High up and Deep below – Dynamic 3D Cartography at the Roof of the World and in Sea-Level Caves

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ABSTRACT

Using the surface changes of *High-Asian Glaciers* and fly-through animations through complex cave systems, two types of *Dynamic 3D Cartography* are presented: First the mapping and visualisation of glacier retreat and down-wasting over decades by means of multitemporal spaceborne imagery and second the user-guided viewer motion over resp. through the *Bornese Gomantong Cave System*. The latter one represents the data-richest 3D cave model globally.

1. PROLOGUE

In the context of cartographic presentation "dynamic" may be considered to have two meanings: First, the depiction of changes of objects of our earth and, second, the visualisation of – primarily complex – objects by means of a user-guided "tour" over, around, or through these objects like simulated overflights or walk-throughs. In the present paper both aspects are covered, using the drastic changes of high-alpine glaciers and an extremely complex cave system as examples.

2. GLACIER DYNAMICS IN HIGH ASIA

2.1. Multitemporal Three-Dimensional Glacier Mapping

After aninitial phase of satellite-based three-dimensional tracings of Himalayan (Bolch et al. 2008a, Bolch et al. 2008b, Bolch et al. 2011,Trauzettel 2013) and Tibetan glaciers (Bolch et al. 2010, Neckel at al. 2014) back to the early 1960s, the importance of the mountain massifs in the (far) West of the Tibetan Plateau and even beyond for both glaciology and in particular climatology became clear.Thus the regions of „Mustag Ata – Kongur Shan“, „Lake Paiku – Shishapangma“ and „Lake Karakul – Pik Lenin“ as well as „Gurla Mandhata North“ and „Gurla MandhataSoutheast – Halji“ have been selected for multitemporal glaciological 3D mapping. For all these study sitesa present-day master DTM using SPOT-5 or ALOS-PRISM data with a geometric resolution of 10 m and GCPs has been generated. In some cases, however, these data had to be complemented by SRTM or ASTER-GDEM data.
In order to secure a homogenous quality of the glacier outlines to be mapped, a comprehensive new survey resp. adaption of the existing Randolph Glacier Inventory for 1970, 2000 and 2010 has been made. For this purpose, historical KH, Landsat, ASTER as well as EO-1 and Orbview-3 data were used (cf. Neckel at al. 2014).
For the Kekesayi Glacier of the Mustag Ata – Kongur Shan study site glacier velocities were determined using Offset Tracking methods. For 2011 velocities of 15 to 25 cm per day were derived for the upper glacier part, however with significantly decreasing velocities towards the glacier terminus (Holzer et al. 2012). An updated publication by Holzer at al. 2015b, compiled in cooperation of the TU Dresden Cartography Research Group and University of Erlangen/ Geography, reports further glacier velocity values measured from ERS-1/2 radar data of the 1990s.
Besides glacier area and flow velocities, a complete scientific treatment of a glacier has, however, also to comprehend the mass balance. In this respect the investigation of the region Purogangri – Lake Lingge by means of optical spaceborne data failed due to too low image contrast which is inevitable

for the stereo-based generation of a DTM. For Mustag Ata - Kongur Shan, KH-9 DTMs showed an average thickness reduction of approx. 20 m for the ablation zone of Kekesayi Glacier during the period 1973 to 2013(Holzer et al., 2015b).
For the study site Lake Karakul – Pik Lenin mass balances were based upon ALOS-PRISM data from 2010 and SRTM-3 data from1999(Golletz 2013). This glacier basin showed a rather heterogeneous image with protruding as well as retreating glaciers (Holzer et al. 2014, Holzer et al. 2015a).

