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COMPARISON OF SRTM ELEVATION DATA WITH CARTOGRAPHICALLY DERIVED DEMS IN ITALY

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ABSTRACT

In this study we evaluated the quality of the DEM acquired by the Shuttle Radar Topography Mission (SRTM) for Italy through comparison with cartographically derived DEMs, available for the Italian territory. Comparison was carried out analyzing differences in elevation and slope angle at regional scale. The comparisons carried out at the regional scale disclose a general increase in slope angle values with the change in resolution and a moderate difference in mean elevation. From these results, we highlighted that improved surface-based DEMs, based on advanced SAR, have vertical values that approach or exceed that of current medium resolution surface products. Moreover, this study helps to provide a benchmark against which future DEM products can be evaluated.

Keywords: Shuttle Radar Topography Mission (SRTM), Digital Elevation Models, Italy, Regional scale analysis

1. INTRODUCTION

One of the most fundamental geophysical measurements of the planet Earth is the shape of the land surface. Knowing surface topography is basic to many earth surface processes analyses. It is essential in analyses of hydrology, geomorphology, and many others, as a means of assessing geomorphologic variables in order to explaining processes and predicting them. Most of the disciplines of scientific research involving the Earth's land surface require topographic data and derived slope, slope aspect, and orthoimage cartographic products (Hohle, 1996). Our capacity to understand and model earth surface processes depends on the quality of the topographic data that are available. With the advent of digital imagery, various datasets of topography have been produced, in a digital format called Digital Elevation Model (DEM). A DEM is a computerized representation of the Earth's terrain (Burrough and McDonnell, 1998), and can be described by a wire frame model or an image matrix in which the value of each pixel is associated with a specific topographic height (Evans, 1980). There are three basic sources of data for the creation of DEMs: (i) data from digitized topographic maps; (ii) field data collected with GPS receivers; and (iii) digital aerial photographs or satellite images.

In recent years, there has been an increasing use of remote sensing techniques to prepare DTMs rather than direct survey. The importance of aerospace observation is obvious: satellites carrying a variety of sensors looking toward the earth are able to collect, at relatively low costs, data broadly consistent with the required spatial, spectral and temporal resolutions in order to interpolate new DEMs (Kobrick, 2006). The globally uniform Shuttle Radar Topography Mission (SRTM) dataset (Rabus et al., 2003, Smith and Sandwell, 2003, Grohman et al., 2006, Gesh, 2006) provides an unprecedented opportunity to unify landscape analyses together with collocated topographic information, which can be used to characterize the landscape and other key variables (Farr and Kobrick, 2000). The SRTM data set in synergy with other remote sensing data sets, can be used to derive a number of major (but not all) parameters constituting a significant part of the different topography consistently at the 11-day time interval during which the SRTM data set was collected. LIDAR (Light Detection and Ranging) is another remote sensing technology used to prepare DTMa. It measures properties of scattered light to find range and/or other information of a distant. In particular is an emerging technology, that offers capability of capturing high density three dimensional points and generating high accuracy DEMs in a fast but not in a cost-effective way especially on a regional scale (Parian and Gruen, 2005).

Given the demand for a product such as the SRTM DEM, it is important to examine carefully the quality of the dataset (Smith and Sandwell, 2003; Rabus et al., 2003; Falorni et al., 2005; Kobrick, 2006, Grohman et al., 2006), comparing it with alternative sources of terrain elevation data. In several papers the accuracy of SRTM X- and C-band DEMs was checked against ground control points measured by differential GPS, (Kocak et al., 2005, Gorokhovic and Voustianiouk, 2006). In this paper, we examine the quality of SRTM data for Italy through qualitative and quantitative comparison with other cartographically derived DEMs, at different resolutions. The comparison is focused on analyzing how accurately the morphology is represented at regional scale and how it affects basin hydrological analysis.

2. AVAILABLE DIGITAL ELEVATION MODELS

In order to evaluate the quality of the SRTM DEM, it was compared with two different digital elevation models: i) the 230 m x 230 m DTM for Italy and ii) the 25 m x 25 m DTM for Umbria Region, central Italy

2.1. THE SRTM DEM FOR ITALY

In this analysis we have used the earlier version of the SRTM that is in a format of 1º x 1º tiles. The SRTM dataset (Figure 1A) in its original format has a resolution of 3-arc-seconds, approximately 90 m x 90 m over the Italian territory. Assembly and local interpolation of the SRTM for Italy was performed importing 91 tiles into ArcInfo 9.0 (©ESRI) using an Arc-Macro Language procedure (Taramelli and Barbour, 2006). The DEM required adjustment during georeferencing in order to correct its geoid-projection by means that the SRTM DEM (orthometric heights) are measured from EGM 96 geoid (an undulating surface which is either lower or higher than the WGS 84 ellipsoid). We first transformed SRTM elevations to geometric elevations (from EGM 96 geoid to WGS 84 ellipsoid). This means that the elevation differences we compute include SRTM vertical error and the deviation of WGS84 ellipsoid from the EGM 96 geoid. The final grid was then georeferenced and projected in the Lambert conformal conic projection.

