

# MT. ACONCAGUA – A CHALLENGE FOR REMOTE SENSING MAPPING ACTIVITIES IN THE ANDES

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**Abstract:** *This paper discusses the integration of various remote sensing based data (SRTM, LANDSAT and ASTER) for generating a topographic map of Mt. Aconcagua (Argentina). Due to the lack of appropriate official topographic maps (1:50.000) Remote Sensing data are the only source which can provide adequate topographic and thematic information. The investigation area is located in the midst of the Central Andes in the Aconcagua Provincial Park (Argentina) with Mt. (Cerro) Aconcagua (6962m), the highest mountain in South America and reaching out up to Argentinean-Chilean-Bolivian Border. Preliminary results from digital and analogue classification (topography, glacier, vegetation, infrastructure, etc.), the methodology, advantages and disadvantages of High Mountain Environment Remote Sensing mapping will be discussed and presented.*

## BACKGROUND

Cartographic information about remote High Mountain Environment of the earth still is shortcoming. Especially for the Aconcagua Region there are no adequate maps available. Due to this reason the authors initiated a project, which aims in the generation of a 1:100.000 map, based on remotely sensed images. The Aconcagua Satellite Image Map is one of a series of maps provided by R. Kostka from various mountain areas of the world (Kailash, Demavend, Annapurna, etc.). A book "Aconcagua und die Anden bis zum Wendekreis des Steinbocks" (R. Kostka, 2006), where geographical basics of the regions were worked out by the authors, lead to the idea to produce a map in scale 1:100.000 for the entire Aconcagua Region. One month lasting field studies in 2003 supply the mapping purposes. Some of the basic mapping results (DEM generation) are still published (R. Kostka, W. Sulzer and M. Wurm, 2006). The main cartographic goal of the project is to generate a regional map (which covers both Chilean and Argentinean areas) with a focus on mountaineering and touristic aspects. Neither governmental nor private cartography fulfill these requirements (Aoneker, 2005; Zagier & Urruty, 2006.; S. Greulich and S. Wettstein, 2006). A new and independently map with realistic, visual easy recognizable information is chosen for this purpose. The investigation area (map extent: 48x48km) covers two countries with different geodetic systems and height differences between 2000 and 7000m. To unify different geodetic information and to represent the relief character of high mountain environment are the main tasks of this project.

## Investigation Area

The Mt. Aconcagua (6963m) is the highest mountain of America, the highest mountain of the southern hemisphere, and the highest mountain of the western hemisphere and the highest mountain outside of Asia. These attributes make the region very attractive for tourists and researcher.

The Aconcagua Massif is located in the transaction zone between the Southern and Central Andes and belongs to the Argentinean provinces of Mendoza in the South and San Juan in the North. The Aconcagua is part of the High Cordilleras (Cordillera Principal), which are mainly formed by volcanic activity, though the mountain itself belongs to a zone (28°-33°S) with no active (cenococic) volcano like many of other northern and southern mountains of the Andes (Tupungato, Maipo, Ojos, ...). A mighty, tertiary complex of Hornblende-Andesit

(Aconcagua complex) was shifted above a mesozoic (mostly marine) basement. The Aconcagua is not located along the main ridges of the High Cordillera, which forms the watershed and political border between Argentina and Chile. The highest peak of America lies about 10km east of the main crest.

