150 Years of International Cooperation in Geodesy: Precursors and the Development of Baeyer's Project to a Scientific Organisation*

Wolfgang Torge

Summary

Geodesy commemorates this year the foundation of the "Mitteleuropäische Gradmessung", which started its activities 150 years ago. Originated from an initiative of the Prussian General Baeyer, this regional geodetic project required international cooperation. Outstanding organization soon led to a scientific body which continuously extended over the globe and finally built a global network of geodetic science, represented today by the "International Association of Geodesy" (IAG).

The following paper first remembers the start of international cooperation at the beginning of modern geodesy, as realized through the arc measurements of the 18th and the early 19th century. First attempts for arc measurements covering central Europe then are found in the first half of the 19th century – connected with the names of Zach, Schumacher, Gauß, Müffling, Bessel and Struve, among others. Based upon a memorandum presented 1861, Baeyer proposed a coordinated proceeding and clearly defined the problems to be solved. This idea soon led to a governmental supported project and an organization which rapidly extended beyond the boundaries of central Europe. This early phase of international cooperation is discussed in more detail. Finally, the later extension of this early structure to a global scientific organization and the increasing incorporation into interdisciplinary geoscientific research is shortly described.

Zusammenfassung

In diesem Jahr gedenkt die Geodäsie der Entstehung ihrer internationalen wissenschaftlichen Vereinigung vor 150 Jahren. Auf Initiative des preußischen Generals Baeyer entstand die »Mitteleuropäische Gradmessung«, ein zunächst räumlich begrenztes Projekt. Die hierzu notwendige internationale Zusammenarbeit wird effektiv organisiert und führt – bei laufender Erweiterung der Aufgabenstellung – schließlich zur globalen Vernetzung der geodätischen Wissenschaft, heute repräsentiert durch die »International Association of Geodesy« (IAG).

Der folgende Beitrag erinnert zunächst an die mit Beginn der modernen Geodäsie einsetzende länderübergreifende Zusammenarbeit bei den Gradmessungen des 18. und des frühen 19. Jahrhunderts. Erste Gradmessungen in Mitteleuropa oder Ansätze hierzu finden sich dann in der ersten Hälfte des 19. Jahrhunderts – verbunden u. a. mit den Namen Zach, Schumacher, Gauß, Müffling, Bessel und Struve. Baeyers Idee eines koordinierten Vorgehens mit klarer Aufgabendefinition führt schließlich – auf der Grundlage einer 1861 vorgelegten Denkschrift – zu einer zwischenstaatlichen Zusammenarbeit, die bald über Europa hinausreicht. Auf diese frühe Phase internationaler Kooperation wird ausführlicher eingegangen, abschließend wird auf die spätere Erweiterung zur globalen Wissenschaftsorganisation und die immer stärker werdende Einbindung in die interdisziplinäre Geoforschung hingewiesen.

Keywords: Arc measurements, Earth figure, General Baeyer, International Association of Geodesy, Mitteleuropäische Gradmessung

1 The Origin of Modern Geodesy and Early International Cooperation: 18th Century

Geodesy, by definition, requires international collaboration on a global scale. This becomes clearly visible with the beginning of modern geodesy, which may be reckoned from the 17th century. The heliocentric world system with the annual revolution of the Earth around the Sun and the daily rotation of the Earth had been accepted at that time, and physics and astronomy postulate an Earth figure flattened at the poles (Perrier 1939, Bialas 1982). The corresponding Earth model is based on the theory of hydrostatic equilibrium (*Newton*** 1687, *Huygens* 1690), the observed polar flattening of Jupiter (*Jean-Dominique Cassini* 1666), and the latitude-dependence of gravity found by pendulum measurements (*Richer* 1672/73, *Halley* 1677/78). This is a great challenge for geodesy: to prove the polar flattening by geometric methods and to determine the parameters of such an Earth model! For a rotational ellipsoid, these parameters would be the semi-major axis and the geometric flattening. The arc measurement method known since antiquity is available for this purpose. Triangulation introduced by *Snellius* (1614/15) offers an efficient procedure to determine geodetic (ellipsoidal) differences in length, while the determination of latitude, longitude and azimuth can be based on well-known astronomical methods. A first attempt in this direction is carried out by *J.-D. Cassini* and his son *Jacques* carrying out a triangulation (1683–1718) along the meridian of Paris. Dividing this meridian arc of 8°20' extension into a northern and a southern part and

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** Names written in italics refer to historical persons, with relevant years of important publications or surveys, and *not* to list of references.

separate evaluation led to an Earth model elongated at the poles, with a negative flattening of –1/95. This result was in agreement with a few older arc measurements, but contradicted the hypothesis of an Earth flattened at the poles.

This is the beginning of the well-known dispute between the followers of Newton (flattening at the poles) and the Cassinis (elongation at the poles) which is solved by the famous arc measurements in Lapland (*Maupertuis*, *Clairaut* et al. 1736/37) and in the Spanish Vice-Kingdom of Peru – today Ecuador (*La Condamine*, *Bouguer*, *Godin* et al. 1735–1744), initiated and organized by the French Academy of Sciences. The early combination of the Lapland arc with the Paris meridian arc revised by *Cassini de Thury* and *La Caille* (1739/40) already yields a polar flattening of 1/304. This is confirmed by the combination of further arc measurements, although the flattening values vary between 1/144 and 1/352. These great French arc measurements not only require political agreements between the countries involved, but also are the beginning of international participation at large-scale geodetic projects. The Lapland expedition, for instance, included the Swedish astronomer *Celsius*, and the Spanish navy officers *Jorge Juan* and *Antonio de Ulloa* actively contributed to the measurements and the evaluation of the Peruvian arc measurement.

