AGrav - An International Database for Absolute Gravity Measurements

H. Wziontek[1], H. Wilmes[1], S. Bonvalot[2]

[1] Federal Agency for Cartography and Geodesy (BKG), Richard-Strauss-Allee 11, 60598 Frankfurt / Main, Germany, (hartmut.wziontek@bkg.bund.de)

[2] Bureau Gravimétrique International, Observatoire Midi-Pyrénées, 14 av. Edouard Belin, 31450 Toulouse, France

Objectives

The steadily growing number of absolute gravimeters and absolute gravity measurements all over the world emphasizes the demand of an overview about existing locations, observations, instruments and institutions involved. As a contribution to International Gravity Field Service (IGFS), a relational database was designed and implemented in a joint development of BKG and BGI and is in operational status now. Two objectives are aimed at: With freely available meta-data and contact details, the database should give an overview about existing stations and observations, serve as a platform for multidisciplinary cooperation and allow the coordination of forthcoming measurements. Among contributing groups or within international projects, an exchange of gravity values and processing details is possible. The database will function as a data inventory, assuring long term availability of the data. Prospectively, the database will be the foundation for a future international gravity reference system and will serve as a pool for geophysical interpretation of absolute gravity observations on a global scale.

Information Levels

To allow sharing the data while respecting the data property of the participating groups, three different levels of providing information content to the database are distinguished:

1. The lowest level is to inform simply about the AG station locations. This involves only the station coordinates. Information about the station owner can be added, but no contact details can be provided unless an observation is stored in the database. This is for groups who established absolute gravity sites and want to enable cooperation by providing access to other teams.
2. The next level of information is to include observation epoch, instrument details and owner - but still without the observation results. Contact to the data owner is possible for everyone. This is important for groups who need to exploit their measurements before sharing the data with others.
3. In the highest level the gravity results are included. The data owner still controls the data, since it is possible to edit the submitted data. To preserve data property, the database provides the gravity values with reduced precision via its public access. The complete value is shared only among the other contributors of gravity data.

Although level 3 is favoured as standard, level 2 is proposed as a compromise in case of difficult data property. However, if it is impossible to provide observation information at all, level 1 is still considered as valuable information for the gravity community.
The data retrieval distinguishes two different views to the data accordingly and foresees the selective handling of level 3 in particular.

meta data or *Who measured Where and When*: This comprises information about locations, instruments, institutions and periods of station occupation, which are freely available. Gravity values (if present) are provided with a reduced precision at the mGal ($10\mu m/s^2$) level. No processing details are available. Links between different data views, allowing a fast navigation, lead to contact details for further information. The intention is to leave the decision of a public release of measurement results in the responsibility of the data providing institution.

complete datasets: All existing information is available, but the access is restricted to contributing groups and enables to share processing results. The user interface allows editing of the data (usually restricted to the own data) and access to supplemental information such as station descriptions.

Data exchange format

Prior to a database setup, an exchange format must be defined which requires a compromise between completeness of the dataset, traceability of the processing scheme and additional efforts for the user. A proposal for an absolute gravity format was already made by J.-P. Barriot (BGI) (Barriot et.al. 2004) and comprises main aspects. Within the development of the European Combined Geodetic Network (ECGN) (Ihde et.al. 2005) standards for absolute gravimeter data have been suggested which are based upon the so-called absolute gravity “project files”. These files are routinely generated by the absolute gravity processing software “g” of micro-g-LaCoste, which is a standard processing software for FG5 and A10 gravimeters and therefore is available for most potential contributors without additional effort. The simple structured text file, which can be easily adopted, contains most of the information requested by BGI and additional processing details. The project file includes information about

- location: site code, site name, coordinates and height,

- instrument: type and serial number, rubidium frequency, laser model and frequencies,
- the observation epoch,
- details of the data acquisition

and observation and processing details like

- gravity value and error estimates,
- gravity gradient and reference height,
- applied reduction models.

