Current Activities of the International Association of Geodesy (IAG) as the Successor Organisation of the Mitteleuropäische Gradmessung*

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Summary
The International Association of Geodesy (IAG) is a constituent Association of the International Union of Geodesy and Geophysics (IUGG) since 1922, and the successor organization of the Mitteleuropäische Gradmessung. Its activities have changed dramatically from its beginning in 1862 till today. While it started with the aim of determining the regional anomalies of the Earth's curvature in Europe by connecting astronomical observatories through triangulation networks, it concentrates now on the observation and modelling of the phenomena and effects of physical processes in the System Earth employing mainly space techniques. The structural and scientific developments over time are summarised, and the present structure and activities are described in detail.

Zusammenfassung
Die Internationale Assoziation für Geodäsie (IAG) ist eine konstituierende Assoziation der Internationalen Union für Geodäsie und Geophysik (IUGG) und die Nachfolgeorganisation der Mitteleuropäischen Gradmessung. Ihre Aktivitäten haben sich seit dem Beginn im Jahre 1862 bis heute dramatisch verändert. Während das Ziel anfangs die Bestimmung regionaler Anomalien der Erdkrümmung in Europa durch Verbindung der astronomischen Observatorien mit Triangulationsnetzen war, konzentrieren sich die Arbeiten heute auf die Beobachtung und Modellierung der Erscheinungen und Effekte

* Modifizierte und ins Englische übersetzte Fassung eines Vortrages im Rahmen des Festkolloquiums »150 Jahre Mitteleuropäische Gradmessung in Sachsen« am 1. Juni 2012 in Dresden.

physikalischer Prozesse im System Erde mit Weltraumbeobachtungsverfahren. Die strukturellen und wissenschaftlichen Entwicklungen werden zusammengefasst und die heutigen Strukturen und Arbeiten werden beschrieben.

Keywords: International Association of Geodesy, Mitteleuropäische Gradmessung, Reference Frames, Gravity Field, Geodynamics, Global Geodetic Observing System

1 Introduction

The International Association of Geodesy (IAG) is the successor organization of the Mitteleuropäische Gradmessung which was created in 1862 (Baeyer 1861, 1862). After the changeover to the Europäische Gradmessung (1867) and the Internationale Erdmessung (1886), it became in 1922 one of the Sections of the International Union of Geodesy and Geophysics (IUGG), which had been established in 1919. The present name (International Association of Geodesy, IAG) was resolved at the IUGG General Assembly in Stockholm 1930 (officially adopted in 1946), when all the Sections of IUGG became Associations (Levallois 1980). Today there are eight Associations incorporated in IUGG (Tab. 1).

The aim of the Mitteleuropäische Gradmessung proposed by J. J. Baeyer (1861) was to connect the numerous astronomical observatories in Central Europe by triangulation networks in order to determine the regional and local anomalies in the Earth's curvature, i. e. the deflections of the vertical, and thus the structure of the geoid as a particular surface of the *Earth's gravity field* (Torge 1996, 2012). Baeyer also mentioned the scientific problem of *interpreting* these anomalies with respect to the structure and composition of the outer layers of the Earth. The combined network would, of course, also serve as a unified European horizontal *reference frame*, and thereby form the basis for geodetic *positioning and applications*. All these objectives are identical with those of today's Commissions of the IAG: *Reference Frames*, *Gravity Field*, *Geodynamics*, *Positioning and Applications*. At the inaugural meeting of the Mitteleuropäische Gradmessung in 1862 and at the first General Conference 1864 in Berlin, the questions of the reference ellipsoid, the required accuracy (error limit) and standards (unit of length) were discussed (Torge 2005), which are current topics of IAG's *Inter-Commission Committee on Theory (ICCT)* and the *Global Geodetic Observing System (GGOS)*.

Tab. 1: Associations of the International Union of Geodesy and Geophysics (IUGG)

IACS	International Association of Cryospheric Sciences
IAG	International Association of Geodesy
IAGA	International Association of Geomagnetism and Aeronomy
IAHS	International Association of Hydrological Sciences
IAMAS	International Association of Meteorology and Atmospheric Sciences
IAPSO	International Association for the Physical Sciences of the Ocean
IASPEI	International Association of Seismology and Physics of the Earth's Interior
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior

While the general justification and the structural elements of international geodetic cooperation have thus been maintained in principle, the detailed objectives have changed dramatically due to the revolutionary technologic developments in the second half of the last century:

1. Extremely precise electronic time measurements replaced the mechanical instruments for most geodetic observations (geometric distances, gravimetric free fall accelerations).
2. Geodetic space techniques (satellites and radio-astrometry) replaced most terrestrial technology.
3. Computers allow the processing of the tremendous amount of data generated by the new geodetic techniques.

These developments led to a very high accuracy of the estimated geodetic parameters (e. g. coordinates and gravity values), and the detection of small temporal variations in the Earth's geometry (deformations), gravity field (mass displacements), and orientation in space (rotation) became thus achievable. The traditional definition of geodesy as the science of the measurement and mapping of the Earth's surface (Helmert 1880) extended to the quantification and integrated analysis of the phenomena and effects of physical processes in the System Earth, i. e. the measurement of geodynamics and global change (Drewes 2006). The IAG has taken account of these changes by adapting its structure and research program according to the new challenges.

