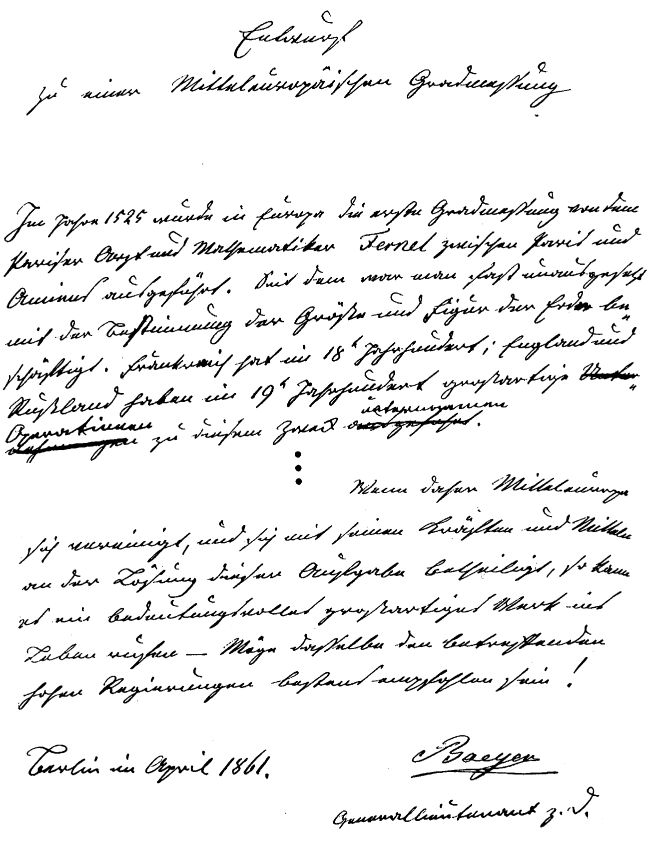

Fig. 2. Hand-written draft (first and last lines) of Baeyer's memorandum 'Entwurf zu einer Mitteleuropäischen Gradmessung', presented to the Prussian authorities in April 1861, from Dick (1994)

The memorandum in Fig. 2 describes the great arc measurements in western (Paris meridian) and eastern (Dorpat meridian) Europe and emphasizes the excellent conditions for corresponding investigations in central Europe, namely a multitude of astronomic observatories and local triangulations, which only had to be put in order, and eventually improved and connected by additional measurements, in order to obtain a large-scale geodetic network (Fig. 3). On 20, June 1861, Baeyer's plan was approved by order of the Prussian royal cabinet. First negotiations between representatives of the states of Prussia, Austria and Saxony took place in Berlin from 24 to 26 April 1862 (Levallois 1980).

The participants of this first meeting were as follows:

J. J. Baeyer, Lieutenant-General z.D., Prussia
A. von Fligely, Major-General and Director of the Military-Geographic Institute Vienna, Austria
C. von Littrow, Director of the Astronomic Observatory Vienna, Austria
J. Herr, Professor for Spherical Astronomy and Higher Geodesy, Polytechnical School Vienna, Austria
J. Weisbach, Professor at the Royal Montanistic Academy Freiberg, Saxony
C. Nagel, Professor of Geodesy, Polytechnical School Dresden, Saxony
C. Bruhns, Professor of Astronomy, University Leipzig, Saxony.

At the end of 1862, Baeyer was able to identify 16 states or countries that had entered the project: Austria, Belgium, Denmark, France (allowed the use of data necessary for the project), seven German states (Baden, Bavaria, Hannover, Mecklenburg, Prussia, Kingdom of Saxony, Saxe-Gotha), Italy, The Netherlands, Poland (through Russia), Sweden and Norway (in personal union), and Switzerland. This was a great success: an international scientific (governmental) organization had been established within a remarkably short time. Among the representatives were well-known scientists, but also experienced military officers, as the national surveys in most of the countries were then in the hand of military agencies.

