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The ASTER DEM Generation for Geomorphometric Analysis of the Central Alborz Mountains, Iran

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ABSTRACT

This research focuses on the ASTER DEM generation for visual and mathematical analysis of topography, landscapes and landforms, as well as modeling of surface processes of Central Alborz, Iran. ASTER DEM 15 m generated using tie points over the Central Alborz and Damavand volcano with 5671 m height from ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) satellite data using PCI Geomatica 9.1. Geomorphic parameters are useful to identify and describe geomorphologic forms and processes, which were extracted from ASTER DEM in GIS environment such as elevation, aspect, slope angle, vertical curvature, and tangential curvature. Although the elevation values are slightly low in altitudes above 5500 m asl., the ASTER DEM is useful in interpretation of the macro- and meso-relief, and provides the opportunity for mapping especially at medium scales (1:100,000 and 1:50,000). ASTER DEM has potential to be a best tool to study 3D model for to geomorphologic mapping and processes of glacial and per glacial forms above 4300 m asl.

Keywords: Remote sensing, GIS, ASTER DEM, geomorphometry, Central Alborz

INTRODUCTION

Digital elevation models (DEMs) are best tools for visual and mathematical analysis of topography, landscapes and land forms, as well as modeling of surface processes (Dikau *et al*., 1995; Giles, 1998; Millaresis and Argialas, 2000; Tucker *et al*., 2001)). Bishop *et al*. (2001) used a DEM of Nanga Parbat to map glaciers in the rough mountain terrain of the western Himalayas. A DEM offers the most common method for extracting vital topographic information and even enables the modeling of flow across topography, a controlling factor in distributed models of landform processes (Dietrich *et al*., 1993; Desmet and Govers, 1995). DEMs play also an important tool for the analysis of glaciers and glaciated terrains (Etzelmüller *et al*., 1997; Baral and Gupta, 1997; Krzytek, 1995). To accomplish this, the DEM must represent the terrain as accurately as possible, since the accuracy of the DEM determines the reliability of the geomorphometric analysis. Currently, the automatic generation of a DEM from remotely sensed data with sub-pixel accuracy is possible (Krzytek, 1995). DEMs can be generated from stereo satellite data derived from electro-optic scanners such as ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer). The ASTER sensor offers simultaneous along-track stereo-pairs, which eliminate variations caused by multi-date stereo data acquisition.

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This paper presents a DEM derived from ASTER satellite data of the Central Alborz in North Iran. Fieldwork at the Damavand Volcano was conducted only on the western side during March and April 2008 and focused on geomorphological mapping with special respect to geomorphologic processes as well as glacial and per glacial forms above 4300 m asl. Aerial photographs with a resolution of 2/5 m from 1997 were used for orientation and to monitor the geomorphologic mapping. The climatic conditions in the Damavand of Alborz region are treated in the Damavand book from (Al-Rousan *et al*., 1997). In one of its detailed study deals with the topo-climatic structure around the volcanic cone, identifying four slope zones and two valley zones. The topographic information was derived from a section of the ASTER DEM data. As fieldwork was not possible on the southeastern side, a detailed, realistic geomorphologic mapping of the entire study area is only possible with the help of DEM data.

STUDY AREA

The study area is a part of the Alborz range of Alp- Himalaya belt in the north of Iran. The Central Alborz corresponds to the East-West trending mountain range bounding the Caspian domain to the South. It is located between 35° 30' N to 37° 05' N latitudes and 51° 19' E to 54° 03' E longitudes (*Fig. 1*). It connects to the Talesh and the Lesser Caucasus structures to the West and the Eastern Alborz structures to the East. Central Alborz contains different geological units from Precambrian to Quaternary ages. These units, assembled in complex systems of thrusts and folds, deformed during several orogeneses related to the closure of Tethyan basins (Proto Tethys, Paleo Tethys, and Neo Tethys). Since Neogene, Iran is undergoing the N-S collision process between Arabian and Eurasian plates and the lateral force of the northwards converging Indian plate along its eastern border. Old structures are uplifted and reactivated, especially along the ancient margins. In Central Alborz, the recent activity is controlled by the E-W trending structures such as the North Tehran fault, the Musha fault in the South and the north Alborz fault, and the Khazar fault in the north.