2 Changes of IAG's Structure and Program in the Second Half of the 20th Century

Until 1939, when the last IAG General Assembly before the Second World War was held in Washington, USA, the organization of the IAG was structured in Commissions, which were formed quite casually and managed rather loosely (Tardi 1963). At the first General Assemblies after World War II (1948 in Oslo, Norway, 1951 in Brussels, Belgium), a strict division into Sections was set up which continued until the beginning of the satellite age in the 1960s (Tab. 2). The new *Sections I (Triangulation)* and *III (Geodetic Astronomy)* dealt with the traditional objectives since the beginning of the Mitteleuropäische Gradmessung; the determination of the *Geoid (Section V)*

Tab. 2: IAG Sections (until 1999) and Commissions (since 2003)

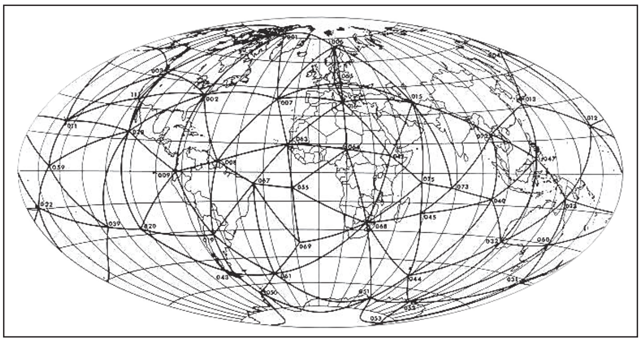
General Assembly	I	II	III	IV	V
1948 Oslo	Triangulation	Levelling	Geodetic Astronomy	Gravimetry	Geoid
1951 Brussels	Triangulation	Levelling	Geodetic Astronomy	Gravimetry	Geoid
1954 Rome	Triangulation	Levelling	Geodetic Astronomy	Gravimetry	Geoid
1957 Toronto	Triangulation	Levelling	Geodetic Astronomy	Gravimetry	Geoid
1960 Helsinki	Triangulation	Levelling	Geodetic Astronomy	Gravimetry	Geoid
1963 Berkeley	Geodetic Positioning	Levelling and Crustal Motion	Geod. Astronomy & Artif. Satellites	Gravimetry	Physical Geodesy
1967 Lucerne	Geodetic Positioning	Levelling and Crustal Motion	Geod. Astronomy & Artif. Satellites	Gravimetry	Physical Geodesy
1971 Moscow	Control Surveys	Space Techniques	Gravimetry	Theory and Evaluation	Physical Interpretation
1975 Grenoble	Control Surveys	Space Techniques	Gravimetry	Theory and Evaluation	Physical Interpretation
1979 Canberra	Control Surveys	Space Techniques	Gravimetry	Theory and Evaluation	Physical Interpretation
1983 Hamburg	Positioning	Advanced Space Technology	Determination of the Gravity Field	Theory and Evaluation	Geodynamics
1987 Vancouver	Positioning	Advanced Space Technology	Determination of the Gravity Field	Theory and Evaluation	Geodynamics
1991 Vienna	Positioning	Advanced Space Technology	Determination of the Gravity Field	Theory and Evaluation	Geodynamics
1995 Boulder	Positioning	Advanced Space Technology	Determination of the Gravity Field	Theory and Evaluation	Geodynamics
1999 Birmingham	Positioning	Advanced Space Technology	Determination of the Gravity Field	Theory and Evaluation	Geodynamics
2003 Sapporo	Reference Frames	Gravity Field	Earth Rotation and Geodynamics	Positioning and Applications	Inter-Commission Cm'tee on Theory
2007 Perugia	Reference Frames	Gravity Field	Earth Rotation and Geodynamics	Positioning and Applications	Inter-Commission Cm'tee on Theory
2011 Melbourne	Reference Frames	Gravity Field	Earth Rotation and Geodynamics	Positioning and Applications	Inter-Commission Cm'tee on Theory

was its principal initial aim, and *Levelling (Section II)* was a fundamental technique of surveying. *Gravimetry (Section IV)* gained increased significance through the development of the transportable pendulum apparatus by R. von Sterneck at the end of the 19th century (Helmert 1913) and the field gravimeters developed in the 1930s by LaCoste (1934) and Thyssen & Schleusener (Schleusener 1934).

The Sections incorporated Study (later named Permanent) Commissions and Special Study Groups for specific tasks, e.g. the adjustment of triangulation and levelling networks, astronomical and gravimetric observations, geoid computations, and others.

As some principal scientific achievements in the 1950s and the beginning of the 1960s we may mention (I) the electronic distance measurements (Demuth 1958) which ushered in the trilateration method over traditional triangulation, (II) progress in the reduction of the effects of gravity and atmospheric refraction in spirit levelling (e.g. Lucht 1972), (III) the intensified and improved azimuth, latitude and longitude determinations as well as simultaneous observations by zenith cameras (e.g. Ramsayer 1969), (IV) the establishment of gravimeter calibration lines and a world gravity network (Großmann 1960), and (V) the gravimetric global Columbus geoid (Heiskanen 1957) and the European Bomford geoid (Bomford 1964).

At the General Assembly 1963 in Berkley, USA, a thorough revision of the Sections was performed, in particular to account for the development of electronic and electro-optic techniques (in particular for distance measurements) and the geodetic use of the recently emerging artificial satellite observations. The general naming *Geodetic Positioning (Section I)* substituted for Triangulation, and *Section III* was extended to *Geodetic Astronomy and Artificial Satellites*. Since the improved levelling techniques led to the detection of many regional height changes with time, *Section II* was amplified to the study of – mainly vertical – *Crustal Motions*. Furthermore, the Geoid determination was complemented by more general subjects and renamed *Physical Geodesy (Section V)*.



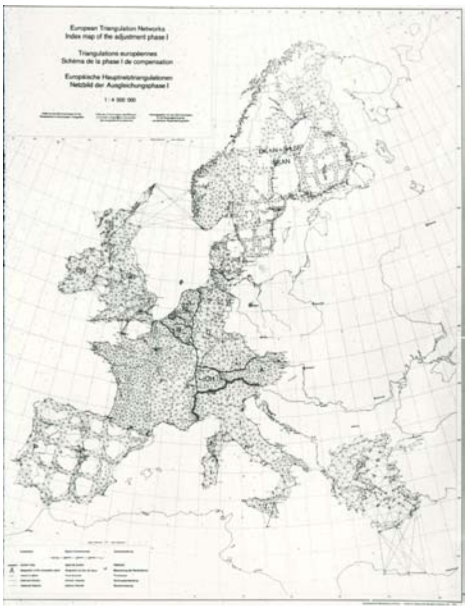
Schmid 1974

Fig. 1: Satellite triangulation network

Among the most important advancements of the 1960s were the first optical observations of the balloon satellites Echo 1, Echo 2 and PAGEOS, which concerned Sections I and III, and led after its purely geometrical adjustment (satellite triangulation) to the first three-dimensional global reference network (Schmid 1974) with a precision in the order of a few metres for 3D-coordinates (Fig. 1). In *Section II*, a variety of recent crustal movements were reported in many countries, and an Inter-Union Commission on Recent Crustal Movements (CRCM) was established (Pavoni and Green 1975). *Section IV* organized gravity measurements along international calibration lines (Torge 1971) and computed – together with *Commission III, the International Gravimetric Commission* – the International Gravity Standardisation Network (IGSN71, Morelli 1974). The objectives of *Section V Physical Geodesy* were certainly for the most part defined by Moritz (e.g. 1970). At the General Assembly 1967 in Lucerne, Switzerland, the Geodetic Reference System 1967 (GRS67) was adopted, which formed the basis for all geometric and gravimetric reference frames (IAG 1971).