Already at this early stage, the scientific programme of the project was defined in more detail and slightly extended. In addition to the proper arc measurements (selection of the astronomical points and connection of the existing geodetic networks by additional triangulations, and establishment of more baselines in order to strengthen the scale of the meridian arc), the questions of the reference ellipsoid (the 1841 Bessel ellipsoid was introduced), the length standard (comparison of the different standards used in the participating countries), and the required accuracy (definition of an error limit for the inclusion of older triangulation) were discussed. In addition, the data sources to be exploited were extended to include pendulum gravity measurements, which introduced the physical component into the previously geometrics-only problem.

In 1864, the first 'General Conference of the Representatives to the Central European Arc Measurement' took place in Berlin, which we might consider as the forerunner of the General Assemblies of the IAG and IUGG. At this conference, the organizational structure (Permanent Commission with annual meetings being responsible for the scientific management, Central Bureau as an executive, General Conferences at three-yearly intervals) was fixed, as well as the research programme. The scientific recommendations of this first conference included the following.

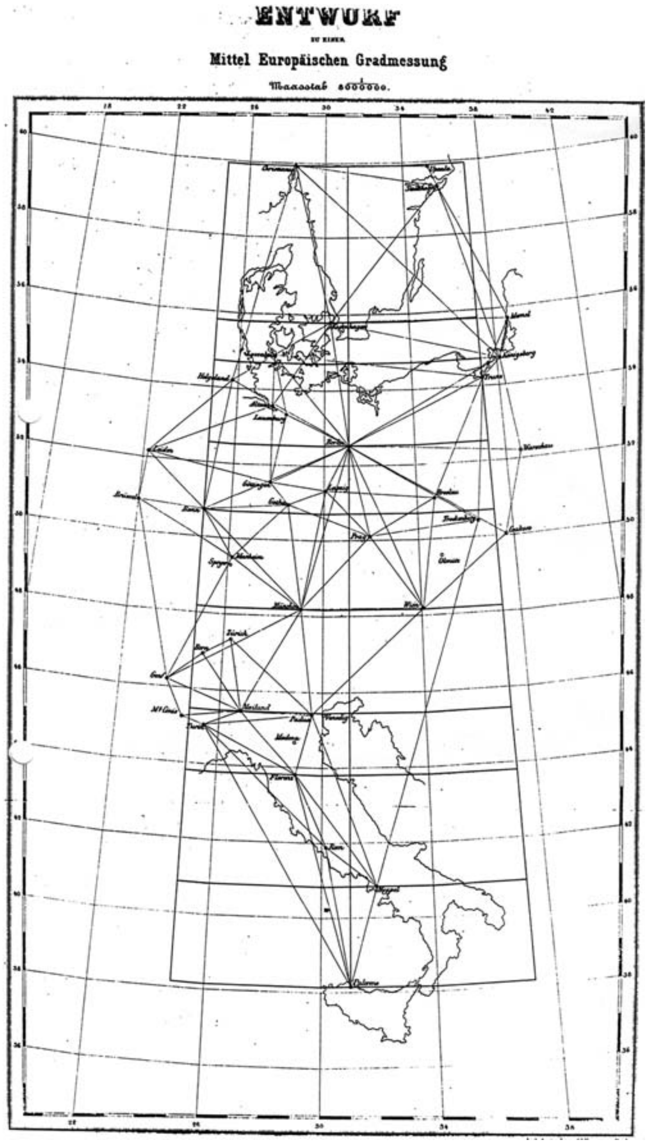

Fig. 3. Network sketch of the proposed 'Central European Arc Measurement', including astronomical observatories and connecting lines to be calculated from triangulation nets, from Baeyer's April 1861 memorandum

1. Bessel's toise should be used as the length unit for the geodetic calculations.
2. All measures must be compared with Bessel's toise.
3. The relationships between all units in use and the metre should be determined.