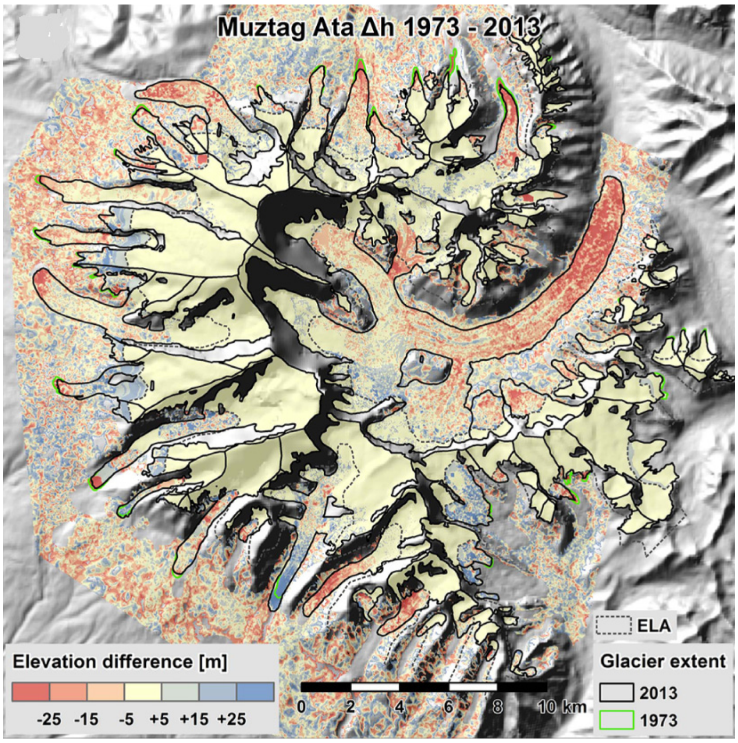

Figure 1: Co-registered difference image 1973–2013 after outlier and gap-filling processing for glacier mass-balance and vertical uncertainty calculation showing the down-wasting of Kekesayi Glacier. From Holzer at al. (2015b).

The geodetic glacier mass balance determinations of the Gurla Mandatha Massif were based on DTMs derived from the very recent tri-stereoscopic Pléiades data of 2013, set in relation toSRTM-3 of 1999. Joint research activities of the TU Dresden Cartography Group and the University of Tübingen/Geography resulted in comparisons with DTMs generated by means of SAR interferometry using SRTM-3 data from 1999 and TanDEM-X data from 2012. For the Gurla Mandatha Massif they showed an average mass loss of -0.07±0.31 m w.e.a^{-1} (Pléiades) to –0.11±0.20m w.e.a^{-1} (TanDEM-X) over the period from 1999 to 2012/13. From 1964 onward occurred an average mass loss of 6.0±2.1% as well as a retreat by 175.0±5.0 m. These rather exact values are significantly lower than the ones published in previous studies (Wiemann 2013,Holzer et al. 2014).
During a field campaign in 2012 terrestrial stereo photos taken at Naimona'nyi Glacier were used to produce a local DTM applying the Structure from Motion approach. This relief model served the purpose of determining the down-wasting of the glacier tongue. These findings corroborate the results stemming from spaceborne data which are described byHolzer et al. (2014).
For the benchmark study sites Gurla Mandatha Southeast – Halji, Lake Paiku – Shishapangma und Mustag Ata – Kongur Shan historical as well as contemporary optical data were processed in order to derive geodetic mass balances. For the Lake Paiku – Shishapangma Basin they were calculated by means of KH-9 data reaching back until 1973 (Amado 2015, Nikolakakou 2014).ForMustag Ata – Kongur Shan and Gurla Mandatha Southeast – Halji high-resolution Pléiades tri-stereo data – to some

extent funded by the ORFEO-RTU Project of CNES (https://rtu-pleiades.kalimsat.eu) – were used to calculate geodetic mass balances (Amado 2015, Nikolakakou 2014, Holzer et al. 2014, Holzer et al. 2015b) but also to carry out a mapping campaign for a new trekking map of this region (Buchroithner et al. 2014).

2.2. GLOF studies in the Nepalese Himalaya

The DTM generated within these activities had a resolution of 1m and was subsequently also used for remotesensing-based investigations of the GLOF-prone glaciers above the 1000-year old Tibetan Buddhist monastery of Halji in Humla, NW Nepal. It served the analysis of glacier behaviour which also led to the quantification of the ice mass loss within the period 1999 to 2013. Together with the result of a complex hydrological modelling of the Halji GLOFs these findings were published in a paper by Kropacek et al. (2014).