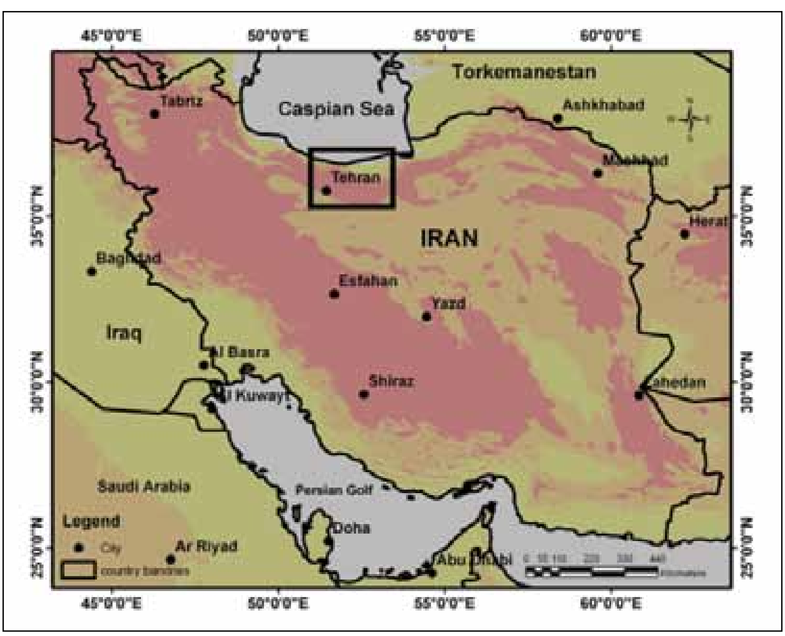

Fig.1: Location map of the study area in the Central Elburz of North Iran over ASTER Imagery

ASTER INSTRUMENT AND DATA SET

ASTER is a high-spatial-resolution, multispectral imaging system flying aboard TERRA, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). An ASTER scene covering 61.5-km × 63-km contains data from 14 spectral bands. ASTER is comprised of three separate instrument subsystems representing different ground resolutions: three bands in the visible and near infrared spectral range (VNIR, 0.5-1.0 µm) with 15 m spatial resolution, six bands in the shortwave infrared spectral range (SWIR, 1.0-2.5 µm) with 30 m resolution, and five bands in the thermal infrared spectral range (TIR, 8- 12 µm) with 90 m resolution. In the VNIR one nadir looking (3N, 0.76-0.86 µm) and one backward-looking (3B, 27.7° off-nadir) telescope provide black-and-white stereo images, which generate an along-track stereo image pair with a base-to-height ratio of about 0.6. The potential accuracy for the DEM from ASTER could be on the order of ±7 to ±50 m (RMSE). ASTER is capable of recording 771 digital stereo pairs per day, and cross-track pointing out to 136 km allows viewing of any spot on Earth at least once every sixteen days. One ASTER-level 1A raw data scene, acquired on July 28, 2005, was downloaded from the USGS EROS Data Center (EDC) EOSDIS Core System (ECS).

DEM GENERATION AND 3D-VISUALIZATION

ASTER scenes are distributed in a data format called HDF-EOS, which can be imported by the software Ortho-Engine as part of the PCI Geomatica 9.1. Using this software, DEMs can be generated automatically. For DEM extraction only the VNIR nadir and backward images (3N and 3B) are used. Al-Rousan *et al*. (1997) described a detailed procedure of the DEM generation using the Geomatica software. The geometric model being used is a rigorous one; it reflects the physical reality of the complete viewing geometry and corrects distortions that occur in the imaging process due to platform, sensor, earth, and cartographic projection conditions. After rigorous models (co-linearity and co-planarity equations) are computed for the 3N and 3B images, a pair of quasi-epipolar images is generated from the images in order to retain elevation parallax in only one direction. An automated image-matching procedure is used to generate the DEM through a comparison of the respective gray values of these images. As ground control points (GCPs) were not available, 23 tie points (TPs) were collected between the stereo-pair. For 11 TPs the elevation value was known. The total RMS of the TPs was < 1.17 pixel. The DEM was generated at 30 m resolution with the highest possible level of detail, and the holes were filled by automated interpolation (*Fig. 2*). The overall quality of the DEM was outstanding, with only few artifacts mostly representing lakes. The DEM was re-sampled to 15 m to exploit full ortho-image resolution. The three-band VNIR nadir-looking image (1, 2, 3N) was orthorectified using the extracted DEM. Several perspective scenes and 'fly-by' simulations were developed showing the Damavand peak from different views and in different scales. Although GCPs were not available, the absolute elevation of the ASTER DEM is of good accuracy and allows analysis of the macro- and mesorelief. In the altitudes above 5500 m asl., elevation values are low, due to the internal smoothing procedures of the Geomatica software. ASTER DEMs in general are known to be often too low (personal communication, PCI). Nevertheless, the developed 3D-views demonstrate the high quality of the DEM and the potential for more detailed image interpretation.

