Developing Model for Utilization of Global Earth Gravimetrical Models in Macedonian Territory

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Key words: EGM, geoid, GIS, geoid undulation, earth gravitation, geoid height.

SUMMARY

In this paper, model for utilization of global Earth Gravitational Models (EGM) for entire area of Macedonia through developing GIS datasets is shown. Due to actual situation in Macedonia with the national geoid, which is still under development, utilization of global EGM's for surveying issues is more than necessary.
During our analyses, three existing global models have been used, i.e. EGM 2008, EGM 96 and EGM 84. Comparing of the results between three models, were calculated based on joint GRID model with points which covers all country territory. Maximum and minimal differences between the models, extreme values of geoid heights (height of geoid above/bellow the WGS84 ellipsoid) in three geoids, mean differences and other data-calculations, are given in a paper.
Based on three models and differences between the models, six maps for the territory of Macedonia were compiled. For map background, such as data for cities and boundaries, open and free Macedonian Global map data has been utilized, as official data developed by the national mapping authority of Macedonia. Within the paper, only three maps EG models with geoid heights are shown.
For the elevations data, ASTER global Digital Elevation Model (DEM) with 30m spatial resolution has been utilized. Based on DEM and geoid heights, ellipsoidal heights for entire territory of Macedonia were calculated and used for compilation of a map with ellipsoidal heights for Macedonia. All results in all analyses, represents the values based on WGS 84 datum.
Calculation with online geoid calculators, such as GeoidEval, gave us feedback for calculated geoid heights. Control points were selected by criteria to cover all territory of Macedonia. From the calculated values, we found the differences between calculated geoid heights with online geoid calculators and those exported from models in GIS platform, are very low, which comes as result of interpolation, as well as by generalizing of raster EGM dataset.
Main purpose of analyses and developed GIS datasets for geoid heights, ellipsoidal heights and elevations, is their usage by the geo community in Macedonia, mainly for direct obtaining of elevations during GPS measurements, till the establishing of state gravimetrical network.

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1. INTRODUCTION

The relief of Macedonia is characterized by large and high mountain massifs giving way to extensive, flat valleys and plains. The valleys are interconnected by low passes or deep ravines, such as those of Derven, Taor, Veles, Demir Kapija and Ciganska Klisura on the River Vardar, and Kresna and Rupel on the River Strumica. Macedonia is a predominantly mountainous country, with 14 mountain peaks higher than 2000 meters, and the highest is Golem Korab with 2753 meters. Macedonia, just like the rest of the Balkan countries, is located in a peculiar seismic region (figure 1).

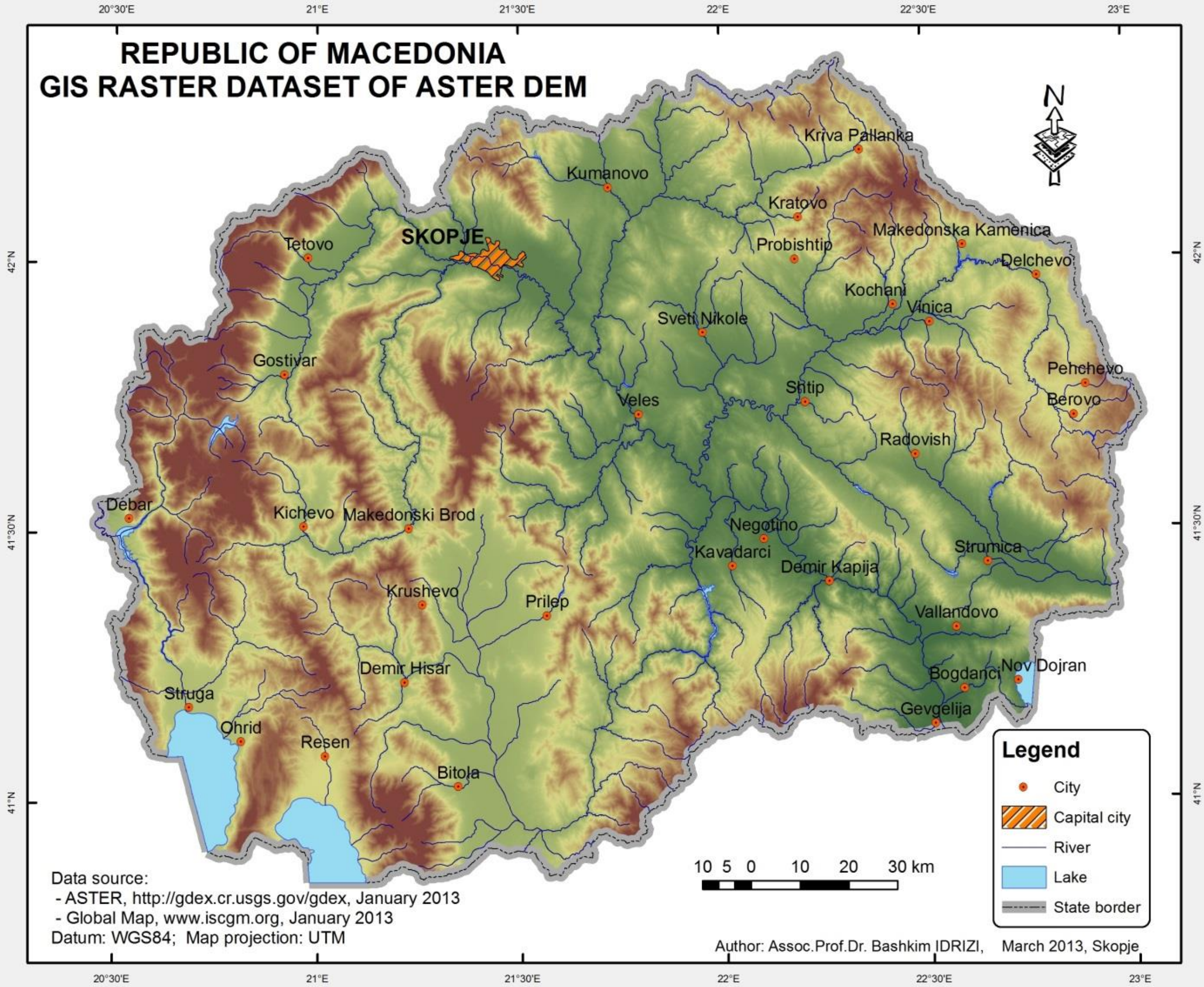

Figure 1. Relief of Macedonia, based on ASTER Global DEM

Based on ASTER global digital elevation model (DEM) (http://asterweb.jpl.nasa.gov/), in figure 1 the relief of Macedonia has been shown. Aimed to create a test model for further analyzes of data of global gravitational models within Macedonian area; grid with 25635 points (1km spatial resolution) has been created. For all points of test model, elevations from ASTER DEM and geoid heights from EGM 08/96&84 have been extracted.