The Sections were restructured eight years later at the General Assembly 1971 in Moscow, Soviet Union. *Section I* was renamed *Control Surveys*, now also including levelling, *Section II* was dedicated to all *Space Techniques*, including radio-astronomy, as Very Long Baseline Interferometry (VLBI) had become a new geodetic technique for positioning and Earth rotation observations. *Gravimetry* changed to *Section III*, and a new *Section IV Theory and Evaluation* was established taking account of the rapid development of the electronic and computer technology requiring refined methods. The name Physical Geodesy, which includes also many parts of the other sections, was changed to *Physical Interpretation (Section V)*.

To exemplify the development of electronic, computer and space technologies, and as a link from the Mitteleuropäische Gradmessung to modern IAG results, we may mention the European Triangulation Network (Réseau Européen des Triangulations, RETrig), which was a central project of *Section I* and *Commission X Continental Networks* in the 1970s. In practice, this was the continuation of Baeyer's project for a unified network in Europe. It was revived in 1947, after the Second World War, by an order of the US Army Map Service (AMS) and the IAG agreed to participate with reservations, recognising that the purpose was rather more of a military than of a scientific nature (Kobold 1980). This led to the European Datum 1950 (ED50, Fig. 2). At the General Assemblies in Brussels (Belgium) 1951 and Rome (Italy) 1954, IAG decided to continue the project, extending the triangulation chains to the combination of complete national networks. After including more electronic baseline measurements for the scale determination, and employing the new computer techniques for solving the large equation systems, the result was the ED79, and later, with the inclusion of satellite positioning results (Transit Doppler, satellite laser ranging, and VLBI), to the ED87 (Ehrnsperger 1991). So, one may conclude that Baeyer's proposal of the (Mittel-) Europäische Gradmessung was realised 125 years later.



(Ehrnsperger 1991)

Fig. 2: European Triangulation network (RETrig): ED50 (left) and ED87 (right)

A fundamental push in *Space Techniques* was achieved in the 1970s by the development of satellite laser ranging (SLR) and the launch of geodetic satellites such as LAGEOS and STARLETTE (Reigber 1981). These measurements and their data analyses were not only a breakthrough for *Control Surveys (Section I)* but also for *Gravimetry (Section III)* and *Physical Interpretation (Section V)*. *Section IV Theory and Evaluation* took up these challenges studying the consequences for the Geodetic Boundary Value Problem and the solution of large equation systems. A new Geodetic Reference System (GRS80) was adopted at the General Assembly 1979 in Canberra, Australia (Moritz 1980).

At the General Assembly 1983 in Hamburg, Germany, there was mainly an update of Section names, maintaining the previous general structure. A relevant change was the name of *Section V* to *Geodynamics*, because this included not only Physical Interpretation, as before, but also specific techniques, analysis methods, and projects, in particular for plate tectonics, sea level change, Earth rotation, etc., i. e. the modelling of all mass displacements in the System Earth and the forces driving these processes. This structure remained unchanged until 2003 when a complete reorganization was performed.

The main geodetic progress in the last two decades of the 20th century was based on the revolutionary results of space techniques for applications in all fields of geodesy. General topics such as satellite missions and orbit determination were dealt with in *Section II* and *Commission VI Space Techniques for Geodesy and Geodynamics* (Drewes and Dow 2002). Necessary theoretical and methodological studies were carried out in *Section IV* (Grafarend 1997). The results led in *Section I* to a new definition and realisations of global (Boucher 1990) and regional (e. g. Adam et al. 2002, Hoyer et al. 1998) reference systems, in *Section III* to improved models of the gravity field (e. g. EGM96, Lemoine et al. 1998, Fig. 3), and in *Section V* to advanced modelling of Earth rotation (e. g. Schuh 1999) and crustal deformation (plate kinematics and inter-plate deformations, Drewes 1998).

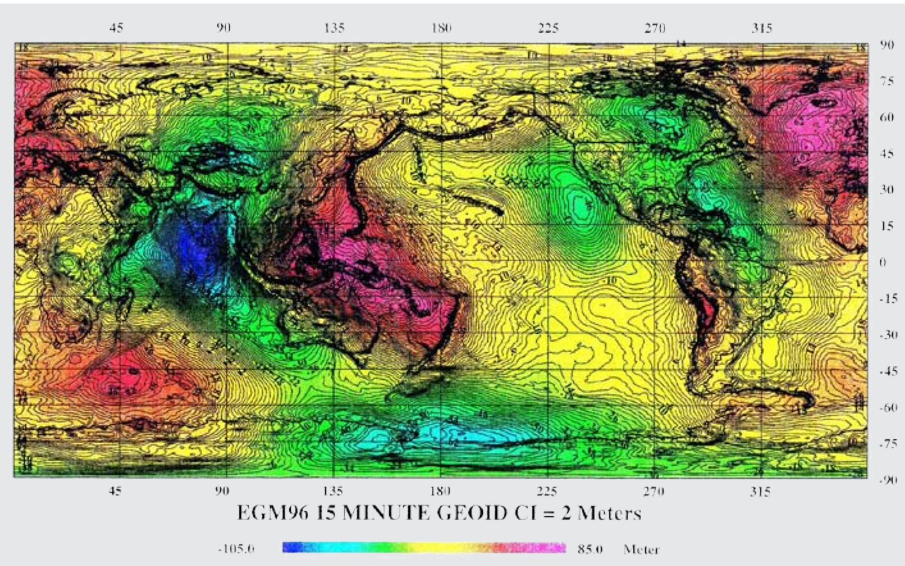
The tremendous outcome of the work of IAG in the second half of the last century cannot be summarised in one paper and can hardly be overstated. There are fundamental results and findings in all fields of geodesy. This includes theory and methodology, basic geodetic networks (reference frames and positioning), regional and global gravity field models (geoid and gravity anomalies), and geodynamic models (plate tectonics and Earth rotation). They are documented in many publications, and articles and reports may be found in the various IAG journals and series: Journal of Geodesy, IAG Symposia Series (both published in Springer-Verlag), and the quadrennial IAG Reports (Travaux de l'AIG).