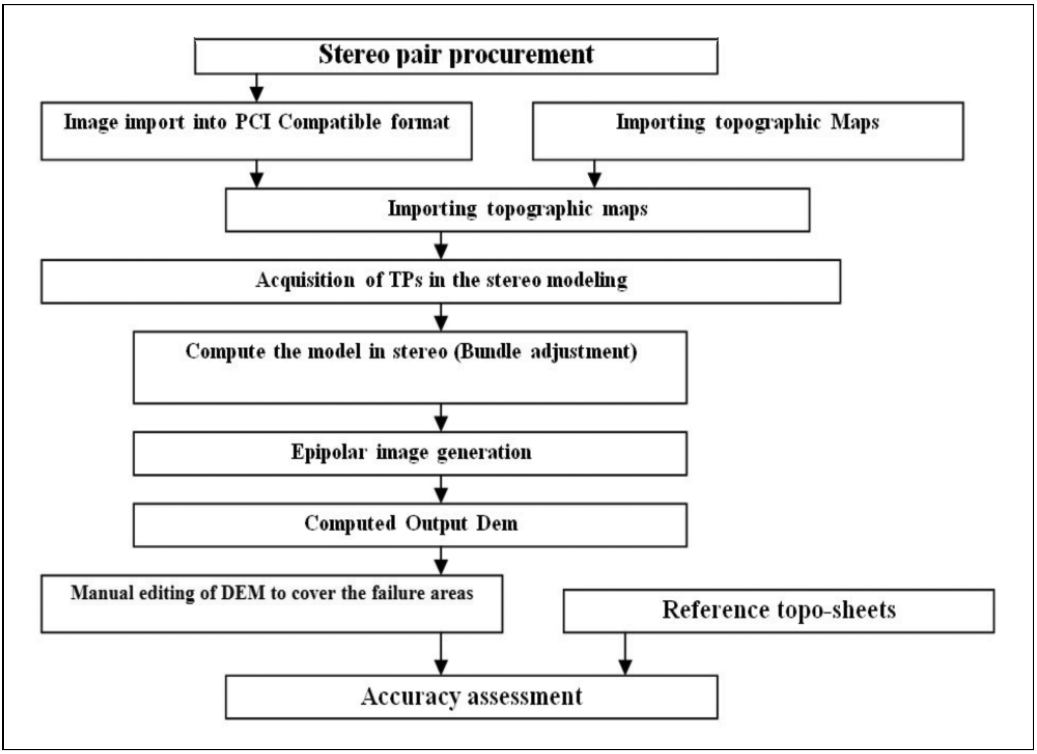

Fig. 2: Diagram of generating DEM from ASTER data

GEOMORPHOMETRIC ANALYSIS

Five geomorphic parameters, which are useful to identify and describe geomorphologic forms and processes (Pirasteh *et al*., 2010a, b), were extracted using the ArcGIS software V9.2 and ArcView GIS: elevation, aspect, slope angle, vertical curvature, and tangential curvature. Flow lines and the catchment areas of the rock glaciers were extracted using the 'hydrologic modeling' tool of the ArcView software. The elevation is graphically presented in a hypsometric map with eight classes, which at Damavand volcano at the same time represent altitudinal belts (*Fig. 3*), e.g. the green class is vegetation cover, the yellow class is a transition zone, and the gray class represents firn fields. In general the ASTER DEM is to low if compared with reality: the summit is only at 5565 m asl. (reality: 5671 m asl.), and the mean altitude is only 4842 m asl. (reality: ~ 4930 m asl.). This fact is mainly caused by the lack of GCPs and smoothing procedures of the Geomatica software. Topography can be generalized into eight aspect classes, and this may also help to identify geomorphologic features (*Fig. 4*). For example, differences in aspect may be an indicator of valley asymmetry. Another map demonstrates the slope angle in ten classes (*Fig. 4*). The class with the lowest slope has a relatively steep upper boundary (5°) in accordance with the general relief, which comprises nearly no flat areas. Other slope classes may be useful to identify specific geomorphic forms: for example, rectilinear slopes have a slope of 25-35° per definition and should be found in the corresponding two classes of the slope map. Slope curvature is of special interest for morphological and hydrological problems. Both curvatures are shown in maps of five classes: The vertical curvature is the second derivation of elevation regarding slope (*Fig. 4*); and the tangential curvature is the second derivation of elevation relating to aspect (*Fig. 4*).