Table 1 describes in detail the identifiers of the proposed exchange format. The line-based structure of the text file is simple: Each identifier is followed by the values, delimited by a colon. In cases where the values exceed a single line, e.g. tidal parameters, the data can be expanded over the following lines. However, such data cannot be extracted automatically while inserting new data into the database.

Since data and meta-data are closely related, a strict separation is not possible. The gravity value and related parameters are considered as primary data, while information like station location and measurement epoch are addressed as meta-data. Information about the gravimeter or supplemental data used for gravity corrections have an intermediate position, but are treated as meta-data as well. Due to independent operation of individual institutions and the lack of a central coordination, meta-data about the station location are heterogeneous and difficult to harmonise. Therefore this information must be specified supplemental to the project file to ensure consistency. Two further definitions are necessary to characterize location and observation exactly:

- A *site* (station) is defined as a location with one or more gravimetric observation points/monuments in close spatial relationship with equal environmental (atmospheric, hydrologic) influences. Usually the distance between such points should not exceed a few ten meters. Most of the sites have only one observation point. A site is unambiguously identified by its country- and site-code.
- An *observation epoch* is defined as a period of an instrumental setup and continuous data acquisition. Short interruptions due to technical demands are accepted within one epoch. More than one processing result per observation epoch is possible and a final gravity value may be assigned outside automated processing schemes under consideration of external corrections. The observation period will be characterized by a mean point in time.

Further, three main types of stations will be distinguished: field stations, station with laboratory conditions and reference stations. Usually, absolute gravity stations are indoors, have a concrete foundation and are insulated against most environmental influences. Such conditions are denoted as laboratory conditions. A reference station is a regional gravity comparison site or a station where the national gravity standard is realized.

Extended applications result from the concurrent existence of additional geodetic or geophysical sensors at the site, like permanent GNSS, Satellite Laser Ranging, VLBI, superconducting gravimeter, tide gauge, hydrological sensors etc. These observations make the stations valuable for investigation of like the uplift or subsidence induced by geodynamic, climate or human processes. Initiatives like GGOS, GMES or GGP propose the definition of data interfaces to include the gravimetric observations. Criteria should be developed and fixed in Working Group of Absolute Gravimetry and in the Global Geodynamics Project.

Based on the information provided by the project files together with the above definitions, the following data model was set up.

Data model

The various relationships between different groups of data suggest relational database design. The main objects are four tables which hold information about stations, instruments, the involved institutions and finally the observation, all shown in dark green in figure 1. This approach avoids redundancies when data appear more than once in different context. The tables are then related to each other by sets of matching keys. A further advantage of the relational concept is the option of a stepwise development and flexible future extension. The four main tables and their features are:

1. Stations (*tbStations*): Name and site code of the station are stored. According to the definition above, at least one pier is assigned to each station, using the child table *tbPoints*. Coordinates are specified separately for each pier. Different network identifiers can be assigned to each station, using a n:m relation. Further, a class should be assigned to characterize the measurement conditions. Currently three classes are distinguished: reference station and stations with laboratory and field conditions.
2. Gravimeters and their components (*tbMeters*): This table contains the list of instruments. Because an absolute gravimeter consists of several interchangeable parts (Laser, Dropping chamber etc.), only type, serial number and a log (?) are available here. Optionally, a more detailed description of the meter components and its history can be stored with the child table *tbComponents*.
3. Institutions (*tbInstitutions*): Used to store name and contact information of institutions which carry out measurements and/or own a gravimeter. This table will also be used to organize the database access.
4. Observations (*tbObsEpochs*): Here, reference time and final result (gravity value) for an observation epoch are saved. Different processing results can be stored for each epoch, using the child table *tbProcs*. Perspectively, the

child tables *tbSetData* and *tbDropData* can be used to store mean values of sets and the results for every drop experiment.

Supplemental information, such as station descriptions, measurement protocols or log-files, which cannot be stored efficiently inside a database are provided as individual data-files which are stored in a file system, are linked to the respective records and can be downloaded directly.

