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USING ASTER AND SRTM DEMS FOR STUDYING GLACIERS AND ROCKGLACIERS IN NORTHERN TIEN SHAN

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Abstract

Digital elevation models (DEMs) derived from satellite data are increasingly used for geomorphologic and glacial analysis. Recently, digital elevation data from the Space Shuttle Radar Topography Mapping Mission (SRTM) in ~90m grid resolution is available for many parts of the earth. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) produces simultaneous stereo-pair data allowing the generation of detailed DEMs with a resolution of 15 to 30m. ASTER-DEMs have been generated for selected areas in Sailiskiy and Kungey Alatau. The analyses were verified with results from field work. Clouds represent one of the main problems in ASTER DEM generation; such cloud-covered areas were marked, clipped and filled with SRTM data. The accuracy of the DEM was evaluated by comparison with a DEM derived from contour maps. With the help of geomorphic analyses and satellite images a map of the glaciers and rockglaciers could be produced. Using the Software ArcGIS the area, geomorphic features and solar radiation conditions of selected glaciers and rockglaciers was calculated. The results show that the DEM is of good acuracy and is useful for an interpretation of the macro- and mesorelief.

Introduction

A DEM offers the most common method for extracting topographic information and enables the modeling of surface processes. DEMs play also an important tool for the analysis of glaciers and glaciated terrains (Bishop et al. 2001, Kaeaeb et al. 2002, Duncan et al. 1998, Etzelmüller & Sollid 1997, Kaeaeb et al. 2002, Sidjak & Wheate 1999). To accomplish this, the DEM must represent the terrain as accurately as possible. DEMs can be generated from contour lines, with radar-interferometry such as the SRTM-DEM or stereo satellite data derived from electro-optic scanners such as ASTER. This report presents a DEM derived from ASTER and SRTM data of Sailiskiy and Kungey Alatau (Kasakhstan/Kyrgyzstan). Fieldwork was conducted in several valleys in late Summer 2002 and 2003 and focussed on obtaining GCPs from GPS and geomorphological mapping with special respect to glacial and periglacial forms. Satellite data (Landsat ETM7, year 1999 and ASTER, years 2000 and 2001) were used for orientation and support mapping. As fieldwork was not possible in the whole northern Tien Shan, a detailed, realistic geomorphological mapping of the entire area is only possible with the help of DEM data. This report presents the first results of an ongoing work, in which the actual situation and the possible change of geomorphology and glaciers is studied.

