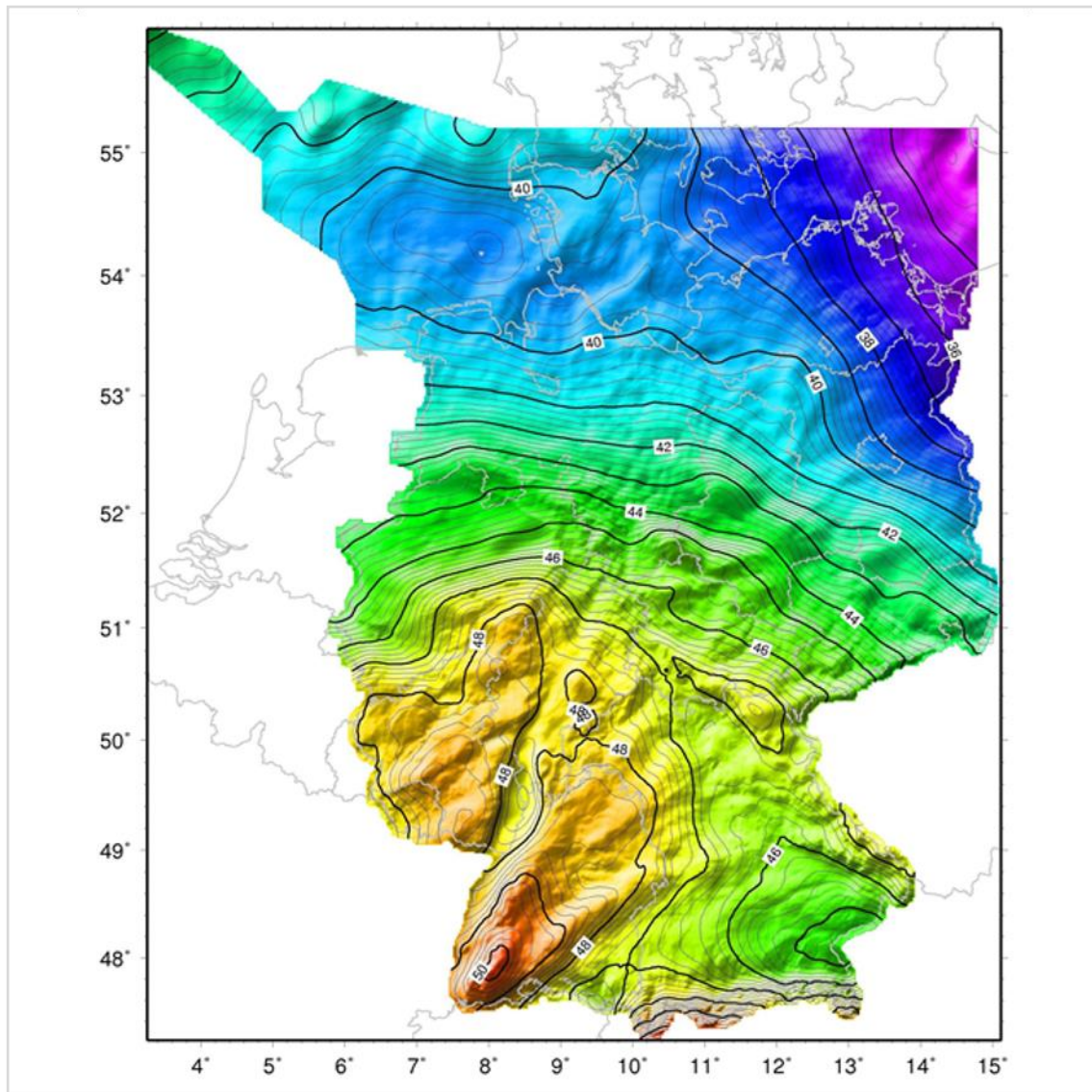# Documentation

Quasigeoid of the Federal Republic of Germany
GCG2016/2023

Product as of February 2024

Content

1   Overview of the dataset

Product:	GCG2016/Update 2023
Content:	The German Combined Quasigeoid describes the official height reference surface of the German land survey above the reference ellipsoid of the Geodetic Reference System 1980 (GRS80). It can be used to transform ellipsoidal heights determined by GNSS observations into physical heights determined by leveling and vice versa.
Area:	Territory of the Federal Republic of Germany (cf. detailed information under no. 2.1)
Spatial structure:	Grid file 30" x 45"
Spatial reference:	ETRS89 in the realization ETRS89/DREF91 (realization 2016) of the German national survey (ETRS89_Lat-Lon[1], position status 889) in relation to the reference ellipsoid GRS80 and leveling heights in the DHHN2016 (DE_DHHN2016_NH[1], height status 170)
Accuracy:	Height anomaly: < 1 cm (Alps max. 2 cm, German Baltic Sea 1 – 2 cm, German North Sea 2 – 6 cm)
Currentness:	2016 (Baltic Sea 2023)
Resolution:	Position: geographical latitude 30", geographical longitude 45 (approx. 0,9 km x 0,9 km), Height anomaly: 0,1 mm
Data formats:	ASCII (latitude, longitude, height anomaly) Binary incl. interpolation program Trimble format (.GGF) LEICA format (.GEM) TOPCON format (.gff) SurvCE format (.gsf) JAVAD format (.db3, .dat) GeoTiff (.tif)
Data supply*:	Download
Changes from previous version:	Yes (see no. 2.2 for details)
Historical data:	Yes (see no. 3)
Data volume:	96 MB

---

[1] Name according to "Coordinate Reference Systems and Units for AFIS-ALKIS-ATKIS" of the GeoInfoDok of AdV

Data source:	Own computations (regional gravity field modeling for the GCG2016), see overview for utilized data (gravity and DEM) (https://sgx.geodatenzentrum.de/web_public/Datenquellen_Quasigeoid.pdf)

2   Description of the dataset and online services

2.1   Content of the original version GCG2016

This section describes the status of the original version from 2016. For changes in the Baltic Sea area in the update 2023, see item 2.2.

The determination of the quasigeoid of the Federal Republic of Germany is a joint project of the State Survey Offices, the BKG and the IfE Hannover.

The quasigeoid allows the transformation between ellipsoidal heights in the ETRS89/DREF91 (realization 2016) and normal heights in the DHHN2016.

In Germany the official reference system ETRS89 is provided for users by means of the SAPOS station infrastructure. In case that ellipsoidal heights are provided by the SAPOS service, leveling heights in the DHHN2016 can be computed without further corrections:

$$H^{DHHN} = h^{ETRS} - \zeta^{ETRS}_{DHHN}$$

The following data were used for the determination of the quasigeoid:

−   gravity disturbances (δg) derived from 860 000 point gravity values obtained from the databases of the State Survey Offices, the BKG, the Insitut für of Geodesy (IfE) Hannover, des Federal Maritime and Hydrographic Agency (BSH), the German Gravity Archive, the Employers' Association of Oil and Gas Production (WEG), the neighboring states of the Federal Republic of Germany and from the model DTU13 (Andersen et al., 2013) in marine areas,
−   approx. 470 quasigeoid heights (ζ_{SN}) derived from ellipsoidal heights from GNSS measurements at benchmarks in the ETRS89 and normal heights in the DHHN2016,
−   digital terrain models (Germany: DGM25, Europe: EuroDEM) and bathymetric data of the BSH and the worldwide model GEBCO (http://www.gebco.net, status 2004),
−   global gravity field model EIGEN6C4 (Foerste et al., 2014)

The basis for the quasigeoid model are two independent computations of the BKG and the IfE. The computation method of the BKG is based on the adjustment of point masses in frame of a „Remove-Compute-Restore" technique. The gravity measurements (gravity disturbances) are used as input data for the computations. These data were previously reduced i) by the gravitational influence of topography and ii) by the long-wavelength part of a global geopotential model. After the adjustment both parts are added again to the computed quasigeoid heights.

A grid of point masses in a depth of 5 km and a grid distance of approx. 5km is introduced as the unknown quantity to be determined. From the point masses determined in the adjustment a gravimetric quasigeoid is computed that is adjusted to the official reference systems ETRS89/DREF91 (realization 2016) and DHHN2016 by a correction surface. The correction surface is computed by an interpolation/collocation technique on the basis of a dataset of GNSS/leveling points that comprises approx. 470 points.

The quasigeoid computation of the IfE is based on the „Remove-Compute-Restore" technique too. First in a two-step solution method free air anomalies and topographical data together with a global geopotential model are combined by an integration approach to a gravimetrical solution of the quasigeoid. In a second computation step the GNSS and leveling heights are included by collocation approaches.

The computed quasigeoid heights of both models have a mean agreement of better than 0.5 mm; the standard deviation is 9.7 mm (land territory 4.6 mm). The final quasigeoid is obtained by averaging both model heights.