3 The New IAG Structure since 2003

At the General Assembly 1999 in Birmingham, United Kingdom, a thorough review of the IAG structure was initiated in order to establish a new structure in 2003. The key elements were (Beutler 2004):

- The new structure should have a focus;
- The new structure should be based on the three fields of modern geodesy, namely the geometric shape, the orientation in space, and the gravity field of the Earth; and
- The new structure should (better) incorporate the IAG services.

With respect to the latter point it must be mentioned that IAG, besides the Sections and later Commissions, has its own or is involved in multidisciplinary international scientific services since the early years of the Europäische Gradmessung (Tab. 3). The task of the services is to generate products relevant for geodesy and for science and applications, using their own observations and/or observations of other services, to disseminate them among the scientific community, and to make them available for use in practice. The first Service, the Bureau International de Poids et Mesures (BIPM) was created in 1875, when the Convention of the Metre was signed by representatives of seventeen nations. The International System of Units (SI), adopted in 1960, is one of the modern products of BIPM. Today, the Time Department is most involved in IAG activities. Other important services since early times are the International Bibliographic Service (IBS), the International Latitude Service (ILS, in 1962 renamed International Polar Motion Service), and the Bureau International de l'Heure (BIH). The latter two were integrated in 1987 into the newly established International Earth



Lemoine et al. 1998

Fig. 3: Geoid representation from EGM96

Rotation Service (IERS), in 2003 renamed International Earth Rotation and Reference Systems Service (with the same abbreviation IERS). At present there are fifteen international scientific services incorporated in IAG (Tab. 3).

These Services were subordinated to the Sections and not incorporated with representatives in the IAG Executive Committee until 2003, and therefore they did not have a say in IAG governance and organizational affairs, and they were not very visible in the scientific community and in public. As a remedial action, the 1999 Review Committee recommended that the Services be raised to the same level as the Sections, which were to be renamed Commissions.

The new Commissions were to be aligned to the three fields of geodesy and their applications under the names *Reference Frames* (geometry), *Gravity Field*, *Earth Rotation and Geodynamics*, and *Positioning and Applications*. Another outcome of the review was the decision that theory must not be seen as an independent scientific topic, but be integrated in Commissions. Consequently, an *Inter-Commission Committee on Theory (ICCT)* was proposed. In order to provide the Association with communication and information and to improve the public relation of IAG, a *Communication and Outreach Branch (COB)* was established.

For the focus of the IAG structure envisaged in the restructuring procedure, the Review Committee proposed long-term *IAG Projects*, which were referred to as its "flagships". They should be of a broad shape and of highest interest and importance for the entire field of geodesy. Following the conclusions of an IAG Symposium in Munich 1998 (Beutler et al. 2000), a *Global Geodetic Observing System* was proposed as the first *IAG Project*.

As a result of the review commenced in 1999, the new structure of IAG was adopted by the *IAG Council*, i.e. the representatives of the member countries which wield legislative power, and established at the General Assembly 2003 in Sapporo, Japan. The recommendations of the Review Committee were included in the new *IAG Statutes and Bylaws* at the same time. The general structure of IAG as an Association of IUGG is shown in Fig. 4. There is cooperation with other Unions in terms of services, programs,

Tab. 3: IAG International Scientific Services

1875	BIPM	Bureau International de Poids et Mesures
1889	IBS	International Bibliographic Service
1899*	ILS	International Latitude Service (1962: renamed IPMS, 1987: integrated into IERS)
1912*	BIH	Bureau International de l'Heure (1987: integrated into IERS)
1933	PSMSL	Permanent Service of Mean Sea Level
1951	BGI	Bureau Gravimetrique International
1956	ICET	International Center for Earth Tides
1962*	IPMS	International Polar Motion Service (follow-on of ILS)
1987	IERS	International Earth Rotation (2003: and Reference Systems) Service
1992	IGeS	International Geoid Service
1994	IGS	International GPS Service, (2005: renamed International GNSS Service)
1998	ILRS	International Laser Ranging Service
1999	IVS	International VLBI Service for Geodesy and Astrometry
1999	IDEMS	International Digital Elevation Models Service
2003	ICGEM	International Center for Global Earth Models
2003	IDS	International DORIS Service
2004	IGFS	International Gravity Field Service
2008	IAS	International Altimetry Service

