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EFFECT OF THE DIFFERENCE BETWEEN SURFACE AND TERRAIN MODELS ON GRAVITY FIELD RELATED QUANTITIES

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Abstract

Topographic masses have a strong impact at the medium and short wavelengths of the gravitational signal generated by the mass of the Earth, thus in gravity field modelling digital terrain models (DTM) data are routinely involved. In this study the verification of the Shuttle Radar Topographic Mission (SRTM, Jarvis et al. 2008) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) which is a product of METI and NASA has been done by comparing them to the national horizontal and vertical control networks of Hungary. SRTM data fits better to geodetic ground control points than ASTER GDEM, since some artefacts have been found in ASTER elevation set which impede further use of ASTER without any pre-processing. Since SRTM is an "unclassified" surface model including all those points which reflected to the scanning radar signal thus tree canopy height has been compared to SRTM minus DTM differences in a hilly test area where a local and accurate DTM having 20 m × 20 m horizontal resolution was available. Considerable agreement has been found between forest height and model differences. Model differences have been evaluated to determine their effect on gravity related quantities. Their influence on geoid height has been found insignificant, but the change in the investigated second derivatives of the potential is considerable.

Surface models and evaluation their vertical accuracy for Hungary

Tabl. 1. Overview of the investigated elevation models

features	ASTER GDEM	SRTM3 DEM
data sources	stereo pair of images	radar interferometry
resolution	1 arc sec (~30 m)	3 arc sec (~90 m)
data acquisition period	2000- 2007	2000 (february 11 day-long campaign)
vertical accuracy	± 20 m (95% confidence)	± 16 m (90% confidence)
coverage	~ 83N- 83S	~ 60N- 56S
missing data	cloud cover	topographically steep areas, water bodies

To validate SRTM3 and ASTER GDEM (Tabl. 1.) quality the surface models have been compared to about 54 and 27 thousand control points of the Unified National Horizontal Network (EOVA) and the Unified National Height System (EOMA) of Hungary respectively (Tabl. 2), using bilinear interpolation method.

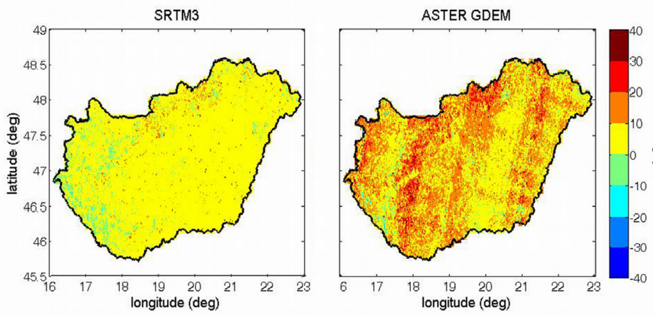
Tabl. 2. Statistics of model comparison with geodetic network points (units in m)

statistics	Horizontal Network		Vertical Network	
	ASTER	SRTM3	ASTER	SRTM3
Minimum	-58.3	-40.4	-178.2	-184.4
Maximum	201.3	187.4	217.6	205.9
Mean	10.4	3.8	7.1	1.2
Standard dev.	± 8.8	± 5.4	± 8.1	± 5.9

Disregarding large discrepancies in some individual points the differences between horizontal control points and SRTM3 are rather small (Fig. 1, left side). Beyond the statistics ASTER differences (Fig. 1, right side) display a strange stripe-like pattern. These step anomalies are caused from the different swath-orientated stack number zones. Stack numbers shows the number of ASTER DEMs (a DEM is a result one flight over the same area) contributing to the final ASTER GDEM, step anomalies cause an offset in the ASTER GDEM tiles.

The difference among vertical network points and the surface models shows a similar pattern (not shown here), indicating that SRTM3 fits better to ground data than ASTER GDEM.

Fig. 1. Differences the heights of horizontal control network points and SRTM3 and ASTER respectively (outliers removed)



Comparison of terrain and surface models in a local test area using tree canopy height map

The investigated area was chosen in the south part of the country and has an area of approximately 7.5 km × 5 km and is located in a hilly region of the Mecsek Mountains. The elevation of the topography varies between 130 and 300 meters; the south part of the area is covered by forests. The digital terrain model (DTM) was generated by scanning the 1:10,000 topographic maps of this region. DTM was derived by bilinear interpolation from the points of the digitized topographic contour lines onto the grid of SRTM3 heights for point wise comparison.

For the investigation of model differences only the SRTM3 elevations have been used, because of the artefacts related to ASTER GDEM discussed in the previous section.

The difference

$$\delta H = H_{SRTM} - H_{DTM} \qquad (1)$$

should agree with the tree canopy height. For its investigation a forest height model was used. It was produced using the tree canopy height data bank valid for the epoch 2001 and maps showing the boundaries of the woods classified by species and ages of trees.