The large differences found for the flattening (and naturally also for the semi-major axis) of an Earth ellipsoid led to first discussions on the figure of the Earth, starting already in the 18th century. In the beginning it is tried to keep the ellipsoidal Earth model, and to explain local and later also large-scale deviations through the effects of topography, geology, and continent-ocean distribution. Different strategies are proposed in order to solve this problem, including the reduction of local anomalies and the introduction of a latitude- or longitude-dependent flattening parameter. Around 1800, the time is ripe for a new definition of the Earth figure, which is introduced soon after by *Gauß*, *Bessel*, and others (see below). This coincides with national geodetic surveys organized or sponsored by the respective governments, following the country-wide triangulation carried out for the "Carte de France" (*Cassini de Thury*, 1733–1750). We also recognize significant improvements in the measurement techniques, characterized by the bimetal baseline apparatus, the *Borda* repetition circle, and the *Ramsden* second theodolite. These technical developments are accompanied by a remarkable progress in theory, as the transition from the plane or spherical computation to the ellipsoidal one (*Legendre*, *Lagrange*, *Laplace*, *Gauß*, and others), and the introduction of the least-squares method (*Gauß*, *Legendre*). Another example for early international collaboration then is the trigonometric connection between the astronomic observatories in Paris and Greenwich (1784–1787), which also represents the beginning of the geodetic survey of Great Britain under the direction of the Ordnance Survey (*Roy*, *Mudge*, *Colby*, *James*).

2 Central Europe at the Turn of the 19th Century: Military Triangulations and the Beginning of Arc Measurements

The political situation in central Europe is less favourable for large-scale triangulations of high standard. This is due to the strong separation into local territorial units, which is especially pronounced in Germany; for the history of geodesy in Germany we refer to Torge (2009). Among the remarkable exceptions are the triangulations carried out in the dukedom of Oldenburg (*Georg Christian von Oeder*, 1781–1785) and in the principality, and later kingdom, of Saxony (*Friedrich Ludwig Aster*, 1780–1811), both following the example of the geodetic survey of Denmark (1762–1779) under *Thomas Bugge*. An important intermediate phase occurs at the turn of the 19th century, with the extension of French influence over central Europe through the Napoleonic wars. The military surveys carried out by the well-trained French engineer-geographers are based on triangulation, and shall extend the French map of scale 1:86400 on the occupied or allied countries. Triangulation of the occupied German regions left of the Rhine (1802–1809) is connected with the name of *Tranchot*. The upper Rhine area is surveyed by *Henry* (1804), while *Epailly* performs a rapid triangulation of Hannover (1805–1806), and *Bonne* establishes a first trigonometric network in the allied Bavaria (1801–1807). The Batavian Republic is triangulated by *Krayenhoff* (1802–1811). All these triangulations are connected to the new arc measurement along the Paris meridian (1792–1798) carried out by *Delambre* and *Méchain* in order to define the metre as a natural unit of length, and thus refer to the geodetic datum provided by the Paris observatory. This is also valid for the Prussian military triangulation of Westphalia (1795–1805) carried out under the direction of Colonel *von Lecoq*, in a period when Prussia had withdrawn from the coalition against France. At the end of the Napoleonic wars, Prussia reorganized its mapping organizations and concentrated them on the General Staff (Torge 2002). Under the direction of General *von Müffling*, *Tranchot's* triangulation of the Rhineland is continued since 1814, and continued through Hesse and Thuringia to Prussia's eastern provinces, reaching Berlin in 1820 and Breslau in 1828, East Prussia finally is connected in 1832. *Müffling* had already participated in *Lecoq's* triangulation of north-western Germany and the triangulation of Thuringia, and he early develops the idea of a longitude arc measurement between Dunkirk (northern-most baseline of the Paris meridian arc) and the Seeberg baseline near Gotha (see below). For this purpose *Müffling* (being governor of Paris, which was occupied by allied troops) contacted *Delambre* in 1815, but the project failed for obvious reasons.

Here, we have to refer to the activity and the influence of the astronomer *Franz Xaver von Zach*, who – at the turn from the 18th to the 19th century – developed Gotha to a centre of scientific exchange in astronomy and geodesy (Brosche 2001). *Zach* had been asked in 1802 by the king of Prussia to perform a triangulation of Thuringia, and from this develops the plan of an arc measurement in the centre of Germany, covering a difference of 4° in latitude and 6° in longitude, respectively. Among others, *Gauß* and *Müffling* take part in the following astronomic and geodetic observations, and in the measurement of the Seeberg baseline (1803–1805). With the revival of the war between Prussia and France, this first scientific geodetic enterprise in Germany abruptly ends in 1806. Nevertheless, *Müffling* holds the Seeberg baseline (which was partly measured only) for suited to provide the scale of the Prussian triangulation chains established since 1814, and he introduces a reference ellipsoid based on calculations of *Zach* and others, with a flattening value of 1/310. A second computation (1824, flattening 1/315.6) utilizes observations on and between the observatories Seeberg, Mannheim, and Dunkirk – here, the (at that time Lieutenant) *Baeyer* appears the first time, as a scientific collaborator of *Müffling*. As a volunteer, *Johann Jacob Baeyer* had taken part in the war of liberation against Napoleon, and then completed the military school in Koblenz. Since 1816 he is engaged in topographic and trigonometric surveys in Thuringia and in the Rhineland, carried out under the direction of *Müffling*. In 1821, he is detached to the Trigonometric Bureau of the Great General Staff, where he starts a rapid career. Further experience in precise measuring techniques is collected by *Baeyer* when carrying out first order triangulation (1821–1830), this later makes him to an ideal partner of *Bessel* at the East Prussian arc measurement (see below).