In order to compute elevation and slope on the basis of SRTM height data and to correlate the elevation difference (SRTM-reference DTMs) to elevation and slope in the analysis we had to use an interpolation processes across missing pixels. The original SRTM data contains 1,305,584 pixels of missing values (about 3% of the territory), covering an area of 10,575 km2. To remove the missing pixels, we performed interpolation using a minimum curvature algorithm. The main point in doing that is that SRTM data suffer from specific problems (like slope vertical accuracy dependency, Miliaresis and Paraschou 2005).

So if we calculate elevation and slope from SRTM data with void then an error is introduced in slope and elevation due to the height errors evident in SRTM. SRTM computed slope could then present much greater in magnitude errors than the vertical elevation error related to the interpolated voids.

Finally we prepared the SRTM to carry out hydrological analysis on a regional scale, masking and distinguishing lakes without internal drainage outflow and with internal drainage outflow. The lake masking was also used as “clipping boundary” to mask out water-surface backscatter problems.

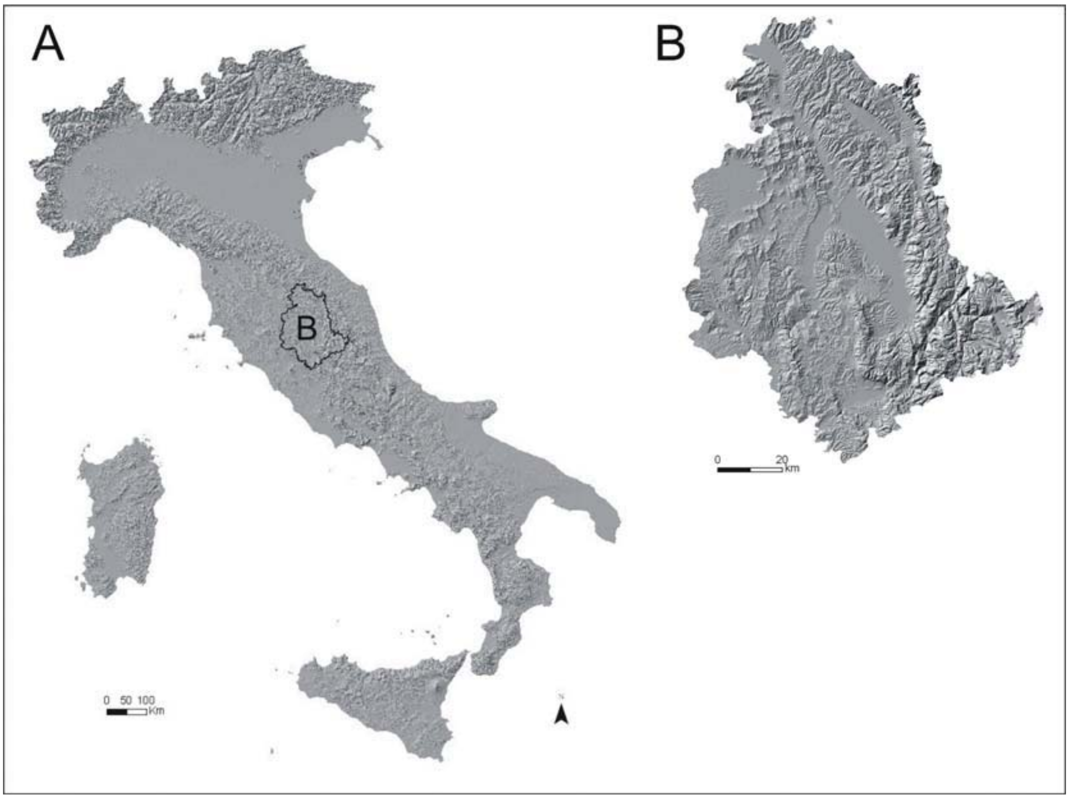

Figure 1 - Shaded relief images: (A) SRTM DEM.. (B) 25 m x 25 m DEM for the Umbria Region.

2.2. THE 230 M X 230 M RESOLUTION DEM FOR ITALY

The low resolution elevation data available for Italy (230M DEM, Figure 2) was obtained from the archive of “Mean Height Values for Italy” compiled by estimating mean elevation values by both manual and machine methods from 1:25,000-scale topographic maps (Carrozzo et al., 1985). The manual data, prepared for Central and Southern Italy, for Sicily and Sardinia, were read off contour maps using a square-grid template spaced at 7.7 arc-seconds of latitude and 10 arc-seconds of longitude. Each point was assigned an elevation value to the nearest meter, by averaging contour lines and spot heights within each grid square. Machine-gathered data were obtained for the rest of the country (i.e., Northern Italy) by computer interpolation of digitized contours. The elevation data obtained by both methods were organized into 280 matrices of 160 rows and 180 columns arranged on a geographic grid, each matrix corresponding to an IGMI (Italian Geographic Military Institute) topographic sheet in the 1:100,000-scale series (Carrozzo et al., 1985).

A joint CNR/USGS project assembled the DEM for Italy at a ground resolution of 230 m x 230 m by mosaicing and correcting all 280 files of the original mean elevation archive (Reichenbach et al., 1993).