The former gravimetric network in the territory of Macedonia is connected to the gravimetric measurements, performed in the second half of the last century, when Macedonia was a part of former Yugoslavia. The first systematic approach towards the basic gravimetric works and surveys dates from 1951, when the Geographic Institute and the Head Geodetic Authority of Yugoslavia initiated a systematic approach in the establishment of gravimetric networks, the regional and local gravimetric measurements, and ultimately, the production of gravimetric maps, produced as a result of those measurements.

For the purpose to be achieved, a primary requirement was to undertake calibration works for defining the absolute gravimetric level and the scale of the basic geodetic networks. For providing unique gravimetric scale, the large base Belgrade – Skopje was established, which afterwards was expanded towards north to Subotica and towards south to Bitola. The works regarding the establishment of the gravimetric network of first order were performed in parallel to the works for the calibration bases. The network of first order had 15 points and was developed in a shape of a central system, with 14 closed triangles and its central point was located in the gravimetric point Belgrade. The overall points were stabilized with concrete monuments, positioned in the proximity of adequate airports. It should be emphasized that the values of the absolute accelerations were determined in regard to the Potsdam system.

For the purpose of performing several local and regional re-measurements, it was necessary to develop a gravimetric network of second order. The network was developed in a shape of closed polygons with length of 150 to 250 km, with several knot points and an average distance of 10 km. Because the network from second order was partially developed without a prior agreed plan, it was concluded that a new and more homogenous gravimetric network, with a larger point density, should be established. Thus, the so-called *Basic Gravimetric Network* was established (figure 2).

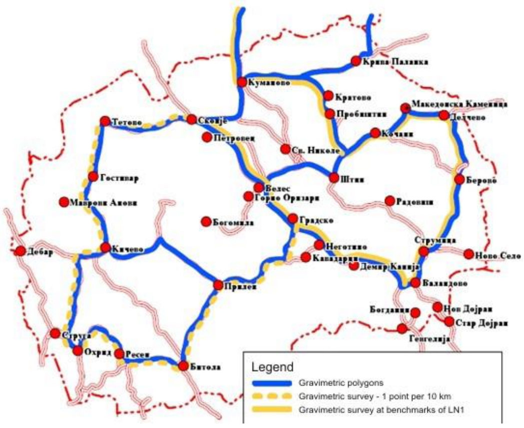

Figure 2. Basic Gravimetric Network in Republic of Macedonia (Odalovic O., 2009)

All measurements in the established Basic Gravimetric Network were performed in the period of 1964-1967. The network was developed in a shape of closed polygons, and included the large base Belgrade - Skopje and the basic gravimetric point Belgrade. Hence, the Basic Gravimetric Network provided an accurate, stable and permanent gravimetric foundation for all the practical and scientific purposes in our country.
To the accuracy, evaluated through the measurement standard of one range of one unclosed polygon, in the basic gravimetric network was 0,021 mgal, which shows that the network was very homogenous and accurate (Idrizi B., Ribarovski R., 2010).

In a "Study for the leveling and gravimetric networks in Macedonia" are defined two variants of the new 1st order gravimetric network of Macedonia. In both variants is projected the basic (zero) gravimetric network defined with three absolute gravimetric points, which should be measured by the absolute gravimeters. The first variant is composed by 32 points that form the 27 polygons, and the second variant with 24 points that form 19 polygons, which should be measured by the relative gravimeters. (Idrizi B., Ribarovski R., 2010).
On October 2010, conducted by Swedesurvey (Lantmateriet) with financial support by SIDA (Swedish International Development Cooperation Agency), have been realized the absolute gravity measurements in three points in Macedonia, located nearby Ohrid, Valandovo and Skopje (Figure 3.). Actually, efforts for realizing of relative gravimetric network of Macedonia are undertaken.

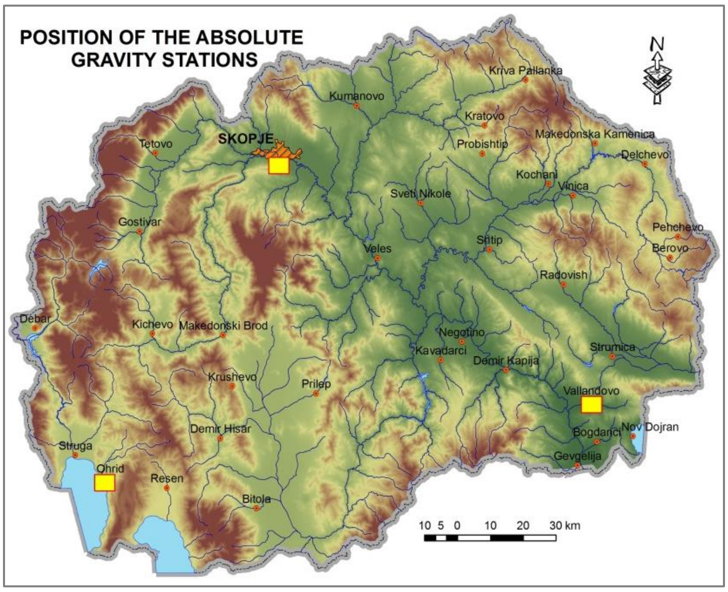

Figure 3. Position of the Absolute Gravity Stations in Macedonia

2. Global Earth Gravimetrical Models

In the absence of local/state gravimetric networks, geodetic practice often use global Earth Gravimetric Models, which includes data for entire area of the world. Till today, National Geospatial-Intelligence Agency (NGA) has built three global Earth gravimetric models in the

years 1984, 1996 and 2008, known as models EGM84, EGM96 and EGM08.
The Geosciences Division in the Office of Geomatics at NGA is responsible for collecting, processing, and evaluating gravity data (free-air and Bouguer gravity anomalies). These data are then used to compute gravimetric quantities such as mean gravity anomalies, geoid heights, deflections of the vertical, and gravity disturbances. All of these quantities are used in World Geodetic System 1984 support, navigation systems, mapping projects, and different types of surveys (http://earth-info.nga.mil/GandG/wgs84/gravitymod/index.html, March 2013).

Three global gravitational models are open for download and utilization through the official web page of NGA, as well as from many other web pages. One of the WEB GIS based free product via internet is the geoportal of surveying.org web page, where can be found very wide range of special spatial data, such as weather, NGS (national geodetic survey), USGS maps, geoid heights, magnetic declination, state plan systems, UTM zones etc. In mentioned geoportal, within the field of geoid heights, three existing earth gravitational models (EGM84, 96 and 08) are included to give geoid heights in three models by clicking in any place of the world. In figure 3, the example of geoid heights obtained from surveying.org geoportal for the center of Skopje is shown.

