Evaluation of SRTM3 and GTOPO30 Terrain Data in Germany

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Abstract. High-resolution terrain data are crucial for gravity field modelling in mountainous regions. In areas without national digital elevation models (DEMs) available, fill-ins from global models have to be used. For this purpose, the global models GTOPO30 (30" resolution) and SRTM3 (3" resolution) are considered. The SRTM3 model has been released recently from the analysis of the Shuttle Radar Topography Mission and covers the latitudes between 60°N and 54°S, while the GTOPO30 model is a global public domain data set completed already in 1996.

In this contribution, 1" x 1" national DEMs for Germany are used to evaluate the global models. The differences between the best national models and the SRTM3 data show a standard deviation of 7.9 m with maximum differences up to about 300 m. The largest differences are located in open-cast mining areas and result from the different epochs of the DEMs. Histograms of the differences reveal a clear deviation from the normal distribution with a long tail towards too high SRTM3 elevations. The evaluation of GTOPO30 shows that the longitudes should be increased by 30" (one block) in Germany. For the shifted GTOPO30 DEM, the standard deviation of the differences with respect to the best national model is 6.8 m, roughly 75 % smaller than for the original model.

Keywords. Digital elevation model, DEM, terrain data, DEM evaluation, SRTM3, GTOPO30

1 Introduction

High resolution digital elevation models play an important role in gravity field modelling, as the short wavelength gravity field variations are highly correlated with the topography. The modelling is usually based on the remove-restore procedure, where the terrain data are used to smooth the gravity field observations in order to avoid aliasing effects and to facilitate gridding and field transformations, for details see, e.g., Forsberg and Tscherning (1981), Denker (1988), Forsberg and Sideris (1989), and Sideris and Forsberg (1991).

In view of continental geoid computations, e.g., for Europe (Denker and Torge 1998), it has to be considered that digital elevation models (DEMs) are not available for some countries, either because they have not been created or because of confidentiality reasons. Therefore, in these areas fill-ins from global models have to be used. For this purpose, the SRTM3 model with a resolution of 3" × 3" (JPL, 2004) and the public domain global model GTOPO30 with a resolution of 30" × 30" (LP DAAC, 2004) can be used.

In this contribution, 1" x 1" national DEMs for Germany are used to evaluate the global models SRTM3 and GTOPO30. The differences between the national DEMs and the SRTM3 and GTOPO30 models are analyzed and the statistics are provided for different relief types. Moreover, the terrain models are compared to elevations from gravity stations.

2 Digital Elevation Models (DEMs)

A short description of all digital elevation models (DEMs) used in this study is given in Table 1. The area of investigation is between 47° - 56° north latitude and 5° - 16° east longitude.

The Shuttle Radar Topography Mission (SRTM) occurred Feb. 11-22, 2000 and successfully fulfilled all mission objectives. The SRTM data covers most of the land surfaces between 60° north latitude and 54° south latitude (targeted land coverage was 80% of the Earth's landmass). Following the calibration and validation phase, the raw data were processed continent by continent into digital elevation models. Details on the SRTM mission and concepts are explained, e.g., in Bamler (1999). So far, an unedited data set with a resolution of 3 arc second (SRTM3) was released to the public domain. This product is preliminary and is distributed for evaluation by the research and applications user community. It can be downloaded from ftp://edcsgs9.cr.usgs.gov/pub/data/srtm/ (USGS, 2004). The National Geospatial-Intelligence Agency

Table 1. Digital elevation models (DEMs) for the area 47°N – 56°N and 5°E – 16°E.