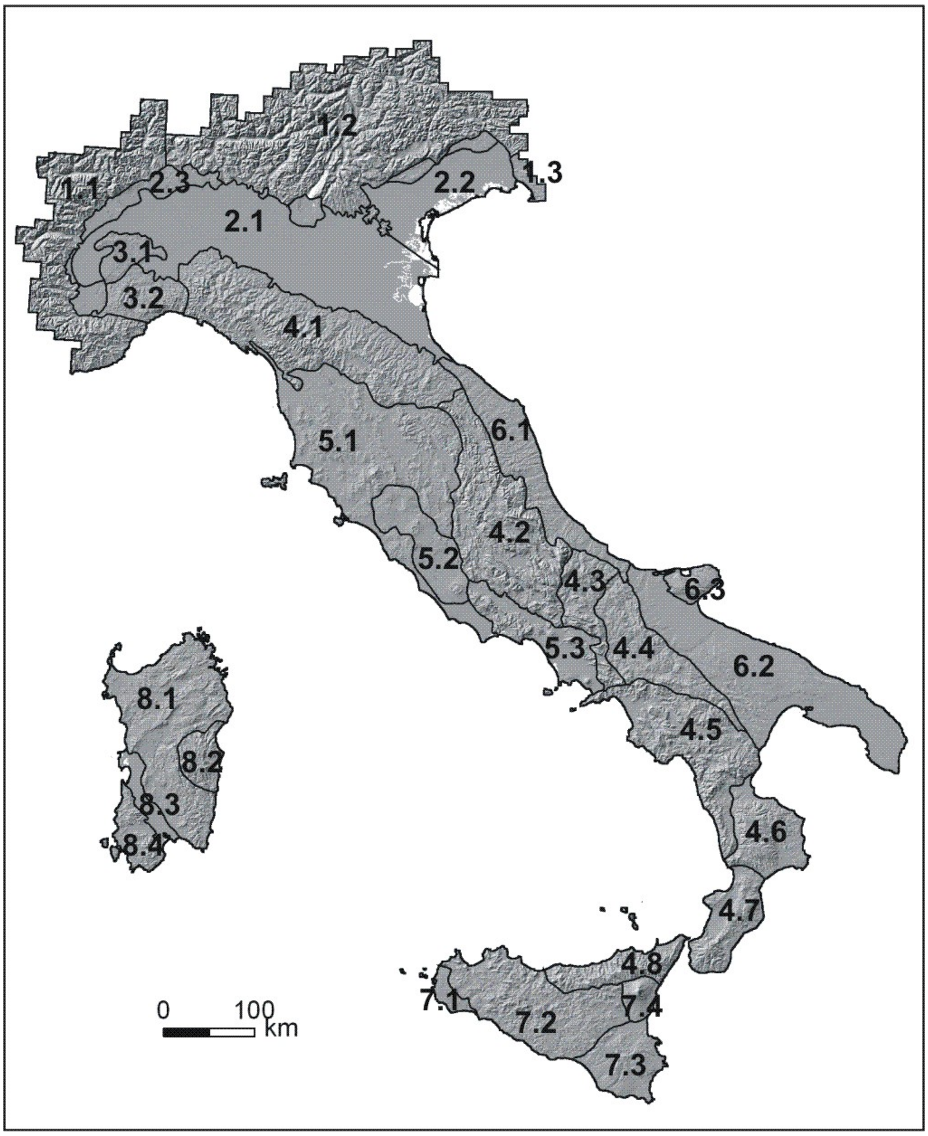

Figure 2 – Topographic divisions of Italy (Guzzetti and Reichenbach, 1994). The shaded relief image was obtained from the 230 m x 230 m DEM. See table 1 for division names.

2.3. THE 25 M X 25 M DEM FOR THE UMBRIA REGION

The 25 m x 25 m DEM for the Umbria Region (25M DEM, Fig.1B) was prepared by interpolating the digital contour lines obtained from IGMI topographic maps. The 131 digital topographic sheets at 1:25,000-scale that cover the Umbria region were available in the UTM projection, zones 32 and 33, European Datum 1950. We processed the DEM through three steps. In the first step, we verified the contour lines to check elevation value and geometry. In the second step we assembled the corrected the 131 individual sheets into 21 partially overlapping..

The third and final step consisted in interpolating the DTM from the available contour lines. First, a triangular irregular network (TIN) was constructed from the contour lines. In the areas where contour curvature was large (e.g. along sharp ridge tops and bottom valleys) the interpolation generated inferred breaklines and used them in the production of the TIN. The TINs were then converted into grids and assembled in one single raster file.

To mitigate artifacts, un-realistic features in flat areas, erroneous scarps due to lack of elevation data, we added auxiliary contour lines and spot heights to the original elevation data. For the purpose we used detailed topographic maps at 1:10,000-scale (CTR, series Regional Technical Cartography). We verified the consistency of the contour lines and the hydrological network. We repeated the last step generating new TINs and a new 25 m X 25 m grid. The final step in the DEM production was the identification and the removal of "sink" and "peak" pixels along the hydrologic network. In the DEM elevation ranges from a minimum of 40 m a. s. l. to a maximum of 2484 m a. s. l.