Fig. 2. and 3. show that elevation models differences are in agreement with the forest height, for example in the southwest, in the south or in the east part of the forestry area.

Fig. 2. Differences SRTM minus DTM in forest-clad regions. Black lines indicate the boundaries of woods

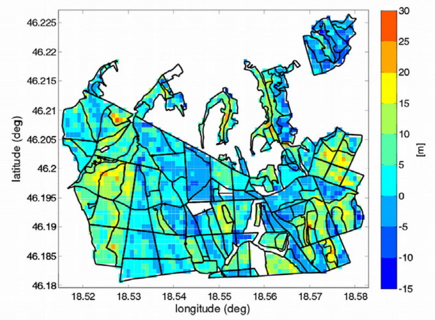
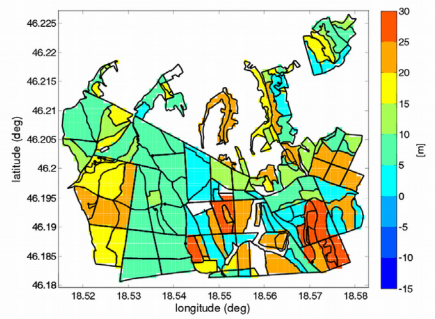
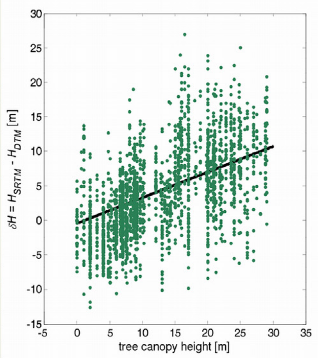


Fig. 3. Tree canopy height map of the test area



Taking the scatter plot (Fig. 4.) of the canopy height and the SRTM minus DTM differences given by Eq. (1) it can be noticed that there is a moderate relation between them characterized by r = 0.65 correlation coefficient. δH model differences in forest-clad regions with respect to different vegetation height intervals are given in Tabl. 3. It can be seen that those are consistent with the height of vegetation.

Fig. 4. Correlation canopy height with elevation model difference



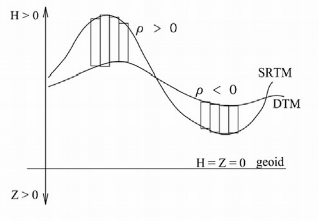
Tabl. 3. Eq (1) differences in forest-clad regions as a function of tree canopy height intervals

tree canopy height intervals [m]	$\delta H \geq 0$ [%]	$\delta H < 0$ [%]
0 – 5	29	71
5 – 10	62	38
10 – 15	77	23
15 – 20	90	10
20 – 25	92	8
25 – 30	91	9

Calculating gravitational effect of elevation model differences

δH model differences have been analyzed in order to compute their effect on the disturbing potential and on its derivatives using the prism-integration forward modelling method. In planar approximation rectangular prisms have been utilized for the discretization of the δH differences in a right rectangular coordinate system having a Z axis pointing downward. A constant densities of $\rho = 2\ gcm^3$ and $\rho = -2\ gcm^3$ were applied when SRTM surface was above and below the DTM topography, respectively. This way the density model represents the elevation differences as mass surplus and mass deficiency (Fig. 5). The density distribution map shows (Fig. 6) that SRTM elevations are higher in the southern forest-clad part of the test area. The computations have been carried out on geoid surface (i.e. $H = 0\ m$) using rectangular prisms having uniform horizontal size of 90 × 60 meters, which is approximately equal to the resolution of SRTM3 at the latitude of the test site.

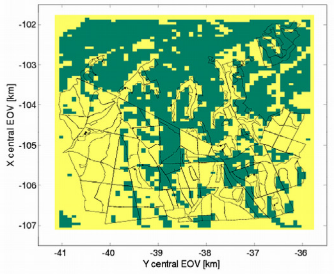
Fig. 5. Explanation of density model (mass surplus and mass deficiency) and the orientation of vertical coordinate axes used for elevation and prism modelling



$H_{SRTM} > H_{DTM}$ → mass surplus

$H_{SRTM} < H_{DTM}$ → mass deficiency

Fig. 6. Prism model and density distribution for computation of its gravitational effect. Coordinates are given in central map projection system (EOV) of Hungary.



ρ = -2 gcm^{-3}

ρ = +2 gcm^{-3}

Gravitational effect of model differences on gravity related quantities

The gravitational effect of the δH differences has been determined on geoid height (N), gravity anomaly (Δg) and horizontal gradients of the vertical component of the gravity vector (T_{zx}, T_{zy}) (Tabl. 4).

