



Influence of digital elevation model resolution on gravimetric terrain correction over a study-area of Croatia

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High-resolution digital elevation models (DEMs) have become available in the last decade. They are used in geodesy and geophysics as the main data for modeling of topographic mass effects included in gravimetric and gradiometric measurements. In modeling process, gravimetric terrain correction is the central quantity which accounts for the variations of topographic masses around measured stations. This study deals with one segment of terrain correction computation: the impact of the resolution of digital elevation models. Computations are performed on study area of Republic of Croatia. Newly created DEM/DBM for the study area is created from global digital surface model ASTER for continental area, and digital bathymetric model GEBCO for the sea area. DEMs with lower resolution were created by resampling of the created ASTER/GEBCO DEM/DBM in 1" resolution. Terrain correction map is computed and published for the first time for the Republic of Croatia. The differences between terrain correction solutions obtained by using lower resolution DEMs compared to the solution obtained by using DEM with 1" are indicating average influence of DEM resolution on terrain correction from $0,5 \cdot 10^{-5}$ to $3 \cdot 10^{-5}$ m s⁻², for DEMs with lower resolution than 5". The results also reveal that rugged and mountainous areas are particularly problematic in such computations.

Keywords: ASTER, digital elevation model, GEBCO, resolution, terrain correction

1. Introduction

Gravity measurements are used in many scientific and expert tasks in geosciences. Depending of the required accuracy of specific task, measurements are reduced for different effects, such as instrumental errors, tidal influence, air pressure, as well as topographic effects. According to Tsoulis and Tziavos (2002) reduction of topographic effects is the central issue in local and regional model-

ing of the Earth's gravity field. In geodesy, topography-reduced gravity measurements are used in modelling of the geoid as the reference surface for physical heights systems (e.g. Hackney and Featherstone, 2003). Terrain correction represents the most significant and sensitive part of the full budget of topographic effect in gravity measurement as it filters variations of topographic effects and density anomalies. In geophysics, terrain correction is used for reduction of the residual topographic effects together with gravitational effect of the spherical or plane Bouguer plate. Complete Bouguer anomalies are obtained as a results, which are used in investigations of the Earth's internal structure (LaFehr, 1991; Brkić, 1994; Hackney and Featherstone, 2003; Hofmann-Wellenhof and Moritz, 2005). In geophysical explorations demands on the accuracy of gravity measurements after applying all corrections is around $0.035 \cdot 10^{-5} \text{ ms}^{-2}$ (Leaman, 1998). Thereby corrections and filtering of all external effects should be applied with at least the same order of accuracy and significance level.

In the past, before modern computers became widely spread, terrain correction was calculated by division of topography around gravity station on Hammer zones (Hammer, 1939). This was a tedious task which was often ignored except in the areas of most complex and mountainous topography. One of the first terrain correction computations using DEMs, in which heights are defined in a regular grid, was performed by Kane (1962). Since then, many authors have improved methods and algorithms for terrain correction computation (Sideris, 1985; Parker, 1995; Tsoulis, 1998; Brkić, 2001; Tsoulis, 2001). Cogbill (1990) improved former methods and applied new method for terrain correction computation up to the distance of 250 m from the gravity stations. Forsberg (1993) studied effects of topography in local and regional geoid modeling. Brkić (1994, 2001) improved terrain correction computational methods in spatial and spectral domains by implementation of three-dimensional crustal models. He made initial computation with three layers of depths and densities over the part of the Republic of Croatia. Chen and Macnae (1997) computed terrain correction for aero-gradiometric measurements and concluded that crustal density has to be known with an accuracy of 100 kg m^{-3} or better. Banerjee (1998) reduced gravimetric measurements in highly demanding area of north-western Himalayas. He presented new computational method and obtained terrain effects within 170 km from gravity measurements. His method resulted in much smoother gravity anomalies compared to other methods. Nowell (1999) gives an overview on gravity terrain correction and discusses some special cases for computations such as readings on the seabed, towers and under ground. Bajracharya and Sideris (2005) and Tziavos et al. (2010) studied aliasing and systematic effects of digital elevation models on different topographic reduction methods, such as Helmert's second condensation method, Rudzki's method, etc. Hećimović and Bašić (2006) investigated impact of the DEM resolution on residual terrain model (RTM) correction for gravity anomalies and geoid undulations. The smoothest field was obtained when $20' \times 30'$ DEMs were used.

Apart from hereby presented references and large number of other studies, the influence of DEM resolution and accuracy on terrain correction, as well as variable density of topographic masses, have not been researched enough (Huang, 2012).

For achieving higher reliability of computed topographic effects, each improvement of the computational method or inclusion of input digital elevation model (DEM) of higher accuracy or resolution should be considered. Therefore, the main objective of this study is to obtain more detailed information on one important aspect of terrain correction computation- impact and effect of resolution in DEMs on the accuracy of gravimetric terrain correction. According to *e.g.* Tziavos et al. (2010) DEMs have a crucial role in gravity field related studies. At the regional and continental spatial scales DEMs with *very* high resolution, such as SRTM DEM in 1", have become available only in the last few years, therefore no similar empirical studies have been published so far. As resolution is one of DEMs main attributes (along with vertical accuracy) which affects both accuracy and speed of computations of terrain effects, it is necessary to evaluate the error which emerges due to the usage of lower resolution DEMs.