DEM	Resolution	Accuracy	# elev.	# undefined elev.
SRTM3-1	3" x 3"	16 m	142,584,001	329,304
SRTM3-2	3" x 3"	16 m	142,584,001	0
GTOPO30	30" x 30"	30 m	1,425,600	256,077
FRG-1A	1" x 1"	20 m	1,283,040,000	613,792,787
FRG-1B	1" x 1"	20 m	1,283,040,000	619,754,163
FRG-2A	1" x 1"	20 m	1,283,040,000	612,159,380
FRG-2B	1" x 1"	20 m	1,283,040,000	618,606,658

(NGA) is currently editing and verifying the SRTM data to bring them into conformance with map accuracy standards, and these "finished" data will then be released to the public by the end of 2005 (JPL 2004). According to the accuracy specifications, the absolute vertical accuracy (90% linear error) is 16 meters and the absolute horizontal accuracy (90% circular error) is 20 meters for SRTM3 (Bamler, 1999; JPL, 2004). The elevations are given relative to the EGM96 geoid, and the horizontal datum is WGS84. Furthermore, it should also be noted that the SRTM is a "first return system" which provides elevations based on whatever the radar has bounced off from. While in many instances the elevations may be referring to actual ground level, this is not the case in dense forests, built-up areas, etc. (Showstack, 2003).

The presently available unedited "research-grade" SRTM3 data in particular may contain numerous voids (regions with no data) and other spurious points, and in addition to this, water bodies are not well-defined because they produce very low radar backscatter (JPL, 2004). Table 1 gives the statistics for the original (downloaded) SRTM3 data set, which is denoted as SRTM3-1. The number of undefined elevations in the study area is 329,304, i.e. 0.23% of all values. The SRTM3-1 model is also depicted in Fig. 1, where the undefined elevations are shown as black dots. In flat areas, most of the undefined values are associated with water bodies, e.g., along the Rhine and Danube river and in lake districts. Moreover, a significant number of undefined elevations are located in the Alps area with very high mountains and narrow gorges. As a complete DEM is required in gravity field modelling applications, a second version, denoted as SRTM3-2, was created, where the undefined elevations were replaced with interpolated values from neighbouring data (weighted mean).

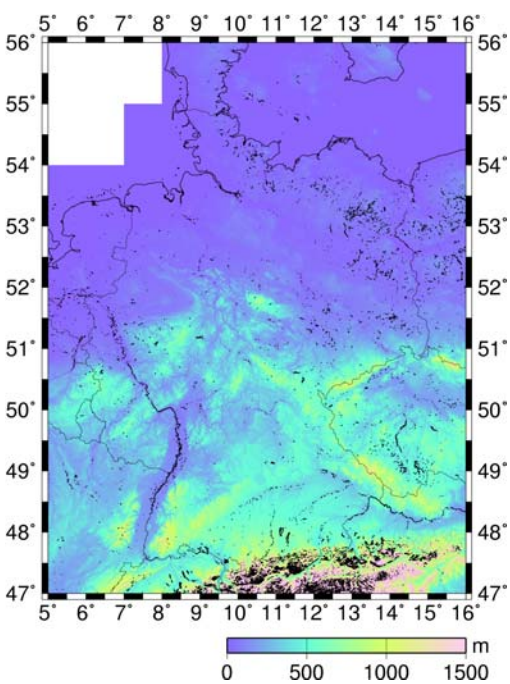

Fig. 1. SRTM3-1 digital elevation model. Data voids are marked as black dots.

Moreover, also the GTOPO30 data with a resolution of 30" × 30" (LP DAAC, 2004) were considered in this investigation, mainly because the SRTM data does not cover Northern Europe, which is part of our target area for geoid computations. The GTOPO30 data were downloaded by ftp from LP DAAC (2004). The DEM has global coverage and was derived from several raster and vector sources of topographic information. The horizontal coordinates refer to WGS84 and the elevations are referenced to mean sea level (MSL). The accuracy varies by location according to the source data. In Germany, the major data source is the digital terrain elevation data (DTED) from NGA (e.g., NGA, 1996) and the vertical accuracy is specified as 30 meters (90% linear error). The GTOPO30 DEM is also listed in Table 1; the undefined values are all located in ocean areas and were replaced by zero values for the subsequent comparisons.