3. THE ANALYSIS

In this paper we evaluated the quality of the SRTM DEM and in particular how the morphology is represented at regional scale, implementing different types of analysis. Qualitative analyses were achieved through visual inspection and examination of shaded relief images obtained from the DEMs, and through the evaluation and the comparison of the river networks derived automatically from the available DEMs. Quantitative tests include the analysis of the differences in elevation and terrain gradient at regional scales. At the regional scale tests were carried out using both sub-basin divisions and the topographic divisions for Italy defined by Guzzetti and Reichenbach (1994).

3.1. COMPARISON OF THE SRTM DEM AND THE 230 M X 230 M DEM USING THE TOPOGRAPHIC DIVISION FOR ITALY

To compare the SRTM DEM with the low resolution 230 m x 230 m DEM for Italy we used the 30 topographic divisions of Italy established by Guzzetti and Reichenbach (1994). The sub-divisions should ideally maximize internal homogeneity and between-unit heterogeneity, and are characterized by unique groups of morphometric parameters. Italy was partitioned into topographic provinces and sections, adopting a semi-quantitative approach that combined an unsupervised three-class cluster-analysis of four derivatives of altitude, visual interpretation of morphometric maps, and comparative inspection of small-scale geological and structural maps (Figure 2 and table 1). Provinces are first-order divisions with distinct or unique geomorphologic characteristics that distinguish them from neighboring areas. Boundaries between provinces correspond to major morphological and geological features or coastlines. Sections are the minor topographic divisions within provinces. Section boundaries are less distinct and generally more open to interpretation. Based on the distribution of morphometric parameters and in particular on the dispersion of elevation and gradient the 30 topographic divisions can be grouped into five main classes or terrain types: plains, low hills, hills, low mountains, and high mountains (Figure 3, inset). The two extremes - plains and high mountains - show very distinct morphometric attributes representing low and gentle versus high and steep terrain types. Between these two extremes low mountains, hills and low hills constitute three separate groups. We investigated the differences between the SRTM DEM and the 230M DEM by computing the dispersion of elevation and the dispersion of slope angle within each topographic subdivision. Figure 3 shows the value of the dispersion of elevation and of slope obtained from the 230M DEM (in black) and the SRTM (in gray). In the figure, the arrows show the difference between the two DEMs for each topographic division. Inspection of Figure 3 reveals that values of the dispersion of slope computed from the SRTM DEM are larger than the corresponding values obtained from the 230M DEM, for most of the topographic subdivisions. Values of the dispersion of elevation computed for the two DEMs exhibit a reduced variation, for most of the topographic provinces. We attribute the differences to the higher spatial resolution of the SRTM DEM that is capable of better capturing the terrain characteristics and roughness. For three sections (sections 1.1, 1.2 and 1.3, corresponding to the Alpine mountain chain) values of the dispersion of elevations computed from the SRTM is lower than the corresponding values from the 230M DEM. We attribute this anomaly to the interpolated values (through missing pixels) in the SRTM DEM, which are quite numerous in the Alpine mountain chain.

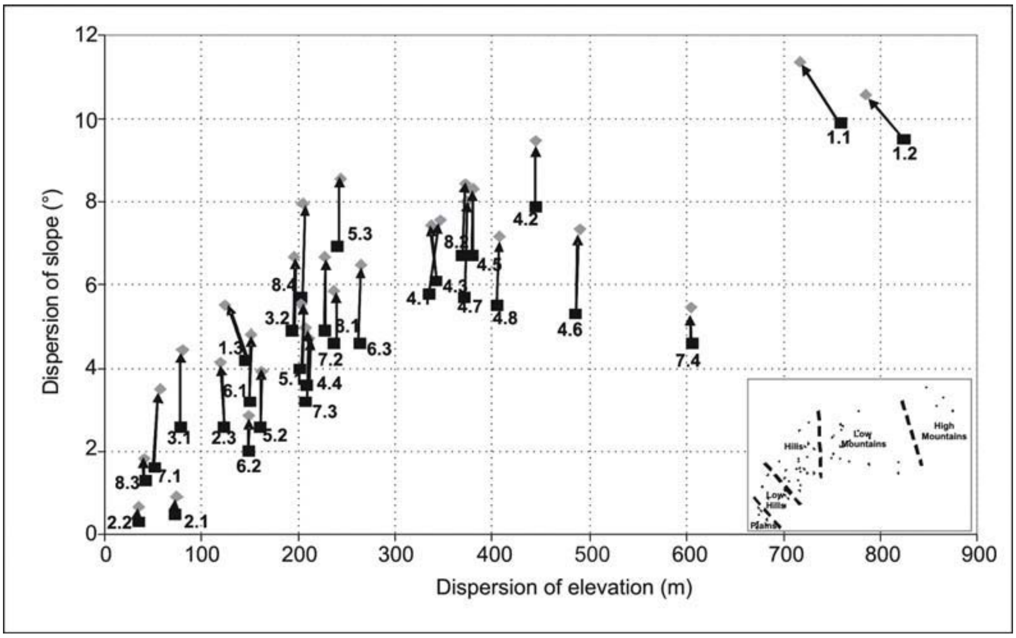

Figure 3 - Dispersion of slope versus dispersion of elevation. Topographic units are grouped into five terrain types: plains, low hills, hills, low mountains and high mountains.