The structure of this paper is as follows. The introduction to digital elevation models (DEMs) is given in the first part of this paper. Models used for computations, digital surface model ASTER (Advanced Spaceborne Thermal Emission and Reflection; see, Tachikawa et al., 2011) and digital bathymetric model (DBM) GEBCO (General Bathymetric Chart of the Oceans; see, Mayer et al., 2018), are described. The concept of terrain correction, including mathematical equations, is explained. Creation of the first high resolution DEM/DBM model for the territory of Republic of Croatia is briefly explained as well as steps of post-processing where lower-resolution DEMs are obtained. Results of the numerical study are presented in the results section. Results of terrain correction computed with high resolution DEM are compared with results of computed terrain correction using lower resolution DEMs. The differences between very-high resolution DEM solution and numerous lower-resolution DEMs shall indicate the influence of DEM resolution on terrain correction values over the study area.

2. Terrain correction

Terrain correction (δg_{tc}) is geophysical quantity which filters gravitational effect caused by topographic masses around measured gravity station. It is computed analytically using numerical integration or spectrally using fast fourier transforms (FFT).

Initial formulas are derived from the *Newton's Universal law of gravity* for gravity potential of three-dimensional body in the outer *mass-free* space. Derived

formula for terrain correction δg_{tc} in plane approximation is (Tziavos and Sideris, 2013, pp. 344):

$$\delta g_{tc}(x_P, y_P, H_P) = G \iiint_H^{H_P} \frac{\rho(x, y, z)(H_P - z)}{\sqrt{(x_P - x)^2 + (y_P - y)^2 + (z_P - z)^2}} dx dy dz \quad (1)$$

where: P is gravity station (computational point) for which terrain correction is calculated, (x_p, y_p) are plane coordinates of gravity station P , H orthometric heights above geoid, (x, y, z) local Cartesian coordinates of integration points (centroid of the geometrical bodies), G universal gravitational constant (Mohr et al., 2016), $\rho(x, y, z)$ density of topographic masses.

The principle of computation is in splitting topography around gravity station on regular geometrical bodies for which gravitational effect may be calculated using analytic equations. Terrain correction is then obtained by summing up gravitational effects of all geometrical bodies around gravity station up to some distance. Among many others (see, e.g. Tsoulis et al., 2003; Heck and Seitz, 2007), rectangular prisms are one of the possible geometrical bodies which can approximate topography. Exact analytic expression for terrain correction of the rectangular prism is (Nagy 1966, Garcia Abdeslem 1992, Nagy 2000):

$$\delta g_{tc} = G\rho \left\| \left\| \left\| x \ln(y+r) + y \ln(x+r) - z \tan^{-1} \left(\frac{xy}{zr} \right) \right\|_{x_1}^{x_2} \right\|_{y_1}^{y_2} \right\|_{z_1}^{z_2} \quad (2)$$

where: $r = \sqrt{x^2 + y^2 + z^2}$, (x, y, z) are planar coordinates of prism's tops. According to equation (2), terrain correction for each rectangular prism Q is obtained by integration over eight tops (Fig. 1).

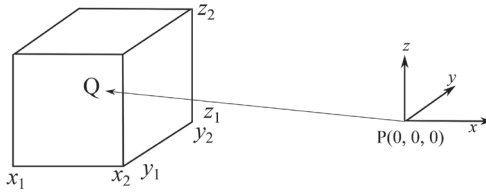


Figure 1. Rectangular prism Q with constant density value ρ (Nagy, 1966).

Coordinates of rectangular prism $x_1, x_2, y_1, y_2, z_1, z_2$ are obtained by conversion from geodetic to planar coordinates according to:

$$x_1 = R \frac{2\pi}{360} \left(\lambda_Q - \lambda_P - \frac{\Delta\lambda}{2} \right) \cos\varphi_P, \quad x_2 = R \frac{2\pi}{360} \left(\lambda_Q - \lambda_P + \frac{\Delta\lambda}{2} \right) \cos\varphi_P$$

$$y_1 = R \frac{2\pi}{360} \left(\varphi_Q - \varphi_P - \frac{\Delta\lambda}{2} \right), y_2 = R \frac{2\pi}{360} \left(\varphi_Q - \varphi_P + \frac{\Delta\lambda}{2} \right)$$

$$z_1 = 0, z_2 = H.$$

Total value of terrain correction is obtained by summing up contributions from all rectangular prisms Q_i in an integration area around gravimetric point P . It is crucial to precisely compute gravitational effect for the area in the nearest proximity because topographic masses there have highest contributions and then decrease with increasing distance from the gravity station. For larger distances from the gravity station, computationally intensive equation (2) may be replaced with approximative expression (MacMillan, 1958; Forsberg, 1984):

$$\delta g_{tc} = G\rho \left[xy \log(z+r) + xz \log(y+r) + yz \log(x+r) - \frac{x^2}{2} \tan^{-1} \frac{yz}{xr} - \frac{y^2}{2} \tan^{-1} \frac{xz}{yr} - \frac{z^2}{2} \tan^{-1} \frac{xy}{zr} \right] \quad (3)$$

which will significantly decrease computational speed under negligible errors.