The national DEMs originate from the German Military (AMilGeo, 1992) and have a resolution of 1" × 1". The models cover the territory of Germany and were derived by digitization of 1:50,000 maps in the years 1985 to 1990. The horizontal datum of the models used in this study is WGS84. The elevations are referenced to MSL. The absolute vertical accuracy (90% linear error) is specified as 20 meters and the absolute horizontal accuracy (90% circular error) is 26 meters (AMilGeo, 1992). Several versions of the original DEM were derived (see Table 1). The original DEM is FRG-1A, while the model FRG-2A contains some updates south of 49.5°N latitude. In addition, the versions FRG-1B and FRG-2B were derived from the corresponding "A" versions by excluding data in two sub-areas outside of Germany, located in the Alps Mountains (Austria) and Ore Mountains (Czech Republic); this was done because in these areas obviously less accurate fill-ins were used in the national DEMs (see also below). Table 1 summarizes the main features of the national DEMs.

For the evaluation of the SRTM3 and GTOPO30 DEMs, the 1" × 1" elevations from the national DEMs were averaged to 3" × 3" and 30" × 30" grids, respectively. During this step, also a re-interpolation was necessary due to the underlying different grid coordinate systems.

3 Evaluation of SRTM3

The SRTM3 DEMs were evaluated by comparisons with the national models. The statistics of the differences are provided in Table 2. Moreover, the differences between the original SRTM3-1 model and the national models FRG-1A and FRG-2A are depicted in Figs. 2 and 3 for the complete study area (top) as well as for a sub area in southern Germany (middle). In addition, Figs. 2 and 3 (bottom) also contain histograms of the corresponding differences for the complete study area.

From Figs. 2 and 3 it is clear that the largest differences between the SRTM3-1 and national DEMs are located in southern Germany in the mountainous Alps region, in the Czech Republic, as well as in the opencast mining districts around Leipzig and Halle, north of Dresden (Lausitz) and west of Cologne. The discrepancies in the mining districts are clearly related to the different epochs of the DEMs, i.e. the SRTM data are up-to-date, while the national DEMs were created in the 1980s. From Figs. 2 and 3 it is also clear that the agreement between the SRTM3-1 DEM and the national FRG-2A model is superior as compared to the FRG-1A model. Moreover, Fig. 3 documents that FRG-2A contains low quality fill-ins in some areas in southern Germany and to some extent also in the Czech Republic. This was the main reason for removing the two sub-areas shown in Figs. 2 and 3 (marked by dotted patterns), leading to the corresponding FRG-1B and FRG-2B DEMs, respectively.

The statistics of the differences, shown in Table 2, also prove that the largest differences are located in the two sub-areas mentioned above. In the comparisons of the original SRTM3-1 DEM with the FRG-1B and FRG-2B models, the standard deviations reduce by about 3% as compared to the corresponding FRG-1A and FRG-2A models, and the maximum differences reduce from more than 800 m for the "A" models to about 350 m for the "B" models. The comparison with the national DEM FRG-2B yields a standard deviation of the differences of 7.9 m with maximum discrepancies up to 324 m (0.08 % of the differences are larger than 50 m and 0.01 % are larger than 100 m). For FRG-1B the corresponding figures are slightly larger, i.e. the standard deviation is 8.3 m and the maximum discrepancy is 365 m (0.14 % of the differences are larger than 50 m and 0.02 % are larger than 100 m).

In all comparisons of the SRTM3-2 models, where the data voids have been filled by a simple weighted mean prediction, the discrepancies with the national DEMs deteriorate as compared to the original SRTM3-1 data set. The relevant standard deviations increase by about 10 % and the maximum differences go up to about 900 m for both the "A" and "B" versions of the national DEMs (see Table 2). A more detailed inspection of the results

Table 2. Differences between 3" × 3" DEMs. Units are m.