3 First Half of the 19th Century: Arc Measurements and New Definition of the Earth Figure

The first half of the 19th century is characterized by a refined definition of the Earth figure and by state geodetic surveys of high quality, which are often also related to the global problem. This again requires international collaboration, which is differently marked according to personal engagement, scientific networks, and political strategies.

At the century's beginning is the new state survey of Bavaria (1808–1828), which is outstanding in originality and quality, and connected with the name of *Johann Georg von Soldner*. It links up with the previous French work, but is distinguished significantly through the quality of the measurements (new survey instrumentation developed by the Bavarian workshop of *Reichenbach*), the introduction of the Soldner-coordinates, and the development of a complete theory of a geodetic survey. The Bavarian state survey is intended to serve as geometrical basis for a real estate cadastre *and* for topographical mapping, a strategy reaching far into future! The exploitation of data for global geodesy is not intended, although Soldner is well aware of the respective problems. As regarding the effect of the Earth oblateness on the orbit of the moon he proposes, for instance, to determine a reference flattening by combining the existing arc measurements in western Europe with an arc to be established in western Africa (Soldner 1810).

Fig. 1: Carl Friedrich Gauß (1777–1855). Oil-painting by Gottlieb Biermann (1887), after an original portrait by Christian Albrecht Jensen.
Copy Göttinger Universitätssternwarte, Gauß-Gesellschaft Göttingen

Of outstanding importance are the geodetic activities of *Carl Friedrich Gauß* (Fig. 1), whereat we especially consider the arc measurement of the kingdom of Hannover (1821–1823), Großmann (1955). This enterprise is initiated by the Danish astronomer *Heinrich Christian Schumacher*, who is in charge of a new triangulation of Denmark, based on a north-south directed arc measurement. In 1816, he suggests to *Gauß* (since 1807 Professor of Astronomy in Göttingen) to extend the Danish arc through Hannover and possibly via Hesse and Bavaria until Italy:

> *"… Der König hat mir die nötigen Fonds zu einer Gradmessung von Skagen bis Lauenburg … bewilligt … wäre es nicht möglich, dass Sie … durch Hannover fort bis gegen Gotha, oder bis an die bayerischen Dreiecke führten …".*

Gauß immediately responds very positively:

> *"… Diese Gradmessung in den k. dänischen Staaten wird uns … über die Gestalt der Erde schöne Aufschlüsse geben. Ich zweifle indessen gar nicht, dass es in Zukunft zu machen sein wird, Ihre Messungen durch das Königreich Hannover südlich fortzusetzen …".*

By order of King George IV (1820), *Gauß* gets the permission to continue the Danish arc measurement through Hannover. Reconnaissance, angle measurements and computations of the triangulation chain connecting the observatories Göttingen and Altona are carried out by *Gauß* himself, and it is this project where he invents the heliotrope, and applies the method of least-squares developed by him. From the very beginning he considers the arc measurement (which later will be extended to a triangulation of the whole kingdom) as a part of a future trigonometric network covering Europe. This becomes visible in a letter (1821) directed to his scholar *Gerling* (Professor in Marburg and since 1821 Director of the trigonometric bureau, and as such responsible for the triangulation of the electorate of Hesse):

> *"… Es wäre gewiß äußerst wichtig, wenn der größte Teil von Europa vollständig mit einem Netz überzogen wäre, und nach und nach werden wir dahin kommen; jeder Staat sollte es sich zur Ehre rechnen, seinen Anteil daran so gut zu liefern, dass er würdig sei, neben den besten zu stehen"* (Lehmann 1955).

Consequently, *Gauß* connects his arc measurement not only to the Danish meridian arc in the north, and – after proper extension – to the *Krayenhoff* triangulation of the Netherlands, but also to the triangulation of *Müffling* and to the geodetic survey of Hesse. He also thinks to include the triangulations carried out by *Bohnenberger* in Württemberg and by *Eckhardt* in the grand duchy of Hessen-Darmstadt into a future European network. *Gauß'* intention obviously is the common adjustment of a central European arc from Denmark to Italy, using the original data. Unfortunately, his endeavours to get the observations of *Soldner* from the Bavarian government lead to a success only in 1827 – at that time *Gauß* had already given up his plan of a large-scale computation (Großmann 1955).

Fig. 2:
Wilhelm Struve (1793–1864). Portrait by Eduard Hau (1837)
http://commons.wikimedia.org/wiki/File:Wilhelm_Struve._1837.jpg

The Russian-Scandinavian latitude arc measurement (1816–1852) along the 27° E meridian represents another international geodetic enterprise of that time, with relevance to the later project of *Baeyer* (e.g., Pettersen and Müller 2009, Lemke 2011). It starts from two arcs independently established in the Baltic provinces of Russia, one by the Colonel (later General) *Carl Tenner*, and the other one by Professor *Friedrich Georg Wilhelm Struve* (Fig. 2), Director of the astronomic observatory in Tartu, Estonia (then Dorpat). In 1828 the two arcs were connected and extended to the north and to the south, finally reaching a length of about 2800 km between the Arctic Ocean and the Black Sea. In 2005, this arc with more than 30 still existing monuments has been included in the UNESCO world heritage list.