4. After the determination of the relationship between Bessel's toise and the metre, all results should be published in metres and in toises.
5. In addition to the trigonometric determination of heights, first order levelling should be carried out in all countries participating in the Central European Arc Measurement.
6. The heights in each country should be referred to a single zero point, and all these points should be connected by precise levelling.
7. The mean sea level of the various seas should be determined preferably by recording devices, and the zero points of the tide gauges should be included in the levelling.
8. As a result, a general height system for Europe should be selected.

The Central Bureau began its work in 1865 (financed by Prussia), with Baeyer as President. In 1867, after Portugal, Spain and Russia joined the association, the name of the organization was changed to the 'European Arc Measurement'. At this 2nd General Conference, the importance of gravity measurements was emphasized, and a recommendation reaching far beyond geodesy was passed, namely that to establish an international Bureau for Weights and Measures and to produce a new metre standard. Also in 1867, Baeyer applied to create a Prussian Geodetic Institute. In 1870, this institute was established in Berlin, and entrusted with the operation of the Central Bureau. In 1892, it moved to a specially constructed building located on the Telegraphenberg in Potsdam, which today hosts the geodetic section of the GFZ, the German Geo-Research-Center (Fig. 4).

The General Conferences held in the two decades of the Baeyer period took place in cities in Germany and Austria: Berlin (1864 and 1867), Vienna (1871), Dresden (1874), Stuttgart (1877) and Munich (1880). A highlight for the organization, and for Bayer's work, was the conference in Rome (1883). Baeyer, then at the age of 89, could not attend, but received a gold medal specially dedicated to him by the Italian Arc Measurement Commission. Although this first period of the Association was governed by the outstanding personage of Baeyer, the work of the presidents of the Permanent Commission should also be acknowledged; these were as follows.

1. 1864–1868: Peter Andreas Hansen (1795–1874), Director of the Gotha Observatory, Thuringia.
2. 1869–1874: August von Fligely (1810–1879), General, Director of the Military-Geographic Institute, Vienna, Austria.
3. 1874–1886: Carlos Ibáñez e Ibáñez de Ibero (1825–1891), General, Director of the Geographical and Statistical Institute, Madrid, Spain.

It is remarkable that the Central European Arc Measurement and the European Arc Measurement organizations developed so rapidly in the 1860s, eventhough this period was characterized by a number of wars in central Europe: between Prussia and Denmark (1864, Prussia allied with Austria), Prussia and Austria (1866, Austria allied with several German states), and Prussia together with the other German states and France (1870–71), which finally led to the unification of the German states to a German empire under Prussian leadership.

Fig. 4. Building of the former Geodetic Institute Potsdam, seat of the Central Bureau of the International Geodetic Association and its forerunners from 1892 to 1921 and now part of the Geoforschungszentrum Potsdam (GFZ). Courtesy GFZ Potsdam

We now briefly describe some of the investigations and results obtained in the first epoch of the organized geodetic operations in Europe (Lambert 1950; Völter 1963; Torge 1996).

According to the project definition, primarily horizontal geodetic control data (triangulation, baselines) were collected. The number of triangulation points in Europe increased from 2010 in 1862 to 5546 in 1912, and around 100 baselines were available at the start of the project. Connected to astronomical observatories, and with many intermediate astronomic latitude and longitude determinations, these networks delivered deflections of the vertical. A remarkable enterprise was the connection of the Spanish triangulation with Algeria (1879), where triangles with a maximum side length of 270 km were observed from mountain stations, under the direction of General Ibáñez and Major F. Perrier, Chief of the geodetic section of the French general staff. (His son, General Georges François Perrier, became Secretary General of the IAG in 1922 and kept this office until his death in 1946.)

It is odd that the results of the Prussian Geodetic Survey, which had been led by Baeyer for a long time, were not accepted for the arc measurement project by him. He accused the State Survey of making too many errors and of not keeping the accuracy rules necessary for the arc measurements. This led to a confrontation between Baeyer and the Geodetic Survey, which involved a number of scientists and lasted until Baeyer's death. On the other hand, as the Prussian army was not too popular in the countries around Germany, due to the wars that led to the unification of Germany in 1871, Baeyer certainly gained a lot of sympathy, especially with the military representatives of those countries.