STUDY AREA

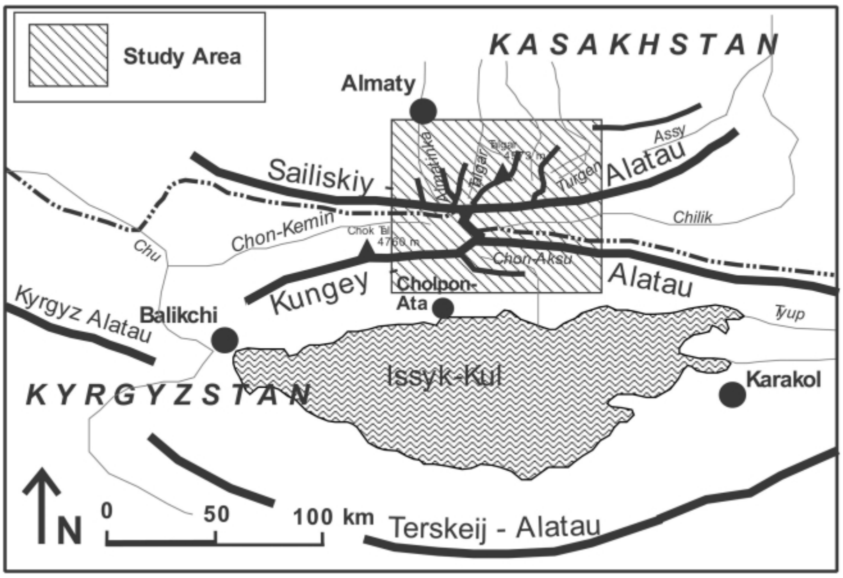

Fig. 1: The location of the study area

Sailiskiy and Kungey Alatau (aprox. 42°30' – 43°30' N and 75° - 79° E) represent the northern part of the Tien Shan at the border between Kasakhstan and Kyrgyzstan. The mountain ranges rise up in the north from the Kazkh Steppe at an altitude of about 800 m asl. up to nearly 5000 m asl.. An intramountanious basin, which is filled by Lake Issyk-Kul (1608 m asl.) marks the southern edge. The study area is situated in the continental climate regime, but with greatly differences within small distances. The precipitation rises from lower than 600 mm/a at the northern edge up to more than 1000 mm/a in an altitude of aprox. 3500 m asl. and diminishes to around 200 mm/a at the edge of Issyk-Kul. Field work and the generation of the ASTER-DEM concentrated on the valleys near the central node of the mountain ranges (fig. 1).

ASTER AND SRTM BACKGROUND

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 x 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. During the SRTM-Mission in February 2000 aprox. 80% of the earth-surface were measured with methods of radar-interferrometry. Recently the calculated DEM with a resolution of 3" (aprox. 90m) is available for Eurasia including the northern Tien Shan.

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DEM GENERATION

DEMs can be generated automatically using the Geomatica 8.2 package from PCI Geomatics. For DEM extraction only the VNIR nadir and backward images (3N and 3B) are used. An automated image-matching procedure is used to generate the DEM through a comparison of the respective gray values of these images. For this study an ASTER scene from october 2000 (cloud cover 5%) was used. For calculating the scene 20 ground control points (GCPs) were collected by GPS during the field work and by using topographic maps with the scale 1:100 000 (better maps were not available). For better image matching 25 tie points (TPs) were collected between the stereo-pair in all parts and different altitudes (e.g. foreland, valley, mountain peak). For all TPs the approximately elevation value was known. The total $RMSE_{x,y}$ of the scenes were < 1,33 pixel, resp. < 20 m. The DEM was generated at 30 m resolution with the highest possible level of detail, and small holes were filled by automated interpolation. The overall quality of the DEM was satisfying, with only few artifacts. Clouds represent the main problem of the ASTER DEM-generation. Therefore the cloud-covered areas were marked, clipped and filled with the SRTM-Data. To get seamless transitions between the different data sets a blending procedure was used.

Evaluation of the DEM

The ASTER DEM was evaluated comparing with the SRTM DEM and with a DEM derived from contours based on topographic maps, scale 1:100 000 with an equidistance of 40 m. The contour lines of selected valleys were digitized and spline interpolation was used to generate the DEM. A grid resolution of 30 m were selected, matching to the ASTER DEM. The altitude and the contour lines of the SRTM DEM are nearly correct in all areas (average difference to contour DEM ~5m). The ASTER-DEMs of northern Tien Shan gives lower elevation values (up to ~100 m) at SE-exposed steeper slopes (> ~35°), and higher elevation values (up to ~50 m) at N- and NW-exposed slopes than SRTM DEM. However, the altitude of the valleys and mountain ridges is very similar and in the the average altitude differs only in three meters. Results from other analyses show, that the ASTER DEMs could be of good accuracy, but the altitude is often slightly to low (Bolch & Kamp 2003, Eckert and Kellenberger 2002, Kamp et al. 2004).

Geomorphometric Analysis

Five geomorphic parameters, which are useful to identify and describe geomorphological forms and processes, were extracted using the software ArcInfo and ArcView: elevation, aspect, slope angle, vertical curvature, and tangential curvature. Topography was generalized into eight aspect classes. The slope angle helps to identify specific geomorphic forms: for example, rectilinear slopes (German: 'Glatthaenge') have a slope of 25-35° per definition. Vertical and tangential curvature are of special interest for morphological and hydrological problems. Mesoscale objects such as rockglaciers can be identified in several locations; the rockglacier front is characterized by a convex profile curvature and convex tangential curvature. A detailed study was conducted in Left Talgar, big and small Almatinka Valley with a focus on the periglacial and glacial forms at Sailiskiy and Kungey Alatau. A map of glaciers and rockglaciers could be produced using topographic maps, field data, the satellite images and the DEM (fig. 2).