Fig. 3:
Friedrich Wilhelm Bessel (1784–1846). Portrait by Christian Albrecht Jensen (1839)
http://en.wikipedia.org/wiki/Friedrich_Wilhelm_Bessel

Russia suggests in 1829, to connect the triangulation in the Baltic provinces with the trigonometric chains of the Prussian general staff, which meanwhile had reached West Prussia. *Friedrich Wilhelm Bessel* (Fig. 3), Professor at the University of Königsberg and director of the astronomic observatory, strongly promotes the Russian proposal and emphasizes the importance of such a connection for global geodesy:

> *"… durch die Vergleichung der geodätischen Verbindung von Königsberg und Dorpat, mit derjenigen welche durch astronomische Beobachtungen gegeben worden ist, ein neues Resultat für die Figur der Erde zu erlangen …"*.

By including a baseline and astronomical observations, the proposed pure trigonometric connection is widened to a proper arc measurement (1831–1836), with (now) Major *Baeyer* participating as representative of the Prussian General Staff (Hamel and Buschmann 1996). The collaboration between the ingenious astronomer *Bessel* – his geodetic work has significantly promoted theory and practice at the developing science of geodesy – and the geodesist *Baeyer*, well experienced in triangulation, proved to be extremely successful (Eggert 1911). The high quality of this arc measurement set new standards for geodetic work, and gave rise to a scientifically based renewal of the triangulation in Prussia, with *Baeyer* as responsible personage. The final report (1838) on the arc measurement in East Prussia is edited by *Bessel* and *Baeyer*, and again clearly states the idea of a European contribution to the determination of the figure of the Earth:

> *"… eine Verbindung, welche, indem sie auch die meisten europäischen Sternwarten berührt und also, durch die Vergleichung häufiger und über den größten Theil von Europa vertheilten astronomischen Beobachtungen, mit der beziehungsweisen Lage für die Bestimmung der Figur der Erde, wenigstens in dem Umfange dieses Welttheils zu erhalten, welche den darauf zu gründenden Schlüssen viel größeres Gewicht verhiess, als die abgesonderten Gradmessungen bisher haben gewähren können …"*.

Parallel with these arc measurements, the discussion on the figure of the Earth – assumed to be a rotational ellipsoid – continues and finally converges to a refined definition. This is caused not only by the discrepancies between the results of different arc measurements, but also by a first evaluation of globally distributed pendulum measurements. *Laplace*, e.g., publishes flattening values between 1/321 and 1/336 in the "Méchanique Céleste" (1799), as derived from pendulum observations. The new definition of the "mathematical" figure of the Earth then is especially connected with the names of *Gauß* and *Bessel*.

In a letter to *Schumacher* (1823), *Gauß*, e.g., discusses the deflection of the vertical of 5.5'' observed between Göttingen and Altona and states:

> *"… so beweiset dies nur, dass im Kleinen die Erde gar kein Ellipsoid ist, sondern gleichsam wellenförmig von dem die Erde im Großen darstellenden Ellipsoid abweicht …".*

In the report on the arc measurement in Hannover (Gauß 1828) we then find the definition:

> *"… was wir im geometrischen Sinn Oberfläche der Erde nennen, ist nichts anderes als diejenige Fläche, welche überall die Richtung der Schwere senkrecht schneidet, und von der die Oberfläche des Weltmeeres einen Theil ausmacht …".*

This means the introduction of a physically defined figure of the Earth, later by *Listing* called "geoid": the gravity field now becomes an essential part of geodesy! The ellipsoid now plays the role of a geometrically simple Earth model, approximating the geoid:

> *"… Bei dieser Lage der Sache hindert aber noch nichts, die Erde im ganzen als ein Revolutionssphäroid zu betrachten, von dem die wirkliche (geometrische) Oberfläche überall bald in schwächern, bald in kürzern, bald in längern Undulationen abweicht …".*

Gauß also expresses the idea of a European arc measurement, as later realized by *Baeyer*:

> *"… vielleicht ist die Aussicht nicht chimärisch, dass einst alle Sternwarten von Europa trigonometrisch unter einander verbunden sein werden …".*

In connection with the arc measurement in East Prussia, *Bessel* also states that the real "mathematical" Earth figure may significantly deviate from a rotational ellipsoid:

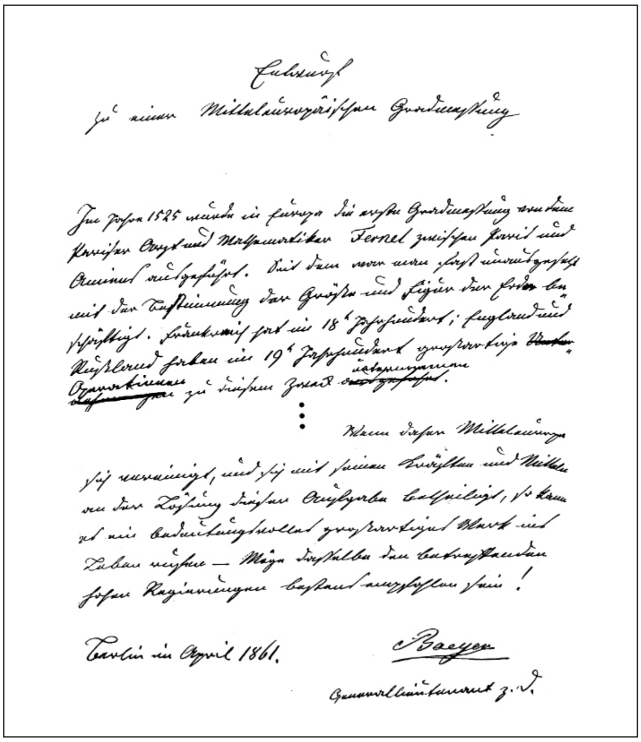
> *"… Wenn man auch diese Oberfläche der Erde im ganzen als der Oberfläche eines elliptischen Rotationssphäroides nahe kommend betrachtet, so kann man doch nicht läugnen, dass beide nicht vollkommen zusammenfallen. Die vorhandenen Messungen von Meridianbögen zeigen nämlich entschiedene Unregelmäßigkeiten des Fortschreitens der Polhöhen, welche man als Folgen kleiner Erhöhungen der Oberfläche der Erde über, oder ihrer Vertiefungen unter der Oberfläche des zur Vergleichung genommenen Rotationssphäroides ansehen muß …".*

The determination of the deviations of the geoid from a reference ellipsoid thus has become the fundamental problem of global geodesy. This is justified all the more as the ellipsoids computed by *Delambre* (1810), *Walbeck* (1819), *Airy* (1830), *Everest* (1830), *Bessel* (1841) and others have proved to be a solid basis for the computation of national geodetic surveys (Straßer 1957).