Large-scale first-order geometric levelling started in most European countries, following the experience gained from France and Switzerland. It soon became the standard procedure for precise height determination, and completely superseded the trigonometric method for the establishment of national height systems. Recording tide gauges were installed at all seas surrounding Europe, and connected to the first-order levelling networks.

In order to increase the number of gravity stations, the Repsold workshop in Hamburg was asked to construct a transportable reversible pendulum apparatus. A limited number of gravity measurements were carried out by this method until about 1900, but the results were not satisfactory. This was due — among other reasons — to the effects of co-oscillation (detected and investigated by C.S. Peirce from the US Coast and Geodetic Survey) between the pendulum, its support and the ground, and led to a multitude of investigations on the theory of the reversible pendulum.

The General Conference had already chosen the metric system in 1867. The International Metre Convention of 1875 then finally solved the early-recognized problem of the different length units in use, and established the International Bureau for Weights and Measures in Sèvres near Paris. With a new stable metre standard and copies distributed to the countries that had signed the Metre Convention, the same length unit was now available in all countries. (Prussia introduced the metre in 1870, leaving the 'Bessel foot', which had been derived from the length of a second-pendulum by Bessel, after very careful investigations between 1835 and 1837.)

Triggered by the geodetic activities of the Arc Measurement organization, H. Bruns, Professor of Mathematics at the University of Berlin, published a study on the fundamental problem of geodesy, which looked far into the future, and described consequences for the programme of the organization (Bruns 1878). Defining the determination of the Earth's gravity potential as the principal task of geodesy, he developed a three-dimensional model for the solution of this problem that employed all available astronomic, geodetic and gravimetric observations. However, it took nearly a whole century before this approach of solving the figure of the Earth without any hypothesis and without the introduction of an ellipsoid could be successfully taken up in geodesy, using space techniques as the main tools.

In 1882, the Senate and the Geographic Society of the city of Hamburg asked the Permanent Commission to deal with the unification of the geographic longitudes by selecting one zero meridian and to suggest a corresponding decision. This question was discussed at the General Conference in Rome in 1883, which was also attended by observers from Great Britain and the United States as countries extremely interested in this problem. The Conference decided to select the Greenwich meridian as the zero meridian for longitude, with the Universal Time referred to it. At the 1884 Meridian Conference in Washington, a general agreement on this definition was obtained, and gradually all countries referred their longitudes to the Greenwich meridian.

At the 1883 Conference, a first step to observing the Earth as a dynamic system in space was recognized. The Italian astronomer E. Fergola proposed to monitor the location of the Earth's rotation axis with respect to the solid Earth by latitude observations on the same parallel. In 1884–85, F. Küstner observed the predicted latitude changes in Berlin, which led to the systematic investigation of polar motion starting in 1889.

This carries us to the next period of the 'Internationale Erdmessung', characterized by increasing international participation, by the extension of the problems to be tackled, and by the outstanding figure of F.R. Helmert acting as Director of the Central Bureau.

4 Extension and deepening — the 'Helmert' period: 1886–1916

Baeyer died in 1885, and the first General Conference after his death, held in Berlin in 1886 with Wilhelm Foerster (1832–1921), Director of the Berlin Astronomical Observatory as Chairman, brought a new convention on the organization, which was called 'Internationale Erdmessung' ('Association Géodésique Internationale' in French, translated into English 'International Geodetic Association'). Until 1889, the United States, Mexico, Chile, Argentina and Japan agreed with the convention, and Great Britain joined the Association in 1898. Following the proposals made by Prussia, an annual financial contribution from the countries was provided to the Permanent Commission and the Central Bureau, and the Director of the Central Bureau and a Permanent Secretary became responsible for the performance of the scientific and administrative work of the Permanent Commission. Voting at the General Conferences now followed the principle of one voice per country, which reduced the overwhelming influence of the German states. The tendency of reducing individual influences and strengthening the international basis, as well as the independent position of the Central Bureau, was pursued at the renewal of the convention in 1895 and 1906. The more international character of the Association can be seen also from the locations of the General Conferences: Paris (1889), Brussels (1892), Berlin (1895), Stuttgart (1898), Paris (1900), Copenhagen (1903), Budapest (1906), London and Cambridge (1909), and Hamburg (1912).