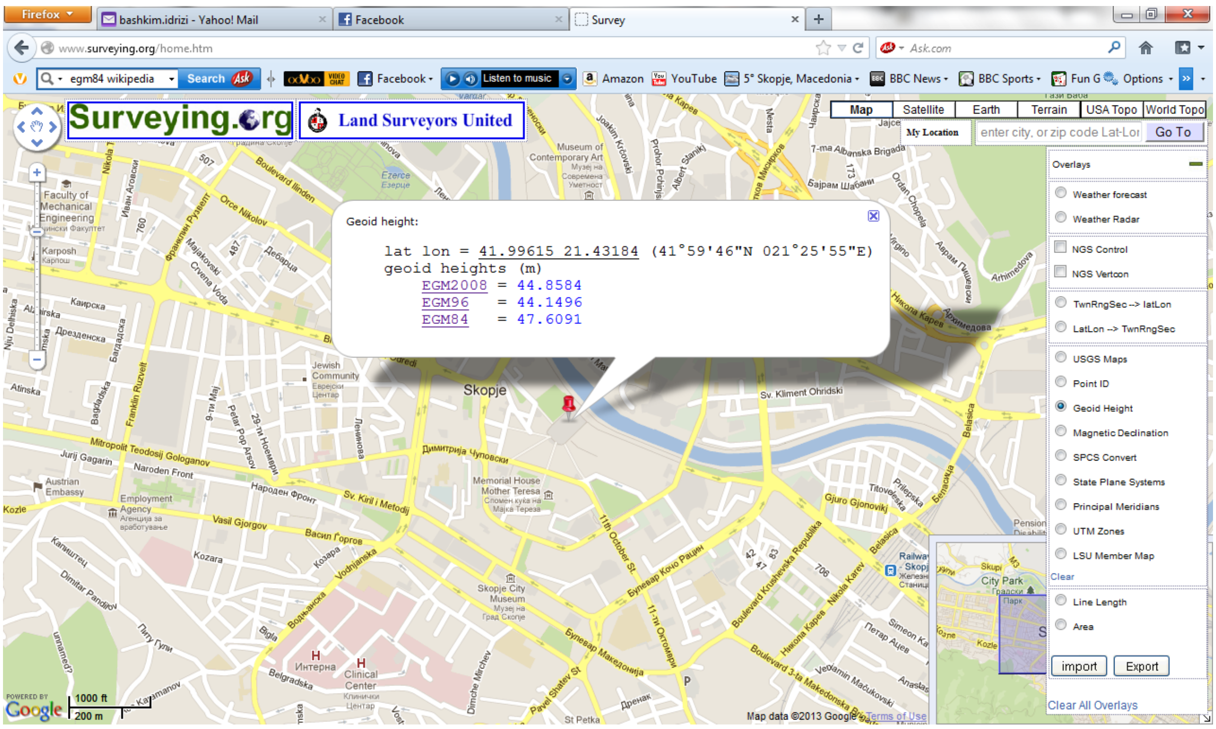

Figure 3. Geoid heights in three earth gravitational models 84, 96 and 08, for center of Skopje (http://www.surveying.org/home.htm, March 2013)

2.1 EGM08

The official Earth Gravitational Model EGM2008 (code 3859) has been publicly released by the U.S. National Geospatial-Intelligence Agency (NGA) EGM Development Team. This gravitational model is complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159. Computing the geoid undulation values are realized with respect to WGS 84 ellipsoid. Full access to the model's coefficients and other descriptive files with additional details about EGM2008 are provided from the next link http://earth-info.nga.mil/GandG/wgs84/gravitymod/index.html
Harmonic synthesis software provided by NGA applies a constant, zero-degree term of -41cm to all geoid undulations computed using EGM2008 with the height anomaly to geoid undulation correction model. Similarly, all pre-computed geoid undulations incorporate this constant zero-degree term. This term converts geoid undulations that are intrinsically referenced to an ideal mean-earth ellipsoid into undulations that are referenced to WGS 84. The value of -41 cm derives from a mean-earth ellipsoid WGS84. In next figure, map of EGM08 with 2.5' geoid heights is shown.

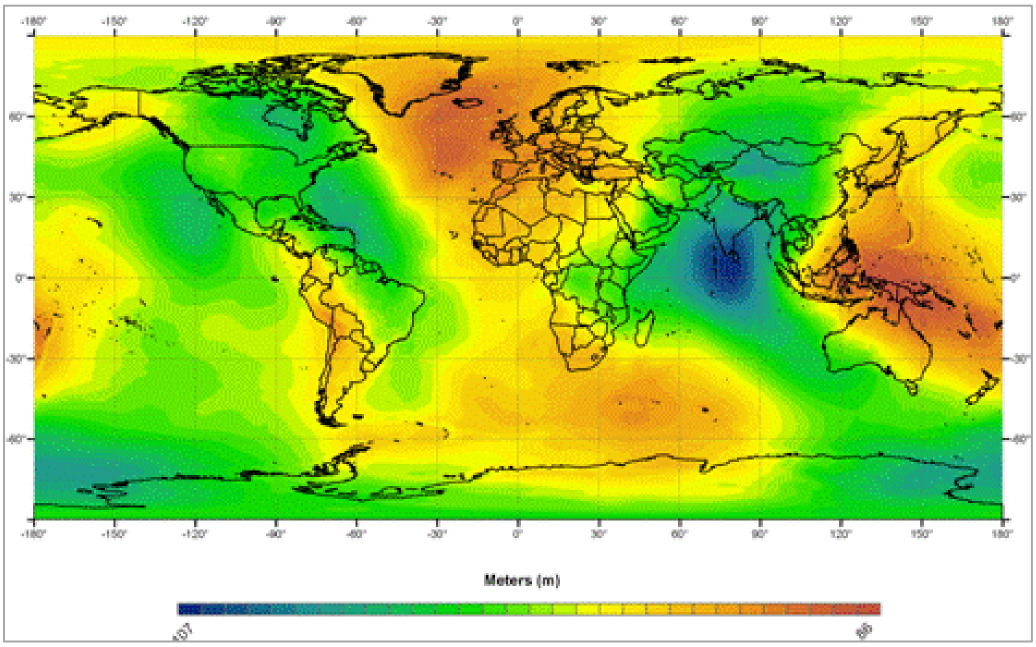

Figure 3. EGM 08 2.5' Geoid Height
(http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/egm08_wgs84.html, March 2013)

2.2 EGM96

Earth Gravitational Model EGM96 (code 5773) is a geopotential model of the Earth consisting of spherical harmonic coefficients complete to degree and order 360. It is a composite solution, consisting of a combination solution to degree and order 70, a block

diagonal solution from degree 71 to 359, and the quadrature solution at degree 360. It is a result of collaboration between the National Imagery and Mapping Agency (NIMA), the NASA Goddard Space Flight Center (GSFC), and Ohio State University.
The project took advantage of new surface gravity data from many different regions of the globe, including data released from the NIMA archives. Major terrestrial gravity acquisitions by NIMA since 1990 include airborne gravity surveys over Greenland and parts of the Arctic and the Antarctic, surveyed by the Naval Research Lab (NRL) and cooperative gravity collection projects, several which were undertaken with the University of Leeds.
NIMA also computed and made available 30'×30' mean altimeter derived gravity anomalies from the GEOSAT Geodetic Mission, altimeter derived anomalies derived from ERS-1 by Kort & Matrikelstyrelsen (KMS), (National Survey and Cadastre, Denmark) over portions of the Arctic, and the Antarctic, as well as the altimeter derived anomalies of Schoene [1996] over the Weddell Sea.
The official Earth Gravitational Model EGM96 has been publicly released by the National Geospatial-Intelligence Agency (NGA) EGM Development Team. This gravitational model is complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159.

