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## Extraction and Validation of Geomorphological Features from EU-DEM in The Vicinity of the Mygdonia Basin, Northern Greece

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**Abstract.** The European Union Digital Elevation Model (EU-DEM) is a relatively new, hybrid elevation product, principally based on SRTM DEM and ASTER GDEM data, but also on publically available Russian topographic maps for regions north of 60° N. More specifically, EU-DEM is a Digital Surface Model (DSM) over Europe from the Global Monitoring for Environment and Security (GMES) Reference Data Access (RDA) project - a realisation of the Copernicus (former GMES) programme, managed by the European Commission/DG Enterprise and Industry. Even if EU-DEM is indeed more reliable in terms of elevation accuracy than its constituents, it ought to be noted that it is not representative of the original elevation measurements, but is rather a secondary (mathematical) product. Therefore, for specific applications, such as those of geomorphological interest, artefacts may be induced. To this end, the purpose of this paper is to investigate the performance of EU-DEM for geomorphological applications and compare it against other available datasets, i.e. topographic maps and (almost) global DEMs such as SRTM, ASTER-GDEM and WorldDEM™. This initial investigation is carried out in Central Macedonia, Northern Greece, in the vicinity of the Mygdonia basin, which corresponds to an area of particular interest for several geoscience applications. This area has also been serving as a test site for the systematic validation of DEMs for more than a decade. Consequently, extensive elevation datasets and experience have been accumulated over the years, rendering the evaluation of new elevation products a coherent and useful exercise on a local to regional scale. In this context, relief classification, drainage basin delineation, slope and slope aspect, as well as extraction and classification of drainage network are performed and validated among the aforementioned elevation sources. The achieved results focus on qualitative and quantitative aspects of automatic geomorphological feature extraction from EU-DEM at a water basin level, with the use of Geographical Information Systems (GIS).



## 1. Introduction

Digital Elevation Models (DEMs) are a fundamental source of information in Geosciences and of paramount importance for Geomorphology [1], [2], [3], [4]. It is therefore not coincidental that SRTM - the first almost global DEM derived from satellite data - has been characterized as "...the most dramatic advance in cartography since Mercator..." [5]. Since more than a decade, it is also widely accepted that the "...the quest for a more and more accurate description of the global topography...shall become a continuous task..." [5], [6], [7]. This is also recognized at political level, with policies such as those related to the Infrastructure for Spatial Information in the European Community (INSPIRE) making explicit reference to the need for DEMs for land, ice and ocean surfaces (terrestrial elevation, bathymetry and shoreline) [8].

In this context, the European Union Digital Elevation Model (EU-DEM) is a relatively new hybrid product, principally based on SRTM DEM and ASTER GDEM data, but also on publically available Russian topographic maps for regions north of 60° N. More specifically, EU-DEM is a Digital Surface Model (DSM) over Europe from the Global Monitoring for Environment and Security (GMES) Reference Data Access (RDA) project - a realisation of the Copernicus (former GMES) programme, managed by the European Commission/DG Enterprise and Industry.

The first version (v.1) of EU-DEM was released in October 2013. For the first year, the data were provided without a formal validation [9]. Subsequently, an independent statistical validation, scheduled as part of the GIO (GMES Initial Operations) land monitoring service activities, was officially released in August 2014 [11].

Even if EU-DEM is indeed more reliable in terms of elevation accuracy than its constituents, it ought to be noted that it is not representative of the original elevation measurements, but is rather a secondary (mathematical) product. Therefore, for specific applications and especially for those of geomorphological interest, artefacts may be induced.

To this end the purpose of this paper is to initiate an investigation on the performance of EU-DEM for geomorphological applications and compare it, from a geomorphological viewpoint, against its constituents (SRTM, ASTER-GDEM) as well as against other higher accuracy available datasets, i.e. topographic maps and (almost) global DEMs such as SRTM, ASTER-GDEM and WorldDEM™. The investigation is carried out in Central Macedonia, Northern Greece, in the vicinity of the Mygdonia basin.