* = no longer existing

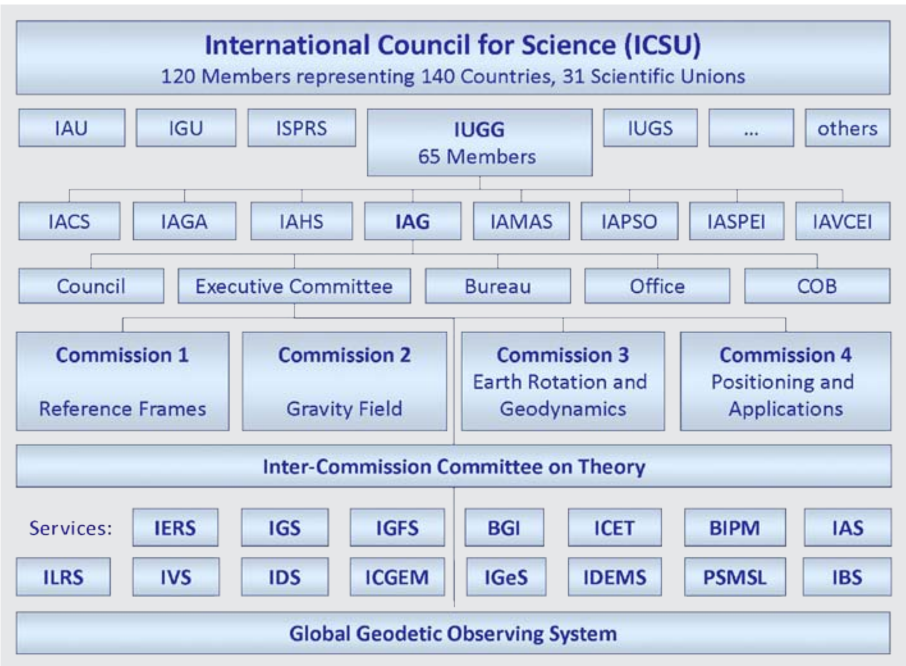


Fig. 4: General structure of IAG within IUGG since 2003

projects, and joint boards (IAU = International Astronomical Union, IGU = International Geographical Union, ISPRS = International Society of Photogrammetry and Remote Sensing, IUGS = International Union of Geological Sciences).

The *Executive Committee (EC)* is the entity to administratively direct the activities of IAG. It is led by the *Bureau* consisting of the President, the Vice-President and the Secretary General, and assisted by the *IAG Office*. Other members of the EC are the immediate Past-President, the President of the COB, the Presidents of the four Commissions, the Chairperson of GGOS, three representatives of the Services, and two Members at Large selected in order to improve geographical and organizational balance. The latter regulation is very important, since many regions of the world, in particular developing countries, are traditionally not well represented in the Commissions and Services.

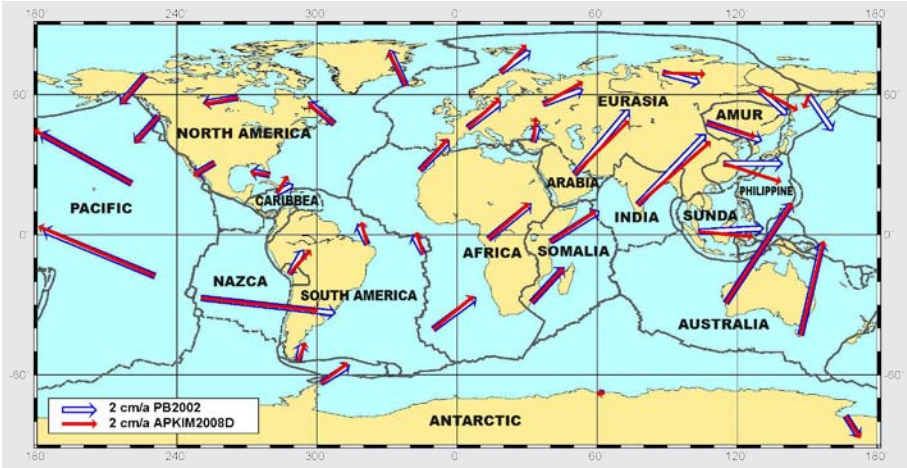


Fig. 5: Comparison of geodetic (APKIM2008D derived from ITRF2008) and geophysical (PB2002) plate models

The *Global Geodetic Observing System (GGOS)* was established in 2003 as an IAG Project in its planning phase. The mission is to monitor the geodetic and the global geodynamic properties of the Earth as a *system*. It works with the IAG Services, Commissions and the ICCT to provide unique, mutually consistent and easily accessible geodetic products (including the geometric reference frames and the gravity field) and the relevant geodetic constants for science and society. The detailed rationale of GGOS is described in several publications (Rummel et al. 2005, Drewes 2007, Beutler and Rummel 2012). It may be summarised by two principal tasks, namely

1. internally to coordinate the consistent and reliable observing and processing activities of all IAG components, in particular by using identical standards and conventions, and
2. externally disseminate and propagate the IAG products to the scientific community and society in general, and in particular to give policy makers the necessary information for their decisions with respect to global change and geodynamic processes (e.g. sea level rise, earthquakes, tsunamis, and other natural hazards).

In 2007, GGOS was transferred from an IAG Project to a full IAG Component (identical to the Commissions and Services).

The new Commissions and the ICCT started their activities by initially continuing the work of the previous Sections. *Commission 1 Reference Frames* took over the work of the global and regional networks and the relation to the celestial reference system in cooperation with the IAU and the IERS. Results may be found in the Proceedings of the first Commission 1 Symposium in 2006 (Drewes 2009). An example is the International Terrestrial Reference Frame (ITRF) 2005 and 2008 (Fig. 5). *Commission 2 Gravity Field* continued together with the IGFS the terrestrial – in particular absolute and superconducting – gravity observations and geoid determinations, and was involved in the new satellite gravity missions (CHAMP, GRACE, GOCE) since its beginning. Results were published in the Proceedings of the first Symposium in 2008 (Mertikas 2010). *Commission 3 Earth Rotation and Geodynamics* concentrated on Earth tides, crustal deformation and the effects of geophysical fluids (Dehant et al. 2005, Gross 2009, Gross et al. 2009). *Commission 4 Positioning and Applications* dealt with applications in science, such as precise GNSS positioning, troposphere and ionosphere modelling (e.g. Schmidt et al. 2008), and practice, i.e. positioning and engineering (e.g. Rizos 2007).

4 The Present IAG Scientific Structure and Program

The present program of the IAG was set up during and following the General Assembly in Melbourne, Australia, June/July 2011. It is an update of the previous programs (since 2003) with slightly modified *Sub-Commissions* (SC, Fig. 6).

Commission 1 will concentrate on investigations for the improved definition and realisation of terrestrial and celestial reference systems and their interactions by combining in an optimal way the space geodetic techniques. Extreme precision is required in order to detect the small variations that may be caused by seismic processes, and to provide a reliable reference frame for practical (e.g. earthquake displacements) and scientific (e.g. monitoring global change) applications. To give an example: If we want to detect the magnitude of the sea-level rise (today about 3.5 mm/year) and eventual accelerations, we need an accuracy of 0.1 mm/year or better. As sea-level changes are observed by satellite altimetry, the satellites being tracked from terrestrial stations, we need the station coordinates with this precision, i. e. positions with 0.1 mm and its variations with time (velocities) with 0.1 mm/year, stable over decades.