Difference	#	Mean	Stddev	Min	Max
SRTM3-1 - FRG-1A	74,234,512	+2.69	8.56	-447.0	+848.0
SRTM3-1 - FRG-1B	73,589,462	+2.68	8.30	-365.0	+339.0
SRTM3-1 - FRG-2A	74,405,567	+2.74	8.16	-421.0	+848.0
SRTM3-1 - FRG-2B	73,710,998	+2.72	7.90	-324.0	+258.0
SRTM3-2 - FRG-1A	74,373,176	+2.67	9.42	-818.0	+848.0
SRTM3-2 - FRG-1B	73,708,498	+2.66	9.02	-818.0	+848.0
SRTM3-2 - FRG-2A	74,554,083	+2.69	9.48	-941.0	+918.0
SRTM3-2 - FRG-2B	73,835,063	+2.69	8.95	-941.0	+918.0

Table 3. Differences SRTM3-1 minus FRG-2B (3" x 3" DEMs) for different relief types. Units are m.

Relief	#	Mean	Stddev	Min	Max
low	38,417,922	+0.53	6.00	-320.0	+162.0
medium	34,342,758	+5.02	8.84	-213.0	+230.0
alpine	950,318	+8.10	12.27	-324.0	+258.0

Table 4. Differences between 3" × 3" DEMs and gravity station heights (gelev). Units are m.

Difference	#	Mean	Stddev	Min	Max
FRG-1A - gelev	247,017	+0.14	6.37	-270.1	378.4
FRG-1B - gelev	247,017	+0.14	6.37	-270.1	378.4
FRG-2A - gelev	247,017	+0.17	6.24	-149.1	378.4
FRG-2B - gelev	247,017	+0.17	6.24	-149.1	378.4
SRTM3-1 - gelev	246,900	+1.87	6.94	-210.2	389.5
SRTM3-2 - gelev	247,017	+1.85	7.95	-795.2	594.4

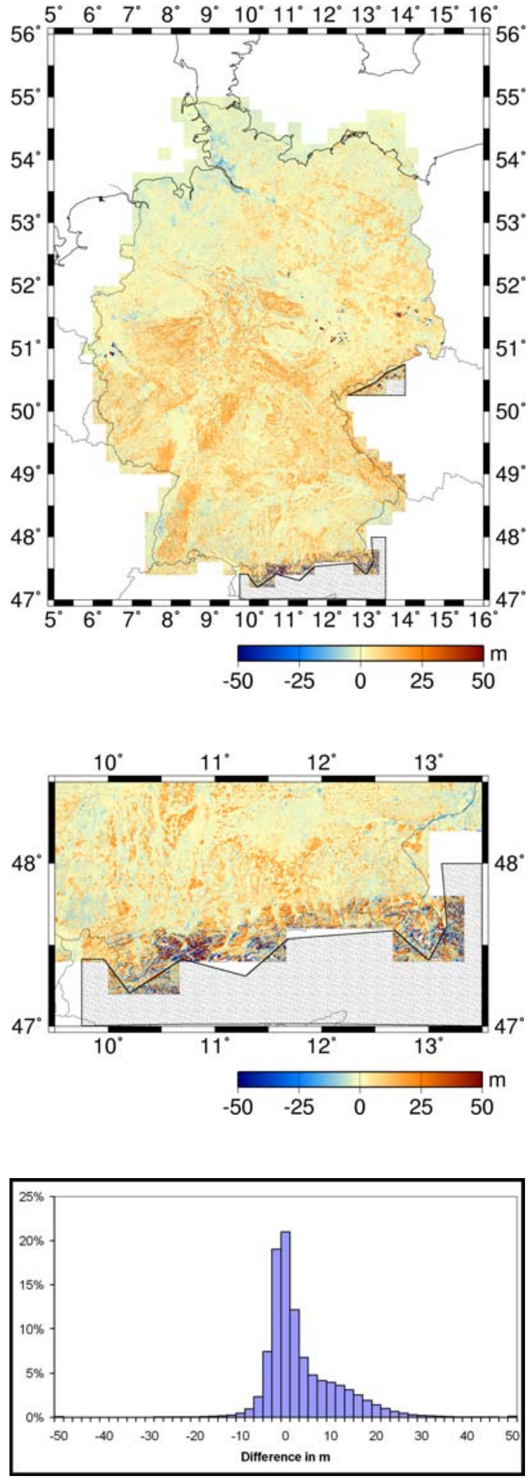

Fig. 2. Differences SRTM3-1 minus FRG-1A for complete study area (top) and a sub area in southern Germany (middle), supplemented by a histogram of all differences (bottom). The two polygon sub-areas excluded in the corresponding FRG-1B model are marked by dotted patterns.