The model is provided for the whole area of Germany, alternatively for 5 subareas:

Northeast: Berlin, Brandenburg, Mecklenburg-Vorpommern, Sachsen, Sachsen-Anhalt, Thüringen
South: Baden-Württemberg, Bayern
West: Hessen, Nordrhein-Westfalen, Rheinland-Pfalz, Saarland
Northwest: Bremen, Hamburg, Niedersachsen, Schleswig-Holstein
Coast: Marine areas until 55.2° N or for the area of the exclusive economic zone of Germany (North Sea), respectively.
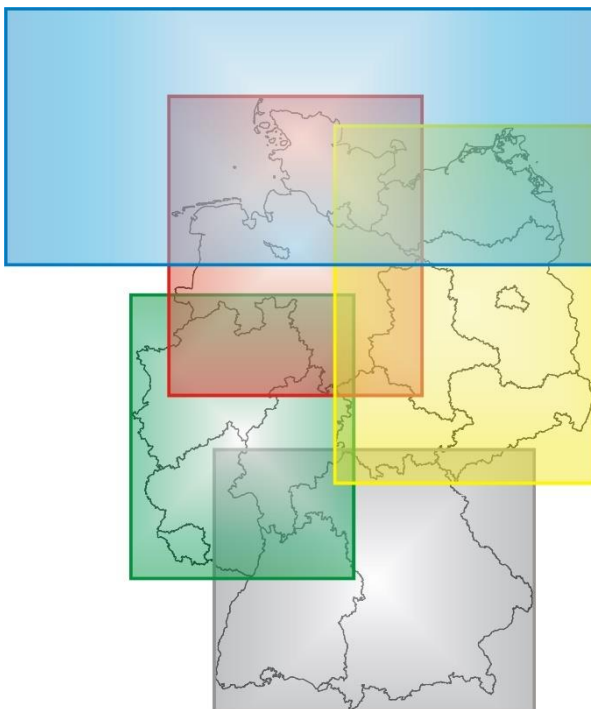
Fig. 1: Subareas of GCG2016

References

Andersen, O. B., P. Knudsen, S.Kenyon, J. K. Factor, S.Holmes: The DTU13 Global marine gravity field – first evaluation; OSTST Meeting, Boulder (pres.), October 2103

Förste, C., Bruinsma, S. L., Abrikosov, O., Lemoine, J.-M., Marty, J. C., Flechtner, F., Balmino, G., Barthelmes, F., Biancale, R.: EIGEN-6C4 The latest combined global gravity field model including GOCE data up to degree and order 2190 of GFZ Potsdam and GRGS Toulouse; 5th GOCE User Workshop, Paris (pres.), November 2014

2.2 Changes from previous version GCG2016

This section describes the changes in the course of the update 2023.

The update of the GCG2016 is required in connection with the implementation of the unified height reference for the nautical maps of the Baltic Sea (Baltic Sea Chart Datum 2000 – BSCD2000) by the Baltic Sea states.

The BSCD2000 is based on the European geodetic standards (ETRS89 for 3D coordinates, historical mean sea level of the Normaal Amsterdam Peil (NAP) as zero level for heights), which are mostly identical with the standards of the German reference systems. The height reference surface of the BSCD2000 is realized by a unified quasigeoidmodel (BSCD2000 Transformation Grid) realisiert, which was fitted to the national geodetic reference frames of the Baltic Sea states on land. To this end, the BSCD2000 Transformation Grid was harmonized with the current versions of the official national geoid models as far as possible.

As a requirement for the computation of the BSCD2000 Transfomation Grid, extensive gravimetric surveys were carried out by the Baltic Sea states. These works have been co-financed by the European Union within the project „Finalizing Surveys for the Motorways of the Sea" (FAMOS).

Hence, in the area of the German Baltic Sea the BSCD2000 Transformation Grid provides the following improvements compared with the original version of the GCG2016:

- updated gravimetric database for nearly the entire Baltic Sea,
- a newly computed quasigeoid model,
- accuracy in the German Baltic Sea area now ca. 1 – 2 cm and
- cross-border harmonization between the Baltic Sea countries along the maritime boundaries

The release of the BSCD2000 Transformation Grid as the height reference surface for maritime applications in November 2023 implies an **Update** of the GCG2016 **in the Baltic Sea area**. This ensures maximum consistency of the official height reference surface in Germany and the height reference of the nautical maps in the Baltic Sea. The use of different models for different applications and user groups within Germany is avoided. Furthermore, for the reasons stated above, the update of the GCG2016 provides an improvement of the accuravy in the German area of the Baltic Sea.