Commission 2 is concerned with modelling the mass transports in the System Earth which can be seen in variations of the gravity field. In order to make use of the extraordinary observational precision of satellite gravity missions such as GRACE and GOCE (and follow-on missions), sophisticated models for data analysis and parameter estimation on Earth (downward continuation) have to be developed. Geoid variations caused by changes of the water cycle (changes in groundwater and soil moisture, run-off, desertification) are in the order of millimetres. To calibrate the observations on the ground, we need reliable terrestrial gravity measurements. Therefore, the investigations on gravimetry and gravimetric networks will be continued. The resulting data will not only serve for calibration purposes but also for the study of temporal gravity changes.

Commission 3 has some modifications to its structure. The five Sub-Commissions are dedicated to the major fields of geodynamics: Earth tides, Earth rotation, crustal deformation, cryospheric deformation, as well as earthquakes and tectonics. The fluids inside and outside the Earth, and its effects on variations of the Earth rotation are an important subject of studies. These are carried out in close cooperation with the IERS Geophysical Fluids Centre and include the atmosphere, the oceans and the continental hydrosphere. The studies of earthquakes and tectonics continue the activities of the former Working Group of European Geoscientists for the Establishment of Networks for Earth-science Research (WEGENER).

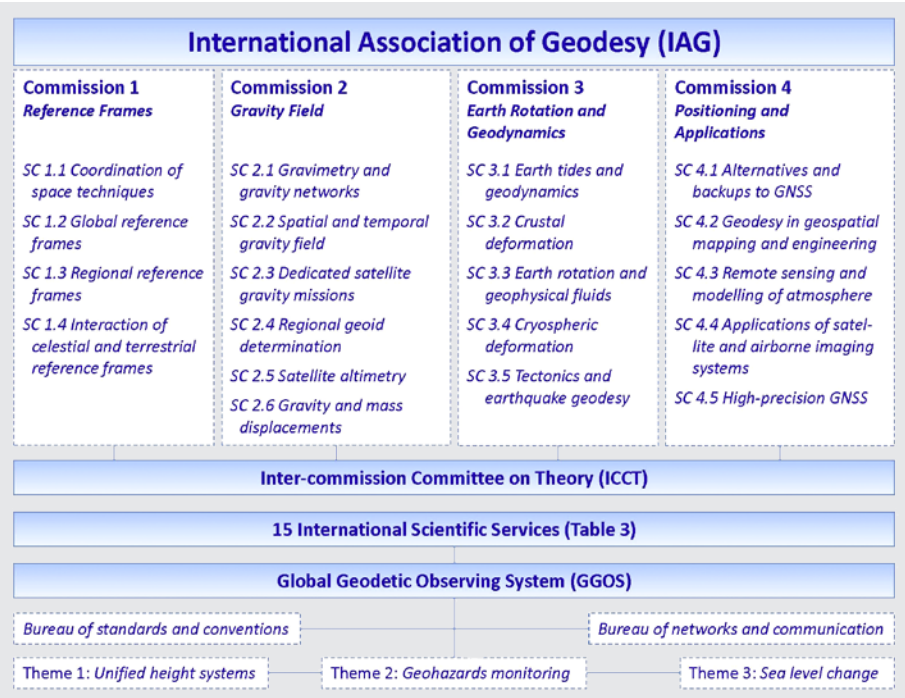


Fig. 6: Scientific structure of the IAG Commissions and GGOS for the period 2011–2015

Commission 4 is the connection of IAG to applications in science and practice, including outside the IUGG. The studies of alternatives and backups to GNSS, geospatial mapping and engineering, and satellite and airborne imaging systems are for the benefit of manifold users. The sensing and modelling of the atmosphere (troposphere and ionosphere), high-precision GNSS, and GNSS reflectometry are useful for applications in science and in practice. The Commission continues to maintain connections to the IAG sister organizations such as the FIG, ISPRS, and others. They also organize a number of joint international meetings and participate in common programs and projects.

The *ICCT* has established Joint Study Groups together with Commissions, Services and GGOS in all fields of geodesy (see below).

The *GGOS* was restructured in order to better coordinate its activities. The guiding body is now the *GGOS Consortium* comprising representatives of the IAG Commissions and Services. The decision making body is the *GGOS Coordinating Board* consisting of 16 members, either ex-officio (e. g. chairpersons of GGOS entities) or voted by the *Consortium*. The *GGOS Executive Committee* comprises the GGOS Chair- and Vice-Chair-persons, and three selected members. The *GGOS Science Panel* is an independent and multi-disciplinary advisory board that provides scientific support. Administration and day-to-day work is done by the *GGOS Coordinating Office*. The main scientifically coordinating entities are the *Bureau for Standards and Conventions* to look after, promote and expand the consistent use of all standards and conventions in IAG products, and the *Bureau for Networks and Communication* to deal with the existing and planned station networks of the different observation techniques. The scientific work of GGOS is currently structured in three *Themes*: *Unified Height System*, *Geohazard Monitoring*, and *Sea-Level Change*. An overview of the complete IAG structure for the period 2011–2015 is shown in Fig. 6.

The IAG *Services* have in general their own Terms of Reference (ToR) and programs, in many cases compiled together with other organizations (Unions, external Associations, Commissions and Programs). They are approved by the *IAG EC*. The details of the services' activities, which are mainly in the context of the generated products, may be viewed via the Internet. The URLs can be found at the IAG Homepage.

The Commissions, ICCT and GGOS establish in addition to the indicated Sub-Components (Sub-Commissions, Bureaus, and Themes) specific *Projects*, *Study* and *Working Groups*, which are installed for a four-year period in order to study and/or solve clearly defined problems. If these groups deal with topics concerning more than one Commission or a Commission and a Service, they are called *Joint Project / Study / Working Group (JP, JSG, JWG)*. The ICCT has only *Study Groups*, and GGOS has only *Working Groups*. All these Groups are listed below. Some Study and Working Groups are also established within the Sub-Commissions. These are not listed here. The detailed structure and a report on the General Assembly 2011 in Melbourne, Australia, is also given in Müller (2012).