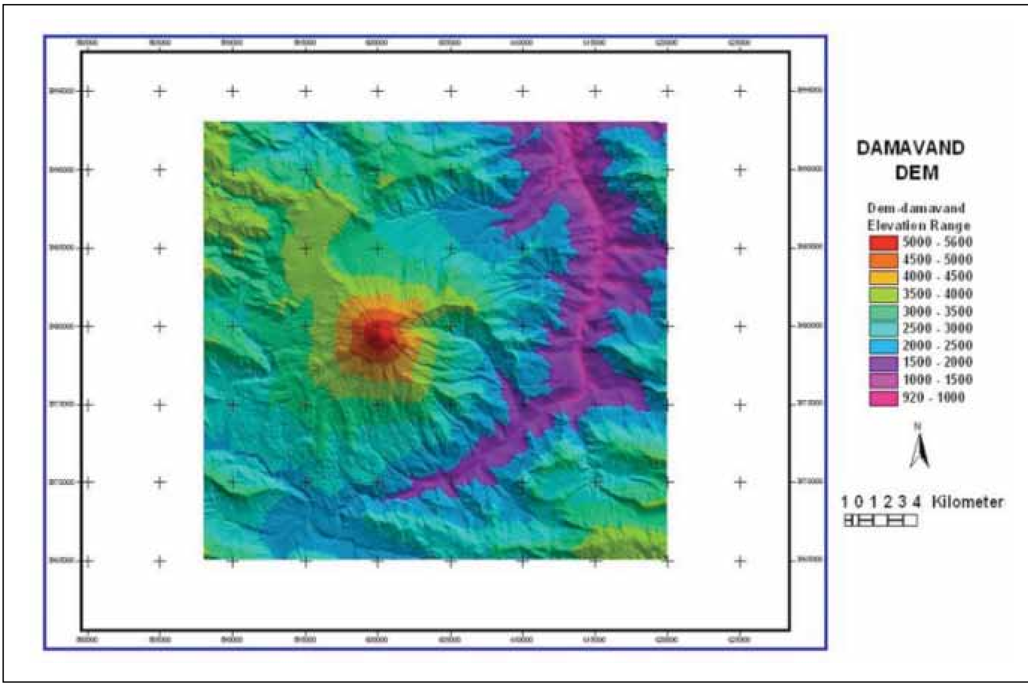

Fig. 3: Morphometric parameters of Central Alborz, deriving from the ASTER DEM: The digital elevation model (DEM) derived from ASTER satellite data of Central Alborz, representing elevation in eight classes

Obviously, ridges have (very) convex and divergent profiles, and valleys have mostly (very) concave and convergent profiles. Meso-scale objects such as rock glaciers can be identified in several locations; the rock glacier front is characterized by a convex profile curvature and convex tangential curvature. In general, profile and tangential curvature are realistic even though the ASTER DEM contains a few artifacts caused by perspective. A special interest of the study was a focus on the per glacial forms at Damavand volcano peak. A per glacial map could be produced using the DEM (*Fig. 4*), and the area of each per glacial form was calculated. Recti-linear slopes cover most of the study area. Non-vegetated solifluction mainly appears on the rectilinear slopes; slightly vegetated solifluction reaches up to the lower limit of the rectilinear slopes; and vegetated solifuction is very exceptionally. Also, rock glaciers occur very rarely in general, but in some valleys they may cover up to 5 % of the area. Striated and patterned ground, breaking blocks, and firn cover smaller areas. A more detailed analysis was undertaken for the rock glaciers in the Gaznak Valley. Knowledge about the geomorphometry is also important for a hydrologic modeling. The more accurate the DEM is the better the modeling results. Flow lines and surface run-off were calculated to delimit the catchment areas of the rock glaciers. The ASTER DEM seems to be precisely regarding the flow lines by comparing it with the virtual image (*Fig. 5-7*). The surface run-off shows very good results especially for the most active rock glaciers.