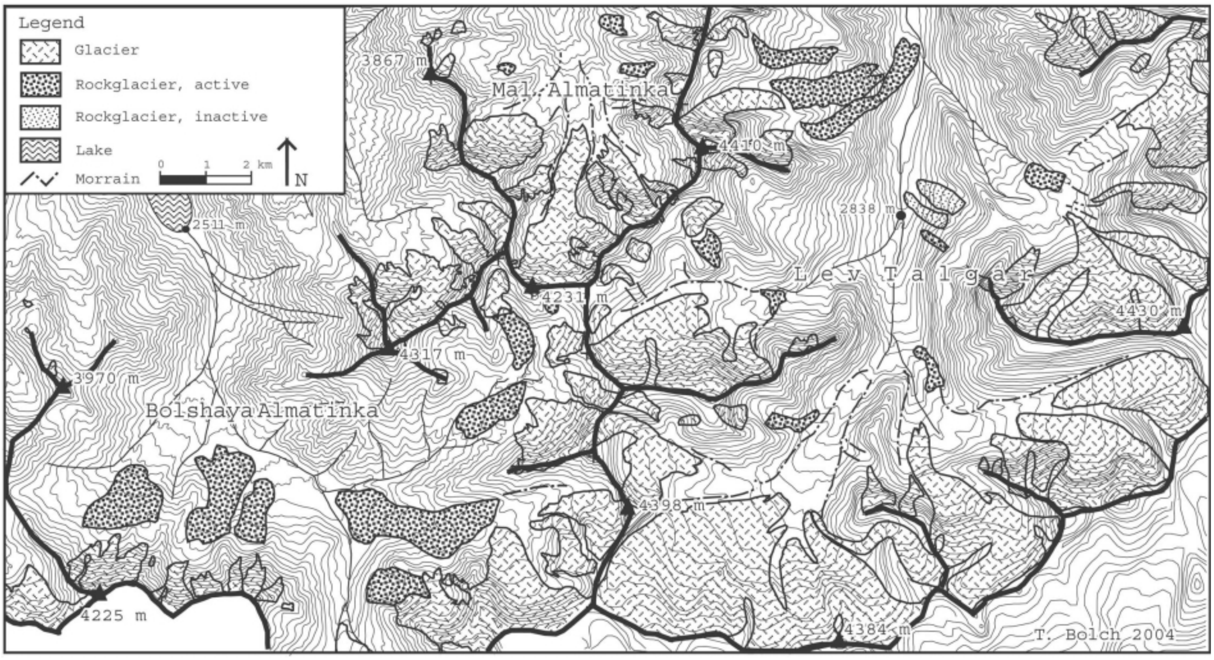

Fig. 2: Glaciers and Rockglaciers in Almatinka and Talgar Valley

Using a GIS the area of the rock glaciers and glaciers could be calculated easily (Table 1). This calculation represents the situation in the year 1999. The base for the study area is the area above 3000 m in the parts of the valleys seen in figure 2 . The areas show a small decrease compared to the situation in 1990 taken from Vilesov & Uvarov 2001. Furthermore it is remarkable, that the Left Talgar Valley has a much higher glaciated area then the Bolshaya Almatinka Valley, whereas the rockglaciers dominate more in the Bol. Almatinka Valley. In Mal. Almatika Valley there is only a small area covered by rockglaciers. Detailed studies of the rockglaciers without DEM data were published by Gorbunov & Titkov 1989, Kokarev et al. 1997 and Schroeder 1992.

Table 1: Areas of Glaciers and Rockglaciers in Almatinka and Talgar Valley

	Mal. Almatinka	**Bol. Almatinka**	**Lev. Talgar**
Glaciers			
Total Area [km²]	6,1	17,7	43,6
Portion of Study Area [%]	27,3	18,5	36,9
Rockglaciers			
Total Area [km²]	0,4	7,5	4,2
Portion of Study Area [%]	1,7	7,9	5,0

The minimum, maximum and average altitude, resp. slope of the glaciers and rockglaciers calculated from the DEM shows table 2. It is remarkable, that the average altitude of the the glaciers in left Talgar is highest, but is lowest of the rockglaciers.