The most important input data for computations are heights H which are taken from some available DEM. Another important parameter is selection of the representative crustal density for the computational study-area. Usually, density is approximated by some constant value, such as 2670 kg m^{-3} , which is considered as globally most optimal mean value of crustal density (*e.g.* Hinze 2003). Independently from computational method and used DEMs, the accuracy of computations is limited by several factors such as: i) planar approximation of terrain, ii) singularity of mathematical expressions, iii) inaccuracies in geometry of the body which approximates topography, iv) errors in heights from DEM, v) non-existence of reliable and realistic density models, etc. (Brkić and Bašić, 2000, Brkić 2001; Hackney and Featherstone, 2003; Bašić and Bjelotomić, 2014).

3. Methods

Fortran code TC, distributed within geoid modelling programming package GRAVSOF (engl. Geodetic Gravity Field Modelling Programs) is used in computations (Forsberg, 1984; Forsberg and Tscherning, 2008). Practical implementation of computations in TC is done by division of topography in two zones, near and far, depending of the distance from computation point, which regulated by two parameters – radiuses r_1 and r_2 (Fig. 2). Two types of DEMs have to be prepared as input data; one with higher resolution (fine DEM), and one with lower resolution (coarse DEM). Coarse DEM is obtained by averaging of fine DEM

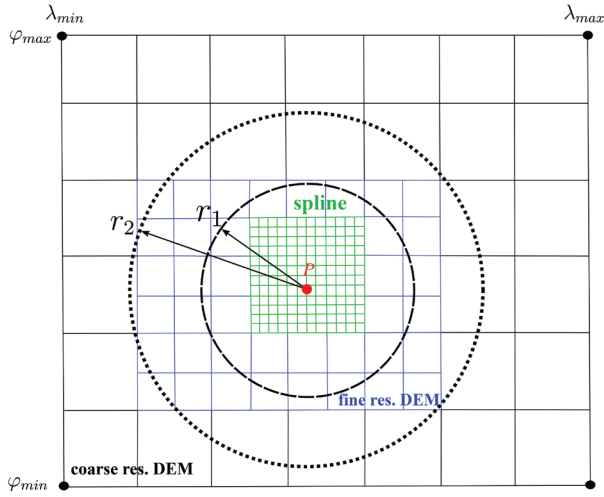


Figure 2. Implementation of fine and coarse DEMs depending of the radiuses of integration r_1 and r_2 .

using some commonly used gridding method, such as bilinear, bicubic or moving average.

Fine DEM is used up to the radius r_1 , and *coarse* DEM is used from radius r_1 to radius r_2 . For the value of radius r_1 it is enough to select double value of the cell size of coarse DEM, although 20 km seems to be standard value. For computation of far zone effects radius $r_2 = 200$ km may be used, with necessity to account for the effect of the Earth's curvature (Forsberg, 1984; Nowell, 1999). Equation (2) is used in *near* zone computations, whereas *far* zone effects are computed using approximative equation (3).

3.1. The main input data: Digital elevation models

Digital Elevation Models are the main input data in computations of terrain correction. Generally, DEMs provide information about the heights of the Earth's topography surface and as such have widespread usage in geodesy, geophysics, geoinformatics, hydrology, climatology, geography, navigation, etc. (Hirt et al., 2010). The term *digital elevation model* is typically used for two types of models: a) Digital Terrain Model (DTM), and b) Digital Surface Model (DSM). DTM refers to the heights of the Earth's terrain, whereas DSM refers to the surface which includes Earth's terrain and all other natural and man-made objects, such as vegetation and buildings (Wilson and Gallant 2000). DTM and DSM coincide in areas where there no external objects on the terrain surface (Maune, 2007). Although in this context the term DSM would be more appropriate, as used models include external objects, the term DEM is preferred due to its widespread usage.

DEM quality is described by the corresponding vertical accuracy, *i.e.* how well heights from DEMs describe *real* Earth's topographic surface. Vertical accuracy of DEM is a spatial variable affected by many factors, such as: measurement sensor, terrain complexity, land cover, model resolution, etc. It is typically estimated by using independent data of higher accuracy, such as levelling benchmarks, *i.e.* geodetic points with orthometric heights estimated precise levelling method (Varga and Bašić, 2015).