The differences between the Update 2023 and the original GCG2016 are about 2-3 cm (see Fig. 2). These differences occur exclusively in the offshore areas. There, the GCG2016/Update 2023 is based on the BSCD2000 Transformation Grid. All grid nodes of the GCG2016 which, according to the coastline of the EuroRegionalMap 2021[2], are on the **German mainland** remain **unchanged** in the updated version. The transition is realized in both grids (BSCD2000, GCG2016/Update 2023) in a zone extending 10 km out from the coastline. Therefore, the BSCD2000 Transformation Grid and the GCG2016/Update 2023 are identical in all German land and sea territories except for the border areas with Poland and Denmark. There, differences at the order of 2-3 cm occur due to small differences between the national height reference frames (see Fig. 3). In these areas, it is recommended to use the BSCD2000 Transformation grid for pure offshore applications and the GCG2016/Update 2023 otherwise.

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[2] https://eurogeographics.org/maps-for-europe/euroregionalmap/ (last accessed 27 October 2023)

Further information about BSCD2000 and the download for the BSCD2000 Transformation Grid are available from the homepage of the Baltic Sea Hydrographic Commission (BSHC) which is accessible from the DOI https://doi.org/10.58440/iho-bscd2000. A Release Note has been published in the journal International Hydrographic Review (IHR) with DOI https://doi.org/10.58440/ihr-29-2-n11. Information about the national implementations of the chart datum for the North Sea and the Baltic Sea, respectively, is provided under authority by the Federal Maritime and Hydrographic Agency (BSH).
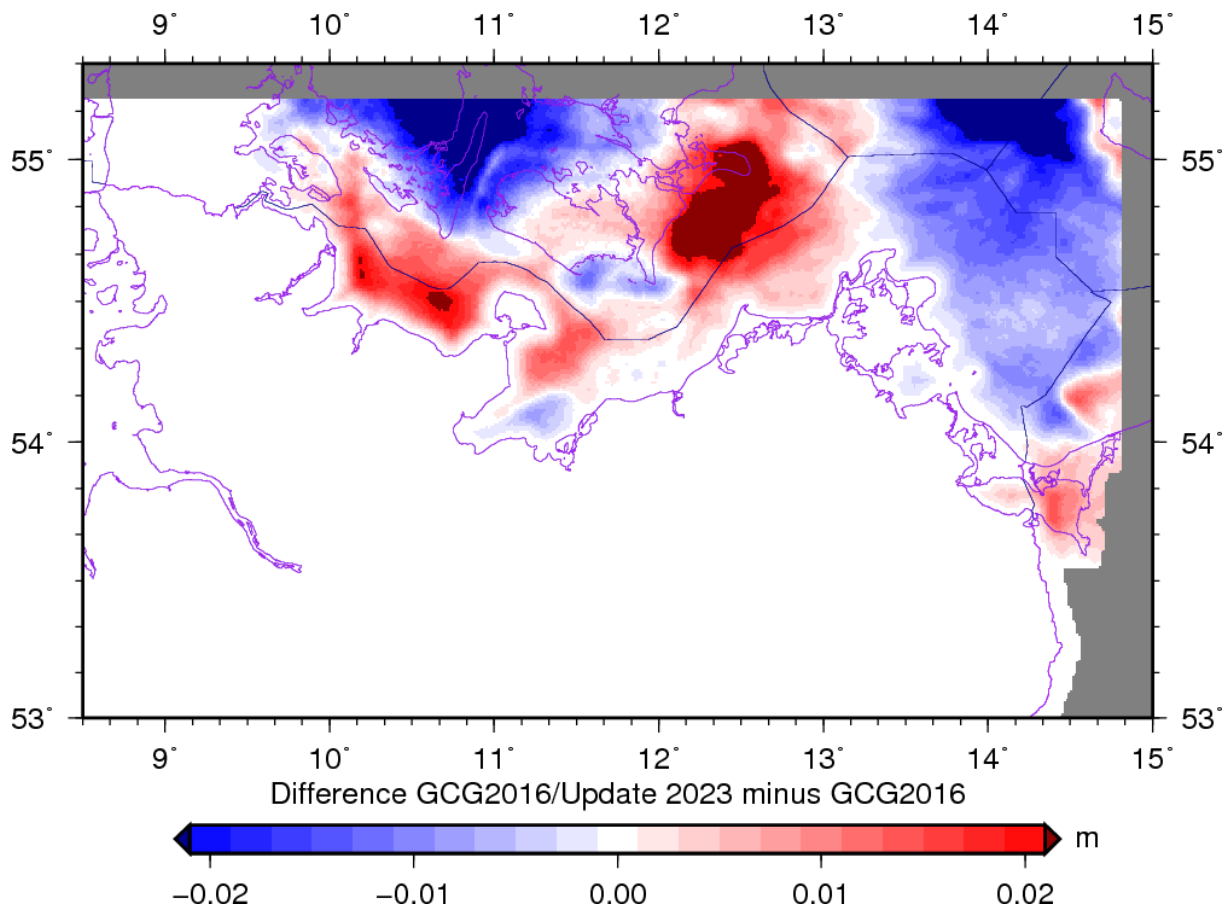
Fig. 2: Differences between GCG2016/Update 2023 and the original version 2016 in the Baltic Sea area
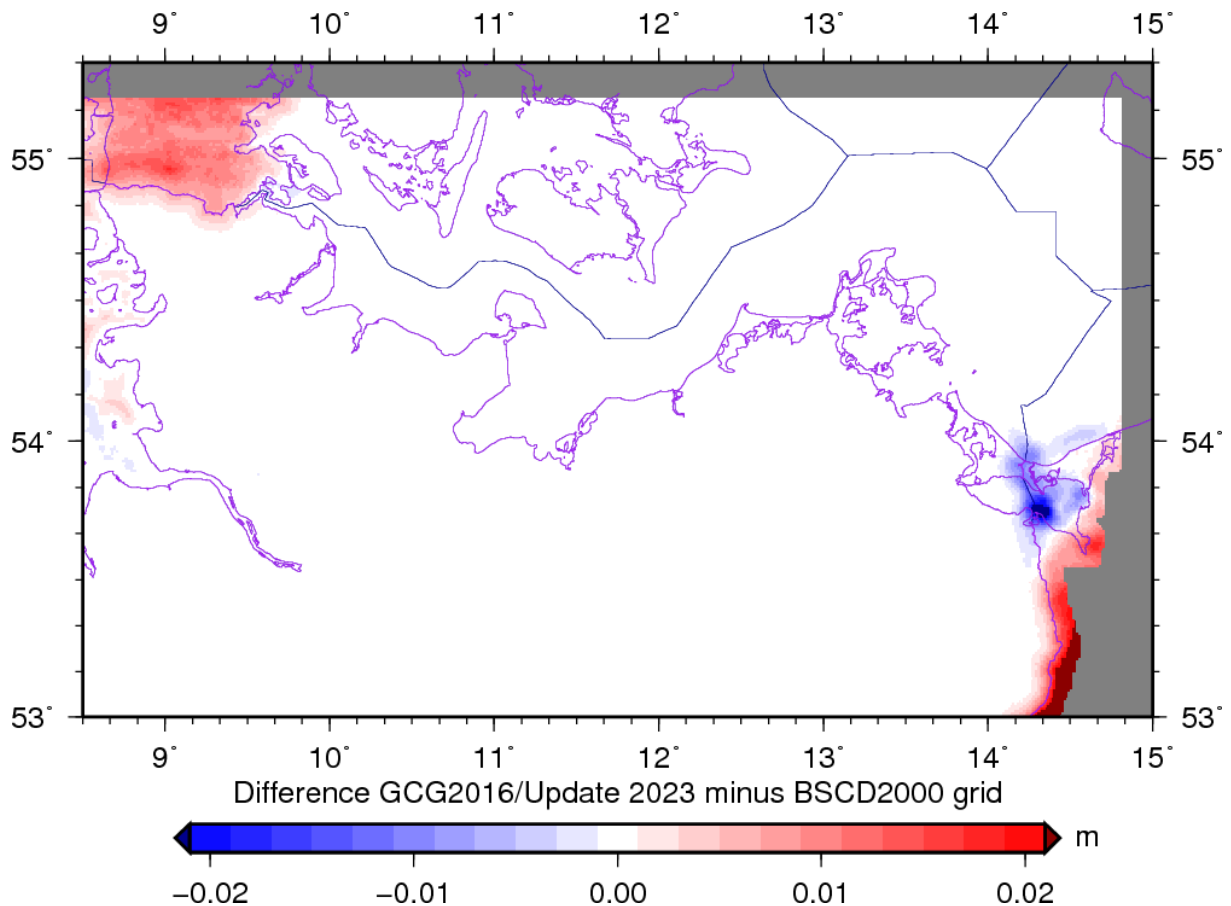
Fig. 3: Differences between GCG2016/Update 2023 und and the BSCD2000 transformation grid in the border regions

2.3   Changes and bugfixes

Change from 4 January 2024:

- Bugfix for the grid files in the Leica format (*.GEM): During conversion to Leica grid format in the version as of 27 November 2023 the pseudo value for masked grid cells was not handled correctly. This caused the quasigeoid height to be interpolated with obviously incorrect values (ca. 500000 m).