Tabl. 4. Statistics of effects on gravity related quantities due to model differences

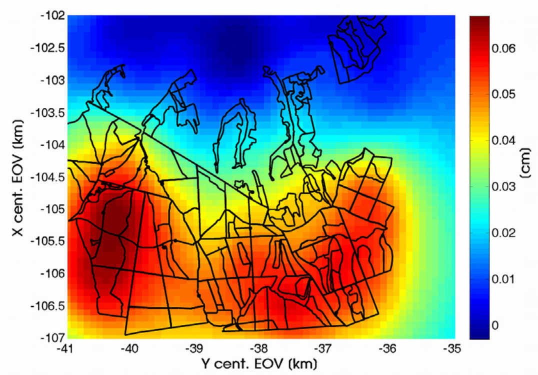
statistics	N [cm]	Δg [mGal]	T_{zy} [E]	T_{zx} [E]
Mean	0.03	-0.10	0.2	0.4
Standard dev.	0.02	0.21	3.6	2.9
Minimum	0.00	-0.69	-12.7	-9.4
Maximum	0.07	0.32	12.0	13.0

The change in geoid undulation (Fig. 7) due to the elevation model differences is small, the largest variation reaches only 0.07 cm in forestry region, which is negligible.

The first derivative of the disturbing potential (gravity anomaly) varies in a 1 mGal (1 mGal = 10^{-5} ms^{-2}) interval, from -0.69 mGal to 0.32 mGal (Fig. 8.). The largest absolute values occur in regions covered by forests. Since the Z axis points downward, i.e. contrary to H, the negative sign indicates that mass surpluses ($H_{SRTM} > H_{DTM}$) are located above the computational point (geoid); consequently positive sign means mass deficiency above the geoid.

The effect of model differences on the investigated second derivatives (Fig. 9.), on horizontal gradients is remarkable. The horizontal derivatives vary between ± 10 E (1 E = 10^{-9} s^{-2}).

Fig. 7. Change in geoid height because of model differences



Gravitational effect of model differences on gravity related quantities (cont.)

Fig. 8. Gravitational effect of model differences on g_z

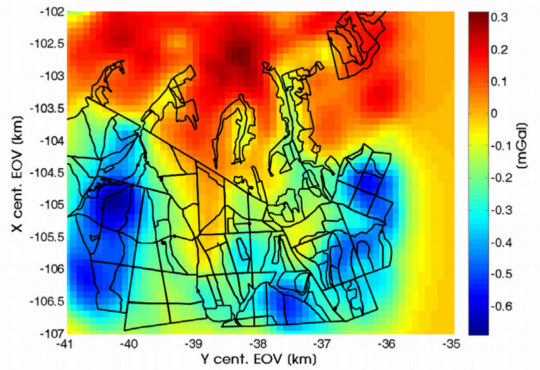
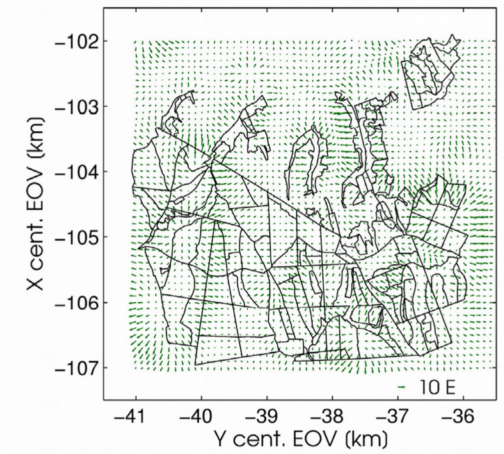


Fig. 9. Gravitational effect of model differences on T_{zx} and T_{zy} components of the Eötvös tensor



Conclusions

Gravity field modelling often take the advantage of the strong correlation between topography and the short wavelength parts of the gravity field. SRTM3 is a freely available global elevation model that could be applied for this purpose. However, SRTM3 is a surface model not a terrain one, thus SRTM3 heights are systematically higher in forest-clad and urban regions.

For a hilly test area located in the Mecsek Mountains, Hungary and covered by woods it has been shown that the model differences can be safely indicated and justified by the available tree canopy height data. Interpreting the deviations between surface and terrain models as mass surplus and mass deficiency its gravitational effect on geoid height, gravity anomaly and some second derivatives of the potential was determined and analyzed.

The effect on geoid height is negligible (< 1 mm), although the change of g_z on the geoid surface due to the differences is in the range of ± 0.5 mGal. Considerable effect was indicated in terms of the second derivatives (horizontal gradients), because these simulated "differential" quantities are close to the order of magnitude of the ones measured by Eötvös type torsion balance instruments all around in Hungary (± 10 E).

For local and regional gravity field determination high resolution national DTMs are preferred extending them with SRTM3 model beyond their borders to model remote masses. However in areas where no local terrain model is available SRTM could be used in geoid determination, since applying remove-restore procedure the gravitational effect of differences between surface and terrain models are supposed to be insignificant.

References

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