4 The "Mitteleuropäische Gradmessung": Baeyer's Idea and its Realization

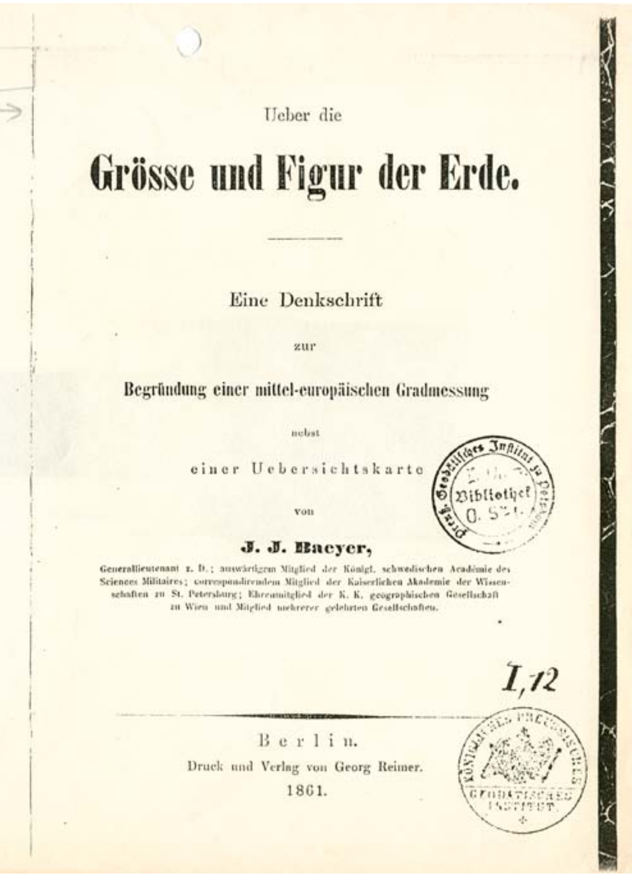
After the East Prussian arc measurement *Baeyer* promotes rapidly, and finally leads the trigonometric department of the General Staff (1843–1857). Under his direction, new triangulation chains are spread out over Prussia, which now follow the high standards set by *Bessel*. Further on, proper connections to neighbouring countries play an important role. The "Küstenvermessung" (1837–1842) connects the trigonometric network in East Prussia with the Danish triangulation, and the later fundamental station Rauenberg originates from a chain to the triangulation around Berlin (1842–1845). The scale of the Prussian first order triangulation is improved by additional baselines, and the connection to the Russian triangulation is strengthened by further ties. Scale comparisons between the Russian and the Prussian baselines and studies on the mean sea level of the Baltic Sea already indicate focal points of the later "Mitteleuropäische Gradmessung", coming into existence with the approval of *Baeyer's "Entwurf zu einer mitteleuropäischen Gradmessung"* (1861), see below. The idea to this proposal certainly builds up on the well-known considerations of *Zach*, *Gauß*, *Müffling*,

Fig. 4: Johann Jacob Baeyer (1794–1885), founder of the "Mitteleuropäische Gradmessung". Oil-painting by Stankiewicz
Deutsches Geoforschungszentrum Potsdam, from Buschmann (1994)


Entwurf
zu einer Mitteleuropäischen Gradmessung

Berlin im April 1861.
Baeyer
Generallieutenant z. D.

Fig. 5: Hand-written draft (first and last lines) of Baeyer's memorandum (1861) for the foundation of a "Mitteleuropäische Gradmessung", from Dick (1994)


Ueber die

Grösse und Figur der Erde.

Eine Denkschrift

zur

Begründung einer mittel-europäischen Gradmessung

nebst

einer Uebersichtskarte

von

J. J. Baeyer,

Generallieutenant z. D.; auswärtigem Mitglied der Königl. schwedischen Académie des Sciences Militaires; correspondirendem Mitglied der Kaiserlichen Akademie der Wissenschaften zu St. Petersburg; Ehrenmitglied der K. K. geographischen Gesellschaft zu Wien und Mitglied mehrerer gelehrten Gesellschaften.

I,12

Berlin.
Druck und Verlag von Georg Reimer.
1861.

Fig. 6: Front page of Baeyer's memorandum (1861) for the foundation of a "Mitteleuropäische Gradmessung".
Deutsches Geoforschungszentrum Potsdam

Struve and *Bessel*, but refinement and realization are affected by different additional events and factors (Dick 1994, Dick 1996, Torge 2005).