Web-based user interface

The database is set up on a MySQL server and is accessed with an apache/php based web front-end. It is installed on two mirrored systems, one located at the Federal Agency for Cartography and Geodesy (BKG) in Frankfurt/Main (Germany), http://agrav.bkg.bund.de, and the other located at the Bureau Gravimétrique International (BGI) in Toulouse (France), http://bgi.dtp.obs-mip.fr .

Both servers provide identical content. At the front-page, a Java-script based map application[1] is incorporated to show the geographic distribution of stations and allow for a location-based selection of the particular information (see figure 2).

Starting from the four main sections, institutions, stations, instruments and observations, the web interface offers two main styles, a list view and a form to show or edit single datasets (figure 3). The list view offers an overview based on selected information shown as table, where sorting by different columns is possible. A search function is implemented to limit the displayed rows to match single criteria which will be applied to one of the columns. Each row has a hyperlink which leads to the detailed information for the specific record. In detailed view, all fields of a particular record are shown. Information in related tables appears in list view again.

Both of these styles exist in slightly modified versions for meta-data and the complete data content. The meta-data version has no editing capability and makes use of links for fast navigation between different datasets. It is accessible without authentication. Gravity values are shown with reduced accuracy of 1 mGal to preserve data ownership. The view with full access to the database is password protected and offers editing capabilities. Editing is possible for individual datasets and is restricted to those records which were created by the actual user. Data of other users are set to be read only. Editing comprises changes of textual information, of related values and the creation of new records. The deletion of records is restricted to avoid accidental loss of data due to the cascaded links of entries in related child-tables, which is necessary to preserve consistency.

Auxiliary information, which is too complex to be stored inside the database itself can be added as files and retrieved later via hyperlinks. In this way it is possible to add station descriptions, photos, instrument logs or other documentation.

Upload of new data

The development work of this database was initiated by the International Gravity Field service (IGFS) and carried out by BKG and in cooperation with BGI. It was coordinated within the IAG Intercommission Working Group on Absolute Gravimetry. The international community of absolute gravimeter owners and the owner of absolute gravity measurements are kindly asked to support this initiative and to contribute to the database.

To enable the user to insert new or update existing data, a web form was set up which enables the upload of project files directly by the user. In this way, the data transfer remains under control of the user, and the user may decide to include the gravity values or not. The upload is organised in a three step process. First, the station must be specified. This can be an existing station, chosen from a list in the database or a new station. In the next step, the observation point at this station must be selected or a new entry will be created. Then, one or more project files for this point can be specified which will be uploaded to the database server and parsed by a script after pressing the upload button. Next, the user has the choice to limit the upload to meta-data only. Already uploaded datasets can be updated or modified. Then, some basic checks will be done, ensuring consistency of the station names and codes in the database. Within a country, a site code can appear only once, and it is excluded to create a new station in the vicinity an existing one. Further, the gravity value will be checked against normal gravity to avoid gross errors. The results of the upload script are shown on a final page, informing the user about details or possibly problems. After successful upload, links to the newly created data are provided for checks or further editing.

There might be cases where this upload procedure is inconvenient, especially if a large number of stations and observations are involved. In these cases it might be more efficient, to send the project-files to the database operator[2] who will upload the data directly on the server. For this purpose a supplemental list with basic station information such as country and site code and pier is required, since this information is not contained sufficiently in the project file. If absolute gravity measurements are already compiled in tabulated form or project files not available, it is still possible to import these data, provided that all basic information about station and instrument are present.

1 currently using the Google Maps API

2 currently the corresponding author

Conclusions

A database for absolute gravity measurements was set up and put into operation in joint cooperation between BKG and BGI. The database is capable to store information about stations, instruments, observations and involved institutions. By this, it allows the exchange of meta data and the provision of contact details of the responsible institutions on the one hand and the storage and long term availability of gravity data and processing details on the other hand. The database can be accessed by a web based interface which provides publicly available meta-data as well as complete datasets for community of users contributing to the archive. A simple exchange format was selected which includes all relevant information and is existent for the majority of users avoiding additional effort. In this way the upload of data to the database is possible, using a web based upload form.