Current Working Groups led by *Commission 1*:
JWG 1.1: Tie vectors and local ties to support integration of techniques (joint with IERS),
JWG 1.2: Modelling environmental loading effects for reference frame realisations (joint with IERS),
JWG 1.3: Understanding the relationship of terrestrial reference frames for GIA and sea-level studies (joint with Commission 3),
JWG 1.4: Strategies for epoch reference frames.

Current Project and Working Groups led by *Commission 2*:
JP 2.1: Geodetic planetology (joint with Commissions 1, 2, 3, and ICCT),
JWG 2.1: Techniques and metrology in absolute gravimetry (joint with IGFS),
JWG 2.2: Absolute gravimetry and absolute gravity reference system (joint with IGFS),
JWG 2.3: Assessment of GOCE geopotential models (joint with IGFS),
JWG 2.4: Multiple geodetic observations and interpretation over Tibet, Xinjiang and Siberia (joint with Commission 3),
JWG 2.5: Physics and dynamics of the Earth's interior from gravimetry (joint with Commission 3),
JWG 2.6: Ice melting and ocean circulation from gravimetry (joint with Commission 3)
JWG 2.7: Land hydrology from gravimetry (joint with Commission 3),
JWG 2.8: Modelling and inversion of gravity-solid Earth coupling (joint with Commission 3).

Current Study Group led by *Commission 3*:
JSG 3.1: Gravity and height change inter-comparison (joint with Commissions 1 and 2)

Current Study Groups led by the *ICCT*:
JSG 0.1: Application of time series analysis in geodesy (joint with GGOS and all Commissions),
JSG 0.2: Gravity field modelling in support of height system realisation (joint with Commissions 1, 2, and GGOS),
JSG 0.3: Methodology of regional gravity field modelling (joint with Commissions 2, 3),
JSG 0.4: Coordinate systems in numerical weather models (joint with all Commissions),
JSG 0.5: Multi-sensor combination for the separation of integral geodetic signals (joint with Commissions 2, 3 and GGOS),
JSG 0.6: Applicability of current GRACE solution strategies to the next generation of inter-satellite range observations (joint with Commission 2),
JSG 0.7: High-performance computational methods in geodesy (joint with Commissions 2, 3 and GGOS),
JSG 0.8: Theory and inversion in gravity-solid Earth coupling (joint with all Commissions),
JSG 0.9: Future developments of ITRF models and their geophysical interpretation (joint with Commission 1 and IERS).

Current Working Groups led by *GGOS*:
WG 0.1: Satellite missions,
WG 0.2: Earth system modelling,
WG 0.3: Data and information systems,
WG 0.4: Outreach and user linkage,
WG 0.5: ITRS standard.

Working Groups subordinated to the *GGOS Themes*:
JWG 0.1.1: Vertical Datum Standardisation (joint with Commissions 1 and 2, and IGFS)
JWG 0.2.1: New technologies for disaster monitoring and management (joint with Commission 4)

5 Conclusions

The International Association of Geodesy can look back to a history of 150 years. It has overcome enormous problems caused by wars and economic crises. Technological and scientific changes were challenges requiring innovative instrumental and methodological developments. At present, the monitoring and modelling of the features and processes of global change and natural disasters are a duty for science and society, and therefore in the focus of IAG. Geodesy is capable of observing and representing many of these effects, e.g. those caused by variations in the complete water cycle and even small seismic deformations. The present IAG program is designed to address such requirements.

More details on the IAG program may be found in the Geodesist's Handbook (a quadrennial special issue of the Journal of Geodesy), the most recent being published in 2012. Results of the activities are published in the IAG Symposia Series and in the biennial Reports (Travaux de l'AIG). Further information is available at the IAG Homepage (www.iag-aig.org). For questions please contact the IAG Office (iag@dgfi.badw.de).

References

Adam, J., W. Augath, C. Boucher, C. Bruyninx, A. Caporali, E. Gubler, W. Gurtner, H. Habrich, B.G. Harsson, H. Hornik, J. Ihde, A. Kenyeres, H. v.d. Marel, H. Seeger, J. Simek, G. Stangl, J. Agria Torres, G. Weber: Status of the European Reference Frame – EUREF. Springer, IAG Symposia, Vol. 125, 42–46, 2002.

Baeyer, J.J.: Ueber die Größe und Figur der Erde. Eine Denkschrift zur Begründung einer mittel-europäischen Gradmessung. Verlag Georg Reimer, Berlin, 111 + 6 S., 1861.

Baeyer, J.J.: General-Bericht über den Stand der mitteleuropäischen Gradmessung. P. Stankiewicz' Buchdruckerei, Berlin, 7 S., 1862.

Beutler, G.: The new IAG structure. J. Geodesy (77) 560–564, 2004.

Beutler, G., H. Drewes, R. Rummel: Reflections on a new structure for IAG beyond 2000 – conclusions from an IAG Section II Symposium in Munich. Springer, IAG Symposia, Vol. 121, 430–437, 2000.

Beutler, G., R. Rummel: Scientific Rationale and Development of the Global Geodetic Observing System. IAG Symposia Series, Vol. 136, 987–994, Springer 2012.

Bomford, G.: The geoid in Europe and connected countries. Travaux de l'AIG (22) 337–340, 1964.

Boucher, C.: Definition and realization of terrestrial reference systems for monitoring Earth rotation. AGU Geophys. Monograph No. 59, 197–201, 1990.

Dehant, V., O. de Viron, J.-P. Barriot: Geophysical excitation of the Earth orientation parameters EOP and its contribution to GGOS. J. Geodynamics (40) 394–399, 2005.

Demuth, H.P.: Tellurometer Traverse Surveys. Washington, D.C.: U.S. Government Printing Office, 1958.

Drewes, H.: Combination of VLBI, SLR and GPS determined station velocities for actual plate kinematic and crustal deformation models. Springer, IAG Symposia, Vol. 119, 377–382, 1998.

Drewes, H.: Zum Wandel in der Zielsetzung geodätischer Forschung. (The changing objectives in geodetic research, CD). zfv (131) 292–298, 2006.