Initial DEM/DBM, used afterwards for creation of all other DEMs in lower resolutions, was compiled for the territory of $30^\circ < \varphi < 60^\circ$ and $0^\circ < \lambda < 30^\circ$ (Fig.3). Heights for continental areas are taken from ASTER DSM which is a nearly-global DEM with spatial resolution of $1''$ in terms of geographical coordinates, which corresponds to the 30 m distance in the plane, map projection, coordinates. It is freely available for geographic latitudes between $83^\circ \text{ N} < \varphi < 83^\circ \text{ S}$ in GeoTiff files, where each file covers $1^\circ \times 1^\circ$ area with heights in the grid having 3601

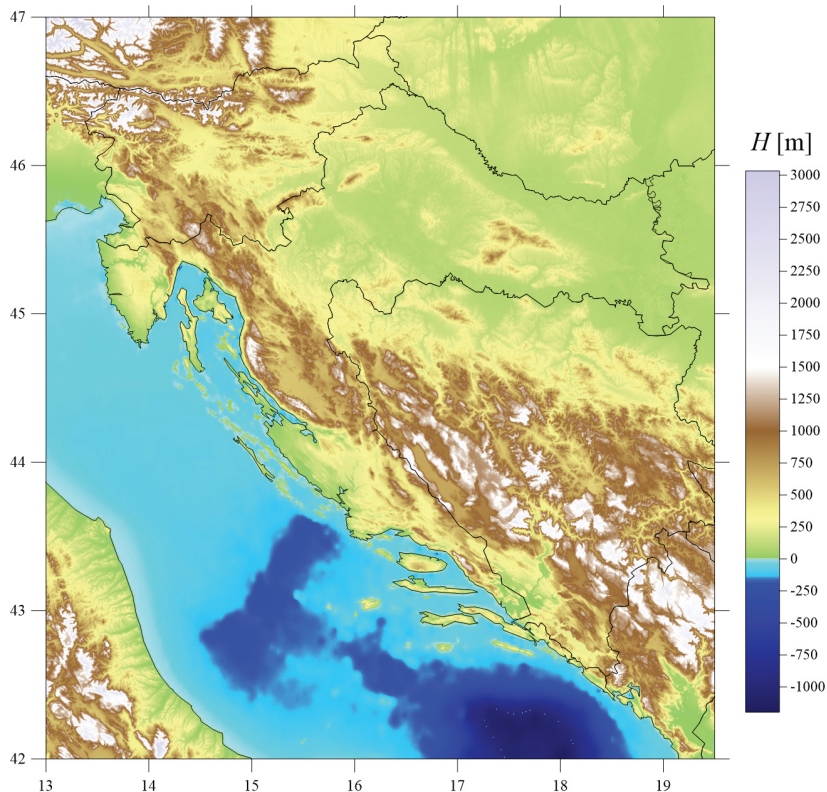


Figure 3. Initial ASTER/GEBCO DEM/DBM obtained as a combination of ASTER DSM-a with $1''$ resolution and global bathymetric model GEBCO2014 which was resampled from original from $30''$ to $1''$.

columns and 3601 rows. Two versions were published in 2009 and 2011, where latter is used in this research. Version 3 is announced and expected to be published which should have included measurements from the ASTER satellites from 2011 until 2017. Vertical accuracy of ASTER DEM version 2 across the continental part of the Republic of Croatia is $\pm 7,1$ m according to root mean square (RMS) (Varga and Bašić, 2013; Varga and Bašić, 2015).

As ASTER DEM does not include bathymetry, *initial* DEM/DBM was filled with depths from the global bathymetric model GEBCO2014 which is distributed in 30" resolution. As bathymetric model had to be resampled from lower 30" to 1" resolution, depths obtained from bathymetric model can be considered as minimally one order less accurate compared to the heights of continents.

After creation of the initial DEM/DBM with resolution 1", seven additional DEMs are created in resolutions 3", 5", 10", 15", 20", 30" and 60" for the area with geographic limits $41^\circ < \varphi < 47^\circ$ and $13^\circ < \lambda < 20^\circ$ using moving average gridding method in GS Surfer (Surfer[®] 13, Golden Software, LLC). Illustrative example of the same topographic detail represented by digital elevation models of different resolutions is given in Fig. 4. Loss of detailedness of topographic structures is evident as the resolution of DEM is lower. For example, the same topographic detail is not visible in sample with 30" compared to the sample having 1" resolution. These eight (8) models were used as fine DEMs in terrain correction computations. One coarse DEM is created with 30" resolution and geographic limits $30^\circ < \varphi < 60^\circ$ and $0^\circ < \lambda < 30^\circ$.

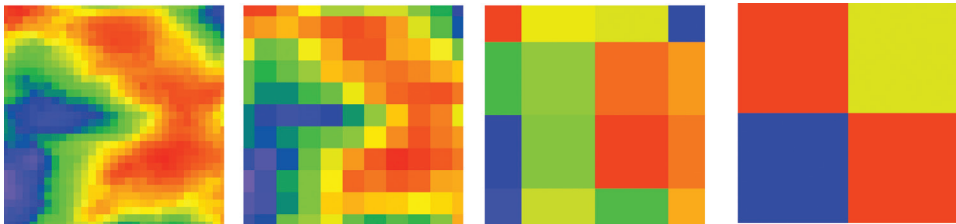


Figure 4. Illustrative example of the topographic detail represented by DEMs with different resolutions (from left to right: 1", 3", 10", 30").

