DEMs of the Cerro Sillajhuay, Chile/Bolivia generated from contour maps and ASTER remote sensing data

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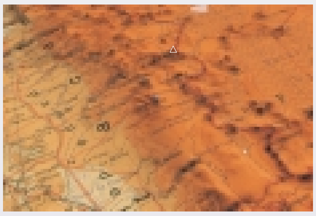


Location of Cerro Sillajhuay in Chile/Bolivia (Topografic map overlayed on Gtopo-30 DEM)

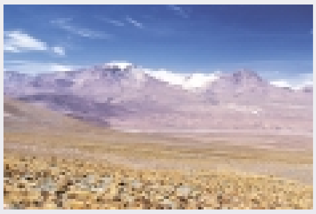
Introduction

Digital elevation models (DEMs) have been increasingly used by geomorphologists for visual and mathematical analysis of landscapes and modeling of surface processes. A DEM offers the most common method for extracting vital topographic information and even enables the routing of flow across topography, a controlling factor in distributed models of landform processes. To accomplish this, the DEM must represent the terrain as accurately as possible.

DEMs can be generated from contour maps, aerial photographs or remote sensing data, e.g. SPOT or ASTER. The new ASTER sensor offers simultaneous along-track stereo-pairs, which eliminate radiometric variations caused by multi-date stereo data acquisition. Few results have been published in peer-reviewed literature about the generation of ASTER DEMs or their quality. This paper compares the quality of two DEMs of the Cerro Sillajhuay derived from contour maps and ASTER remote sensing data.

Study Area

Cerro Sillajhuay (5,982m asl., 19°45'S / 68°42'W) is located in the Andes of Chile/Bolivia, and represents the highest peak of the Andes between 19 and 21 degrees south. The volcano rises ~2000m above the surrounding plain. Precipitation occurs in summer, and the study area is part of the driest part of the Andes.

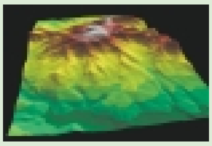


Cerro Sillajhuay (5,982 m) rises ~ 2000 m above the sourrounding plain (view from south)

DEM from Contour Maps

DEM Generation

Using contour maps is an inexpensive and common way to create DEMs. For the Cerro Sillajhuay, a DEM was developed by digitizing contour lines from a rectified topographic map (1:50,000) with 50 m-equidistance. Additionally, depth lines and some ridges were digitized. The TIN-interpolation method was used to generate the DEM, following a grid transformation with smoothing filter. Only a few artifacts had to be debugged manually. The horizontal DEM grid resolution is 50 m, matching the underlying topographic map.



DEM of Cerro Sillajhuay from Contour Maps

Interactive 3D-Visualisation

3D-views of the DEM were created using the software GOLD, which offers real time rendering, and an aerial photograph was mapped over the DEM. "Fly-by" simulations provide additional information about the topography, morphometry and landforms of Cerro Sillujhuay, e.g. rock glaciers.

Rockglaciers in Tacuma Valley (Aerial photograph overlayed on DEM from contours)

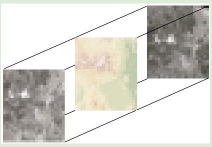
Results

Generating DEMs from contour maps is easy to handle, and the results provide reasonable information for geomorphological or hydrological interpretation. Depending on the available topographic maps, DEMs of higher resolution and detail can be produced, which allows an analysis of even the mesorelief.

ASTER DEM

Instrument

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument flying aboard TERRA, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER provides high-spatial-resolution image data (61.5 km x 63 km) in 14 spectral bands, and consists of three separate instrument subsystems representing different ground resolutions: the Visible and Near Infrared (VNIR, 15 m), the Shortwave Infrared (SWIR, 30 m), and the Thermal Infrared (90 m). In the VNIR one nadir- and one backward-looking telescope provide black-and-white stereo images. These two near-infrared spectral bands (3N and 3B) generate an along-track stereo image pair with a base-to-height (B/H) ratio of about 0.6, and an intersection angle of about 27.7 degrees. The potential accuracy for the DEM from ASTER could be on the order of 25 m.



Generation of ASTER DEM from a stereo pair (3N and 3B)

NVIR-channels overlayed on ASTER DEM

Data Set

One ASTER-level 1A raw data scene, acquired on May 28, 2001, was downloaded for free directly from the USGS EROS Data Center (EDC) EOSDIS Core System (ECS). Fortunately, the Cerro Sillajhuay is located in the center of this image, which is absolutely cloud-free.

DEM Generation and 3D Views

An ASTER scene is distributed in a data format called HDF-EOS, which can be imported by the software Geomatica™ from PCI Geomatics. Using this software, DEMs can be generated automatically. To extract the DEM, only the VNIR nadir and backward images (3N and 3B) are used.

After rigorous models (collinearity and coplanarity 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 x/y residual was <1.17 pixel. The DEM was generated at 30m resolution with the highest possible level of detail, and the holes were filled by automated interpolation. The overall quality of the DEM was outstanding, with only few "failed" areas representing lakes. The DEM was resampled to 15m to exploit full ortho-image resolution.

Tacurma and Blanco Valley (VNIR-channels on ASTER DEM)

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 Cerro Sillajhuay from different views and in different scales.