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Identifier in project file	Description	Used	Database table
General Settings			
Project Name	Label of observation/processing		tbProcs
Institution	Institution performing observation	x	tbInstitutions
Operator	Name(s) of operator(s)	x	tbObsEpoch
Comments		x	tbObsEpochs
Station Data			
Name	Name of station	x	tbStations
Site Code	Station code	x	tbStations
Position	Latitude, Longitude (GRS 80), Height (physical)	x	tbPoints

Instrument Data			
Meter Type	Gravimeter type (acronym)	x	tbMeters
Meter S/N	Gravimeter serial number	x	tbMeters
Factory Height	Reference height of gravity value referred to the instrument base	x	tbProcs
Rubidium Frequency	Frequency of time reference	x	tbProcs
Laser	Laser type and serial numer	x	tbObsEpochs
Laser Locks	List of available laser locks (WEO)		
Laser Modulation Frequency	Laser modulation frequency	x	tbProcs

Acquisition Settings			
Acquisition Version	Software version used for measurement	x	tbProcs
Set Interval	waiting time between acquisition of sets		

Drop Interval	waiting time between individual drops		
Number of Sets	total number of sets		
Number of Drops	total number of drops		
Transfer to Reference Height			
Setup Height	Vertical distance between instrument base and monument	x	tbProcs
Transfer Height	Vertical distance used to transfer gravity value to reference height	x	tbProcs, tbObsEpochs
Gravity Gradient	Linear gravity gradient to at least 4 significant digits	x	tbProcs, tbObsEpochs

Gravity corrections			
Nominal Air Pressure	Height dependent reference air pressure, from standard-atmosphere	x	tbProcs
Barometric Admittance Factor	Air pressure admittance factor used for atmospheric correction	x	tbProcs
Polar Motion Coordinates	Polar motion coordinates (provided by IERS)	x	tbProcs
Earth Tide	potential, wave groups, delta-factors		
Ocean Load	filename, wave groups, amplitudes, phases		

Processing Results			
Processing Version	Software version used for processing		
Date/Time	Date and time of measurement referred to mean observation epoch	x	tbObsEpochs
Gravity	Gravity value	x	tbProcs, tbObsEpochs
Set Scatter	Scatter between set means	x	tbProcs
Measurement Precision	Error estimate obtained from set scatter	x	tbProcs, tbObsEpochs
Total Uncertainty	Uncertainty, including systematic effects	x	tbProcs, tbObsEpochs
Number of Sets Collected	Number of sets acquired	x	tbObsEpochs
Number of Sets Processed	Number of sets used during processing	x	tbProcs
Number of Drops/Set	Number of drops per set	x	tbObsEpochs
Total Drops Accepted	total number of reliable drops		
Total Drops Rejected	total number of faulty drops		
Total Fringes Acquired			
Fringe Start	first interference maximum used	x	tbProcs
Processed Fringes	number of zero crossings used	x	tbProcs