3.2. Terrain correction computation

Terrain correction has been computed for the rectangular area with geographic limits $42.3^\circ < \varphi < 46.6^\circ$ and $13.3^\circ < \lambda < 19.5^\circ$ in resolution $60'' \times 60''$, which includes territorial area of the Republic of Croatia and smaller part of the surrounding countries, mainly Bosnia and Herzegovina, Hungary, Italy, Montenegro, Serbia and Slovenia. As topographic masses in Alpien area and Dinarides have large effects on gravity field, computational area was further extended for approximately 1° around the Croatian political borders (Fig. 5).

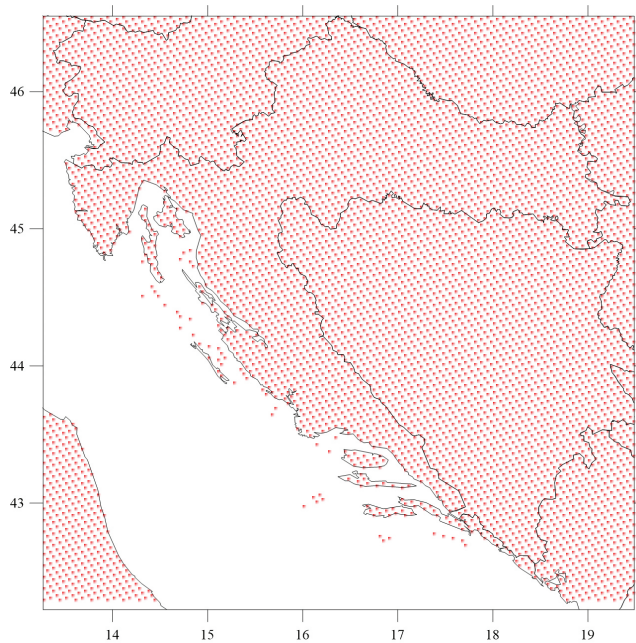


Figure 5. Study area and computation points.

Terrain correction in this study was computed only for continental areas, as terrestrial gravity data are usually available with much higher spatial resolution than marine gravity data, and bathymetry data have almost 30 times smaller resolution which would cause non-comparability of the results.

Results of computations are eight (8) different grids with values of terrain corrections δg_{tc} . Each resulting terrain correction grid covers geographical area $42.3^\circ < \varphi < 46.6^\circ$, $13.3^\circ < \lambda < 19.5^\circ$ in $1' \times 1'$ resolution; grid size is 256 rows and 374 columns, with 68 742 nodes over continental areas having values of terrain correction, and 27 002 blanked nodes over the Adriatic sea. For each solution *fine* DEM with different resolution has been used. In the first solution *fine* DEM has resolution 1", in the second solution resolution 3", and so on. For the sake of simplicity these solutions are referred in the further text as DEM1, DEM3, ..., DEM30, DEM60. *Coarse* DEM with resolution 60" and all other input parameters were fixed identical in all computations. After computations of terrain correction, differences between solutions obtained by using lower resolution DEMs, such as DEM5 (5"), or DEM30 (30"), and solution obtained using highest resolution DEM (DEM1 in 1") resolution, are computed. These differences between solutions indicate errors of computed terrain correction which are caused by using lower resolution DEMs instead of the one with highest available resolution.

4. Results

Table 1 shows statistics of computed terrain correction for each solution depending of *fine* DEM resolution. Statistics in all solutions are nearly similar for all statistical parameters maximal values (around $73 \cdot 10^{-5} \text{ m s}^{-2}$), arithmetic mean ($2.5 \cdot 10^{-5} \text{ m s}^{-2}$) and standard deviation ($4.1 \cdot 10^{-5} \text{ m s}^{-2}$), except for DEM60 solution which has evidently different statistics.

Figure 6 shows terrain correction computed using *fine* DEM with 1" resolution (DEM1 solution). Values of terrain correction for most of the study area, except for mountainous areas, do not exceed $2.5 \cdot 10^{-5} \text{ m s}^{-2}$. As expected, largest values are in mountainous and complex areas where terrain correction has maximal values up to $70 \cdot 10^{-5} \text{ m s}^{-2}$. In lower topography ($0 < H < 300 \text{ m}$) terrain correction has values smaller than $1 \cdot 10^{-5} \text{ m s}^{-2}$, in moderate terrain ($300 < H < 600 \text{ m}$) from 1 to $3 \cdot 10^{-5} \text{ m s}^{-2}$, while in more complex and rough areas ($H > 600 \text{ m}$) most values are larger than $3 \cdot 10^{-5} \text{ m s}^{-2}$.