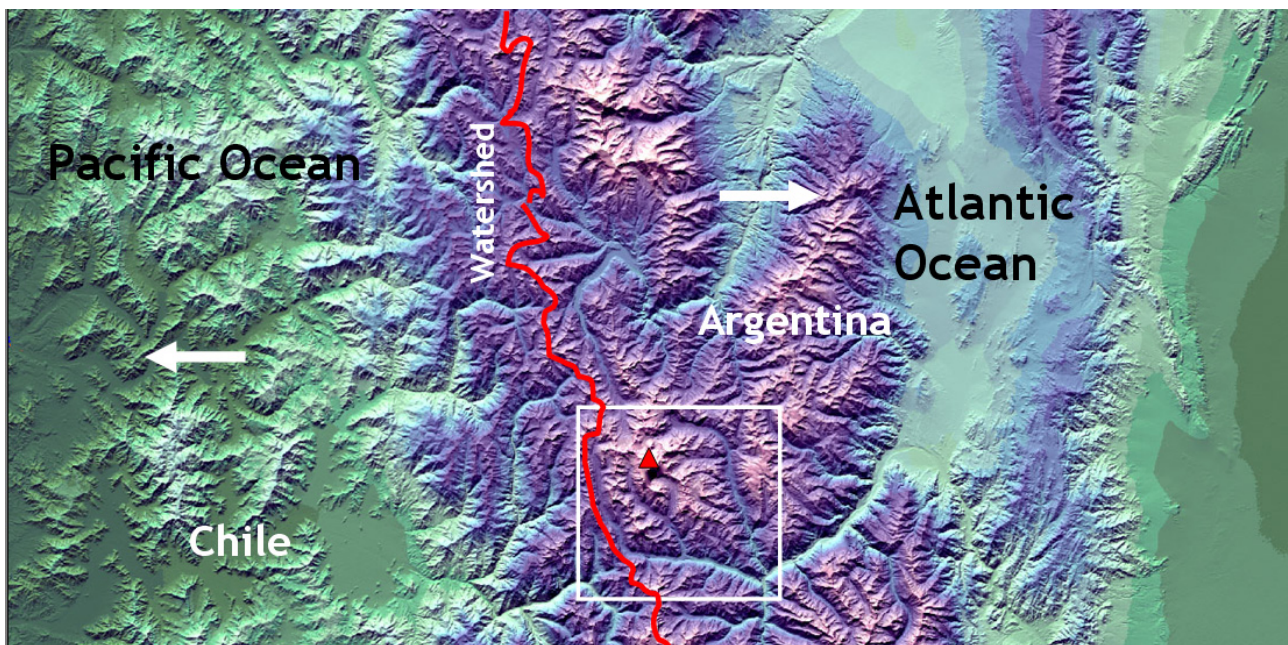


Figure 1: Location of Mt. Aconcagua and extent of the map

### Challenge for Remote Sensing

Remote high mountain areas suffer from appropriate geodata. No or only few very roughly produced data bases are available. Remote Sensing therefore means a valuable tool for providing a basic (GIS-) database for a cartographic product of those mountain regions.

High Mountain Areas are regions, which are especially suitable for providing surface information by means of Remote Sensing (M.F. Buchroithner, 1995). Remoteness, inaccessibility and high relief engender limits for terrestrial methods. Remote Sensing techniques provide useful tools for spatial and especially for height related interpolation of local – field based acquired information. Due to their contactless and spatial extent, aerial photographs and satellite images get an increasing importance for many mountain related topics (LULUC, change detection, hazards, monitoring, etc.). The knowledge of the possibilities and limitations of remote sensing and the careful evaluation of remotely sensed image data are inevitable for the meaningful, effective and financially feasible application of these techniques.

Typical data based problems in High Mountain areas are:

- “Insufficient“ topographic maps (low accuracy, actuality, ...),
- General lack of geodata,
- None documented analogue and digital datasets,
- Few thematically products,
- Low spatial cover,
- Lack of actuality,
- ...

The applicability of Remote Sensing data in high mountain environment has limits itself; the requirements for mapping purposes are listed below:

- Suitable data basis for processing (rectification, image/GIS analyses and presentation; e.g. (digital) topographic maps, DEM, fieldwork, ...)

- Suitable weather condition and season (“nice” weather - RADAR!, less snow, ...),
- Suitable sensors (geometric/spectral/radiometric/temporal –resolution),
- Skilled user for geodata processing – Analyses – Presentation (Image processing/GIS, knowledge about natural and cultural environment, cartographic skills ...).

## SATELLITE IMAGE MAP OF ACONCAGUA IN SCALE 1:100.000

### Available Geodata

The selection of used geodata is based on their easy availability, low or no costs and their common applicability for typical high mountain research tasks:

<b>Topographic maps</b>	<b>DEM</b>	<b>Remote Sensing Data</b>
• Chile (50K, 100K)	• ASTER	• Aerial Photographs
• Argentina (50K, 100K)	• SRTM	• LANDSAT
• Private Cartography	• LANDSAT	• ASTER

Topographic maps of high mountain regions provide useful information about terrain (contour lines, height points, etc.) and about the surface conditions – land cover (rocks, snow and ice, vegetation, etc.). For the purpose of integration into a GIS based system and further analyses following basic information about the maps are required (cf. J. Gspurning, R. Kostka and W. Sulzer, 2004):

- Reference systems with location and height.
- Acquisition and analyses methods and conditions, which are responsible for the accuracy of the product.
- Selection of cartographic representation, which is most essential for comparative studies, their possibilities, advantages and disadvantages, are well documented within the cartographic community.