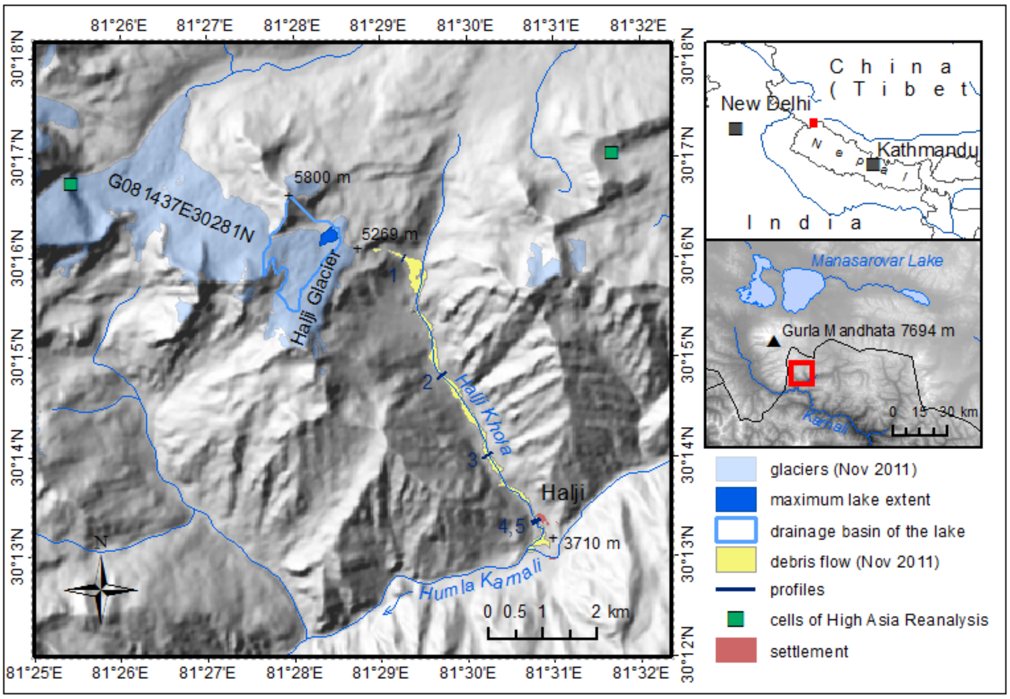

Figure 2: Map of the Halji study area at the southeastern side of the Gurla Madatha Massif. The debris flow has been delineated from a high-resolution image acquired in November 2011 available on Bing Maps. The glacier west of the Halji Glacier is labelled with the RGI (Randolph Glacier Inventory) ID. From Kropacek et al. (2014).

3. THE GOMANTONG CAVE SYSTEM

In continuation of earlier „survey-free“ research activities by McFarlane and Lundberg (Lundberg & McFarlane 2011) in 2012 and 2014 extensive and complex TLS campaigns have been carried out by the cave mapping team of the author in the Gomantong national park, Sabah, Malaysia, Borneo. They served the purpose of 3D-pointcloud surveying of the entire widely ramified system (Wilford 1934, Price 1996) with highest accuracy (some mm) taking several hundreds of scans (Hautz 2013, Hautz et al. 2013, MacFarlane et al. 2013b, McFarlane et al. 2015). The Gomantong Caves represent the most important swiftlet nest harvesting site in Malaysian Borneo (Francis 1987). Based upon detailed laser-scans, tested in different parts of the cave ceiling, an automated method for the shape-based

mapping of the swiftlet and the bat populations has been developed (MacFarlane et al. 2014). To the author`s knowledge this might represent the second approach at a global scale (cf. Azmy et al. 2012). The cave model has been embedded into a UAV-borne DSM (jungle canopy). Currently (October 2014) it has just been finalized and is in the stage of checking for any incidentally left blind spots. This model allows to much better identify the relations between the individual cave entries at different levels: http://faculty.jsd.claremont.edu/dmcfarlane/Borneo/Gomantong.htm
Further, the reader is kindly referred to the following URL:
http://gomantong.photofolio.org/and in particular tohttp://gomantong.photofolio.org/maps-video/.

3.1. Idiosyncracies of Cave Laser-Scanning

With the advent of operational portable 360° laser scanners so far undreamt-of possibilities presented themselves to the speleological community, revolutionizing the cumbersome, practically only pointwise, subterraneous surveying work practiced previously (Teichmann 1999, Schön 2007, Buchroithner & Gaisecker 2009).
The first „real“ laser-scanning campaigns in a cave which is not only an easily accessible *abri* were carried out from 2004 on, probably for the very first time worldwide in the Region of Five in Scotland (The Courier, 03 June 2004; cf. also Marais 2005). Early applications of terrestrial laser scanning (TLS) in caves which were not too difficult to visit are reported from Great Britain (Birch 2008a, 2008b) and Mexico (Canavese et al. 2008). One of the first TLS campaigns in a very complex, only climbable cave system was certainly the one in late winter of 2007 in the Dachstein Southface Cave (Dachsteinsüdwandhöhle) in the Styrian Alps of Austria (Buchroithner & Gaisecker 2009), followed by the one from September 06 through 09, 2007 in the Cave of Arette in the Pyrénées Atlantiques (Journées 2007 de l'Association Française de Karstologie;
http://s391384129.onlinehome.fr/arsip/images/Publication/livret%20guideafk.pdf; further cf. Marais 2005).