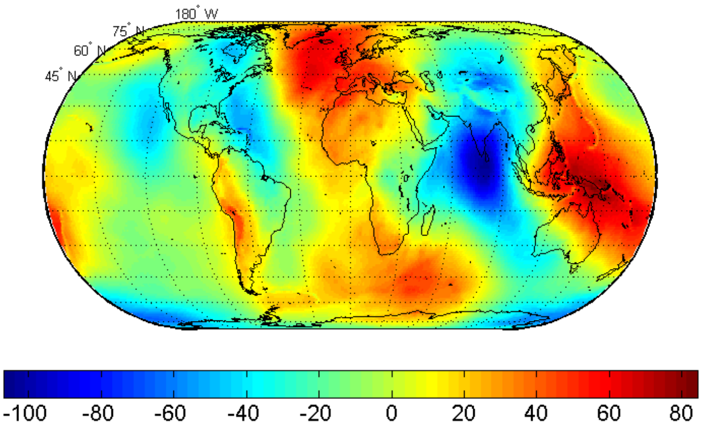

Figure 3. EGM96 Geoid Heights in meters (http://en.wikipedia.org/wiki/EGM96, March 2013)

The Geosciences Division provides the normalized, geopotential coefficients for both the new NGA/NASA EGM96 n=m=360 and the WGS 84 n=m=180 Earth Gravitational Model. It also provides two geoid products, the 15-minute, worldwide geoid height file for EGM96 and the 30-minute worldwide geoid height file for the original WGS 84 model. They are available for unlimited distribution (http://earth-info.nga.mil/GandG/wgs84/gravitymod, March 2013)

2.3 EGM84

EGM84 geoid (code 5203) is a vertical datum first defined in 1984, with its geoid origin in WGS 84 ellipsoid. EGM84 geoid is a vertical datum for Geodesy, defined by information from US National Geospatial-Intelligence Agency (NGA).
Data of EGM84 today have historical importance, without practical utilization. Differences between geoid heights of EGM 84 with two newest models EGM 96 and EGM08 are three to

ten times higher than the differences between EGM 96 and EGM 08.
It has been used in our research just for comparing with two newest models of years 1996 and 2008, and not as a model that can be used at the present time!

3. Developing EGM models for Macedonian territory

3.1 Creating test model

With the aim of creating test model for the existing global Earth Gravitational Models 1984, 1996 and 2008, vector grid with 1km distance between points has been developed for Macedonian territory, in total with 25635 points which covers entire area of Macedonia. As data source for creating the test model, three datasets have been utilized:

1. Macedonian Global Map dataset, from www.iscgm.org web page,
2. ASTER Digital Elevation Model, from http://asterweb.jpl.nasa.gov/ web page, and
3. Earth Gravitational Models 2008, 1996 and 1984, from http://earth-info.nga.mil/GandG/wgs84/gravitymod/ web page.

For all points, geoid heights in EGM08, EGM96 and EGM84, as well elevations have been extracted from the data mentioned above.
Improving the quality of three gravitational models has been achieved by using online geoid calculations GeoidEval utility, which gives guaranty of 1mm RMS error in the interpolated heights.

3.2 EGM08 for Macedonian territory

Based on spatial position of 25635 points of test model in 1km spatial resolution, and EGM 08 data, geoid heights for all points have been calculated for the entire area of Macedonia. Calculation of geoid heights have been realized with precision of 4 decimals after meter (0.1mm), and 1mm RMS of interpolation of geoid heights in points of test model.
From the calculated results, maximum value of geoid heights within EGM08 is 46.396m, while the minimum is 41.1318m. The difference between extreme values within the territory of Macedonia of EGM08 heights is 5.2642m, while the mean height is 44.7032m. Coverage of Macedonian territory in percentage by dividing in intervals of 1m, is given in next table 1:

Table 1. Percentage of geoid heights in Macedonian territory calculated by grid of 1km for EGM08

Geoid heights (m)	Area (km^2)	Percentage
41.1318 - 42	410	1.6%
42 – 43	1296	5.1%
43 – 44	3183	12.4%
44 – 45	9957	38.8%
45 – 46	9473	37.0%
46 – 46.396	1316	5.1%

From the calculated geoid heights, and Macedonian official data in scale 1:1.000.000 within Global Map (www.iscgm.org), map of geoid heights of Macedonia based on Earth Gravitational Model 2008 was compiled. In a next figure 4, the GIS raster dataset with 1km spatial resolution of EGM08 for Macedonia, developed as result of research for developing model for utilization of EGM's in Macedonian territory, is given.