Topographic maps are available with scale: 1:500 000, 1:250 000, 1:100 000 and 1:50 000 in Chile and in scale 1:50.000 and 1:100.000 for Argentina. During the process of scanning, geocoding and mosaicing the severe problem was to unify the different geodetic systems of the two countries.

<b>ARGENTINIEN: 1:50K</b>	<b>CERRO ACONCAGUA</b>	<b>CERRO AMEGHINO</b>	<b>LAS CUEVAS</b>	<b>PUENTE DEL INCA</b>	<b>PUNTA DE VACAS</b>
Geodetic System	No information	No information	No information	No information	No information
Terr.Photogrammetry	1924,1929, 1945	1929, 1945	1924, 1945	1924-29/44/45	1929/43/44/45/48/49
Edition	1950	1951	1951	1951	1952
Representation	Legend, colour edition, Equidistance: 25m, 100m; rock representation				
<b>CHILE: 1:50K</b>	<b>RIO DE LOS LEONES</b>		<b>PORTILLO</b>		
Geodetic System	Int. Ell. 1924, UTM, Mer. 69°W, Lat.:10 000km S of Equator, height: Nivel Medio del Mar				
Aerial Photograph:	1955				
Fieldwork	1964				
Revision	1977		1981		
Edition	1985		1994		
Representation	Legend, colour edition, Equidistance : 50m, 250m; rock representation				

Figure 2: Available Maps of Mt. Aconcagua Region (Source: R. Kostka, W. Sulzer and M. Wurm, 2006)

Due to the limits of GIS suitable parameters and due to the low quality of the maps there was no possibility of further contour line digitizing for generating and DEM of the investigation area (Figure 2). Further information

about infrastructure (traffic network, tourist infrastructure, names, etc.) can not provided from the maps in Argentina due to the fact that the maps have been published in Fifties of the last century. The location of streets, settlements has changed, modern tourist infrastructure is missing.

### Data Processing

The only solution getting appropriate information for the map was to use pure satellite image data. This can be achieved only by a multi-temporal and multi-sensoral approach. Different image data will provide different kind of map information:

Feature	Source
Image information	• ASTER/LANDSAT
Contour lines	• DEM: ASTER/SRTM/LANDSAT
Vegetation cover	• LANDSAT/ASTER
Glacier/Lakes	• LANDSAT/ASTER
Traffic network	• GPS/LANDSAT/ASTER
Perspective views	• DEM/LANDSAT/ASTER
Name	• MAPS, FIELD WORK

The geometric basic for the map sheet is a georectified LANDSAT TM image of 1999. The rectification quality (RMS Error) meets the requirements of a map with scale of 1:100.000. The determining factor for using this satellite scene is the high radiometric quality and low snow cover. Additional LANDSAT TM and ETM+ scenes (1975, 1986, 1987, 1989, 1999, and 2000) and ASTER images (2002 and 2004) are used to provide actual and detailed information about glacier/snow and vegetation distribution. ASTER data, especially, are very suitable for morphological and situation details, due to their higher spatial resolution.