Change from 02.02.2024:

- Bugfix fort the grid files in the Trimble Format (*.GGF) for partial areas Coast („Küste", k), Northeast („Nordost", no), Northwest („Nordwest", nw), South („Süd", s), West (w): During conversion to the Trimble grid format in the version as of 27 November 2023 grid values were stored in reverse order of rows from south to north. This caused wrong quasigeoid values in the order of several centimeters to meters. The grid for the whole area of Germany is not affected.

3 Data acquisition

The data can be obtained free of charge on our website www.bkg.bund.de under the heading „Products and Services" → „Open Data" → Quasigeoid. Previous versions (GCG05, GCG2011, GCG2016) are also available from our archives.

4 Terms of use and copyright

The data are protected by copyright. The data are made available free of charge in accordance with the licence Creative Commons Atrribution 4.0 International. Data licenced under Creative Commons Atrribution 4.0 International may be shared, reproduced and modified under the condition of attribution. The attribution is included in the source note. The source note must be observed.
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© BKG (year of last data acquisition) CC BY 4.0, Datenquellen:
https://sgx.geodatenzentrum.de/web_public/Datenquellen_Quasigeoid.pdf

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5 Contact

Federal Agency for Cartography and Geodesy
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Further information and services can be found at the homepage www.bkg.bund.de under the heading „Products and Services".

Technical remarks and corrections should be directly submitted to:

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Bundesamt für Kartographie und Geodäsie
Außenstelle Leipzig
Karl-Rothe-Str. 10-14
04105 Leipzig

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6   Appendices

6.1   Remarks on data supply

The quasigeoid model is provided in data formats for the operating systems MS WINDOWS (XP/Vista/Windows 7/Windows 10) and LINUX. The download packages include all formats including an inhouse interpolation software for the binary grid format and this documentation.

Remarks on the installation an use of the interpolation program are quoted under no. 6.3.

In all grid formats and regions, the quasigeoid heights (height anomalies) are only provided at the grid nodes within the territory of the Federal Republic of Germany resp. the area of the exclusive economic zone (EEZ) of Germany (maritime regions), according to the figure on the title page. Grid nodes outside these boundaries contain a dummy value. Within the grid, the quasigeoid heights are listed das follows: 1. Descending geographical latitude (north to south), 2. Ascending geographical longitude (west to east).

A free online service available at the BKG website under www.bkg.bund.de/geoid allows computation of quasigeoid heights for single points.

6.2   Description of the data formats

6.2.1   ASCII format

The ASCII files contain one record per grid node, with columns as follows: Latitude and longitude (in degrees), assigned quasigeoid height (in m). The data fields are separated by spaces. The filename extension is „.txt".
The dummy value for grid nodes outside the model area is „999999".

Example:

```
53.64583333    13.86875    36.4582
53.64583333    13.88125    36.4363
...
```

6.2.2   Binary format

The binary file of quasigeoid heights consists of a stream of continuously stored 4 byte records. The first 18 data fields form a header to describe the grid raster, consisting of each 3 integer values (degrees, minutes, seconds*1000000) for min. geod. latitude, max. geod. latitude, min. geod. longitude, max. geod. longitude, grid spacing in latitude, grid spacing in longitude. This is followed by the quasigeoid heights as integer values in 1/10 mm (resp. as binary 99999999 for dummy values outside the Federal Republic of Germany) in the order as described under no. 6.1.

Additionally, an interpolation program to extract quasigeoid values at arbitrary points (within Germany) is provided. The program uses bicubic spline interpolation.

gintbs.exe   Input: Quasigeoid file
Coordinate file of interpolation points. Order of columns (lat-lon or lon-lat) and type of input height (ellipsoidal height or normal height) can be selected.
The filenames are input interactively.

              Output: File with latitude, longitude and interpolated quasigeoid heights. Depending on the user selection, also normal resp. ellipsoidal height are output.
The filename is input interactively.

Example for the input coordinate file:

```
49.027 11.287654987
51.2000001 13.9
48.55 9.0124
etc.
```

The WINDOWS version comes with a graphical user interface „geoid.exe", which also allows conversion of various coordinate formats (e.g. UTM). Specific remarks on the use of this program are included under 6.4.