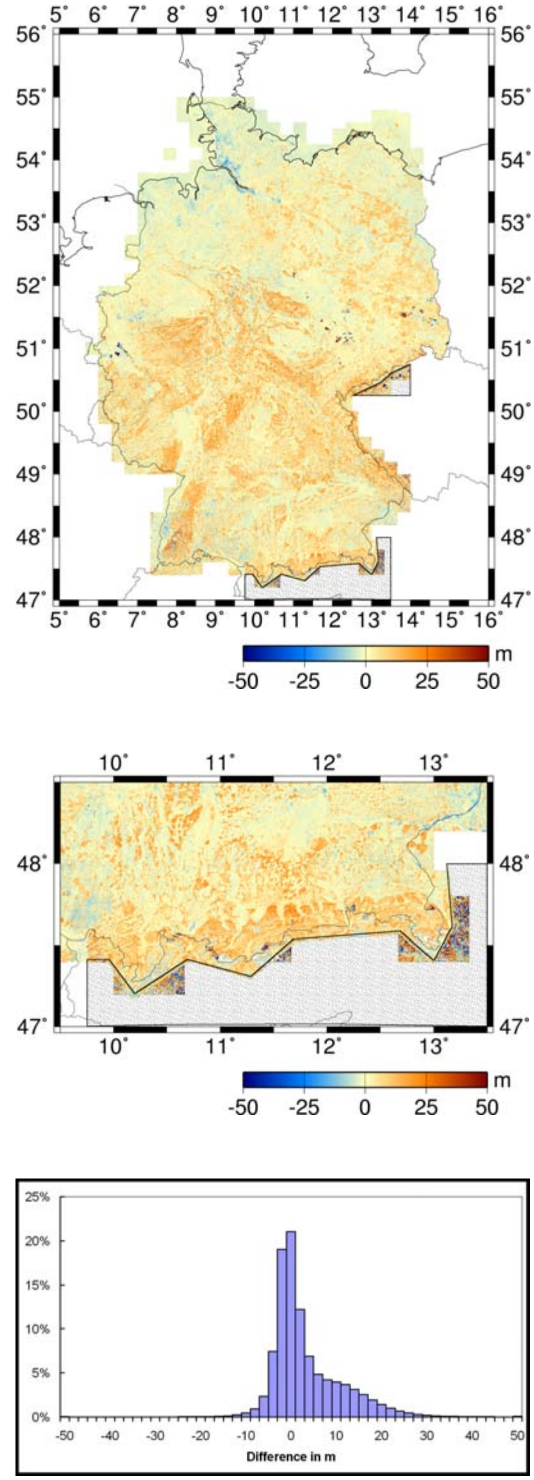

Fig. 3. Differences SRTM3-1 minus FRG-2A for complete study area (top) and a sub area in southern Germany (middle), supplemented by a histogram of all differences (bottom). The two polygon sub-areas excluded in the corresponding FRG-2B model are marked by dotted patterns.

shows that small data voids can be filled by interpolation, but larger data voids in mountainous areas should not be filled by interpolation, as this may lead to large errors. Thus the data voids in the SRTM data pose a significant problem for a number of applications.

Table 3 provides the statistics of the differences between the original SRTM3-1 DEM and the national FRG-2B model for different relief types. While for all three relief types the maximum discrepancies go up to about 300 m, the standard deviations are varying (6.0 m for low, 8.8 m for medium, and 12.3 m for alpine relief).