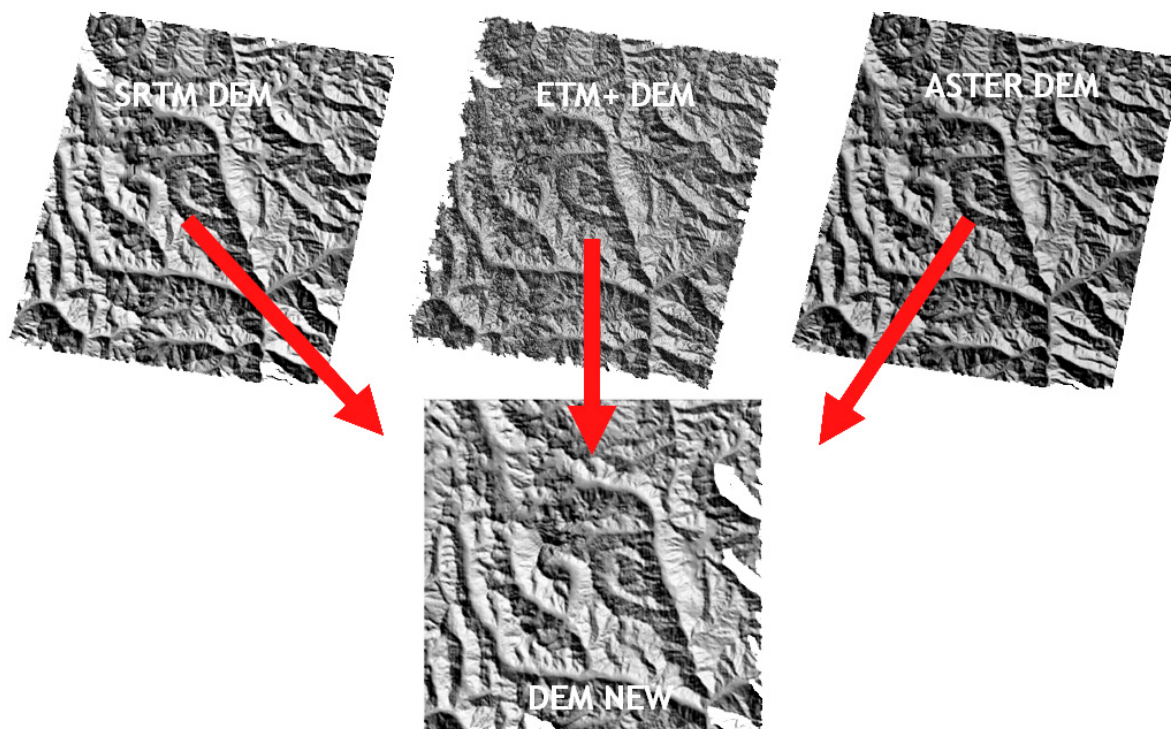


Figure 3: Multitemporal and multisensoral DEM generation

For a DEM generation a combined analyse of multitemporal and multisensoral DEM's were used. Therefore, different ASTER DEM's (to fill up and reduce the aerial extent of "zero-data-values"), a digital elevation model from stereoscopic LANDSAT ETM+ data (M. Wurm, 2004) and the available SRTM elevation model with a resolution of 100m were generated. In a raster to vector and contour line conversion provide a contour line map with an equidistance of 50m. The accuracy of the contour lines is within the limits of a map in scale 1:100.000.

Especially in high mountain regions Remote Sensing techniques provide useful information about the environment. Remote sensing images from space - in this case - can be very helpful for high mountain research. So ASTER and LANDSAT ETM+ data can be used to obtain information about glacier and snow distribution (with a multi seasonal approach) and by means of a digital landuse classification a vegetation layer can be generated. The Aconcagua region is dominated by an alpine vegetation environment, where only in lower parts grassland can be found.