Table 1 – Topographic divisions of Italy established by Guzzetti and Reichenbach (1994). Numbers of the minor divisions are reported in figure 2.

Major division (Province)	Minor division (Section)
1. Alpine Mountain System	1.1 Western Alps
	1.2 Central-Eastern Alps
	1.3 Carso
2. North Italian Plain	2.1 Po Plain
	2.2 Veneto Plain
	2.3 Alpine Foothills
3. Alpine-Apennine Transition Zone	3.1 Monferrato Hills
	3.2 Ligurian Upland
4. Apennine Mountain System	4.1 Northern Apennines
	4.2 Central Apennines
	4.3 Molise Apennines
	4.4 Molise-Lucanian Apennines
	4.5 Lucanian Apennines
	4.6 Sila
	4.7 Aspromonte
	4.8 Sicilian Apennines
5. Tyrrhenian Borderland	5.1 Central Italian Hills
	5.2 Tosco-Laziale Section
	5.3 Lazio-Campanian Section
6. Adriatic Borderland	6.1 Central Apennine Slope
	6.2 Murge-Apulia Lowland
	6.3 Gargano Upland
7. Sicily	7.1 Marsala Lowland
	7.2 Sicilian Hills
	7.3 Iblei Plateau
	7.4 Etna
8. Sardinia	8.1 Sardinia Hills
	8.2 Gennargentu Highland
	8.3 Campidano Plain
	8.4 Iglesiente Hills

3.2. THE COMPARISON BETWEEN THE SRTM DEM AND THE 230M AND 25M DEMS IN WATERSHED

In the second test we evaluate the quality of the SRTM DEM at the watershed scale in the Umbria region (central Italy) where DEMs at different resolution are available. Watershed boundaries were defined using a standard procedure and topographic parameters were used to analyze the difference between pairs of DEMs. The delineation of watersheds was carried out exploiting the eight-direction pour point model. The method of Jenson and Domingue (1988) was used to determine the watershed area and the elevation of the basin outlet for each DEM. In each test area, watersheds were defined for the SRTM DEM, and the boundaries were used to perform a "zonalstat" analysis in each of the other available DEMs. The analysis was used to compute mean slope and mean elevation using the watersheds as polygon masks. To evaluate the difference between DEMs, we first analyzed the relationship between mean slope and mean elevation for each sub-basin and then we compared values of the derivatives for each pair of DEMs.

In the Umbria Region 87 watersheds with a mean area of 100 square kilometers were obtained for the SRTM DEM and statistics of the elevation and the slope were computed for the three available DEMs.

The SRTM DEM shows mean elevation and mean slope value smaller than the 25M DEM and larger than the 230M DEM. For the three DEM, in figure 4A we plotted values of mean slope and mean elevation values computed for the 87 catchments. The open squares represent the 230M DEM catchments, gray diamonds the SRTM DEM catchments and black squares the 25M DEM catchments. In figure 4A the SRTM and the 25M DEM catchments show a similar pattern, whereas values obtained from the 230M DEM exhibit a cluster at low mean slope and low mean elevation values. The same trend is portrayed in figures 4B and 4C. Inspection of plot 4A confirms the increase in mean slope and means elevation values due to the different resolutions of the three considered DEMs. Figures 4B and 4C show the elevation and the slope relationship between the SRTM DEM and the 230M DEM respectively, whereas figures 4D and 4E show the elevation and the slope relationship between the SRTM and the 25M DEMs. In figure 4B the correlation between the two DEMs is very low. This finding may be attributed to errors related to the processing adopted to obtain the 230M DEM. In figure 4C the trend reveals a very poor correlation between mean slope values computed from the 230M DEM and the mean slope values computes from SRTM DEM. Slope values for the SRTM data are significantly higher than the slope values obtained for the 230M DEM. The SRTM accuracy progressively becomes higher with increasing slope angle. This result reveals an under-estimate of the highest slope angle by the 230M DEM. Figure 4D shows the strong correlation existing between elevations obtained from the SRTM DEM and the 25M DEM. The high correlation indicates that the differences between the SRTM DEM and the 25M DEM are within (±) 10 m. In figure 4E few basins, with mean slope ranging between 10 and 20 degrees, exhibit anomalous values, the results of missing data along gentle slopes in the 25M DEM. Slopes are higher for the 25m DEM (Figure 4E).

In the Umbria region, where blue lines derived from topographic maps are available, we compared the stream network computed automatically from the three DEMs. Figure 5 shows the blue lines derived from the topographic maps at 1:25.000-scale and the stream networks computed automatically for the upper portion of the Nera River, in south-eastern Umbria. Figure 5A compares the topographic blue lines with the 230M DEM stream network, figure 5B and 5C compare the topographic blue lines with the SRTM stream network and the 25M DEM stream network respectively.