Table 2 shows statistics of the absolute difference $|\delta g_{tc}|$ between terrain corrections computed using *fine* DEMs with different resolutions compared to the solution obtained using DEM1 in 1" resolution. Results are presented with absolute values $|\delta g_{tc}|$ as the objective here is to evaluate amount not direction and systematics of the error. All statistical parameters (maximum, arithmetic mean, standard deviation) of the absolute values of differences compared to the DEM1 solution are increased when solutions are obtained using DEMs with lower resolution. The exception is maximal difference of $8.8 \cdot 10^{-5} \text{ m s}^{-2}$ in DEM15–DEM1 which is smaller compared to the solution solution DEM10–DEM1 which has maximal difference $9.1 \cdot 10^{-5} \text{ m s}^{-2}$. The explanation for this might be very small difference between DEMs with resolution 10" and 15", which can also be confirmed in all other statistical parameters that are nearly identical. Maximal absolute values of differences between terrain corrections compared to the solution obtained using DEM with 1" resolution is $23 \cdot 10^{-5} \text{ m s}^{-2}$ is in the case when terrain correction is computed using DEM with 60" resolution. Standard deviation of the differences between terrain correction in DEMs with resolution 3" is

Table 1. Statistics of terrain correction (δg_{tc}) as a function of DEM resolution on a study area. Units: 10^{-5} m s^{-2} .

DEM resolution	1"	3"	5"	10"	15"	20"	30"	60"
Index of solution	DEM1	DEM3	DEM5	DEM10	DEM15	DEM20	DEM30	DEM60
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	75.1	73.8	73.5	71.7	69.3	71.0	73.6	68.1
Mean	2.6	2.5	2.5	2.5	2.3	2.4	2.2	1.9
St. dev.	4.3	4.1	4.1	4.1	4.0	4.1	4.0	3.6

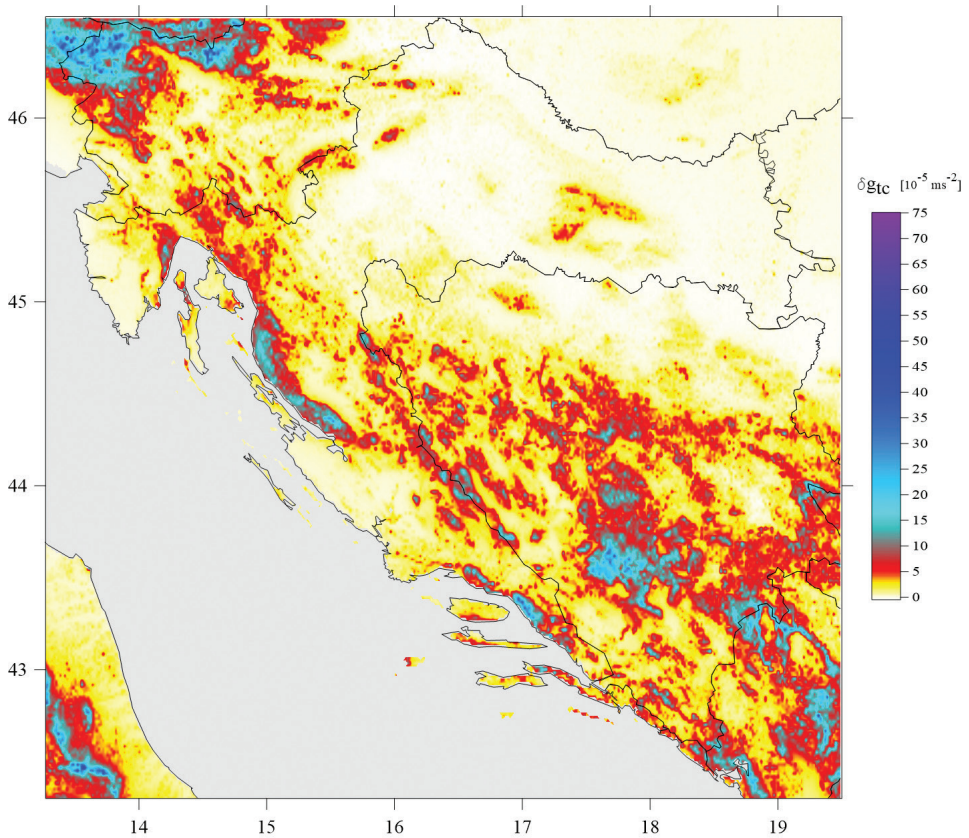


Figure 6. Terrain correction map.

$0.3 \cdot 10^{-5} \text{ m s}^{-2}$, whereas in DEMs with resolution $60''$ it is $1.6 \cdot 10^{-5} \text{ m s}^{-2}$ which indicated the accuracy of computed mean values of absolute values of differences between solutions.

Besides basic statistics (Tab. 2), absolute values of the differences between terrain correction solution ($|\delta g_{tc}|$) are separated in three classes: less than $0.5 \cdot 10^{-5} \text{ m s}^{-2}$, from $0.5 \cdot 10^{-5}$ and $3.0 \cdot 10^{-5} \text{ m s}^{-2}$, and larger than $3.0 \cdot 10^{-5} \text{ m s}^{-2}$. Afterwards, percentage of values in each class is calculated and presented in Tab. 3.