Under the new conventions, the elected presidents were (Figs. 5–7) as follows:

1887–1891: Carlos Ibáñez e Ibáñez de Ibero, who already served as President of the Permanent Commission

1892–1902: Hervé Etienne Auguste Albans Faye (1814–1902), President of the Bureau des Longitudes, Paris

1903–1917: Jean Antonin Léon Bassot (1841–1917), General, Chief Geodetic Section, Service Geographique de l'Armée/Director Nice Observatory.

The Permanent Secretaries were as follows:

1886–1900: A. Hirsch, Director of the Neuchatel Observatory, Switzerland

1900–1921: H. G. van de Sande Bakhuizen, Director of the Leiden Observatory, The Netherlands.

This period of the International Geodetic Association was strongly influenced by Friedrich Robert Helmert (1843–1917) (Fig. 8), who became Director of the Central Bureau in 1886–87 (Wolf 1993). Helmert studied surveying and geodesy, mathematics and physics at Dresden and Leipzig, Germany, and took part in the first-order triangulation of Saxony under Professor Nagel. He held the chair of geodesy at the Technical University of Aachen between 1870 and 1886, and at that time wrote the book '*Die mathematischen und physikalischen Theorien der höheren Geodäsie*' (1880–84), which arguably established geodesy as a proper science. From 1887, he held the chair of higher geodesy at Berlin University, and was Director of the Prussian Geodetic Institute, which continued to host the Central Bureau of the Association.

Fig. 5. General Carlos Ibáñez e Ibáñez de Ibero (1825–1891), President of the Permanent Commission and of the International Geodetic Association 1874–1891. Courtesy Instituto Geográfico Nacional, Madrid

Fig. 6. Hervé E. A. A. Faye (1814–1902), President of the International Geodetic Association 1892–1902, from Levallois (1980)

Fig. 7. General Jean A. L. Bassot (1841–1917), President of the International Geodetic Association 1903–1917, from Levallois (1980)

The main achievements of Helmert's period are as follows. The collection of horizontal control data continued and extended over the Americas, Asia and Africa. National Reports regularly gave the geodetic progress in the participating countries. In 1912, a total of 9211 triangulation points were recorded worldwide, as well as numerous astronomic latitude, longitude and azimuth determinations. Extended meridian and parallel arcs were formed from these triangulations, and deflections of the vertical were derived and published by the Central Bureau. Of note were the re-measurement of the classical Peru arc by French geodesists (1899–1906), the (fourth) measurement along the Paris meridian with extension to Spain and Algeria (1870–1894), the 39° parallel arc measurement across the United States (1871–1898), the African latitude arc measurement along the 30° meridian, starting in 1883 and completed in the 1950s, and a

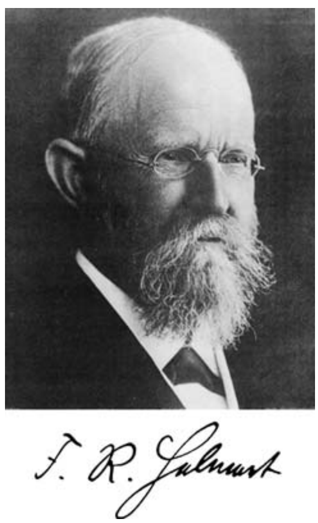

Fig. 8. Friedrich Robert Helmert (1843–1917), Director of the Central Bureau of the 'Internationale Erdmessung' (International Geodetic Association) 1886–1917, from Wolf (1993)

Russian/Swedish latitude arc measurement in Spitzbergen (1898–1902). The triangulation data were used not only for the determination of best-fitting ellipsoids, but also for investigations on isostasy, the outstanding example being the adjustment of the United States triangulation net by O.H. Tittmann and J.F. Hayford.