Visual inspection of figure 5 reveals an increase in accuracy with the increase of the DEM resolution. Total stream length obtained summing all the stream segments in the drainage networks shows an increase from 177 kilometers for the 230M DEM, to 338 kilometers for the SRTM DEM and to 431 kilometers for the 25M DEM. Considering the total length of the blue lines (817 km), only 50% of the stream network was captured by the automatic procedures. The stream network derived from the 230M DEM shows distinctly sharp shape and a random shift that may indicate an inconsistency in the small scale DEM. The SRTM DEM network shows a greater detail in the river shape, longer meandering and therefore longer flow lines. No major differences can be seen when comparing the SRTM and the 25M DEMs where most of the main channels are correctly identified. The result is confirmed by the good correlation of both synthetic river networks with the blue lines shown on the topographic maps at 1:25,000-scale. Network dissimilarities between the SRTM DEM and the 25M DEM can be observed in the floodplain near Visso (see box in figure 5B) where topographic "speckling" explained by missing elevation points and poor interpolation produces significant deviation in the SRTM river network (that could be related to poor coherence between the two antenna of the SRTM interferometer). In other flood plains (not shown in the figure) large flat triangular area derived from the TIN modeling, produce high inaccuracies in the 25M DEM drainage networks.

The synthetic drainage networks were also examined in terms of stream ordering. For this purpose we adopted the Strahler ordering system (Strahler, 1980) that measures the complexity and completeness of the river network. Using the available DEMs, the synthetic drainage network obtained from the 230M DEM reached the 4th order, the network obtained from SRTM DEM reached the 5th order and the network obtained from 25M DEM was of the 6th order. This confirms an increase in the detail of the obtained synthetic networks with increase DEM resolution. As shown in figure 5, most of the first order channels shown in the topographic maps were not identified by the three synthetic drainage networks.

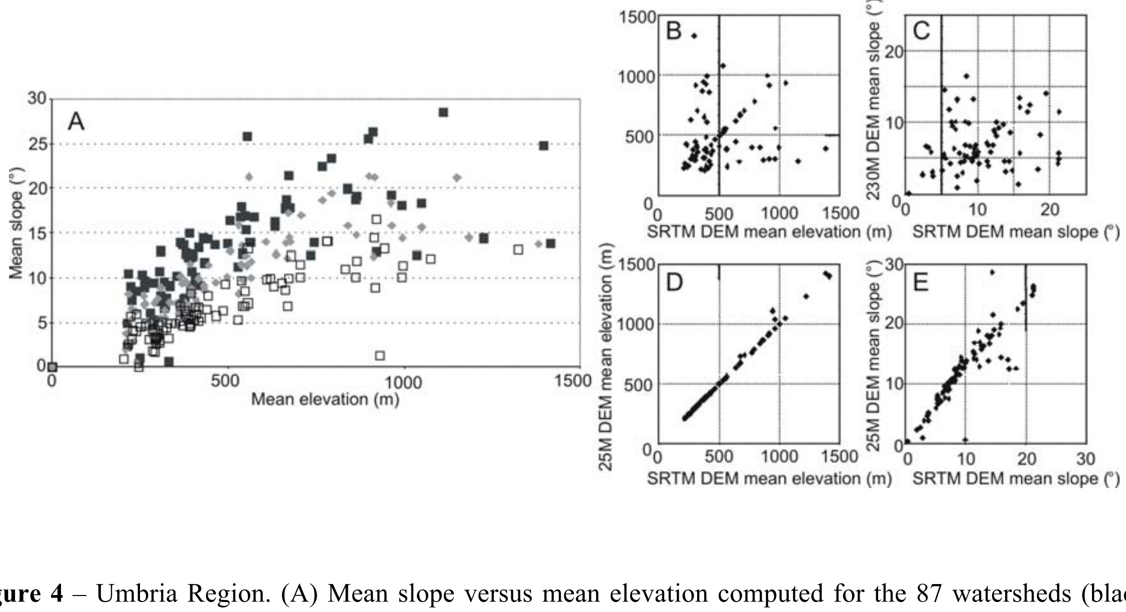

Figure 4 – Umbria Region. (A) Mean slope versus mean elevation computed for the 87 watersheds (black open squares: 230M DEM watersheds; gray diamonds: SRTM DEM watersheds; black square: 25M DEM watersheds). (B) Mean elevation computed from the 230M DEM versus mean elevation computed from the SRTM DEM. (C) Mean slope angle computed from the 230M DEM versus mean slope angle computed from the SRTM DEM. (D) Mean elevation computed from the 25M DEM versus mean elevation computed from the SRTM DEM. (E) Mean slope angle computed from the 25M DEM versus mean slope angle computed from the SRTM DEM.