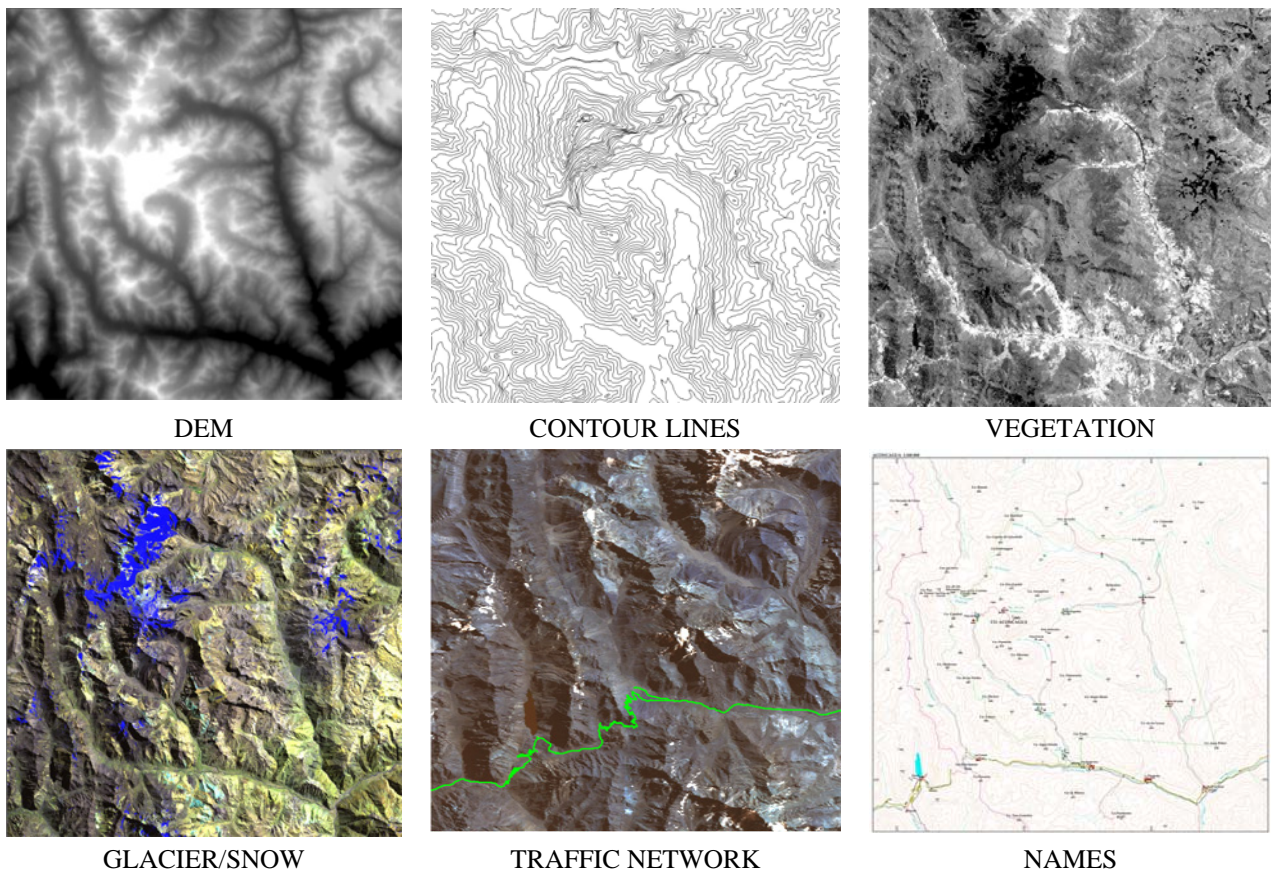


Figure 4: Different map layer

The importance of topically information about changing high mountain environment shows the example of the Horcones Inferior glacier (Figure 5). The left photograph shows a photograph taken by an airplane from January 2006. The Horcones Inferior glacier indicates debris covered - thinned out - glacier tongue, with a length of about 11km. The glacier is reaching the end of the valley, near Confluencia in a height of about 3400m. The right figure shows a perspective view of the same area with ASTER data from January 2004. At this time the glacier has no clear indicates for a glacier surge, his tongue ends 2,5km above the valley conjunction. A similar behavior of the glacier could be observed during 1984 – 1986 (Bottero et al., 2000).