6.2.3 Special formats for third party software of geodetic suppliers

GGF: Special data format for use in TRIMBLE Geomatics Office/TRIMBLE Business Center resp. with TRIMBLE GNSS receivers

GEM: Special data format for use in LEICA Geo Office resp. with LEICA GNSS receivers

gff: Special data format for TOPCON software resp. TOPCON GNSS receivers

gsf: Special data format (Carlson geoid separation file) for use in SurvCE

db3:   Special data format for use in JAVAD applications (GNSS receivers, desktop software, mobile apps)

dat: Special data format for use with JAVAD receiver firmware

6.2.4 GeoTiff

Special data format for use with GIS software (georeference EPSG:4258, derived from binary format using GDAL version 2.4.3)

6.3   General remarks on software and files

```
==========================================================================
 Quasigeoid of the Federal Republic of Germany
 German Combined QuasiGeoid 2016/Update 2023 - GCG2016/2023 -
==========================================================================


Content:               GNSS-leveling fitted gravimetric quasigeoid

Area:                  Federal Republic of Germany

                       Resp. subareas with

                       <g>= NO        for area Northeast
                            WE        for area West
                            SU        for area South
                            NW        for area Northwest
                            KUESTE    for coastal region of North Sea and Baltic Sea

Georeference:          Geographic coordinates in decimal degrees,
                       Ellipsoid GRS80
                       Datum: ETRS89/DREF91 Realization 2016


Directories/ files
-------------------------------------------------
quasigeoid.pdf         - Dokumentation of the quasigeoid for Germany according to the
                         conventions of the geodata center

GCG2016v2023<_g>.jpg - Graphical representation of the extent of the data

\WINDOWS                - Directory with files/programs for use under WINDOWS
                         (XP/Vista/Windows 7/Windows 10)

\LINUX                  - Directory with files/programs to be used under LINUX


Remarks on the files/programs under WINDOWS
-------------------------------------------------

GCG2016v2023<_g>.txt - ASCII file of the quasigeoid

                       - Usable for graphic representations and import in own
                         applications


GCG2016 v2023<_g>    - Binary file of the quasigeoid

                       - Usable for interpolation of quasigeoid heights at points
                         with ETRS89 coordinates in combination with the
                         interpolation program gintbs.exe or the graphical interface
                         geoid.exe

GCG2016v2023<_g>.GGF - Quasigeoid model in TRIMBLE format

                       - Usable within TRIMBLE software Trimble Business Center
                         resp. TRIMBLE GNSS receivers

GCG2016v2023<_g>.GEM - Quasigeoid model in LEICA format

                       - Usable within LEICA software Leica Geo Office resp. in
                         LEICA GNSS receivers
```

```
GCG2016v2023<_g>.gff - Quasigeoid model in TOPCON format

                     - Usable within TOPCON software resp. TOPCON GNSS receivers

GCG2016v2023<_g>.gsf - Quasigeoid model in SurvCE format

                     - Usable within SurvCE software


gintbs.exe           - Interpolation routine (bicubic splines) of quasigeoid values
                       at given points

                          - Input:  - Quasigeoid file (binary format)

                                    - File with point coordinates (ASCII).
                                      Order of columns (lat-lon or lon-lat) and type
                                      of input height (ellipsoidal height or normal
                                      height) can be selected.

                          - Output: - File with latitude, longitude and interpolated
                                      quasigeoid heights (ASCII). Additionally, the
                                      derived normal height or ellipsoidal height
                                      can be output depending on the user input.

                                    - File gintbs.err with remarks about potential
                                      errors in case of unexpected termination of
                                      the program.

                        - All filenames (except gintbs.err) are queried
                          interactively abgefragt.

                        - It is recommended to start the program in a separate
                          command window (Windows+R => cmd.exe) in order to see
                          all program input and output also after the program run
                          has finalized. Otherwise, if the program is started
                          using a double click, the window will be closed
                          automatically.


geoid.exe            - Graphical interface for the interpolation of quasigeoid
                       heights and conversion between ellipsoidal heights and
                       normal heights based on the program gintbs.exe

                     - The coordinates of the interpolation points can be input
                       either in ellipsoidal (geographic) coordinates, cartesian
                       coordinates, or UTM coordinates. Additionally, a point
                       number can be provided.

                     - It is possible to switch between a single point mode
                       (interactive coordinate input) and a file mode.

                     - A conversion between the coordinate formats is possible
                       while maintaining the geodetic datum (ETRS89).
```

```
Remarks on the files/programs under LINUX
-----------------------------------------

GCG2016<_g>.txt      - ASCII file of the quasigeoid

                     - Usable for graphic representations and import in own
                       applications

GCG2016<_g>          - Binary file of the quasigeoid

                     - Usable for interpolation of quasigeoid heights at points
                       with ETRS89 coordinates in combination with the
                       interpolation program gintbs


gintbs               - Interpolation routine (bicubic splines) of quasigeoid values
                       at given points

                         - Input:  - Quasigeoid file (binary format)

                                   - File with point coordinates (ASCII).
                                     Order of columns (lat-lon or lon-lat) and type
                                     of input height (ellipsoidal height or normal
                                     height) can be selected.

                         - Output: - File with latitude, longitude and interpolated
                                     quasigeoid heights (ASCII). Additionally, the
                                     derived normal height or ellipsoidal height
                                     can be output depending on the user input.

                                   - File gintbs.err with remarks about potential
                                     errors in case of unexpected termination of
                                     the program.

                         - All filenames (except gintbs.err) are queried
                           interactively.
```