Table 2: Altitude and Slope of glaciers and rockglaciers in Almatinka and Talgar valley

Glaciers			
	Mal. Almatinka	Bol. Almatinka	Lev. Talgar
Altitude [m asl.]	3443 – 4329 Avg.: 3811	3390 – 4570 Avg.: 3870	3440 – 4575 Avg.: 3984
Slope [°]	0,3 – 64 Avg.: 24,3	0,1 – 79 Avg.: 27,5	0,1 – 79 Avg.: 22,4
Rockglaciers			
Altitude [m asl.]	3439 – 3654 Avg.: 3521	3000 – 3900 Avg.: 3425	2730 – 3882 Avg.: 3286
Slope [°]	4,4 – 27,8 Avg.: 11,7	0,2 – 53,3 16,5	0,9 – 44,5 15,6

The DEM was also used to modell solar radiation, which is a important steering factor of the climate and surface conditions. First results show, that the large glaciers and the catchment areas of the large rockglaciers have a strong deficit of radiation, whereas the rockglaciers themselves are situated in areas with no or little deficit. This is similar to the results of the analysis of Cerro Sillajhuay, Chile/Bolivia (Bolch & Schröder 2001).

Discussion

This study shows, that it was possible to generate a DEM from ASTER-Data with good accuracy for the scenes available for the northern Tien Shan. Ground control points and tie points, which cover the whole scene and different altitudes are necessary. Areas with clouds and areas, where no ASTER-Data was available, could be filled with SRTM data, so that a detailed DEM of the entire northern Tien Shan could be generated. This DEM is very usefull for studying mesoscalic objects like glaciers and rockglaciers. But it could also help to identify other geomorphological forms like morraines or alluvial fans. Furthermore it is a very good base for process modelling, like erosion or mudflow events.

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REFERENCES

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

Bolch, T. & Kamp, U. (2003): Qualityanalyses of digital ASTER elevation models of high mountain areas (Cerro Sillajhuay, Chile/Bolivia) [in German]. - Kartographische Nachrichten Nr. 5, 224 - 230.

Bolch, T. and Schröder, H. (2001): Geomorphologic mapping and diversity analysis of periglacial forms at Cerro Sillajhuay (*Chile/Bolivia) [in Germin]*. (= Erlanger Geographische Arbeiten, 28), Erlangen, 141 pp.

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

Duncan, C.C., Klein, A.J., Masek, J.G. and Isacks, B.L. (1998): Comparison of Late Pleistocene and modern glacier extents in central Nepal based on digital elevation data and satellite imagery. *Quaternary Research*, 49: 241-254.

Eckert, S., and Kellenberger, T. (2002): Qualityanalysis of automatic generated DEMs from ASTER-Data [in German], *Publikationen der Deutschen Gesellschaft für Photogrammetrie und Fernerkundung*, 11, 337-345.

Etzelmüller, B. and 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.

Gorbunov, A.P. & Titkov, S.N. (1989): Rockglaciers in Central Asian Mountains [in Russian], Irkutsk, 164 p.

Kääb, A., C. Huggel, F. Paul, R. Wessels, B. Raup, H. Kieffer, J. Kargel, 2002: Glacier monitoring from ASTER imagery: accuracy and applications, *EARSeL Proceedings, LIS-SIG Workshop, Berne, March 11-13, 2002.*

Kamp, U., Bolch, T. & Olsenholler, J. (2004): Geomorphometry of Cerro Sillajhuay, Chile/Bolivia, Comparison of DEMs from ASTER remote sensing data and Contour Maps. - Geocarto International (in Print).

Kokarev, A., Schesterova, I. & Schröder, H., 1997: The rockglaciers of Sailiskiy Alatau/Tien Shan (Kasakhstan) [in German]. Hallesche Jb. Geowiss., 19, Halle/Saale, 81 – 94.

Schröder, H, 1992: Active rockglaciers in the central part of the northern Tien Shan [in German], Petermanns Geographische Mitteilungen, Bd. 136, Heft 2, 109-119

Sidjak, R.W. and 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.

Vilesov, E. N. & Uvarov, V. N. (2001): The evolution of modern glaciation of the Sailiskiy Alatau in the 20th century [in Russian]. Kazakh State University, Almaty, pp. 252.