Precise levelling continued in many countries, and by connecting national networks and ties to tide gauges, a united European levelling network was constructed. After first evaluations of the mean sea level records (periodic parts, secular trend), it was found that mean sea level around Europe does not belong to one equipotential surface, but that deviations remain less than 0.2 m. The discussion on a common height datum for Europe started, but the problem could only be solved at the end of the 20th century, and is still open in other regions and globally. From the repeated levelling in France (25 years' repetition time), height changes were found and were discussed in connection with suspected recent crustal movements. Although these first interpretations were wrong, they formed another step to considering the Earth's surface as time dependent, and to the later formulation of four-dimensional geodesy.

The number of observed gravity values increased significantly in Helmert's period, due to the development of a relative pendulum apparatus by R. van Sterneck in 1887. About 1400 relative gravity measurements were available at the start of the 20th century, but they referred to different absolute values. This raised the problem of a common gravity reference system, which was solved by a carefully executed absolute determination at the Geodetic Institute at Potsdam (Kühnen and Furtwängler, 1898–1904), and the connection of all other gravity measurements to the Potsdam value. The 'Potsdam Gravity System' (presented by E. Borrass) was adopted in 1909 (using more than 2400 gravity values), and served as gravity standard in metrology, geodesy and geophysics until 1971. First gravity measurements on the oceans were performed by O. Hecker between 1901 and 1909, and were used for the investigation of the Eötvös effect, as well as for obtaining a first impression of the isostatic behaviour of the water-covered areas of the globe.

Theoretical studies and the evaluation of the astrogeodetic and gravimetric data collected and collated by the Central Bureau also brought significant progress in gravity field modelling. While large-scale evaluation of the deflections of the vertical failed due to interpolation problems between the scarce observations, local test areas such as the Harz mountains in Germany provided insight into the gravity field structure, including the local geoid behaviour (Helmert, Galle). Much effort was spent on investigations of the 'reduction' of gravity field data to sea level, and we see the beginning of the interpretation of gravity anomalies with respect to crustal structure and isostasy (Faye, Hayford, Helmert). The increased number of gravity values allowed calculation of improved values for the normal gravity field and the flattening of the reference ellipsoid (formulas by Helmert in 1884 and 1901), which soon served as reference for many practical surveys. First estimates (1910) on the global behaviour of the geoid stem from Helmert, and the development and extensive use of the torsion balance by R.v. Eötvös (since 1890) offers another method for the determination of local gravity field structure, which gained great importance for oil exploration in the 1920s.

The development of a horizontal pendulum by E. v. Rebeur-Paschwitz allowed the first observations of Earth tides (1889–1893), with more regular measurements carried out in Potsdam by Hecker (since 1910). It is here that W. Schweydar (1914) observed the gravimetric Earth tides, and there were even first attempts (1909) to establish a global observing system for studies of crustal movements, jointly with the International Association for Earthquake Research.

The determination of polar motion by astronomic latitude observations was continued in Helmert's period, and put on a solid scientific basis. Observations in Berlin, Potsdam and Prague (1889–90), and the results of an expedition to Honolulu (1891–92, A. Marcuse) with parallel observations in Berlin, clearly show the 'Chandler' period of about 427 days, detected by S.C. Chandler in 1891, and interpreted by S. Newcomb as the Euler period lengthened through the Earth's elasticity (1893). In 1888, W. Foerster took up the question of establishing an international observing system along one parallel. In 1899, the International Latitude Service started regular observations at Mizusawa, Japan (Director H. Kimura), Carloforte, Italy, Gaithersburg and Ukiah, USA, all located on the 39 °08′ parallel. Equipped with specially designed zenith telescopes, the observatories at Tschardjui (later moved to Kitab, Russia, now Uzbekistan) and Cincinatti, USA later joined this service. More observatories followed during the next decades, and this early international observing programme was only replaced and extended in 1988, by the International Earth Rotation Service (IERS). The evaluation of the earlier latitude observations was performed at the Central Bureau in Potsdam, and continued during the First World War (Höpfner 2000).