In the differences between solutions DEM3–DEM1 91% of absolute values of differences are smaller than $0.5 \cdot 10^{-5} \text{ m s}^{-2}$. Contribution of differences smaller than $0.5 \cdot 10^{-5} \text{ m s}^{-2}$ decreases with decrease of DEM resolution. For example, in differences DEM20–DEM1 it is 75%, for differences DEM30–DEM1 it is 66%, and for differences DEM60–DEM1 it is 58%. In the interval from 0.5 to $3.0 \cdot 10^{-5} \text{ m s}^{-2}$

Table 2. Statistics of the absolute values of differences between terrain corrections $|\delta g_{tc}|$. Units: 10^{-5} m s^{-2} .

	3"-1"	5"-1"	10"-1"	15"-1"	20"-1"	30"-1"	60"-1"
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	2.9	4.8	9.1	8.8	11.4	17.2	23.1
Arith. mean	0.2	0.2	0.3	0.4	0.4	0.7	0.9
St. dev.	0.3	0.4	0.6	0.6	0.7	1.1	1.6

Table 3. The percentage of absolute values of differences between terrain correction computed using DEMs with different resolutions and DEM1 solution divided in three classes.

	3"-1"	5"-1"	10"-1"	15"-1"	20"-1"	30"-1"	60"-1"
$ \delta g_{tc} < 0.5 \cdot 10^{-5} \text{ m s}^{-2}$	91%	87%	79%	78%	75%	66%	58%
$0.5 \cdot 10^{-5} \text{ m s}^{-2} < \delta g_{tc} < 3.0 \cdot 10^{-5} \text{ m s}^{-2}$	9%	13%	20%	21%	24%	30%	34%
$ \delta g_{tc} > 3.0 \cdot 10^{-5} \text{ m s}^{-2}$	0%	0%	1%	1%	2%	4%	8%

smallest number of values is in the difference between DEM3–DEM1, while most of the values in this class are in the differences between DEM30–DEM1 and DEM60–DEM1 having 30% and more.

For around 60–70% of the study area, differences are smaller than $2 \cdot 10^{-5} \text{ m s}^{-2}$. Differences are smaller in the areas of simple topography than in hilly and complex areas (Fig.7). Differences between terrain correction for DEM20, DEM30 and DEM60 in mountainous areas are generally larger than $3 \cdot 10^{-5} \text{ m s}^{-2}$, whereas maximal absolute values can even reach $10 \cdot 10^{-5} \text{ m s}^{-2}$.

5. Conclusions

In this study a new DEM/DBM in a 1" resolution is compiled for the territory of Republic of Croatia starting from ASTER DSM for continental area and GEB-CO2014 for sea area. Initially created ASTER/GEBCO DEM was used for creation of lower resolution DSMs that were used for obtaining different solutions of terrain correction.

Terrain correction map was created and published for the continental territory of the Republic of Croatia. Terrain correction is smaller than $5 \cdot 10^{-5} \text{ m s}^{-2}$ for most of the study area, although most prevailing values are from $1 \cdot 10^{-5} \text{ m s}^{-2}$ to $3 \cdot 10^{-5} \text{ m s}^{-2}$. In Velebit and Dinarides terrain correction may reach values up to $10 \cdot 10^{-5} \text{ m s}^{-2}$.

Differences are increased between terrain correction solutions $|\delta g_{tc}|$ with lower resolution DEMs compared to the solution obtained using 1" DEM. For example, differences between solutions 3"-1" and 5"-1" are mostly under $1 \cdot 10^{-5} \text{ m s}^{-2}$ even