3.1.1. Accessibility and Irregularities of Cave Surfaces

In contrast to the use of stationary and mobile TLSs in anthropogenically shaped environments, in particular for urban and industrial applications, 3D surveying and –mapping features some almost immanent idiosyncracies that differentiate it significantly from the common surface applications. First of all, these are the accessibility of the terrain, the irregularities of the surfaces to be recorded, the temperature which is frequently significantly deviating from the ambient surface temperature, the mostly increased air humidity as well as, in a most general way, the problem of dirtying.

3.1.2. High Temperatures, Cave Clay, Mud and Biogene Dirt

On the other hand, the Gomantong Cave System shows exemplarily measured rock temperatures of 33° C at a height of some four meters above ground (Lundberg & McFarlane 2012). This implies that the air temperature in the caves is at least as high, if not higher. Together with the extraordinary humidity values this results in extremely exhaustive working conditions.
Independent of cave lithology one frequently finds cave-clay accumulations on rockfaces – however, frequently in carboniferous caves – as well as allochthone clay sediments in hollows of the cave bottoms. Especially for laser scanning these fine-grained deposits represent notable aggravation of the work, as do the excrements of bats and of cave swiftlets. During the author`s field campaigns in Borneo repeatedly falling "droplets" polluted the scan-mirror, thus causing intricate and time-consuming "cleaning breaks".

Figure 3: Gomantong Caves, Borneo: The author (background) in preparation of a scan, hanging on a catwalk in a slightly overhanging rockface, about 70 m above ground.

3.1.3. Visualisation of Complex Cave Systems

A brief historic account of digital cave depictions and reasons for animated visualization are given by Buchroithner 2015. A fly-through comprehending approx. 22 Gigabyte of data can be found under the following URL. This 10-minute animation of a part of the Gomantong Caves was one of the highlights at the 16th International Congress of Speleology in Brno 2013 and has been resp. still is considered the most data-rich cave visualization internationally. Soon after it could also be found in the Internet:http://www.youtube.com/watch?v=0fYU0Z3dnM0and in high resolution under:
http://faculty.jsd.claremont.edu/dmcfarlane/Borneo/Gomantong.htm
Whereas in the site mentioned above „only“ the point-cloud data of the 2012 NGS TLS expedition are presented, the following URL displays an animated rotational view of the whole 2012/2014 3D cave model. The author believes that to date this might represent the most complex 3D cave model and also visualization worldwide:
http://www.youtube.com/watch?v=_Oo4arXHPVQ&feature=youtu.be
Still, another way of visualizing complex caves has to be mentioned, and that is the possibility to produce a down-scaled physical 3D print of the virtual cave model using one of the latest-generation 3D printers. Figure 4 displays such an approach.
In order to close the circle to up-to-date “classical” cave cartography displayed on planar media in 2.5 D, finally an example of a cave map derived from a nadir projection of a TLS-generated three-

dimensional cave model are given in Figures5 and 6. Possibly this map represents (one of) the most accurate and detailed ones presently available worldwide. Based on the data model processed by the author and his coworkers Guy van Rentergem, Deinze, Belgium, made this map.