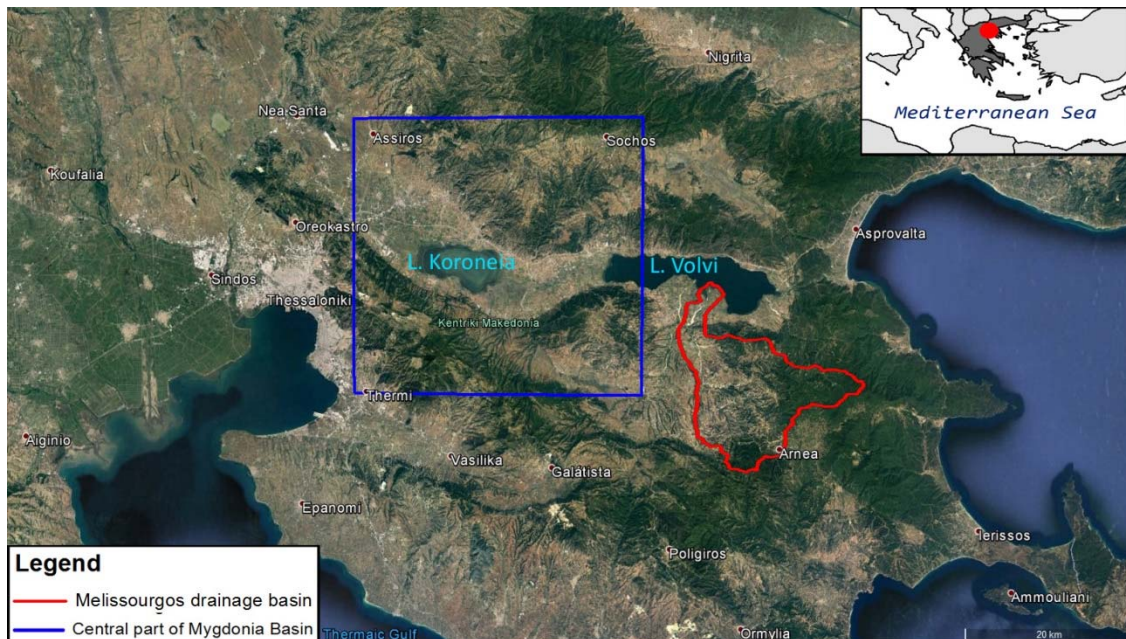
## 2. Study area and data

### 2.1. Study area

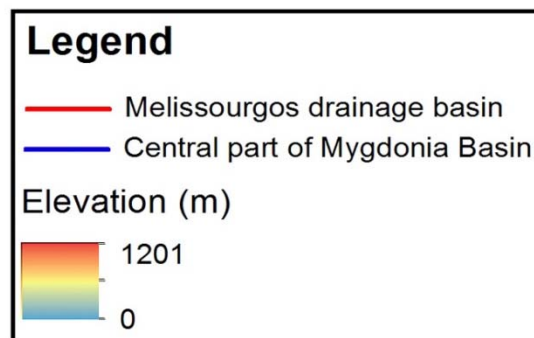
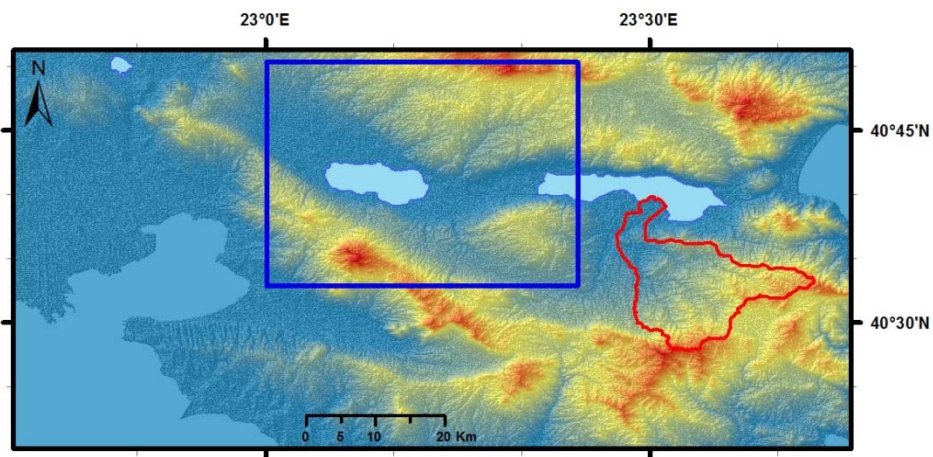
The broader region of Mygdonia Basin - a basin of tectonic origin in Central Macedonia, Greece - corresponds to an area of particular interest for several geoscience applications. This region has also been serving as a test site for the systematic validation of DEMs for more than a decade [12], [13]. Consequently, extensive elevation datasets and experience have been accumulated over the years, rendering the evaluation of new elevation products a coherent and useful exercise on a local to regional scale. The two sub-areas that concern this study consist of the central part of Mygdonia Basin, as well as the Melissourgos drainage basin (Figure 1 and Figure 2).