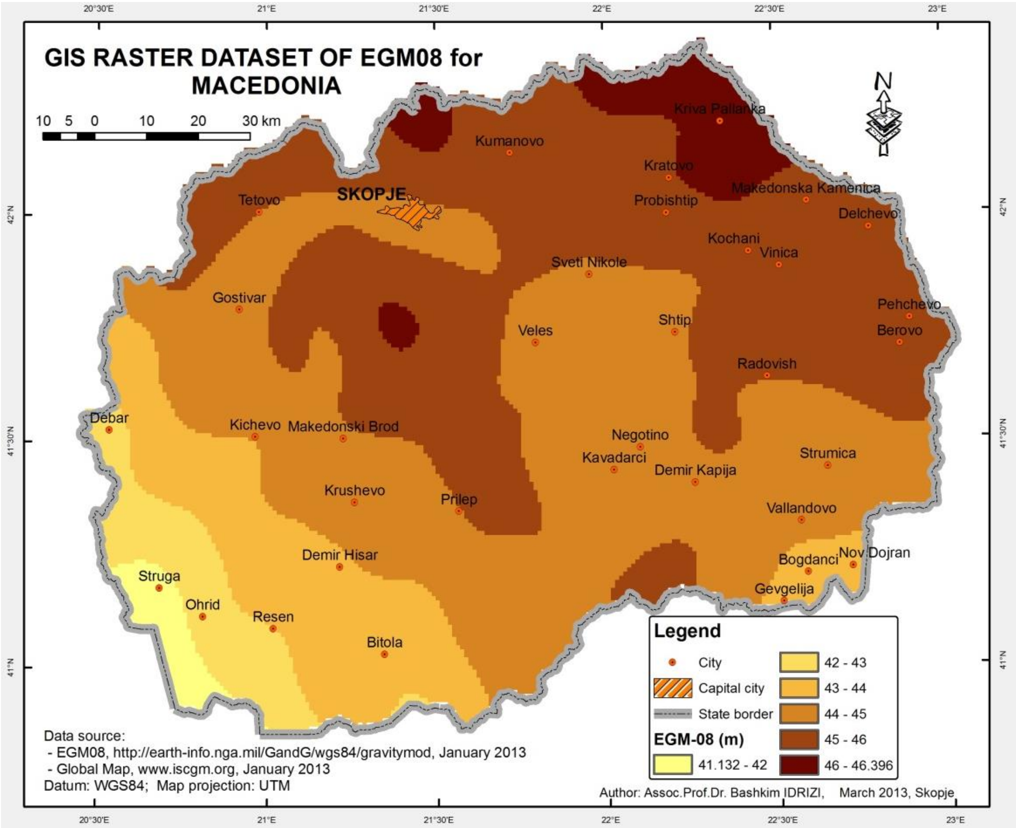

Figure 4. GIS raster dataset with 1km spatial resolution of EGM08 for Macedonian territory

3.3 EGM96 for Macedonian territory

The same procedure as in a case of using EGM 08 for the territory of Macedonia, have been implemented for EGM96 also, by calculation of geoid heights with precision of 4 decimals after meter (0.1mm), and 1mm RMS of interpolated geoid heights of points of test model. The largest value of geoid heights within EGM96 is 45.006m, the lowest one is 41.1952m, mean height is 44.303m, and the difference between extreme values within the territory of Macedonia of EGM96 geoid heights is 3.8108m. In a bellow table 2, the values of percentage coverage of geoid heights with interval of 1m are given.
With same methodology as in a previous case, the GIS raster dataset with 1km spatial resolution of EGM96 for Macedonia is compiled as result of our research, which is shown in bellow figure 5.

Table 2. Percentage of geoid heights in Macedonian territory calculated by grid of 1km for EGM96
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Geoid heights (m)	Area (km^2)	Percentage
41.1952 - 42	319	1.2%
42 – 43	1285	5.0%
43 – 44	4418	17.2%
44 – 45	19504	76.1%
45 – 45.006	109	0.4%

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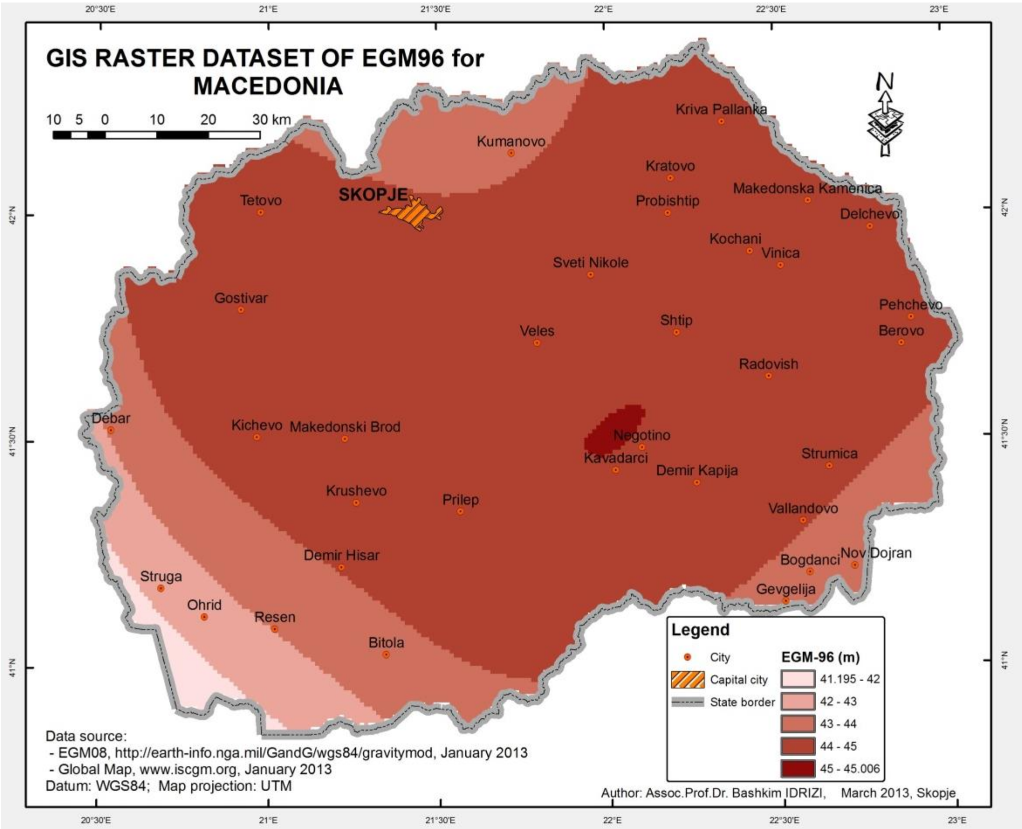

Figure 5. GIS raster dataset with 1km spatial resolution of EGM96 for Macedonian territory

3.4 EGM84 for Macedonian territory

Procedure and methodology for calculation of EGM84 geoid heights for Macedonian territory and their presenting in a compiled map (figure 6) and table 3, were same as in a cases of EGM08 and EGM96, i.e. subheadings 3.2 and 3.3.
Greatest value of geoid heights within EGM84 is 48.3722m, the smallest one is 44.4278m, and the mean height is 47.4659, while the difference between extreme values within the

territory of Macedonia of EGM84 geoid heights is 3.9444m.