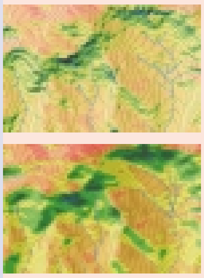
TIR-channels overlayed on ASTER DEM

Results

The resulting perspective scenes demonstrate the high quality of the DEM and the potential for more detailed image interpretation..

ASTER provides an 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 TPs alone.

Comparison of the two DEMs



Solar Radiation, Tacurma and Blanco Valleys: calculated from ASTER DEM (ab.) and from DEM derived from contours (bel.), red represents high, green to blue low values

Method

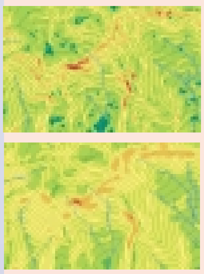
The quality of the DEM from contour maps as well as the ASTER DEM was compared by focusing on the topography, geomorphology, morphometry, and landforms like rock glaciers. Five geomorphic parameters (elevation, slope, aspect, plan curvature, profile curvature) were calculated using ArcGis and ArcInfo. Flow lines and the catchment areas of the rockglaciers were extracted using the "hydrologic modelling" tool of ArcView 3.2. The yearly mean solar radiation was computed using the software SAGA, which enables an integration of the water vapor deficit and the atmospheric pressure.

Results

The Figures on the left and right demonstrate the morphometry and the radiation rates of the Tacurma Valley (where several rock glaciers can be found) and the Blanco Valley of the Cerro Sillajhuay. The calculated flow lines and contour lines were integrated additionally. the moBy By comparing the morphometry of the rock glaciers, the ASTER DEM provides more realistic results: the minimum slope angle of 5° matches the field measurements, and the maximum slope angle of 34° represents the general slope angle of active rock glaciers (35-40°). Both DEMs provide similar slope angles in the catchment areas, but the ASTER DEM offers more details.

Table 1: Comparison of Slope Angle and Solar Radiation for the whole DEMs, the Rockglaciers and their Catchment Areas

	Contour DEM (whole)	ASTER DEM (whole)	Rockglaciers DEM Contour	Rockglaciers ASTER DEM	Catchment DEM Contour	Catchment Areas ASTER
Average Slope Angle	17°	16°	22°	19°	27°	26°
Min. Slope Angle	1°	0°	12°	5°	2°	1°
Max. Slope Angle	51°	63°	31°	34°	48°	60°
Av. daily Solar Radiation	267 W/sqm	266 W/sqm	235 W/sqm	239 W/sqm	224 W/sqm	226 W/sqm
Min. daily Solar Rad.	134 W/sqm	88 W/sqm	193 W/sqm	189 W/sqm	134 W/sqm	88 W/sqm
Max. daily Solar Rad.	310 W/sqm	312 W/sqm	267 W/sqm	271 W/sqm	298 W/sqm	305 W/sqm

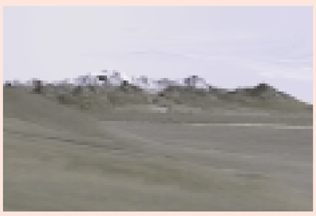


Slope angel, Tacurma and Blanco Valleys: calculated from ASTER DEM (ab.) and from DEM derived from contours (bel.), red represents high and green low values

Although GCPs were not available, the absolute elevation of the ASTER DEM is of good accuracy. In some locations, elevation values are up to low.

Curvatures can be used to evaluate of the morphometric reliability of a DEM. Both DEMs shows good results. The ASTER DEM contents only a few artifacts caused by perspective. Mesoscalic objects like the some rockglaciers at the Tacurma Valley (with a front altitude ["Stirnhöhe"] and a width > 30 m). The front of the rockglaciers is characterized by a convex profile curvature and convex plan curvature.

Also the slope enables an identification of meso-forms. Again the ASTER DEM is of more accurancy, e.g. cliff faces and steep slopes can be better identified.

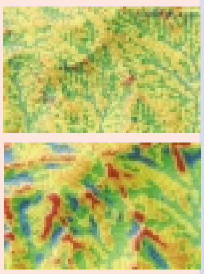


3D-View of Cerro Sillajhuay (view from south,(NVIR-Channels overlayed on ASTER DEM)

According to the geographic situation of the Cerro Sillajhuay, the solar radiation is very high, and radiation extinction is very low. The average daily solar radiation is nearly the same for both DEMs. Rockglaciers and especially their catchment areas show with similar values with both DEMs. Within regard to the steep slopes, the lower ASTER minimum daily solar radiation is more realistic.

Overall, the results demonstrate that both DEMs are usefull for morphometric analysis, but ASTER DEMs offer more detail, are often easier to develop, and available for free for many parts of the earth.

Elevation, Tacurma and Blanco Valleys: calculated from ASTER DEM (above) and from DEM derived from contours (below)



Plan curvature, Tacurma and Blanco Valleys: calculated from ASTER DEM (ab.) and from DEM derived from contours (bel.) red represents convex, blue concav curv.

Acknowledgements

The authors like to thank J. Böhner, University of Goettingen, for solar radiation calculations, S. Röttger, University of Stuttgart, who has implemented the programm "GOLD", and J. Olsenholler, University of Nebraska Omaha, for support in ASTER data handling and DEM generation.

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Text and Layout: Tobias Bolch, Ulrich Kamp and Andreas Kempf