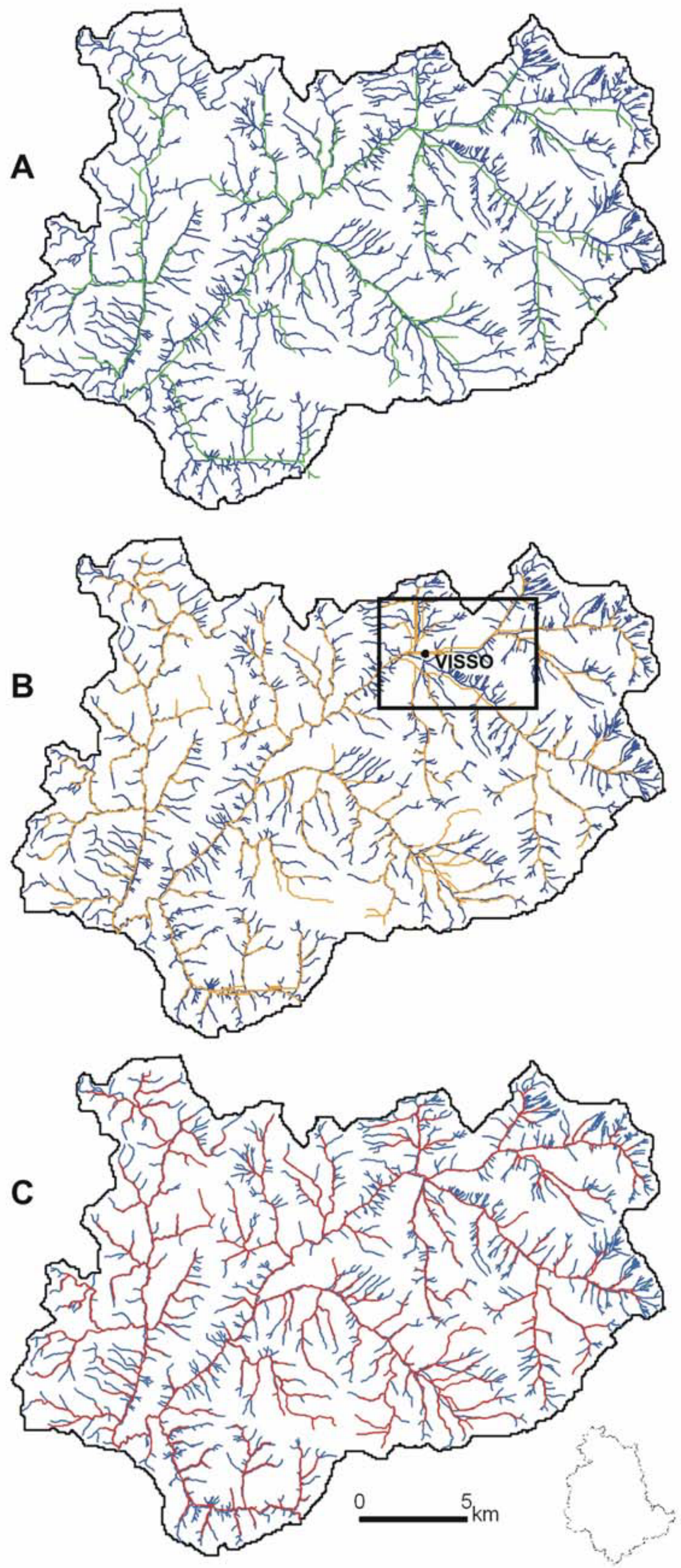

Figure 5 – South-east part of the Umbria Region. Comparison between the stream network derived from the topographic map at 1:25.000-scale (blue lines), and the drainage networks extracted from the three DEMs. (A) Green lines: 230M DEM stream network. (B) Orange lines: SRTM DEM stream network. The black rectangle highlights the Visso plain. (C) Red lines: 25M DEM stream network.

3.3. VISUAL COMPARISON OF DEMS

Visual inspection and examination of shaded relief images obtained from the DEMs was used to evaluate qualitatively the SRTM DEM.

Figure 6 shows three shaded relief images for the portion of the Umbria Region. The image at the top (Figure 6A) was obtained from the 230M DEM, the second (Figure 6B) from the SRTM DEM and the third at the bottom (Figure 6C) from the 25M DEM. The image computed from the 230M DEM shows few topographic features and much surface smoothing: the pixel resolution allows only an a broad representation of the main topographic features.

Visual inspection of the three shaded relief images reveals a distinct improvement in representation of the topography with increasing DEM resolution. Further inspection reveals a moderate increase in topographic details and roughness between the SRTM DEM and the 25M DEM. Major differences occur in the flat areas where the 25M DEM exhibits flat triangular surfaces caused by the TIN interpolation algorithm, a result of the lack of sufficient contour lines in the valley bottom. Although the SRTM DEM has a coarser spatial resolution, it better captures topography in the flat areas. In the SRTM DEM problems in the shaded relief visualization are present in areas of shadow, or areas with dense vegetation and steep slopes (see box in figure 6B).