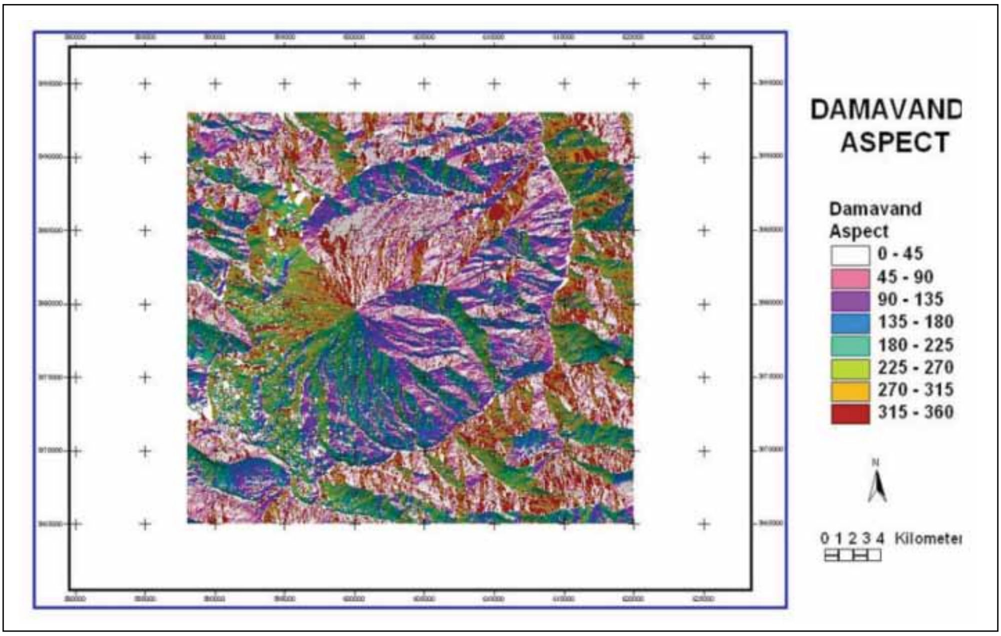

Fig. 4: The digital elevation model (DEM) derived from ASTER satellite data of Central Alborz, representing aspect of Damavand Volcano

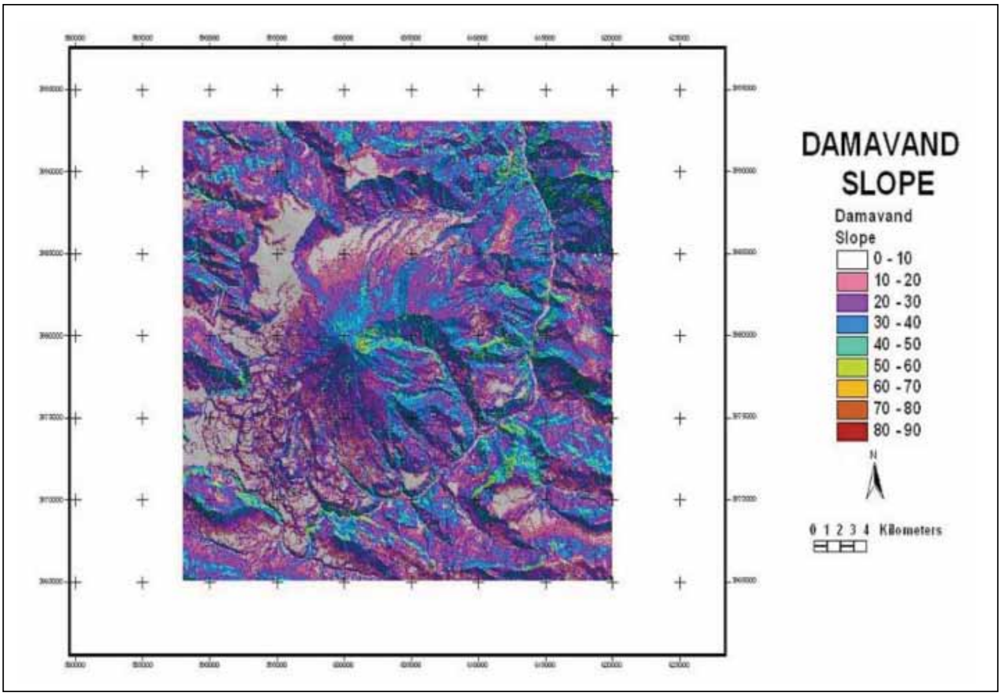

Fig. 5: Morphometric parameters of Central Alborz, deriving from the ASTER DEM, representing slope angle