Table 3. Percentage of geoid heights in Macedonian territory calculated by grid of 1km for EGM84 -

Geoid heights (m)	Area (km^2)	Percentage
44.4278 – 45	221	0.9%
45 – 46	1197	4.7%
46 – 47	4174	16.3%
47 – 48	12984	50.6%
48 – 48.3722	7059	27.5%

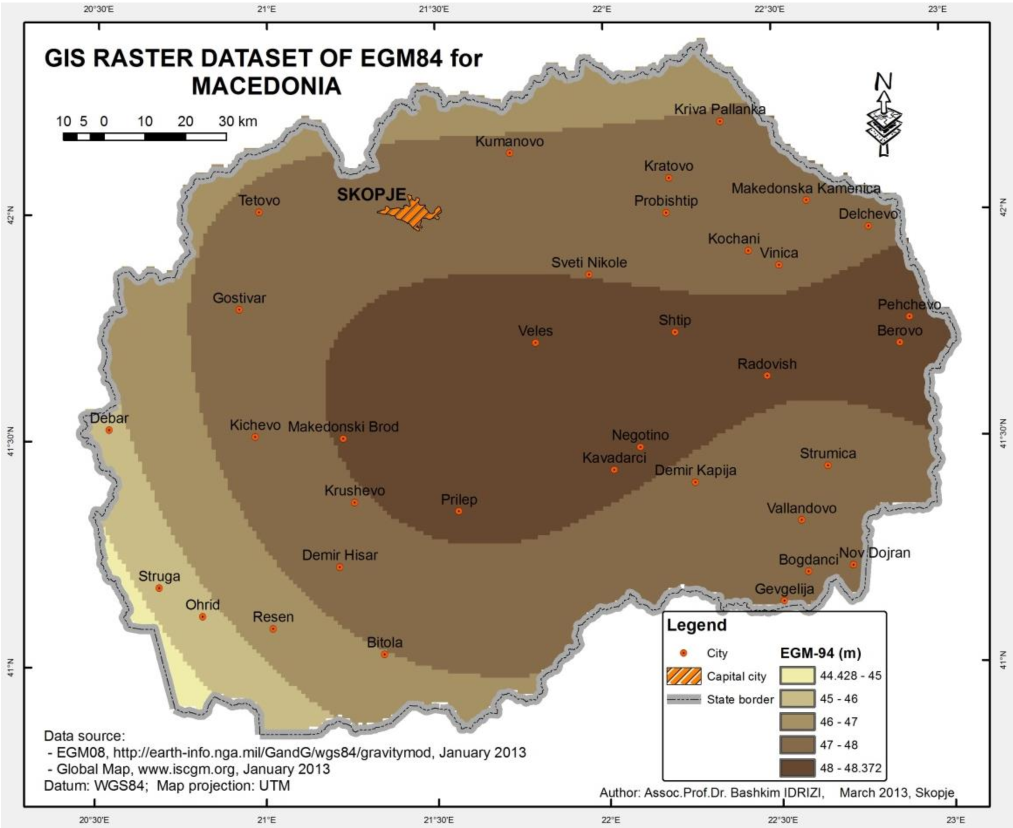

Figure 6. GIS raster dataset with 1km spatial resolution of EGM84 for Macedonian territory

3.5 Comparing of three utilized Earth Gravitational Models for Macedonian territory

From the calculated geoid heights in three models (EGM08, EGM96 and EGM84) for Macedonian territory with 25635 points in 1km spatial resolution, big differences in geoid heights and spatial coverage's of intervals between three models have been recognized. In table 4, differences between extreme values, spatial coverage's of geoid heights in interval of 1m, and mean values of geoid heights and differences between three models are given.

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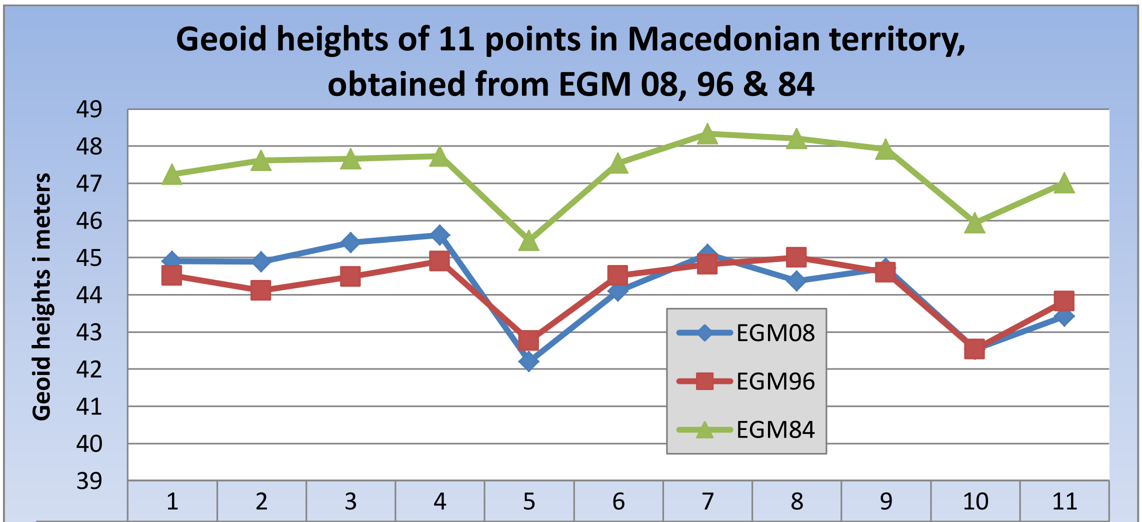
Table 4. Differences between EGM08, 96 & 84 in the territory of Macedonia

Geoid heights (m)		EGM 08	EGM 96	EGM 84	EGM08-96	EGM08-84	EGM96-84
< 42	Area (km^2):	410 (41.1318-42)	319 (41.1952-42)	-	91	-	-
	Percentage:	1.6% (41.1318-42)	1.2% (41.1952-42)	-	0.4%	-	-
42 – 43	Area (km^2):	1296	1285	-	11	-	-
	Percentage:	5.1%	5.0%	-	0.1%	-	-
43 – 44	Area (km^2):	3183	4418	-	1235	-	-
	Percentage:	12.4%	17.2%	-	4.8%	-	-
44 – 45	Area (km^2):	9957	19504	221 (44.4278-45)	9547	9736	19283
	Percentage:	38.8%	76.1%	0.9% (44.4278-45)	37.3%	37.9%	75.2%
45 – 46	Area (km^2):	9473	109 (45-45.006)	1197	9364	8276	1088
	Percentage:	37.0%	0.4% (45-45.006)	4.7%	36.6%	32.3%	4.3%
46 – 47	Area (km^2):	1316 (46-46.396)	-	4174	-	2858	-
	Percentage:	5.1% (46-46.396)	-	16.3%	-	11.2%	-
47 - 48	Area (km^2):	-	-	12984	-	-	-
	Percentage:	-	-	50.6%	-	-	-
> 48	Area (km^2):	-	-	7059 (48-48.3722)	-	-	-
	Percentage:	-	-	27.5% (48-48.3722)	-	-	-
Maximum (m)		46.396	45.006	48.3722	1.39	1.9762	3.3662
Minimum (m)		41.1318	41.1952	44.4278	0.0634	3.296	3.2326
Mean geoid height (m)		44.7032	44.3030	47.4659	-	-	-
Mean difference (m)		-	-	-	0.5258	2.7627	3.1629

Eleven cross points between meridians and parallels with interval of 30’ which pass Macedonian area, have been used for additional analyses of differences between three global EG models. Obtained results are given in next table 5, and in bellow four figures 7 - 10.