Starting point for the development of this proposal is *Bayers* retirement in 1857, which is connected with a far-reaching discordance with the Prussian General Staff. The quarrel originates from fundamentally different opinions on the survey of a state, but is also touched by personal problems. *Baeyer* had meanwhile reached the rank of a Major-General, and could not further advance within the General Staff (Fig. 4). A return to the practical military service as chief of a brigade was planned, although *Alexander von Humboldt* argued that "the King of Prussia owns sufficient officers for commanding a brigade, but only one Baeyer". The appointment of *Helmuth von Moltke* (being younger than *Baeyer*) as chief of the General Staff finally led to an only short-lived construction – under "characterizing" (i.e. obtaining the corresponding rank but remaining with the wages of the previous position) as Lieutenant-General, *Baeyer* is put to the disposition of the new chief. The further development is positively influenced by the fact that *Wilhelm Struve*, now director of the recently established Pulkovo observatory, this year travels through Europe in order to advertise his plan of a longitude arc measurement, running along 52° latitude from Omsk/Ural to Valencia/Ireland. Following a proposal from *Struve*, *Baeyer* is charged with the Prussian part of this international project. With respect to the necessary support, he unfortunately depends on the good will of the General Staff – the officers detached to him are withdrawn again and again. Additionally, in 1859 there arises a conflict with *Otto Struve* who had followed his father *Wilhelm* at Pulkovo observatory. The younger *Struve* intends to take over the direction of the longitude arc measurement and its evaluation – this is not acceptable for the elder and far more experienced *Baeyer*. About 1860, *Baeyer* probably reflects the first time upon an arc measurement in central Europe, for the present concentrated on Germany. This becomes visible through a dedicated voyage to Munich where he meets an obvious interest at the Bavarian General Staff and the cadastral administration, the idea of a memorandum for realizing such a project originates here (Pieper 1996).

In April 1861, *Baeyer* presents the "Entwurf zu einer Mitteleuropäischen Gradmessung" to the Prussian Minister of War (Fig. 5). The objective of this project is the determination of the deflections of the vertical – and thus the relative structure of the geoid – in central Europe. This shall be achieved by exploiting the available triangulations and astronomic observations, and by performing new measurements if necessary; high quality standards are set for the data to be included into the corresponding computations. A memorandum (Baeyer 1861) explains the project in detail and provides a thorough scientific foundation (Fig. 6). The objective of this scientific enterprise is summarized as follows:

"… Die beiliegende Übersichtskarte giebt ein anschauliches Bild von der Vertheilung der astronomisch festgelegten Punkte, an denen die Krümmung der Erdoberfläche … ermittelt werden kann. Innerhalb dieses Rahmens können noch etwa 10 Meridianbögen unter verschiedenen Längen und noch mehr Parallel-Bögen unter verschiedenen Breiten berechnet werden; … Kurz, es bietet sich ein weites Feld von wissenschaftlichen Untersuchungen dar; … die unzweifelhaft zu eben so interessanten als wichtigen Ergebnissen führen müssen … Ein solches Werk kann aber … nicht das Werk eines einzelnen Staates sein; … Was aber der Einzelne nicht vermag, das gelingt vielen! … Wenn daher Mittel-Europa sich vereinigt … so kann es ein bedeutungsvolles, grossartiges Werk ins Leben rufen …".

The proposed project contains about 30 astronomic observatories which already are or should be geodetically connected through triangulation chains, and it covers an area of about 13° of difference in longitude and 29° differences in latitude, respectively (Fig. 7). The main objective – determination of the curvature anomalies of the Earth figure – is extended by including the interpretation of the results. This is specified by examples, as the effect of the Alps on the deflections of the vertical, and an eventually anomalous gravity field behaviour at the European border seas: the geophysical-geological interpretation of the geodetic results is a component part of the project!

On 20th June 1861 – only two months after presenting his memorandum! – *Baeyer's* plan is approved by order of the Prussian royal cabinet, and the Prussian Foreign Ministry asks the governments of the other central European countries for collaboration. This rapid positive decision is to a large part due to the protection of Fürst *Carl Anton von Hohenzollern-Sigmaringen*, president of the State Ministry (Dick 1996). Already in April 1862 first negotiations between representatives of the states of Prussia, Austria and Saxony take place in Berlin, with the following participants: *Johann Jacob Baeyer*, Lieutenant-General z. D., Prussia; *August von Fligely*, Major-General and Director of the Military-Geographic Institute Vienna, Austria; *Carl von Littrow*, Director of the Astronomic Observatory Vienna, Austria; *Josef Herr*, Professor for Spherical Astronomy and Higher Geodesy, Polytechnical School Vienna, Austria; *Julius Ludwig Weisbach*, Professor for Mathematics at the Royal Montanistic Academy Freiberg, Saxony; *Christian August Nagel*, Professor of Geodesy, Polytechnical School Dresden, Saxony; *Carl Christian Bruhns*, Professor of Astronomy, University of Leipzig, Saxony.

At the end of 1862, *Baeyer* presents a "General-Bericht über den Stand der mitteleuropäischen Gradmessung", where he is able to identify 16 states or countries that had entered the project. These are the seven German states Baden, Bavaria, Hannover, Mecklenburg, Prussia, Saxony and Saxe-Gotha, and Austria, Belgium, Denmark, France