Table 1: Description of project file used for data exchange

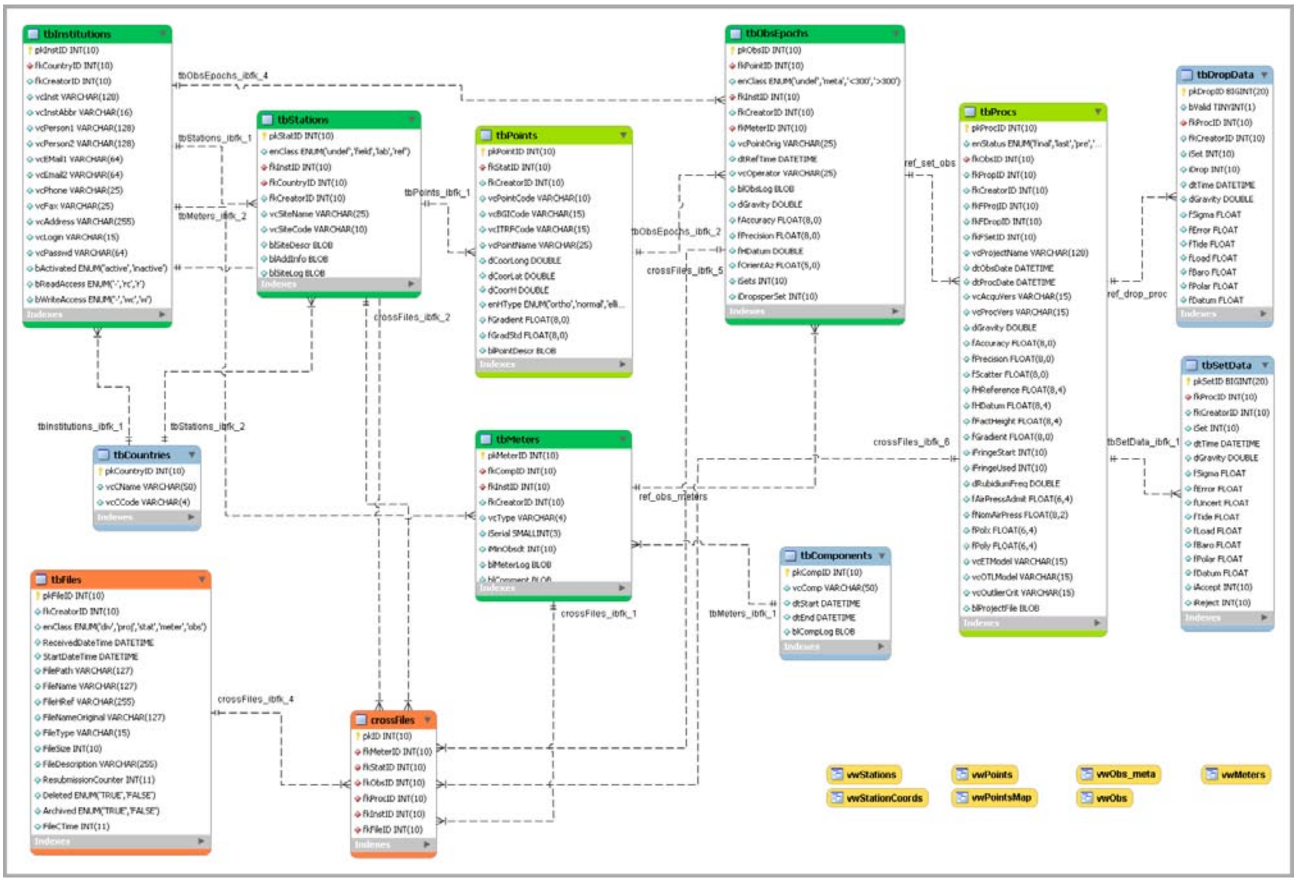


Figure 1: data model of the relational database

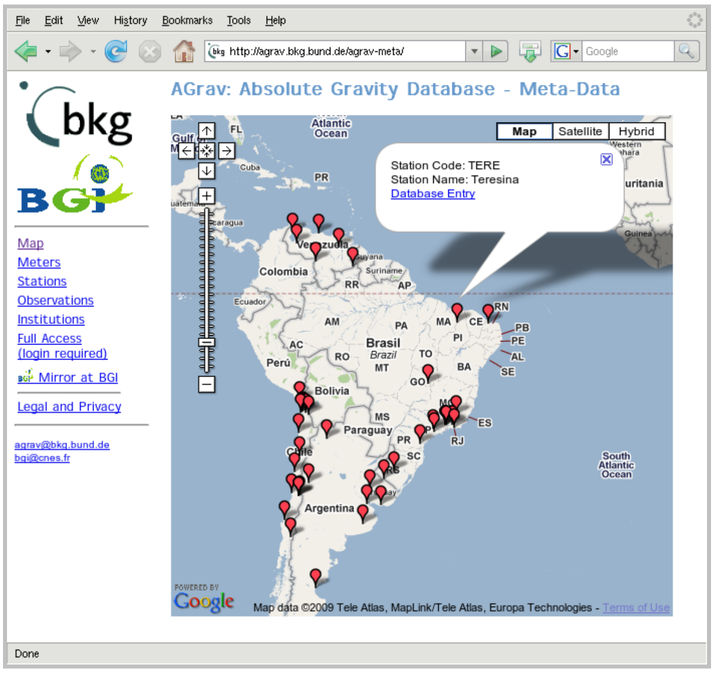
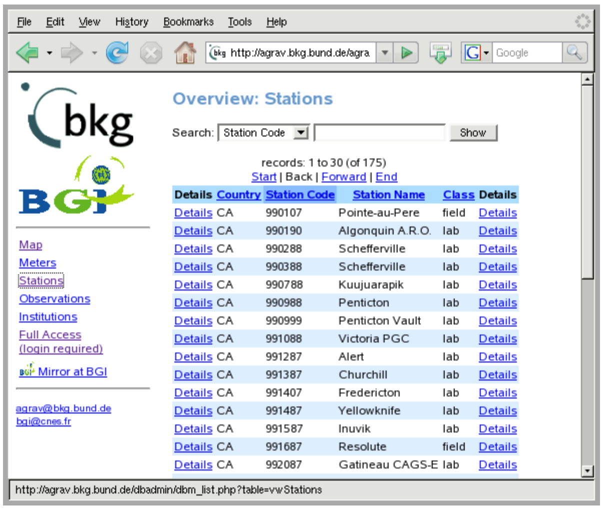