6.4   Remarks on the use of the Windows program geoid.exe

```
Program for the computation of quasigeoid heights - V1.05 (22 August 2012)
==========================================================================
```

The program „geoid" can be used to compute normal heights in DHHN92 or DHHN2016
from ellipsoidal heights given in ETRS89. For the positions input by the user,
height anomalies are interpolated from a selected grid file (quasigeoid model).
Various versions of the quasigeoid model can be used (Versions 2005 and 2011
provide normal heights in DHHN92; Versions 2016 and 2016/2023 provide normal
heights in DHHN2016). Grid files of the quasigeoid models are available for the
entire area of Germany or subareas.

The input coordinates must refer to the reference system ETRS89.
The input is possible in one of the following coordinate formats:
- cartesian coordinates
- ellipsoidal coordinates in decimal degrees or degrees, minutes and seconds
- UTM coordinates (zones UTM32 or UTM33).
It is possible to include a conversion between the coordinate formats during the
computation. However, it should be noted that the reference system ETRS89
(ellipsoid GRS80) is always conserved. The coordinate input can be done
interactively (computation of single points) or in a text file erfolgen.


```
Menu item: Quasigeoidmodell (Quasigeoid model)
----------------------------------------------
```
As a first step, before any computation, the filename of the quasigeoid model must
be selected.


```
Menu item: Interaktive Eingabe (Interactive mode)
-------------------------------------------------
```
The menu item "Interaktive Eingabe" is used to compute normal heights H of single
points. The coordinates can be provided as
- cartesian coordinates (X, Y, Z),
- ellipsoidal coordinates (ellipsoidal longitude L, ellipsoidal latitude B,
  ellipsoidal height h) oder
- UTM coordinates (Northing N, Easting E, ellipsoidal height h).
Ellipsoidal longitude and latitude can be input in decimal degrees or degrees,
minutes and seconds.
The coordinate format must be selected using the respective selection button.
After submitting all input by pressing the button "Berechnen" the normal height H
and the height anomaly N as well as the coordinates in the other coordinate formats
are computed.


```
Menu item: Dateieingabe (File mode)
-----------------------------------
```
In the menu item "Dateieingabe" the names of the input and output file as well as
the respective coordinate formats are queried. The input for each point – point
number and coordinates – are to be separated by at least one space. Each row must
only contain one point.
After pressing the button "Punktnummer in Spalte 1" (Point number in column 1), the
first column is interpreted as point number. The maximum length of the point number
is specified in the according input field. It must not exceed 30 digits. The
computation provides the coordinates in the desired coordinate format of the
reference system ETRS89, the normal height Normalhöhe H and the height anomaly N.
If needed, the first 64 kByte of the input and output files can be viewed using the
menu items "Koordinatendatei Betrachten" (View coordinate file) resp. "Ausgabedatei
betrachten" (View output file).

```
Coordinate formats for input and output in the reference system ETRS89:
-----------------------------------------------------------------------
1. cartesian coordinates:        [Point number]  X  Y  Z

2. ellipsoidal coordinates       [Point number]  B  L  h
   in degrees – decimal:

3. ellipsoidische Koordinaten    [Point number]  B  L  h
   in degrees, minutes, seconds:

6. UTM coordinates:              [Point number]  North  East    h
7. UTM coordinates:              [Point number]  East   North   h
```