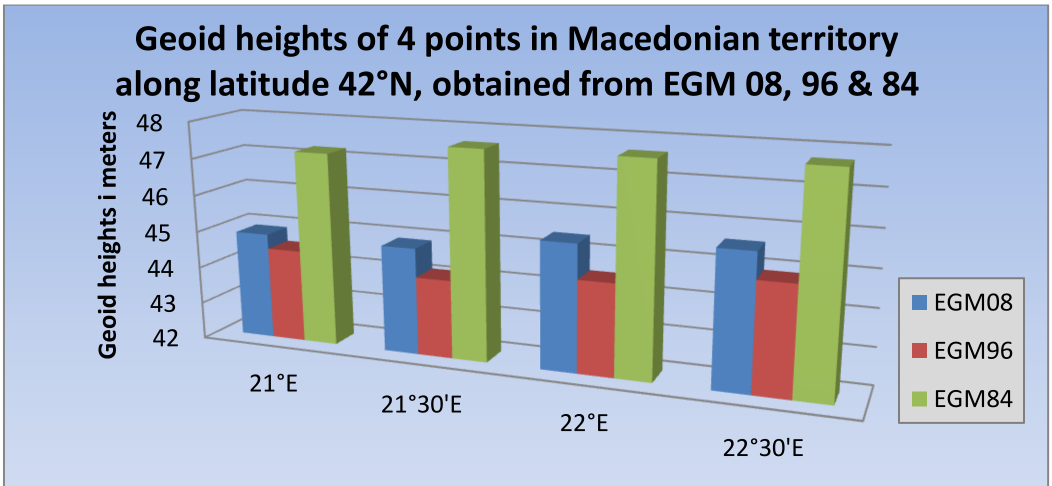
Table 5. Differences between EGM08, 96 & 84 of eleven characteristic cross points between meridians and parallels which pass the territory of Macedonia

Nr.	Latitude	Longitude	EGM08	EGM96	EGM84	EGM08-96	EGM08-84	EGM96-84
1	42°N	21°E	44.9013	44.5105	47.2378	0.3908	-2.3365	-2.7273
2	42°N	21°30'E	44.8893	44.1156	47.6206	0.7737	-2.7313	-3.505
3	42°N	22°E	45.4081	44.4813	47.6539	0.9268	-2.2458	-3.1726
4	42°N	22°30'E	45.603	44.9041	47.7253	0.6989	-2.1223	-2.8212
5	41°30'N	20°30'E	42.2043	42.7707	45.4698	-0.5664	-3.2655	-2.6991
6	41°30'N	21°E	44.0939	44.5237	47.5402	-0.4298	-3.4463	-3.0165
7	41°30'N	21°30'E	45.0847	44.8222	48.3278	0.2625	-3.2431	-3.5056
8	41°30'N	22°E	44.3763	45.0055	48.2022	-0.6292	-3.8259	-3.1967
9	41°30'N	22°30'E	44.722	44.601	47.9228	0.121	-3.2008	-3.3218
10	41°N	21°E	42.5337	42.5364	45.9319	-0.0027	-3.3982	-3.3955
11	41°N	21°30'E	43.4248	43.8262	47.0126	-0.4014	-3.5878	-3.1864



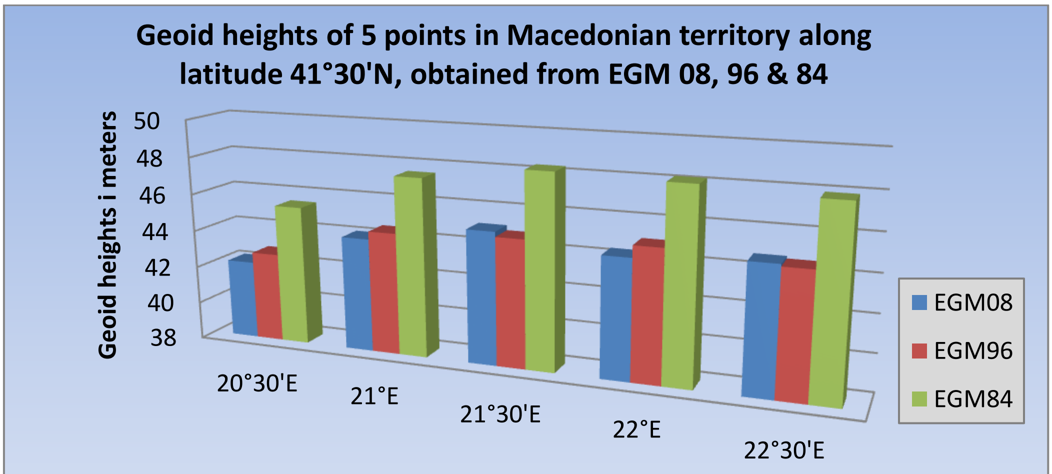
	1	2	3	4	5	6	7	8	9	10	11
EGM08	44.9013	44.8893	45.4081	45.603	42.2043	44.0939	45.0847	44.3763	44.722	42.5337	43.4248
EGM96	44.5105	44.1156	44.4813	44.9041	42.7707	44.5237	44.8222	45.0055	44.601	42.5364	43.8262
EGM84	47.2378	47.6206	47.6539	47.7253	45.4698	47.5402	48.3278	48.2022	47.9228	45.9319	47.0126

Figure 7. Geoid heights of eleven characteristic cross points between meridians and parallels which pass the territory of Macedonia, in EGM08, EGM96 and EGM84



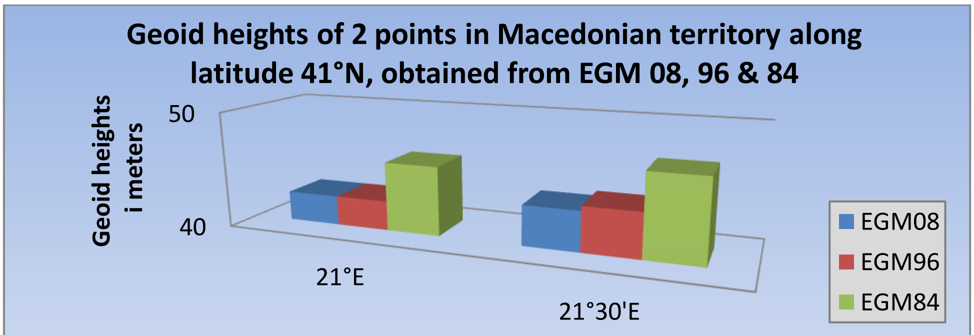
	21°E	21°30'E	22°E	22°30'E
EGM08	44.9013	44.8893	45.4081	45.603
EGM96	44.5105	44.1156	44.4813	44.9041
EGM84	47.2378	47.6206	47.6539	47.7253