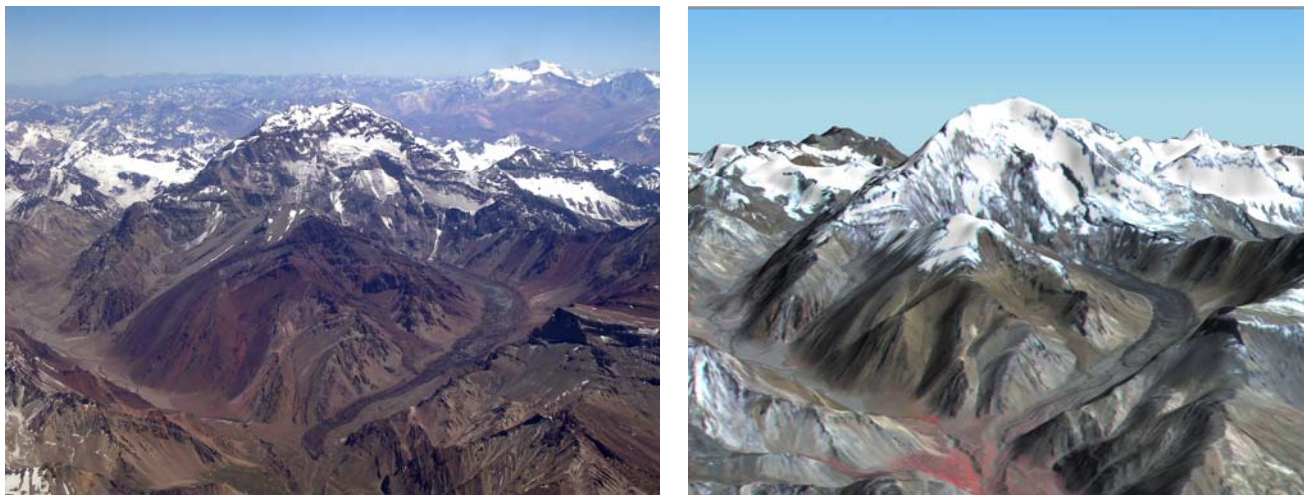


Figure 4: Glacier Surge of the Horcones Inferior glacier (left: photograph of 1/2006 by Deutscher/Hirschmugl; right: perspective view with ASTER data of 1/2004)

The traffic network (roads and railway) was recorded by GPS measurements during the field work, although these elements are well recognizable in the ASTER and LANDSAT data. The main drainage system has been digitized visually in the ASTER images. The information about the name of peaks, rivers, settlement and tourist infrastructure could be obtained by other maps and field work.

#### PREMINILARY RESULTS AND FURTHER INVESTIGATIONS

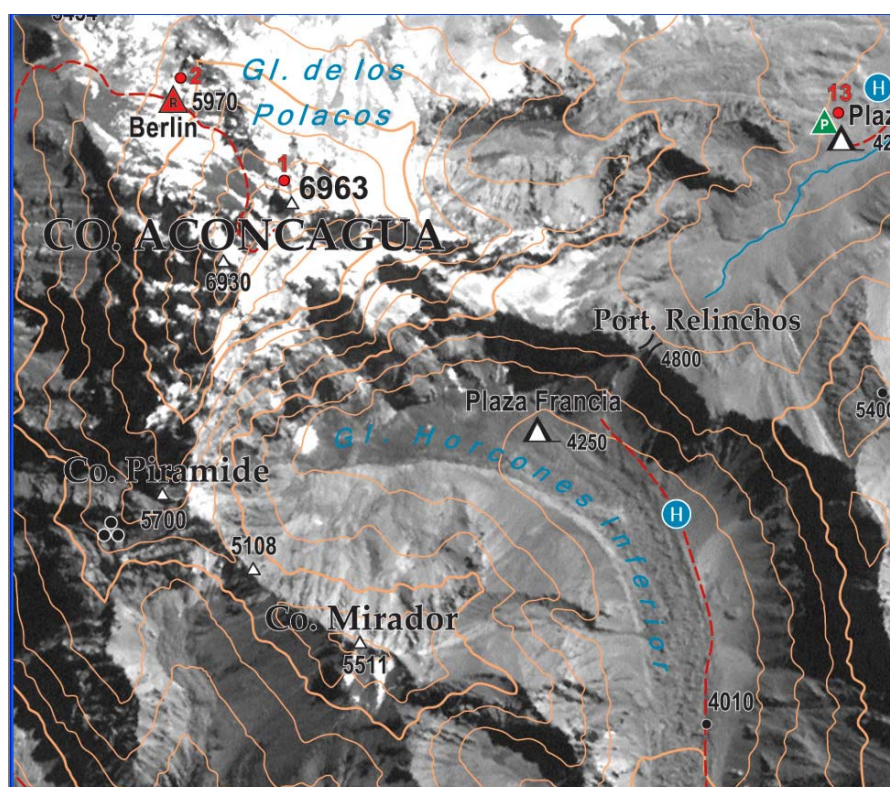


Figure 6: Preliminary result of the Map (sketch)

The aim of this project is to provide basic data base for the generation of a map in scale 1:100.000. The most suitable way for the map creation is an out weighted relationship between time/costs and the achieved quality of the results. This has been done by means of a multisensoral (ASTER/SRTM/LANDSAT) and multitemporal

(1989-2004) data set. The presented study must be seen as an intermediate result. Figure 6 shows a sketch of the map in the area of Mt. Aconcagua and the Horcones Inferior Glacier with some mistakes, which will be refit in the next processing step.

The compilation (preprocessing, merging, raster to vector conversation, evaluation, etc.) of the geodata are most suitable for the generation of a (topographic) SAT-MAP 1:100.000. Further investigations/work are to finalize a digital compilation for printing and to creating a WEB MAP.

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