The topography of the region varies from lowlands to hilly and mountainous regions (Figure 3), while its land cover consists mainly of agricultural areas or pastures (≈60%), shrubs or low vegetation (≈20%) and forests (≈10%).

Regarding the Melissourgos drainage basin (Figure 3), it has been selected as a test site for further investigation, as there is adequate information and geomorphological data based on previous studies, while it is also associated with relatively recent floods events of geomorphological interest [14], [15].

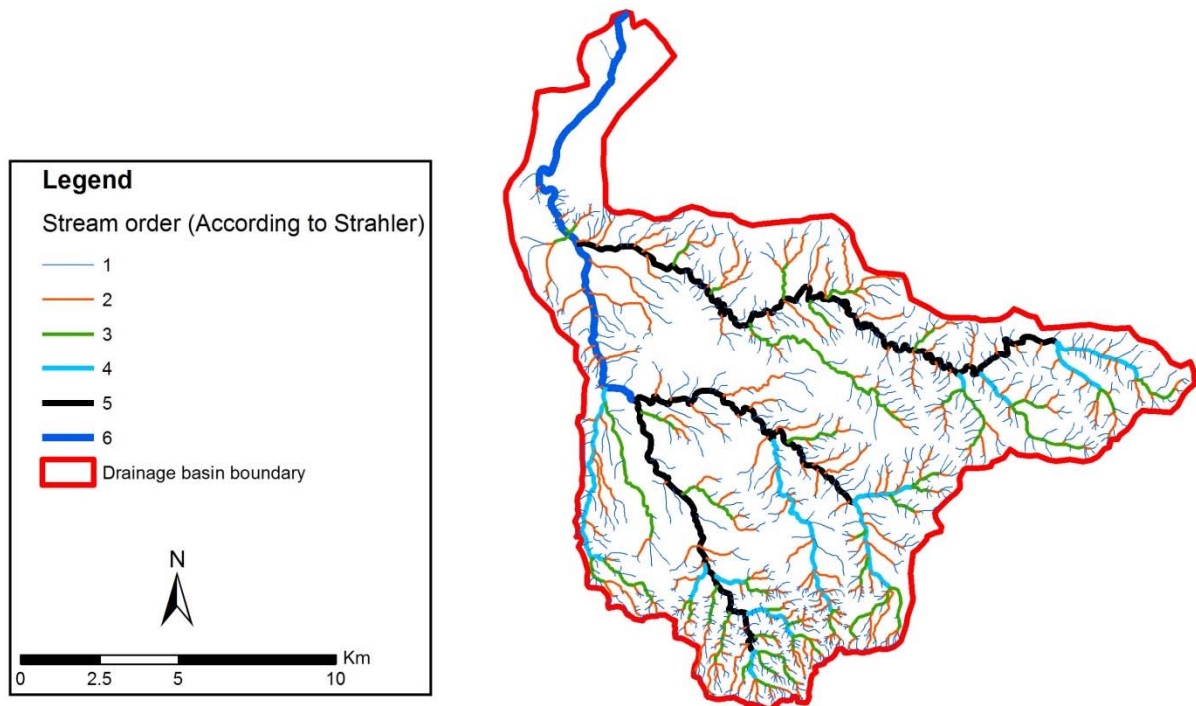


**Figure 1.** Broader area of interest in the vicinity of the Mygdonia Basin (which includes the watersheds of Lake Koroneia and Lake Volvi), near the city of Thessaloniki, in northern Greece. This study focuses on the central part of Mygdonia Basin (blue rectangle) and on the Melissourgos drainage basin (red polygon).



**Figure 2.** Topography of the broader study area.





**Figure 3.** The stream network of the Melissourgos drainage basin, presented according to the Strahler classification system ([20] and [21]). This information has been derived via the digitization of topographical maps (scale 1:50.000).