Furthermore, the histograms of the differences between SRTM3-1 and FRG-1A and FRG-2A (Figs. 2 and 3) show a quite obvious deviation from the normal distribution. There is a long tail towards too high elevations of the SRTM3 model, which is expected due to the fact that SRTM is a "first return system", providing elevations of whatever the radar has bounced off from, and in many instances this is above the actual ground level, e.g., in dense forests, built-up areas, etc. (Showstack, 2003).

Another evaluation of the 3" × 3" DEMs was done by comparisons with the elevations from gravity stations in Germany. The statistics of the differences are provided in Table 4. The standard deviations of the differences are 6.4 m and 6.2 m for the national models FRG-1A/B and FRG-2A/B, respectively and the maximum discrepancies go up to 378 m. The comparisons with the "A" and "B" DEM versions yield identical results, because there are no gravity stations located in the two excluded areas (see Figs. 2 and 3). For the SRTM3-1 and SRTM3-2 DEMs, the standard deviations increase to 6.9 m and 8.0 m, respectively. For SRTM3-2, with the data voids filled by interpolation, some very large differences up to about 800 m show up. This confirms the above conclusion, that the interpolation of larger data voids must be handled with care.

4 Evaluation of GTOPO30

The GTOPO30 DEM was evaluated by comparisons with the national and SRTM3 models. For this purpose, the latter models were averaged using all defined elevations within a 30" × 30" cell. Table 5 shows the statistics for selected comparisons. In addition to the original GTOPO30 model, also a shifted version (GTOPO30-S) was considered, where the longitudes were increased by 30" (one block). This was suggested by a correlation analysis between the original GTOPO30 and national DEMs.

Table 5 clearly proves that the shifted version GTOPO30-S yields a significantly better agreement with the national and SRTM3 data than the original model. The standard deviations of the differences between the original GTOPO30 model and the national and SRTM3 models are about 27 m and

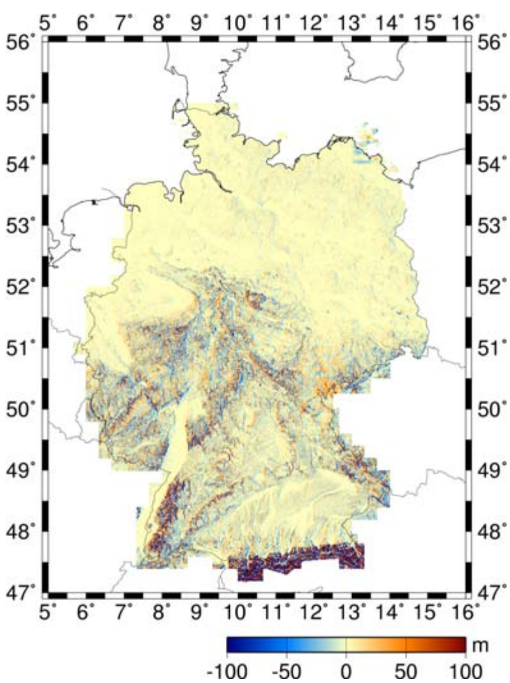

Fig. 4. Differences GTOPO30 minus FRG-2A.

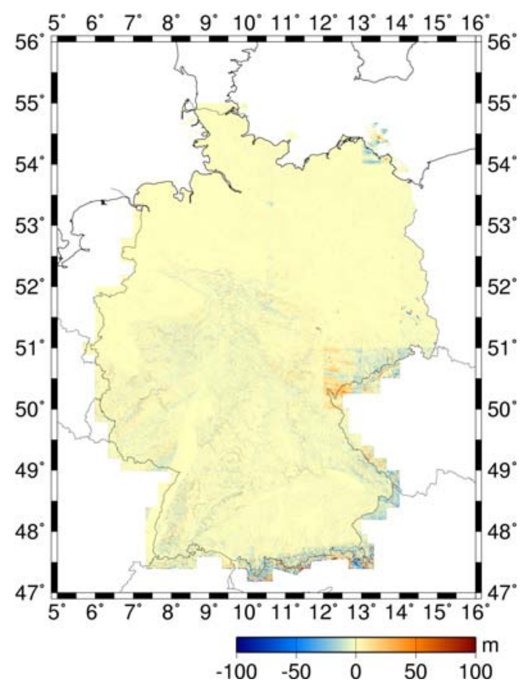

Fig. 5. Differences GTOPO30-S minus FRG-2A.