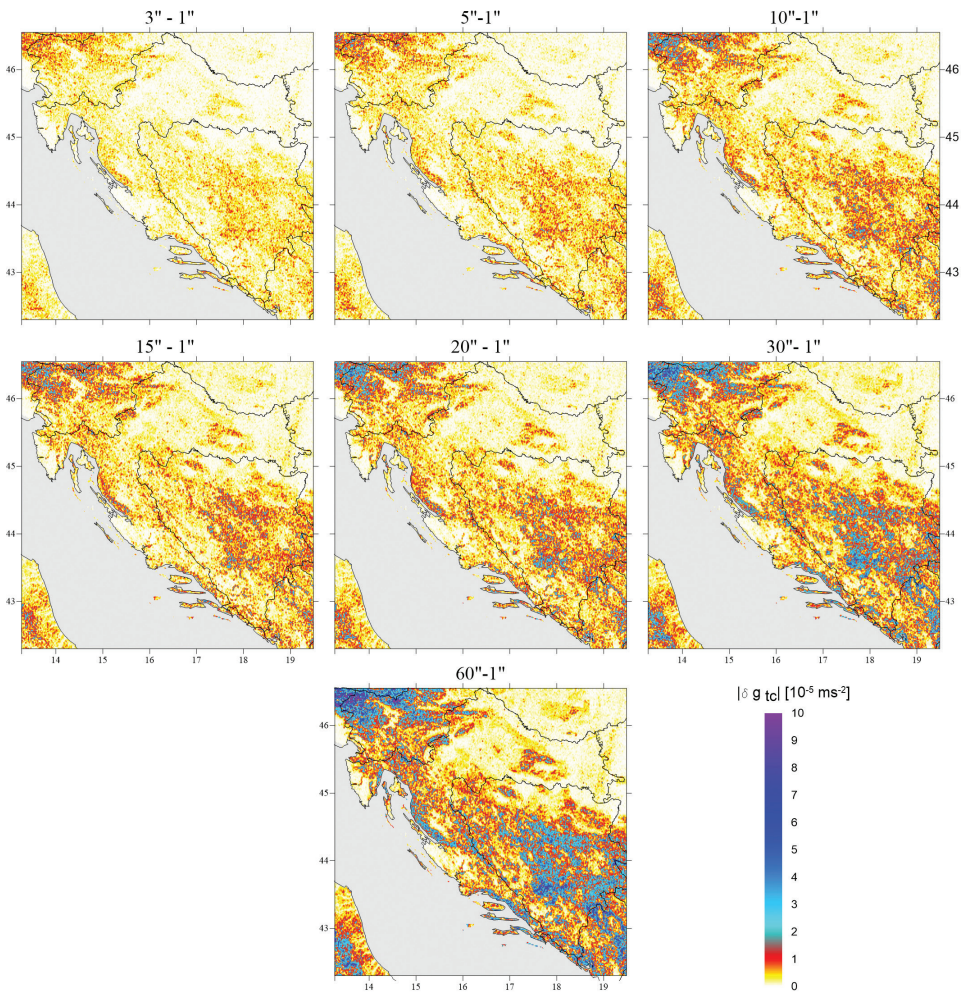


Figure 7. Absolute values of differences of terrain correction ($|\delta g_{tc}|$) computed using DEMs with lower resolution compared to the solution with highest 1" resolution.

for rugged topography. Around 90% of differences are less than $0.5 \cdot 10^{-5} \text{ m s}^{-2}$ in these areas. However, for DEMs with lower resolution DEM10, ..., DEM30, DEM60, differences are below $0.5 \cdot 10^{-5} \text{ m s}^{-2}$ only for lowland areas, whereas for other areas differences are above $1 \cdot 10^{-5} \text{ m s}^{-2}$, while in mountainous areas they reach values larger than $10 \cdot 10^{-5} \text{ m s}^{-2}$.

For comparison purposes, the accuracy of gravimetry using modern relative gravimeters, such as Scintrex CG-6, is from 0,001 to $0,003 \cdot 10^{-5} \text{ m s}^{-2}$. Required accuracy for geological exploration is around $0,01 \cdot 10^{-5} \text{ m s}^{-2}$, for explorations of the oil, gas and minerals around $5 \cdot 10^{-5} \text{ m s}^{-2}$ (Seigel, 1995), for geoid determination

from 1 to $5 \cdot 10^{-5} \text{ m s}^{-2}$ (Farahani et al., 2017). Solutions using DEMs with resolutions 5", 10" and 15" for most of the areas have differences smaller than $1 \cdot 10^{-5} \text{ m s}^{-2}$, which for only rare applications can be ignored. Therefore, according to the requirements of gravity data accuracy for most nowadays applications, it can be concluded that terrain correction must be performed using DEMs with highest possible resolution and accuracy, even in lowlands. Finally, it is confirmed that, concerning today's accuracy of gravity measurements and required accuracy, computation of terrain correction, independent of the used DEM, stays to be sensitive and complex task.

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SAŽETAK

Utjecaj razlučivosti digitalnog modela reljefa na gravimetrijsku korekciju terena nad područjem Hrvatske

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Digitalni modeli reljefa (DMR) visoke razlučivosti postali su javno dostupni tijekom proteklog desetljeća. Koriste se u geodeziji i geofizici kao neophodni podaci za modeliranje utjecaja topografskih masa iz gravimetrijskih i gradiometrijskih mjerenja. U postupku modeliranja, korekcija reljefa je centralna veličina koja filtrira varijacije topografskih masa u okolini mjerenih stajališta. Ovo se istraživanje bavi jednim aspektom računanja gravimetrijske korekcije reljefa: utjecaju razlučivosti digitalnih modela reljefa. Računanja su napravljena na području Republike Hrvatske, u kojima se koristi novoizrađeni digitalni model reljefa napravljen iz globalnog digitalnog modela površine ASTER za kontinentalno područje i digitalnog batimetrijskog modela GEBCO za morsko područje. DEM s manjom razlučivošću napravljen je uzorkovanjem prethodno izrađenog ASTER/GEBCO DEM/DBM-a u 1" razlučivosti. Model korekcije reljefa izrađen je i publiciran po prvi puta za Republiku Hrvatsku. Razlike rješenja korekcije reljefa dobivene korištenjem DMR-a manje razlučivosti i rješenja dobivenih korištenjem DMR-a s 1" razlučivosti ukazuju na prosječni utjecaj razlučivosti DMR-a na korekciju reljefa od $0,5 \cdot 10^{-5}$ do $3,0 \cdot 10^{-5} \text{ ms}^{-2}$ za DMR-ove s razlučivošću manjom od 5". Rezultati također ukazuju na to da su razvedena i planinska područja posebno problematična u računanjima.

Ključne riječi: ASTER, digitalni model reljefa, GEBCO, razlučivost, korekcija reljefa

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