## 2.2. Available data

The topographic/elevation datasets used in this study included the following:

- (a) SRTM DEM version four (v.4); SRTM DEM v.4 is a 3-arcsec resolution (about 69 m x 90 m in the study area) DEM, delivered in 5° x 5° tiles by the Consultative Group on International Agricultural Research - Consortium for Spatial Information (CGIAR-CSI) [16]. More information is provided on the CGIAR website, while a thorough validation of SRTM DEM for the area of interest can be found in [9]. Note that, according to [9], for the area of interest, the CGIAR-CSI SRTM v.4 is identical with SRTM v.2 from NASA. The reason why v.4 is used here is only due to the fact that it is provided in larger tiles than v.2, thus, for a reasonable study area extent, the process of having to mosaic different SRTM DEM tiles can be usually avoided. The data are provided in World Geodetic System of 1984 (WGS 84) latitude and longitude and orthometric height with respect to the Earth Geopotential Model of 1996 (EGM96).
- (b) ASTER GDEM version two (v.2); this stereoscopic product is an improved version of the first release of 2009, with a resolution of 1-arcsec (about 23 m x 30 m in the study area) [17]. It includes 260000 additional scenes to improve coverage, a smaller correlation kernel to yield higher spatial resolution and improved water masking, while a negative 5-meter overall bias observed in ASTER GDEM v.1 was removed in the newer version. ASTER GDEM v.2 is distributed in 1° x 1° tiles. The data are given as WGS 84 latitude and longitude and orthometric height with respect to the EGM96 geoid.
- (c) EU-DEM version one (v.1); It was produced by merging NASA's SRTM DEM v.2 (also known as the "finished" version), with ASTER-GDEM v. 2 1-arcsec data, to generate a 1-

arcsec resolution (about 23 m x 30 m in the study area) DEM, using a weighted averaging approach. EU-DEM has been generated as a contiguous dataset divided into 1° x 1° tiles, corresponding to the SRTM DEM naming convention. These tiles have then been aggregated into 5° x 5° tiles for distribution. According to the European Environment Agency (EEA), the 5° x 5° tiles of EU-DEM have been projected to the European Terrestrial Reference System 1989-Lambert Azimuthal Equal Area projection (ETRS89-LAEA), by the Joint Research Centre (JRC). More specifically, the spatial reference system of EU-DEM is geographic latitude/longitude, with horizontal datum ETRS89, ellipsoid GRS80 and vertical datum the European Vertical Reference System 2000 (EVRS2000), using the European Gravimetric Geoid model EGG08 [9].

- (d) WorldDEM™ [10] is the latest, state-of-the art commercial global DEM derived from TANDEM-X satellite mission data. It offers a complete pole-to-pole coverage and unrivalled accuracy and quality, surpassing that of any global satellite-based elevation model to date. WorldDEM provides ellipsoidal heights (h) from WGS84 and it is delivered in a 12m x 12m (or 30m x 30m) raster with a vertical accuracy of 2m (relative) / 4m (absolute).
- (e) A 1-arcsec DEM of the study area, derived from the digitization of topographic maps (scale 1:50.000) of the Hellenic Military Geographical Service.

### 3. Methodology

Initially, areas corresponding to the maximum extent of lakes Koroneia and Volvi in the central part of Mygdonia Basin (as mapped in the topographical maps) have been masked out using the mean lake water level elevation values of 75m and 37m respectively, in order to avoid contamination of pixel values in the various DEMs. Note that Lake Koroneia in particular has undergone severe degradation during the past decades and has been occasionally completely dried out. Additionally, all available DEMs were clipped to the two areas of interest, whereas all of the above topographic data were transformed to WGS84/UTM, Zone 34N horizontal Datum/Projection and where appropriate, elevations have been converted to orthometric height (H) with respect to the EGM96 geoid. All the processing described in the methodology henceforth was carried out in a Geographical Information System (GIS), namely ArcGIS™ and QGIS.

Subsequent to the pre-processing, EU-DEM was compared against all the available datasets, with respect to the effectiveness of extracting the following geomorphological information: (a) For the central part of Mygdonia Basin; relief classification, slope and slope aspect calculation and (b) For the Melissourgos drainage basin; drainage basin delineation, extraction and classification of drainage network.