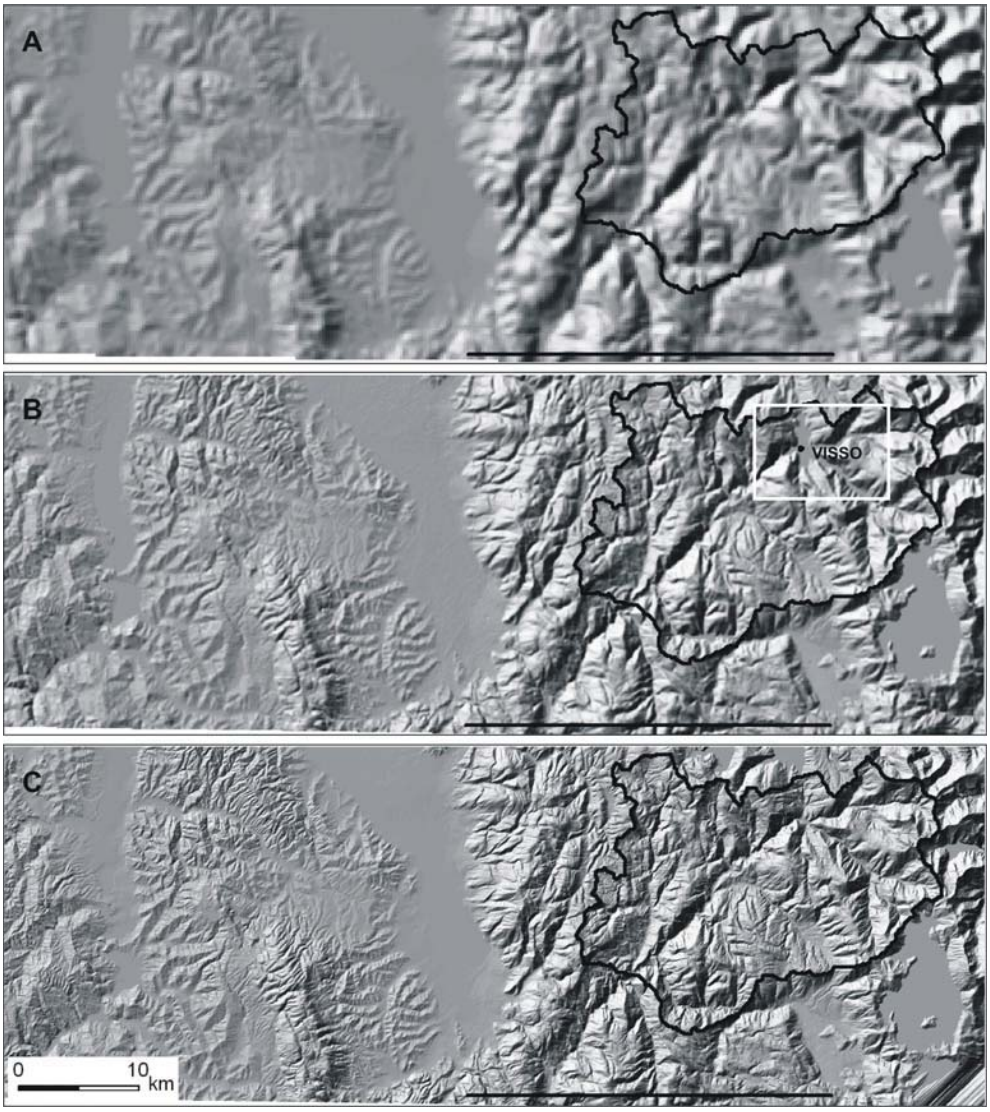

Figure 6 - South-east part of the Umbria Region. Comparison of shaded relief images. (A) 230M DEM. (B) SRTM DEM, the white box highlights the Visso plain. (C) 25M DEM. Black lines show the boundary of the watershed of figure 5.

4. DISCUSSION AND CONCLUSION

In this study we evaluated the quality of the DEM acquired by the Shuttle Radar Topography Mission (SRTM) for Italy through comparison with cartographically derived DEMs, available for the Italian territory. Comparison was carried out analyzing the difference in elevation and slope angle at regional. The analysis carried out using the topographic divisions of Italy indicates that for homogenous portion of the territory there is a significant difference in values of the dispersion of slope computed for the low resolution DEMs and a moderate difference in the dispersion of elevation. In the Alps the dispersion of elevation computed from the SRTM is lower than the corresponding values obtained from the 230M DEM. We attribute the anomaly to the interpolated values (throughout missing pixels) quite numerous in the Alps, where the radar shadowing effect involved the acquisition of missing points.

The comparison carried out at catchment scales confirms a general increase in slope angle values with the change in resolution and a moderate difference in terms of mean elevation. Statistical mean elevation and slope values computed for the SRTM DEM watershed, exhibit a poor correlation with the same parameters derived from the 230M DEM and a strong correlation with data obtained from the 25M DEM. The analysis of the synthetic river networks derived from the three DEMs, revealed major difference between the 230M DEM network and the SRTM DEM network. Only small differences were outlined comparing the SRTM DEM network and the 25M DEM network. In the valley near Visso in Umbria the river network derived from the SRTM DEM exhibits missing values that cause error in the derivation of the upstream drainage network.

The SRTM DEM is the most detailed elevation data base available for the entire Italian State and proves to be a great improvement respect to the 230 m x 230 m resolution available for all of Italy. The elevation values of the SRTM DEM are highly related to the characteristics of the local relief, topography and the presence of missing data in the original data set. The comparison between SRTM data and higher resolution DEMs shows that the STRM has similar information quality.

For hydrological purpose the higher spatial resolution DEMs don't allowed to trace a more detailed river network. Little differences were in fact found between the SRTM hydrological derivatives and other high-medium resolution DEMs derivatives. Finally it's important to point out that the analysis of the SRTM DEMs can provide reference information for the evaluation of other elevation databases.

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