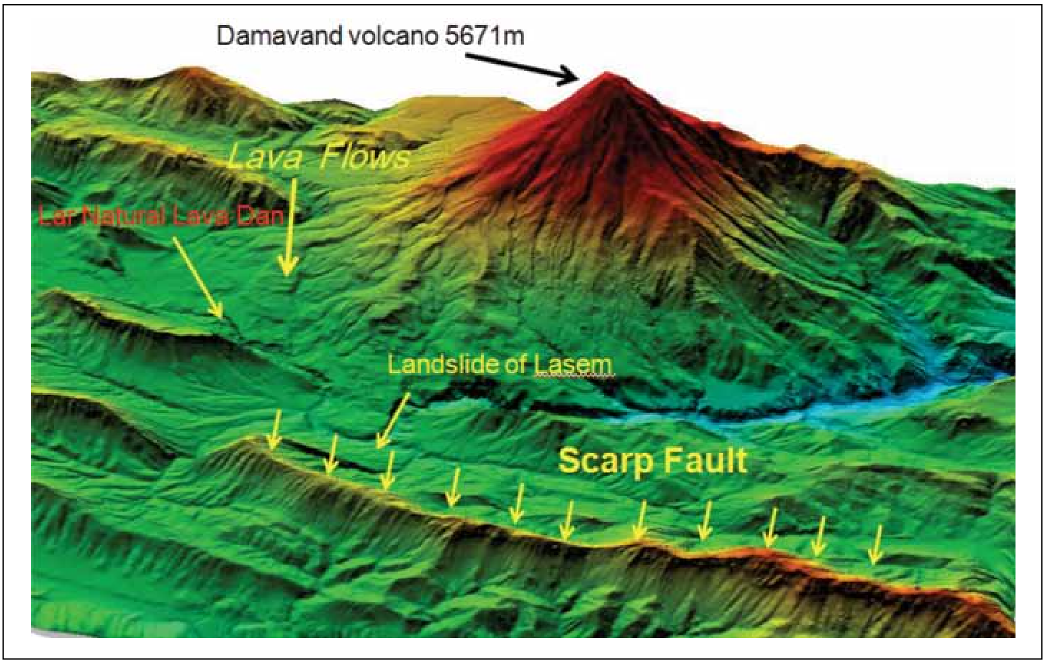

Fig. 6: Morphometric parameters of Central Alborz, deriving from the ASTER DEM, representing hill-shaded relief

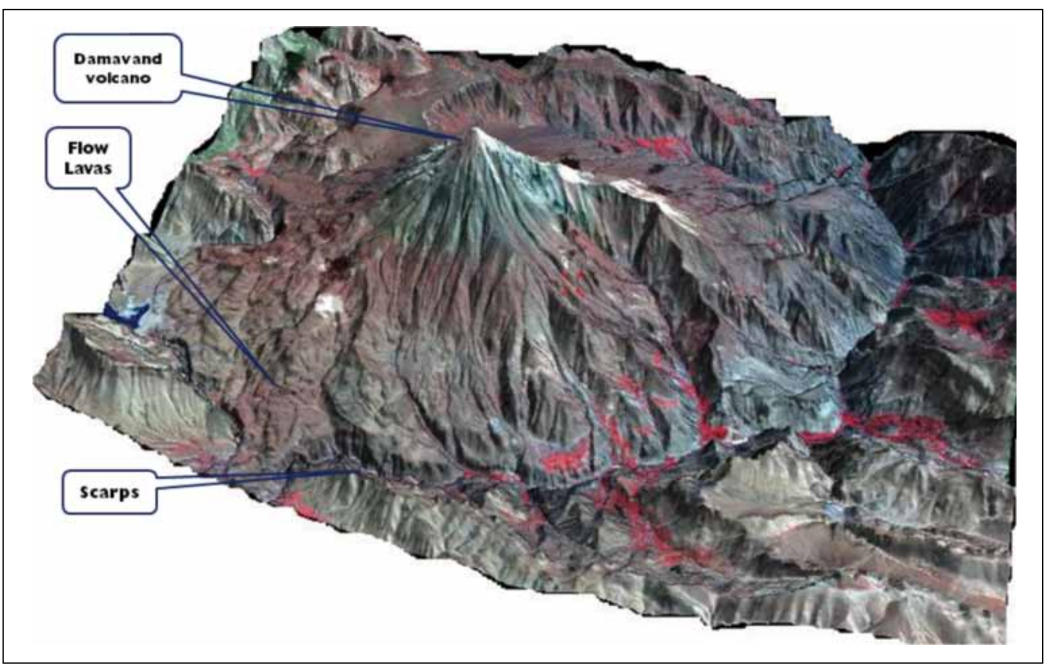

Fig. 7: Morphometric parameters of Central Alborz, deriving from the ASTER imagery, representing 3D surface view