## 4. Results and discussion

### 4.1. Classification of relief

In terms of relief classification (Table 1) in the central part of Mygdonia Basin, the differences among the available DEMs are rather insignificant. Any small discrepancies are mostly related to the different spatial resolution of each dataset, as well as, possibly, to the different geolocation (horizontal) accuracy of each DEM.

### 4.2. Slope

The results for slope inclination (Table 2 and Table 3) indicate considerable deviations among the different DEMs, which can be partly attributed to the diverse spatial resolution of each dataset (e.g. SRTM tends to smooth out steep slopes, due to its coarser sampling). In this respect, the fact that EU-DEM is produced by the combination of ASTER-GDEM and SRTM partially has a negative effect to its performance. Concerning slope aspect (Table 4), there is generally good agreement between the DEMs, while for several slope classes EU-DEM is performing better than its constituents.

**Table 1.** Relief of the study area, using the classification system described in [18].

Elevation (m)	Area (%)				
	Topographic maps	SRTM	GDEM	EU-DEM	WorldDEM
<b>&lt;150 (Plains)</b>	28.52	28.69	29.53	28.68	28.71
<b>150-600 (Hills)</b>	64.03	63.79	63.01	63.78	63.71
<b>600-900 (High hills)</b>	6.51	6.58	6.53	6.62	6.63
<b>&gt;900 (Mountains)</b>	0.94	0.94	0.93	0.93	0.95
<b>Total</b>	100.0	100.0	100.0	100.0	100.0

**Table 2.** Basic slope descriptive statistics derived from the various DEMs.

	Slope (°)				
	Topographic maps	SRTM	GDEM	EU-DEM	WorldDEM
<b>Min</b>	0	0	0	0	0
<b>Max</b>	84	41	55	48	61
<b>Mean</b>	11.5	5.5	8.4	6.0	8.1
<b>StD</b>	13.0	4.9	6.5	5.4	7.1

**Table 3.** Area per slope class, as classified according to [19].

Slope (°)	Area (%)				
	Topographic maps	SRTM	GDEM	EU-DEM	WorldDEM
<b>0-2 (Plain or slightly sloping)</b>	27.27	28.46	12.48	27.62	24.23
<b>2-5 (Gently inclined)</b>	14.20	25.69	23.02	23.84	17.31
<b>5-15 (Strongly inclined)</b>	28.74	40.61	49.32	41.18	40.91
<b>15-35 (Steep)</b>	23.92	5.24	14.95	7.34	17.41
<b>35-55 (Very steep or Precipitous)</b>	4.39	0.01	0.23	0.02	0.14
<b>&gt; 55 (Vertical or overhanging)</b>	1.48	< 0.01	< 0.01	< 0.01	< 0.01
<b>Total</b>	100.0	100.0	100.0	100.0	100.0

**Table 4.** Slope aspect (orientation) by area.

Slope aspect (orientation)	Area (%)				
	Topographic maps	SRTM	GDEM	EU-DEM	WorldDEM
<b>N</b>	9.87	11.65	11.66	10.90	11.05
<b>NE</b>	10.81	10.92	11.01	10.64	10.85
<b>E</b>	10.61	8.19	10.34	8.85	10.12
<b>SE</b>	11.61	11.75	11.50	11.57	11.80
<b>S</b>	12.56	16.63	14.34	15.15	14.18
<b>SW</b>	13.79	16.49	13.64	15.65	14.60
<b>W</b>	11.46	10.18	11.31	10.75	11.47
<b>NW</b>	9.90	8.88	10.67	9.18	9.62
<b>Flat areas</b>	9.38	5.29	5.53	7.31	6.30
<b>Total</b>	100.0	100.0	100.0	100.0	100.0

#### 4.3. Drainage basin

For the Melissourgos drainage basin, the total area of its watershed was estimated for every DEM (Table 5). Note that this does not concern the automatic extraction of the watershed by each individual DEM independently, but instead the calculation of the surface inside the predefined drainage basin boundary (as delineated from the topographical maps). Therefore, the negligible discrepancies observed are only due to the different pixel size (spatial resolution) of each DEM.