Drewes, H.: Science rationale of the Global Geodetic Observing System (GGOS). IAG Symposia Series, Vol. 130, 703–710, Springer 2007.

Drewes, H. (Ed.): Geodetic Reference Frames – IAG Symposium Munich, Germany, October 9–14, 2006. Springer, IAG Symposia, Vol. 134, 2009.

Drewes, H., J. Dow (Eds.): New trends in space geodesy. Adv. Space Res. (30) No. 2, 2002.

Ehrnsperger, W.: The ED87 adjustment. Bull. Geod. (65) 28–43, 1991.

Grafarend, E.W., J. Engels, P. Varga: The spacetime gravitational field of a deformable body. J. Geodesy (72) 11–30, 1997.

Gross, R.S.: An improved empirical model for the effect of long-period ocean tides on polar motion. J. Geodesy (83) 635–644, doi:10.1007/s00190-008-0277-y, 2009.

Gross, R.S., D.A. Lavallee, G. Blewitt, P.J. Clarke: Consistency of Earth rotation, gravity, and shape measurements. Springer, IAG Symposia, Vol. 133, 463–471, 2009.

Großmann, W.: Bestimmung der Schwereunterschiede zwischen europäischen Flughäfen mit einem Askania-Gravimeter GS 12. Dt. Geod. Komm., Reihe B, Nr. 66, München 1960.

Heiskanen, W.A.: The Columbus geoid. EOS (38) 841–848, 1957.

Helmert, F.R.: Die mathematischen und physikalischen Theorien der höheren Geodäsie, Band 1. Teubner Leipzig, 1880.

Helmert, F.R.: Die internationale Erdmessung in den ersten fünfzig Jahren ihres Bestehens. Internationale Monatsschrift (7) 397–423, 1913.

Hoyer, M., S. Arciniegas, K. Pereira, H. Fagard, R. Maturana, R. Torchetti, H. Drewes, M. Kumar, G. Seeber: The definition and realization of the reference system in the SIRGAS project. Springer, IAG Symposia, Vol. 118, 167–173, 1998.

IAG: Geodetic Reference System 1967. Publ. Spec. 3, IAG Central Bureau, Paris, 1971.

Kobold, F.: The European Triangulation Network (RETrig). Bull. Geod. (54) 583–586, 1980.

LaCoste, L.J.B.: A new type of long period vertical seismograph, Physics (5) 178–181.

Lemoine, F.G., S.C. Kenyon, J.K. Factor, R.G. Trimmer, N.K. Pavlis, D.S. Chinn, C.M. Cox, S.M. Klosko, S.B. Luthcke, M.H. Torrence, Y.M. Wang, R.G. Williamson, E.C. Pavlis, R.H. Rapp, T.R. Olson: The development of the joint NASA GSFC and NIMA Geopotential Model EGM96. NASA GSFC TP-1998-206861, 1998.

Levallois, J.J.: The history of the International Association of Geodesy. Bull. Geod. (54) 249–313, 1980.

Lucht, H.: Zur Fehlertheorie des Praezisionsnivellements. Z. f. Verm.wesen (97) 68–73, 1972.

Mertikas, S. (Ed.): Gravity, geoid and Earth observation – IAG Commission 2: Gravity Field Symposium, Chania, Crete, Greece, 23–27 June 2008. Springer, IAG Symposia, Vol. 135, 2010.

Morelli, C., C. Gantar, T. Honkasalo, R.K. McConnell, J.G. Tanner, B. Szabo, U. Uotila, C.T. Whalen: The International Gravity Standardization Net 1971 (IGSN71). IUGG-IAG Publ. Spec. 4, Paris, 1974.

Moritz, H.: Least squares estimation in Physical Geodesy. Dt. Geod. Komm., München, Reihe A, Nr. 69 and OSU Report No. 130, 1970.

Moritz, H.: Geodetic Reference System 1980. Bull. Geod. (54) 395–405, 1980.

Müller, J. (Hrsg.): Berichte zur XXV. Generalversammlung der IUGG – Internationale Assoziation für Geodäsie. zfv (137) 1–31, 2012.

Pavoni, N., R. Green: Commission on Recent Crustal Movements, Inter-Union Commission on Geodynamics. Elsevier Scientific Pub. Co., 1975.

Ramsayer, K.: Geodätische Astronomie. Handbuch der Vermessungskunde, Band IIa, J.B. Metzler-Verlag, Stuttgart 1969.

Reigber, C.: Beiträge der Satellitengeodäsie zum Studium der Physik des Erdkörpers. Z. f. Verm.wesen (106) 628–631, 1981.

Rizos, C.: Alternatives to current GPS-RTK services and some applications for CORS infrastructure and operations. GPS Solutions (11) 151–158, 2007.

Rummel, R., M. Rothacher, G. Beutler: Integrated Global Geodetic Observing System (IGGOS) – science rationale. J. Geodynamics (40) 357–362, 2005.

Schleusener, A.: Messungen mit transportablen statischen Schweremessern. Z. f. Geophysik (10), 369–377, 1934.

Schmid, H.H.: Worldwide geometric satellite triangulation. J. Geophys. Res. (79) 5349–5376, 1974.

Schmidt, M., D. Bilitza, C.K. Shum, C. Zeilhofer: Regional 4-D modeling of the ionospheric electron density. Adv. Space Res. (42) 782–790, doi:10.1016/j.asr.2007.02.050, 2008.

Schuh, H.: The rotation of the Earth observed by VLBI. Acta Geod. Geoph. Hung. (34) 421–432, 1999.

Tardi, P.: Hundert Jahre Internationale Erdmessung. Z. f. Verm.wesen (88) 2–10, 1963.

Torge, W.: Großräumige Schweremessungen mit LaCoste-Romberg-Gravimetern 1964–1970. Dt. Geod. Komm., München, Reihe B, Nr. 183, 1971.

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

Torge, W.: The International Association of Geodesy 1862 to 1922: from a regional project to an international organization. J. Geodesy (78) 558–568, 2005.

Torge, W.: 150 Years of International Cooperation in Geodesy: Precursors and the Development of Baeyer's Project to a Scientific Organisation. zfv (137), 166–175, 2012.

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