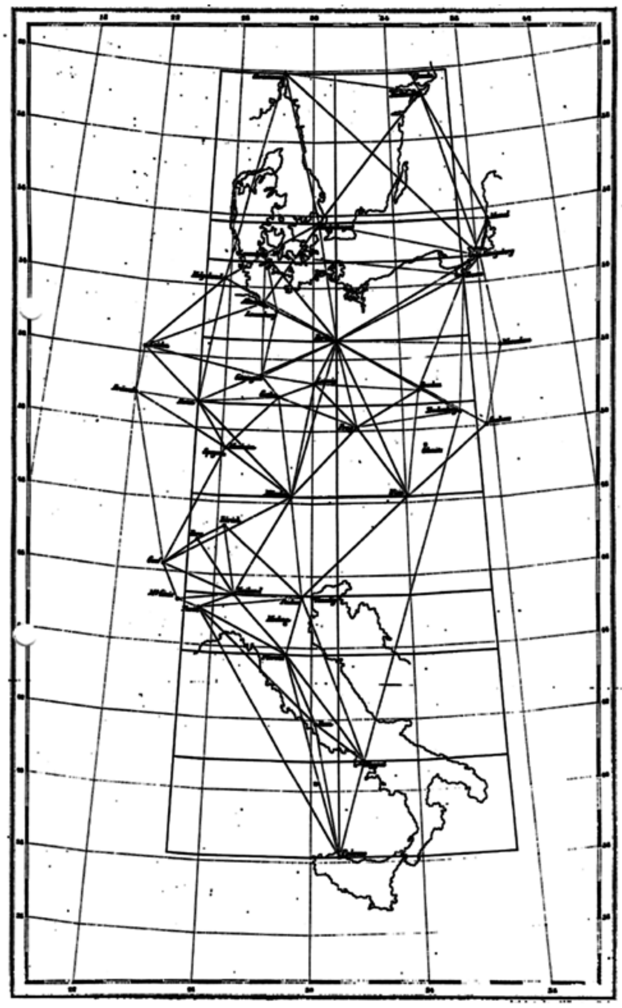


Fig. 7: Network sketch of the "Mitteleuropäische Gradmessung": Astronomical observatories and geodesics to be computed from triangulation (Baeyer 1861)

(allows the use of data necessary for the project), Italy, The Netherlands, Poland (through Russia), Sweden and Norway (in personal union), and Switzerland. This is a great success: an international collaboration for a scientific project reaching far beyond central Europe has been approved by the respective governments, and is carried by leading representatives of science and military geography. The next step to be taken comprises the formation of an effective organization and a more specified definition of the problems to be attacked.

5 Organization and Scientific Program: the 'Baeyer' Epoch 1862–1886

In his general report (1862), *Baeyer* had already planned to subdivide his project into internal, border crossing, and common work. Special and general conferences are proposed for discussion, and a central bureau shall be established in Berlin, being responsible for compilation and reporting of the results. In 1864, the first "General Conference of the Representatives to the Central European Arc Measurement" takes place in Berlin, and fixes the organizational structure as well as the research programme. The organization includes the Permanent Commission, meeting annually and responsible for the scientific management, the Central Bureau as an executive, and General Conferences at three-yearly intervals – a structure which is still visible today at the International Association of Geodesy. The work is divided into three sections, related to organizational affairs, astronomic and physical problems, and geodetic tasks. Among the problems to be attacked we find the regulation of the unit of length, gravity measurements, and a unified height system.

The membership list of the first General Conference naturally shows the predominance of the representatives of the German states, and until the 1880's the German influence is also visible in the location of the General Conferences. But already in 1867, after Portugal, Spain and Russia had joined the project, the name of the organization was changed to "Europäische Gradmessung". With *Baeyer* as president, the Central Bureau starts work in 1866. In 1870 the Prussian Geodetic Institute is established in Berlin and entrusted with the operation of the Central Bureau, *Baeyer* becomes its first director (Laitko 1996). Although this first period of the IAG is governed by the outstanding personage of *Baeyer*, the work of the presidents of the Permanent Commission should also be acknowledged. These were *Peter Andreas Hansen* (1864–1868), Director of the Gotha Observatory, *August von Fligely* (1869–1874), General (see above), and *Carlos Ibáñez e Ibáñez de Ibero* (1874–1886), General and Director of the Geographical and Statistical Institute, Madrid.

Following the program of the "Mitteleuropäische Gradmessung", triangulation is progressing rapidly in the European countries. A remarkable enterprise is the connection of the Spanish triangulation with Algeria (1879), where triangles with a maximum side length of 270 km are observed from mountain stations, under the direction of General *Ibáñez* and Major *F. Perrier*, Chief of the geodetic section of the French General Staff. We also mention the new triangulation of the Kingdom of Saxony (1867–1878) carried out by *Nagel* (see above), setting new standards with respect to the quality of measurement and computation. In Prussia, curiously enough, severe problems arise at realizing the demands of the project. This is due to the separate responsibility for the triangulation of the state (remains at the General Staff) and of the arc measurement project (Geodetic Institute). In this connection, *Baeyer* declares that all measurements of the General Staff carried out since 1858 (*Baeyer* had retired in 1857!) did not satisfy the scientific demands of the arc measurement project. The following confrontation with the General Staff also involves several members of the Permanent Commission, and lasts until *Baeyer's* death (Pieper 1996). 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.

Further achievements of this first phase of international collaboration may be described by the words "Metric System and International Bureau for Weights and Measures", "precise leveling and determination of mean sea level", "European longitude network", "Greenwich zero meridian and universal time", and "absolute gravity measurements with the *Repsold* pendulum apparatus" (Torge 2005). A remarkable step forward at geodetic theory is due to *Ernst Heinrich Bruns*, Professor of Mathematics at the University of Berlin and later (since 1881) Professor of Astronomy at the University of Leipzig. Triggered by the geodetic activities of the "Mitteleuropäische Gradmessung", he publishes a study on the fundamental problem of geodesy which looks far into the future and contains conclusions for the scientific programme of the Arc Measurement organization (Bruns 1878).