ASTER DEM ACCURACY ASSESSMENT

The result of the stereocorrelation over the Central Alborz is summarized in Table 1, along with the vertical accuracy determined by comparing the computed Z-coordinate values at check points with those collected from the topographic maps and GPS surveys.

TABLE 1
Detail of accuracy assessment of ASTER DEM over the Central Alborz

Image to image registration (Pixel)	Image to ground registration		RMSEz (m)	Number of check points (source)	Completeness of stereocorrelation (%)
	Number of GCPs (source)	RMSExy (pixel)			
± 0.78	11 map points (1: 25,000)	5 m (±0.5)	± 18	36 map points (1: 25,000)	96

An elevation transect developed to further compare the ASTER DEM with a topographic map DEM (*Fig. 8*). At the lower elevations, transects from the ASTER DEM agree with those from the topographic map DEM (*Fig. 8*).

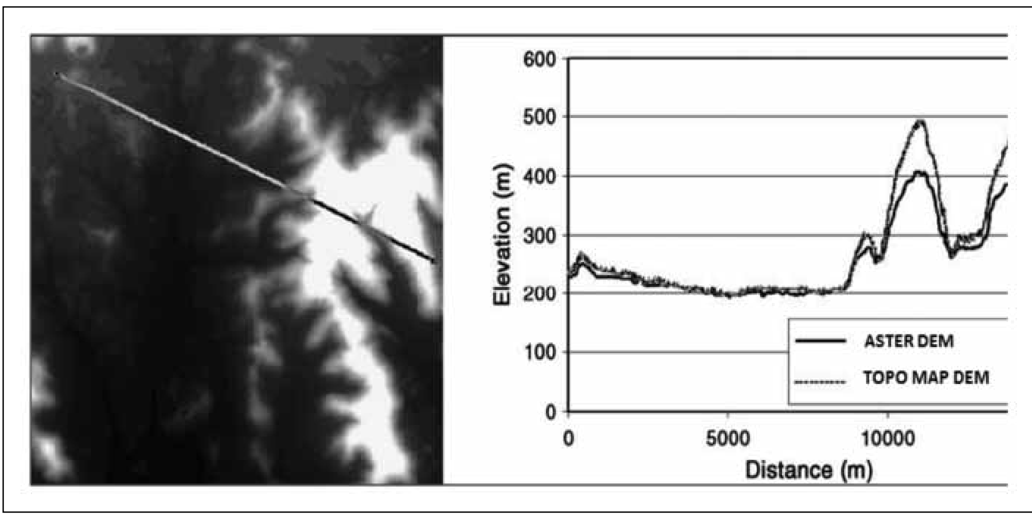

Fig. 8: Profile comparison between ASTER DEM elevations and Topographic map DEM over the Central Alborz

DISCUSSION

While developing an ASTER DEM by using a special commercial software package, the DEM algorithm cannot be changed easily. Often, the software offers only a few parameters for free selection by the operator. For identifying TPs, the operator needs experience in landforms and land covers, because the quality of the TPs is essential for the DEM quality. But when familiar with the software, an operator can develop an ASTER DEM relatively quickly. ASTER DEMs are excellent for virtual-reality visualizations, because they represent quasi ortho-images. The Algorithm Theoretical Basis Document for ASTER Digital Elevation Models (Lang & Welch,

1999) suggests that RMSE values for ASTER DEMs should be on the order of 10 to 50 meters. DEMs produced in other mountainous areas have a preferential failure mode, which is, facets with an aspect of 340 – 140 degrees or slopes over 35 degrees. This is likely due to two factors. First, relative to the ground being examined, the after looking ASTER sensor is set at an azimuth of roughly 10 degrees, making slopes with an aspect of 10 degrees the least likely to be well imaged. Second, these slopes receive the least direct solar illumination, which, by reducing image contrast, increases the probability of image-to-image correlation failure.