This brings us to the end of the 'Helmert' period, with the expiry of the international convention at the end of 1916, and the practical end of most activities due to the start of the First World War in the autumn of 1914.

5 Survival and transition to the IUGG section of geodesy: 1917–1922

The convention on the 'Internationale Erdmessung' expired at the end of 1916, and was not extended due to the First World War. In addition, some of the leading officers of the Association died during these years, among them the President, Bassot, from France (1917), the Vice-President, Sir George Darwin, from Great Britain (1912) and his successor, O. Backlund, from Russia (1916), and the Director of the Central Bureau, Helmert, from Germany (1917).

It is remarkable that some activities of the Association still continued, due to the efforts of two men from neutral countries, Raoul Gautier (1854–1931), Director of the Geneva Observatory, Switzerland, and Hendrikeus Gerardus van de Sande Bakhuyzen (1838–

1923), Director of the Leyden Observatory, The Netherlands, and Secretary of the Association since 1900. They proposed that the neutral nations "maintain the existence of the Association under the terms of the old convention . . . for a period that cannot be precisely defined at present". As a consequence, the Reduced Geodetic Association among Neutral Nations was formed (Denmark, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United States until its entry into the First World War in 1917).

The Central Bureau continued to operate, and received data through the Secretary. The main task of this new organization was the continuation of the International Latitude Service, but some limited specialized research could also be carried out, such as on Earth tides, gravity field features and isostatic reductions. After the First World War, the various Scientific Unions were created between 1918 and 1920, among them the International Union of Geodesy and Geophysics (IUGG), founded in 1919. Although this happened without any interaction with the countries that had formed the Reduced Geodetic Association, the tasks of the 'Internationale Erdmessung' were in practice continued and extended, although the loosers of the war remained excluded for a long time, contrary to the procedure after the Second World War. At the first IUGG General Assembly in Rome in 1922, a Section of Geodesy was constituted as part of the IUGG, with W. Bowie, Director of the Geodetic Section of the United States Coast and Geodetic Survey, as its first President, acting until 1933.

With this inclusion into a more interdisciplinary body, and the change to a non-governmental organization, the next epoch of the organized international collaboration in geodesy started. In 1932, the organization officially adopted the name 'International Association of Geodesy' (IAG). More than 140 years after the start of organized cooperation, the IAG is still very proud of this first epoch, which laid the fundamentals for so many research activities, and demonstrated the transition from a research project to an international organization providing a multitude of results and services for the different demands of science and geodetic practice.

Postscript

The conferences and the results of the forerunner organizations of IAG are well documented in 'Verhandlungen der Allgemeinen Conferenz der Internationalen Erdmessung und deren Permanenten Commission (Comptes-Rendus de la Conférence Générale de l'Association Géodésique Internationale et de sa Commission Permanente)' and in the 'Publikationen des Königl. Preuss. Geodätischen Institutes, Berlin'. A summary of the meetings between 1861 and 1880 is given by Sadebeck (1883). These documents are available at the Geoforschungszentrum Potsdam (GFZ), the support of which is gratefully acknowledged. On the 50th anniversary of the foundation of the 'Mitteleuropäische Gradmessung' there were reports on the origin and development of the Association by the secretary H. G. van de Sande Bakhuyzen (Comptes Rendus des Séances de la dix-septième Conférence Générale de l'Association Géodésique Internationale réunie à Hambourg du 17 au 27 Septembre 1912, Ier Volume, pp. 76–85, Georg Reimer, Berlin 1913) and on the activities of the Central Bureau by Helmert (pp 129–164), and the summarizing paper by Helmert (1913), while the first 100 years of the IAG are reviewed by Hunger (1962) and Tardi (1963).