Table 5. Differences between 30" × 30" DEMs. Units are m .

Difference	#	Mean	Stddev	Min	Max
GTOPO30 - FRG-1B	705,414	-0.37	26.93	-743.0	+567.0
GTOPO30 - FRG-2B	706,627	-0.33	27.68	-811.0	+619.0
GTOPO30 - SRTM3-1	1,169,356	-3.65	42.26	-912.0	+852.0
GTOPO30 - SRTM3-2	1,169,523	-3.69	42.00	-769.0	+702.0
GTOPO30-S - FRG-1B	705,337	-0.59	6.86	-688.0	+434.0
GTOPO30-S - FRG-2B	706,550	-0.56	6.77	-674.0	+460.0
GTOPO30-S - SRTM3-1	1,169,197	-3.75	11.57	-610.0	+730.0
GTOPO30-S - SRTM3-2	1,169,364	-3.79	11.30	-797.0	+550.0

42 m, respectively. The corresponding values for GTOPO30-S are about 6.8 m and 11.5 m, respectively. Thus the longitude shift reduces the differences by roughly 75 %, which is a very significant improvement. The improvement of GTOPO30-S versus the original version is also quite obvious from Figs. 4 and 5, showing the differences between the two GTOPO30 versions and the national model FRG-2A. The maximum differences up to almost 800 m occur in the mountainous parts of the study area (in the Alps). Moreover, some patterns are visible around the Ore Mountains, related probably to the compilation of the GTOPO30 data.

The GTOPO30 DEMs were also compared with the elevations from gravity stations in Germany. The standard deviation of the differences is 30.3 m for the original version and 19.2 m for GTOPO30-S (max. 480 m), and accordingly for the 30" × 30" SRTM and national DEM versions standard deviations from 19.9 m to 20.9 m are obtained.

5 Conclusions

The SRTM3 digital elevation models (DEMs) were evaluated by comparisons with national models for Germany. Two SRTM3 versions were considered. The first model (SRTM3-1) consists of the original data, while in the second model (SRTM3-2) the undefined elevations (data voids) were replaced by interpolated values from neighbouring data (weighted mean). The comparisons revealed that one of the national models contained less accurate fill-ins in some areas outside of Germany. After excluding these areas, the differences between the best national model (FRG-2B) and the SRTM3-1 DEM show a standard deviation of 7.9 m with maximum differences up to about 300 m. The largest differences are located in opencast mining areas and result from the different epochs of the data. The differences were also analyzed for different relief types, yielding standard deviations of 6.0 m for low, 8.8 m for medium, and 12.3 m for alpine relief. Furthermore, histograms of the differences show a clear deviation from the normal distribution with a long tail towards too high SRTM3 elevations. For the SRTM3-2 model, the comparison results deteriorate, i.e. the standard deviation with respect to the best national model is 9.0 m and the maximum differences go up to about 940 m, showing that the filling of data voids by interpolation must be handled with care. Additional comparisons with elevations of gravity stations in Germany gave a standard deviation of the differences of 6.9 m for SRTM3-1 and 8.0 m for SRTM3-2. To sum up, the SRTM3 DEM fully complies with the accuracy specifications.

The evaluation of the GTOPO30 model by national and SRTM3 DEMs demonstrated that in Germany the longitudes of GTOPO30 should be increased by 30" (one block). The longitude shift reduced the standard deviation of the differences to the national and SRTM3 models by roughly 75 %, yielding final values of about 6.8 m and 11.5 m for the national and SRTM3 models, respectively.

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