**Table 5.** Watershed area calculation for the Melissourgos drainage basin.

Topographic maps	Area (Km <sup>2</sup> )			
	SRTM	GDEM	EU-DEM	WorldDEM
202.97	202.93	202.96	202.96	202.96

#### 4.4. Drainage network

In the final processing step within ArcGIS, the stream network for the Melissourgos drainage basin was automatically extracted from each DEM and compared against the digitized drainage from the topographical maps. The comparison was made on the basis of total length per stream order (Table 6).

**Table 6.** Drainage network length per stream order for the studied water basin.

Stream order	Length (Km)				
	Topographic maps	SRTM	GDEM	EU-DEM	WorldDEM
<b>1</b>	318.76	1118.29	3723.45	4854.27	10282.56
<b>2</b>	140.46	316.12	1015.23	1195.67	3026.58
<b>3</b>	60.65	150.47	388.69	374.34	965.23
<b>4</b>	31.35	67.50	94.51	187.25	478.17
<b>5</b>	44.04	7.61	8.56	55.67	184.89
<b>6</b>	15.76	-	-	8.91	16.77
<b>Total</b>	611.02	1659.99	5230.44	6676.11	14954.20

This is the most intriguing comparison, as the differences among the datasets are very striking and there could be various contributing factors and interpretations:

- The information on the topographic maps of Greece concerning the drainage network is in many cases incomplete, while the 1<sup>st</sup> and 2<sup>nd</sup> order streams delineated on the 1:50.000 maps in reality correspond to 3<sup>rd</sup> and 4<sup>th</sup> order streams respectively [22], [23].
- The satellite-based DEMs provide a very large number of 1<sup>st</sup> (and in most cases also 2<sup>nd</sup>) order streams, which is possibly closer to the number of 1<sup>st</sup> order streams encountered in the field, as defined by [24].
- If the 1<sup>st</sup> orders streams derived from SRTM or/and the 1<sup>st</sup> and 2<sup>nd</sup> order streams derived from GDEM and EU-DEM are ignored, then there seems to be a correspondence between the total lengths of the remaining classes as follows; the values for the 1<sup>st</sup> order streams from the topographical maps are very close to those for the 2<sup>nd</sup> order streams of SRTM and the 3<sup>rd</sup> order streams from GDEM and EU-DEM. This fact could either be coincidental or it could otherwise support the first two aforementioned interpretations.

Another interesting observation is that EU-DEM registers the correct maximum stream order (six) of the drainage network, even though its constituents (SRTM and GDEM) fail to do so (they record a maximum of five).

## 5. Conclusions

The main focus of this study was to compare, from a geomorphological perspective, the performance of EU-DEM against its constituents, as well as versus higher resolution and accuracy DEMs. The



persistence on evaluating EU-DEM for geomorphological purposes lies in the fact that this DEM is not the output of original measurements, but a mathematically produced dataset, trying to profit from the synthesis of existing DEMs.

Results indicate that EU-DEM can be used with no particular restrictions for relief classification, watershed area calculation and slope orientation. Under conditions, it is also appropriate for the extraction of slope inclination, but is not necessarily an enhanced product with respect to SRTM and GDEM thereto. Concerning the automatic extraction and classification of drainage networks, further investigation for all DEMs is proposed.

In particular, this includes the validation of geomorphological features extracted from EU-DEM and other DEMs against extensive field work measurements with Global Navigation Satellite Systems (GNSS). It is also considered necessary to extend the investigation to more drainage basins over different areas and perform detailed statistical analysis thereto.

Field work using GNSS for mapping geomorphological elements, such as river/stream networks and slopes shall serve for collecting reliable datasets for the direct comparison of “real” geomorphological features measured in situ with GNSS, against those extracted from the original DEMs, as well as from the “improved” DEMs. This shall contribute to investigating in detail and with higher accuracy field observations and measurements what was really mapped by the various DEMs.

Overall, although space-based observations bear great potential for topographic mapping, mainly due to the synoptic, continuous and coherent way of data collection, as well as availability and ease of access, their use in Geomorphology ought to be carried out with caution. Especially, but not exclusively, artificially (mathematically)-produced DEMs such as EU-DEM ought to be handled with extra care for geomorphological purposes. Finally, another challenge is how Geomorphology will keep benefiting and maximize the impact from the constant improvement, (mainly) in terms of vertical accuracy, of global DEMs and how to produce (on local/regional/global scale) enhanced, Geomorphology-oriented, DEMs from existing global datasets derived from space-based observations.

### **Acknowledgment(s)**

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