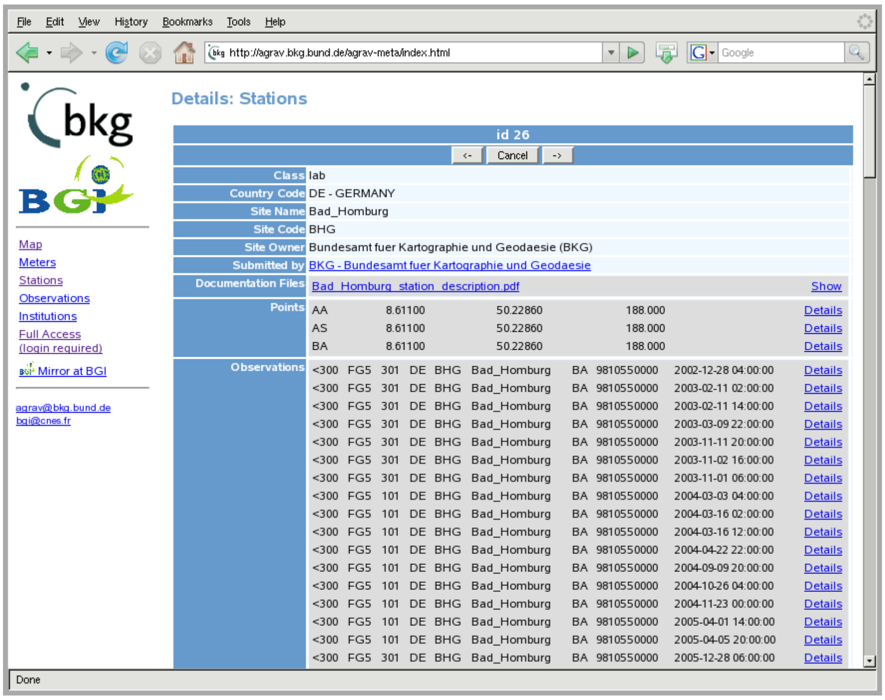


Figure 2: Frontpage of the web-interface of the AGrav database.



a)



b)

Figure 3: web interface for station meta-data .a) list view for meta-data and b) view of meta-data details for specific