CONCLUSION

For Damavand peak, a volcano in the Central Alburz of North Iran, a DEM was developed using ASTER remote sensing data. The results presented here demonstrate that the DEM is useful for morphometric analysis. The scale of a DEM sets the limits for the level of detail for geomorphologic analysis. Today, DEMs from ASTER remote sensing data are reliable sources for an interpretation of the macro- and mesorelief. ASTER DEMs offer relatively great detail, are often easy to develop, and available for many parts of the Earth. In general, the ASTER DEM is accurate, e.g. cliff faces and steep slopes are easy to identify. Analyzing the micro-relief requires a level of detail, which today's DEM resolutions deriving from satellite data do not offer. Here, aerial photographs still are the better choice. ASTER data provides the opportunity for mapping at medium scales (1:100,000 and 1:50,000), and for extracting elevation information from nadir and aft images. The simultaneous along-track stereo data eliminates radiometric variations caused by multi-date stereo data acquisition while improving image-matching performance. In cases where precise GCPs cannot be obtained, it is possible to generate DEMs through tie points (TPs) alone.

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REFERENCES

Al-Rousan, N., Cheng, P., Petrie, G., Toutin, T., & Valadan Zoej, M. J. (1997). Automated DEM extraction and orthoimage generation from SPOT level 1B imagery. *Photogrammetric Engineering and Remote Sensing*, *63*, 965-974.

Baral, D. J., & Gupta, R. P. (1997). Integration of satellite sensor data with DEM for the study of snow cover distribution and depletion pattern. *International Journal of Remote Sensing*, *18*, 3889-3894.

Bishop, M. P., Bonk, R., Kamp, U., & Shroder, J. F. (2001). Topographic analysis and modeling for alpine glacier mapping. *Polar Geography*, *25*, 182-201.

Desmet, P. J. J., & Govers, G. (1995). GIS-based simulation of erosion and deposition patterns in an agricultural landscape: A comparison of model results with soil map information. *Catena*, *25*, 389-401.

Dietrich, W. E., Wilson, C. J., Montgomery, D. R., & McKean, J. (1993). Analysis of erosion thresholds, channel networks, and landscape morphology using a digital terrain model. *Journal of Geology*, *101*, 259-278.

Dikau, R., Brabb, E. E., Mark, R. K., & Pike, R. J. (1995). Morphometric landform analysis of New Mexico. *Zeitschrift für Geomorphologie*, *N.F., Suppl.-Bd.*, *101*, 109-126.

Etzelmüller, B., & Sollid, J. L. (1997). Glacier geomorphometry - an approach for analysing long-term glacier surface changes using grid-based digital elevation models. *Annals of Glaciology*, *24*, 135-141.

Giles, P. T. (1998). Geomorphological signatures: classification of aggregated slope unit objects from digital elevation and remote sensing data. *Earth Surface Processes and Landforms*, *23*, 581-594.

Krzystek, P. (1995). New investigations into the practical performance of automatic DEM generation. Proceedings*, ACSM/ASPRS Annual Convention*, Charlotte, North Carolina, American Society for Photogrammetry and Remote Sensing, *2*, 488-500.

Millaresis, G. C., & Argialas, D. P. (2000). Extraction and delineation of alluvial fans from digital elevation models and Landsat Thematic Mapper images. *Photogrammetric Engineering and Remote Sensing*, *66*, 1093-1101.

Pirasteh, S., Rizvi, S. M. A., Ayazi, M. H., & Amir Mahmoodzadeh. (2010a). Using microwave remote sensing for flood study in Bhuj Taluk, Kuchch District Gujarat, India. *International Geoinformatics Research and Development Journal*, *1*(1), 13-24. Retrieved from www.igrdg.com.

Pirasteh, S., Safari, H. O., Pradhan, B., & Attarzadeh, I. (2010b). Litho-morphotectonics analysis using Landsat ETM data and GIS techniques: Zagros Fold Belt (ZFB), SW Iran. *International Geoinformatics Research and Development Journal*, *1*(2), 28-36.

Sidjak, R. W., & Wheate, R. D. (1999). Glacier mapping of the Illecillewaet icefield, British Columbia, Canada, using Landsat TM and digital elevation data. *International Journal of Remote Sensing*, *20*, 273-284.

Tucker, G. E., Catani, F., Rinaldo, A., & Bras, R. L. (2001b). Statistical analysis of drainage density from digital terrain data. *Geomorphology*, *36*, 187-202.