Figure 8. Geoid heights in EGM08, EGM96 and EGM84, of four characteristic cross points with parallel 42°N, which pass the territory of Macedonia



	20°30'E	21°E	21°30'E	22°E	22°30'E
EGM08	42.2043	44.0939	45.0847	44.3763	44.722
EGM96	42.7707	44.5237	44.8222	45.0055	44.601
EGM84	45.4698	47.5402	48.3278	48.2022	47.9228

Figure 9. Geoid heights in EGM08, EGM96 and EGM84, of five characteristic cross points with parallel 41°30'N, which pass the territory of Macedonia



	21°E	21°30'E
EGM08	42.5337	43.4248
EGM96	42.5364	43.8262
EGM84	45.9319	47.0126

Figure 10. Geoid heights in EGM08, EGM96 and EGM84, of two characteristic cross points with parallel 41°N, which pass the territory of Macedonia

4. Conclusions

Existing gravimetrical network of Macedonia, established in former Yugoslavia, does not match the needs of contemporary methodology and instruments for geodetic and surveying measurements. Actually the project for establishing of new gravimetrical network in Macedonia is ongoing project. Three absolute gravity stations of new state gravimetric network have been already measured and calculated, while the official rules for relative gravimetric measurements and it's realizing are still on preparatory phase.

In a case of absence of state gravimetrical network, like the present situation in Macedonia, utilization of global Earth Gravitational Models are very suitable and useful for practical issues in geodesy field. From the existing global EG models, the latest one EGM08 with gives the highest accuracy data in comparing with both oldest EGM's.
During comparing of EGM08 with oldest versions 96 and 84, very big differences in the geoid height values were recognized. Results shown clear that EGM 96 and EGM 84 can not be used more for geodetic practical issues, however they can be used as models for comparing and evaluation of global gravitational measurements under different time periods.

From developed EGM08 model for the Macedonian territory, and open and free ASTER DEM, for all 25635 points of test model, the ellipsoidal heights based on ellipsoid WGS84 have been calculated, from which the map with ellipsoidal heights for Macedonia has been compiled (figure 11). From the database of calculated values, ellipsoidal heights above the ellipsoid WGS84 in Macedonian territory are from 67.9 to 2684.8m!

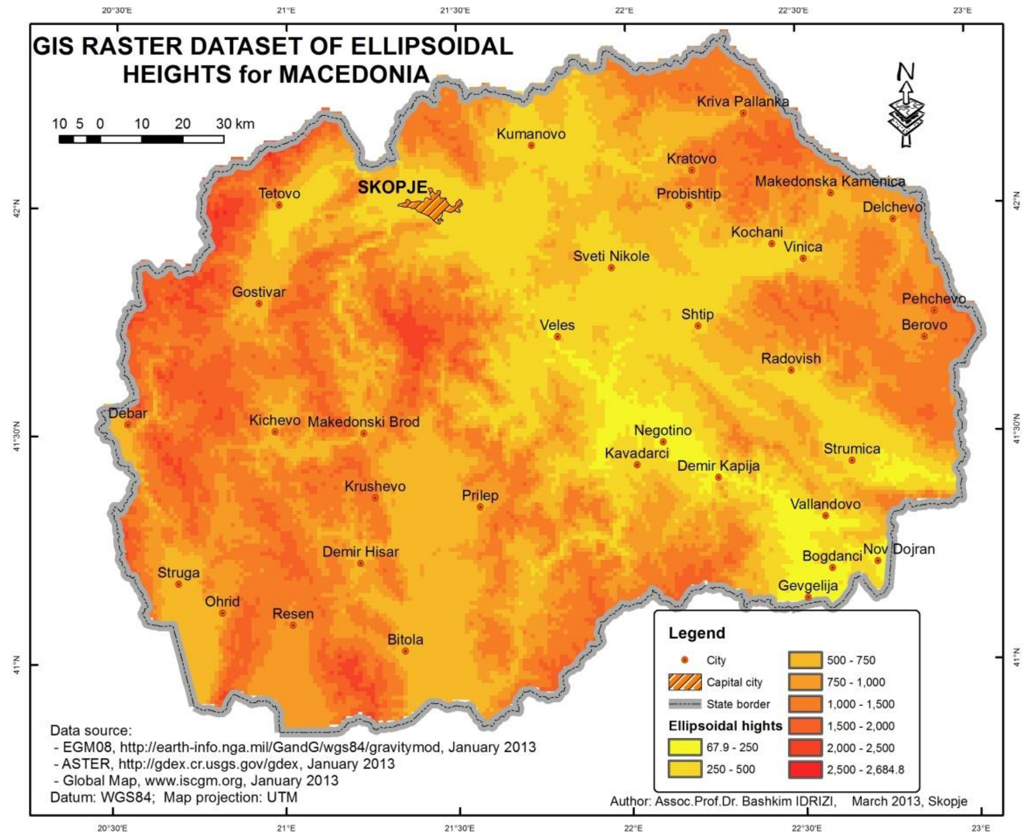


Figure 11. GIS raster dataset with 1km spatial resolution of ellipsoidal heights for Macedonian territory based on EGM08, ASTER DEM and WGS84

Developed database and vector/raster datasets of EGM models and WGS84 ellipsoidal heights within our research, will be open for utilization by all interested institutions and researchers!!!

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BIOGRAPHICAL NOTES

Bashkim IDRIZI, was born on 14.07.1974 in Skopje, Macedonia. He graduated in geodesy department of the Polytechnic University of Tirana-Albania in 1999year. In 2004, hot the degree of master of sciences (MSc) in Ss.Cyril and Methodius University-Skopje. In 2005 he had a specialization for Global Mapping in Geographical-Survey Institute (GSI) of Japan in Tsukuba-Japan. On year 2007, he held the degree of Doctor of sciences (PhD) in Geodesy department of Ss.Cyril and Methodius University–Skopje. He worked in State Authority for Geodetic Works from May 1999 until January 2008. During those period, in 2004 he appointed for head of cartography department, i.e. geodetic works. From October 2003 up to January 2008, he worked as a outsourcing lecturer in State University of Tetova. From February 2008, he works as a cartography and GIS Professor at the State University of Tetova–Tetova. He continuo with working as outsourcing lecturer in geodesy department of the University of Prishtina-Kosova. He is the author of three cartography university books, and more than 85 papers published and presented in national and international scientific conferences related to geodesy, cartography, GIS and remote sensing. From March 2010, he is appointed as president of Geo-SEE (South-European Research Association on Geo Sciences). On November 2011, he has been elected as first President of Pan-national Association of Albanian Surveyors " Karl Gega".

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