References

Baeyer JJ (1861) Über die Größe und Figur der Erde, eine Denkschrift zur Begründung einer mittel-europäischen Gradmessung. G. Reimer, Berlin

Bialas V (1982) Erdgestalt, Kosmologie und Weltanschauung. K. Wittwer, Stuttgart

Bruns H (1878) Die Figur der Erde — Ein Beitrag zur europäischen Gradmessung. P. Stankiewicz, Berlin

Buschmann E (ed) (1994) Aus Leben und Werk von Johann Jacob Baeyer. Institut für Angewandte Geodäsie, Frankfurt am Main

Dick WR (1994) Die Vorgeschichte von Johann Jacob Baeyers 'Entwurf zu einer Mitteleuropäischen Gradmessung'. In: Buschmann E (ed) Aus Leben und Werk von Johann Jacob Baeyer. Institut für Angewandte Geodäsie, Frankfurt am Main, pp 105–144

Dick WR (1996) Zur Vorgeschichte der Mitteleuropäischen Gradmessung. In: Beiträge zum J.J. Baeyer-Symposium, Deutsche Geod. Komm., Reihe E, Nr. 25: 15–27, Frankfurt am Main

Ekman M, Mäkinen J (1998) An analysis of the first gravimetric investigations of the Earth's flattening and interior using Clairaut's theorem. Small Publ Historical Geophysics, no. 4. Summer Institute for Historical Geophysics, Ålands Islands

Gauss CF (1828) Bestimmung des Breitenunterschiedes Zurischen den Sternwarten von Göttingen und Altona durch Beobachtüngan am Ramsdenschen Zenithsector. Carl Friedrich Gauss Werke Bd. IX: 50. Teubner, Leipzig (1903)

Helmert FR (1913) Die Internationale Erdmessung in den ersten fünfzig Jahren ihres Bestehens. Int Monatsschr Wiss Kunst Tech 7(4):397–424

Höpfner J (2000) The International Latitude Service — a historical review, from the beginning to its foundation in 1899 and the period until 1922. Surv in Geophys 21:521–566

Hunger F (1962) Hundert Jahre Internationale Erdmessung. Z Vermess 87:117–125

Lambert WD (1950) The International Geodetic Association (Die Internationale Erdmessung) and its predecessors. Bull Géod 17:299–324

Levallois JJ (1980) The history of the International Association of Geodesy. In: The Geodesist's Handbook 1980. Bull Géod 54:249–313

Perrier G (1939) Petite Histoire de la Géodésie. Comment l'homme a mesuré et pesé la Terre. Alcan, Presses Universitaires de France, Paris [German translation by E Gigas (1950) Wie der Mensch die Erde gemessen und gewogen hat — Kurze Geschichte der Geodäsie. Bamberger Verlagshaus Meisenbach, Bamberg]

Sadebeck M (1883) Register der Protokolle, Verhandlungen und Generalberichte für die Europäische Gradmessung vom Jahre 1861 bis zum Jahre 1880. Publ des Königl Preussischen Geodätischen Instituts, Berlin

Tardi P (1963) Hundert Jahre Internationale Erdmessung. Z Vermess 88:2–10

Torge W (1994) Die Geodäsie im Übergang zur international organisierten Wissenschaft: Zum 200. Geburtstag von Johann Jacob Baeyer. Z Vermess 119:513–522

Torge W (1996) The International Association of Geodesy (IAG) — More than 130 years of international cooperation. J Geod 70:840–845

Torge W (1997) Von Gauß zu Baeyer und Helmert — Frühe Ideen und Iniativen zu einer europäischen Geodäsie. In: Junius H, Kröger K (eds) Europa wächst zusammen — 6. Symposium zur Vermessungsgeschichte in Dortmund 1996. K Wittwer, Stuttgart, pp 39–65

Torge W (2001) Geodesy, 3rd edn. W de Gruyter, Berlin–New york

Torge W (2002) Müfflings geodätisches Wirken in der Umbruchepoche vom 18. zum 19. Jahrhundert. Z Vermess 127:97–108

Völter U (1963) Geschichte und Bedeutung der Internationalen Erdmessung. Deutsche Geod Komm. Reihe C, Nr. 63, München

Wolf H (1993) Friedrich Robert Helmert — sein Leben und Wirken. Z Vermess 118:582–590