The death of *Baeyer* (1885) finishes the first phase of an organized collaboration in scientific geodesy. His achievement for the creation of an international (governmental) geodetic organization has been acknowledged several times already during his lifetime. At the General Conference held in Rome 1883, the Italian Arc Measurement Commission honoured him with a gold medal carrying the laudation:

> *"J.J. Baeyero qui ad terrae mensuras communi studio eruendas nationum sodalitium excitavit Itali laborum socii in conventu septimo Romae MDCCCLXXXIII"* ("Dem J.J. Baeyer, der die Gemeinschaft der Nationen zur Erforschung der Erdmessungen im gemeinschaftlichen Studium anregte, die italienischen Arbeitskollegen auf der 7. Konferenz in Rom 1883" – Übersetzung E. Knobloch, Pieper 1996).

Georges Perrier, the long-standing secretary general of the successor organization "Association Internationale de Géodésie" appreciates him with the words:

> *"Als Baeyer starb, hatte er, dank einer zähen Arbeit, für sein Land einen ersten Platz in der Geodäsie erobert …"* (Tardi 1963).

6 From the "Europäische Gradmessung" to the "International Association of Geodesy": Global Extension and Strengthening of Interdisciplinary Relation

The further development of the scientific organization founded by *Baeyer* can be separated into several phases, and a number of reports is available describing the changes and the scientific achievements which occurred after the *"Baeyer"* epoch (e.g. Helmert 1913, Hunger 1962, Levallois 1980, Torge 1996, Ádam 2008). The *"Helmert"* epoch (1886–1916) is governed by "einem der berühmtesten Geodäten der modernen Zeit" (Tardi 1963).

Friedrich Robert Helmert held the chair of Geodesy at the Technical University of Aachen since 1870, his two-volume book "Die mathematischen und physikalischen Theorien der höheren Geodäsie" (1880/1884) arguably established geodesy as a proper science (Wolf 1993). He became Director of the Prussian Geodetic Institute and the Central Bureau in 1886, and held this position until his death in 1917. The arc measurement organization is immediately extended to a global association called "Internationale Erdmessung" ("International Geodetic Association"), and the scientific programme is significantly enlarged (Torge 1993, Torge 2005). Until 1889, the United States of America, Mexico, Chile, Argentine and Japan agreed with the new convention, and Great Britain joined the Association in 1898. An annual financial contribution from the countries strengthened the power of the Association, and the change of the voting procedure at the General Conferences (one voice per country) reduced the overwhelming influence of the German states. The more international character of the Association can be seen also from the location of the General Conferences, with Paris (1889), Brussels (1892), Berlin (1895), Stuttgart (1898), Paris (1900), Copenhagen (1903), Budapest (1906), London and Cambridge (1909), and Hamburg (1912).

The scientific program naturally further on includes the determination of the geoid curvature, but the collection and evaluation of the corresponding data is extended on the whole globe. The geodetic problem of deriving a geometric and gravimetric Earth model is supplemented by investigations on isostasy. Precise leveling is available now for larger areas and exploited for the investigation of sea level slope and vertical crustal movements. The number of gravity measurements increases significantly, due to the development of a relative pendulum apparatus by *R. v. Sterneck*. This raised the problem of a gravity reference system, solved by a thorough absolute gravity determination at the Geodetic Institute Potsdam and the introduction of the "Potsdam Gravity System", valid until 1971. Gravity measurements on the oceans give a first impression on the isostatic behaviour of the ocean areas. Gravity field modeling starts but is still restricted on smaller and well surveyed test areas, as the Harz mountains. The related problem of gravity reduction to the geoid is investigated intensively, with several solutions valid until today. The time component of the geodetic measurements and the inherent information for astronomy and geophysics is also clearly recognized in this epoch. Among the outstanding examples of this arising "four-dimensional" geodesy is the observation of polar motion which leads to the establishment of the International Latitude Service, as well as first measurements of the solid Earth tides.

The convention on the "Internationale Erdmessung" expired at the end of 1916, and was not extended due to the First World War. Fortunately some activities of the Association could be continued, especially the Latitude Service. This is due to the efforts of *R. Gautier* and *H. G. van de Sande Bakhuyzen*, Directors of the Geneva and the Leyden Observatory, respectively, who organize an "Association Géodésique réduite entre Etats Neutres" (Torge 2005). After the First World War, international science organized itself within the frame of non-governmental organizations, among them is the "Union Géodésique et Géophysique Internationale", founded in 1919. A Section of Geodesy is constituted in 1922, which in 1932 adopts the name "International Association of Geodesy". As the central powers (Germany and its allies) originally remain excluded from this organization, Germany becomes a member country only in 1937. The Second World War again interrupts international collaboration, but now the Federal Republic of Germany is admitted as a member of the "International Union of Geodesy and Geophysics" (IUGG) already in 1951, followed by the German Democratic Republic in 1964.

Embedded in the wide spectrum of geophysical disciplines, the scientific work of IAG especially since the 1950's not only follows classical directions, but increasingly contributes to an interdisciplinary understanding of the system Earth. The fundamental problems of geodesy, i. e. the determination of the Earth figure, gravity field, and rotation, are now mainly attacked by means of geodetic space methods and missions. The focal point of research and service has shifted more and more to the measurement, interpretation, and eventually prediction of temporal variations (e. g. Beutler et al. 2004, Plag and Pearlman 2009, Drewes 2012). But IAG, looking back now on a history of 150 years, still remembers with pride and gratitude its origin and the foundation initiated and realized by *Johann Jacob Baeyer*. A special session on the history and development of IAG is scheduled at the IAG Scientific Assembly to be held in Potsdam in 2013.

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Author's adress
Prof. (em.) Dr.-Ing. Wolfgang Torge
Institut für Erdmessung, Leibniz Universität Hannover
Schneiderberg 50, 30167 Hannover