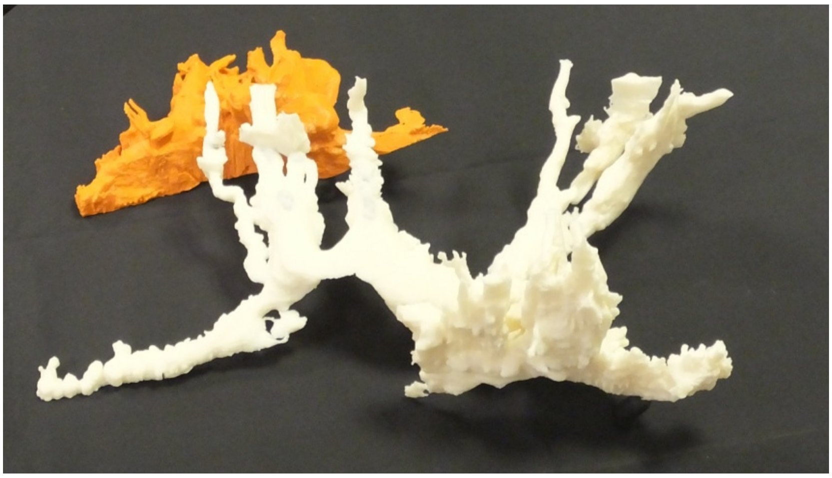

Figure 4: Physical representation of the virtual cave model (out of plastic) of the Gomantong Caves (surveying state autumn 2014), generated with a 3D printer at the W.M. Keck Science Department of the Claremont McKenna College, California. Orange: lower Simud Hitam/Black Cave (cf. Fig. 5), white: upper Simud Putih/White Cave. Total extension from left to right approx. 50 mm. Courtesy Donald MacFarlane, Claremont College, California.

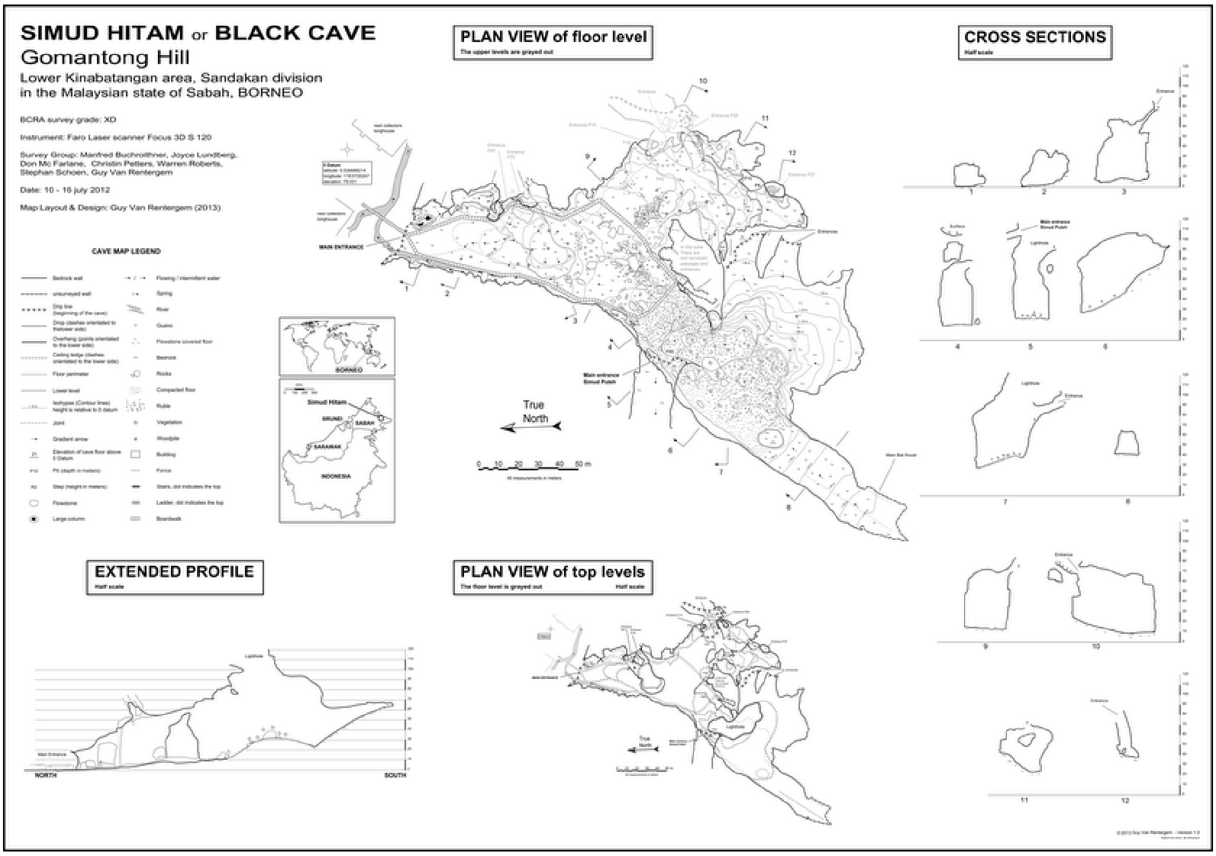

Figure 5: Map example showing part of the complex Gomantong Cave system.

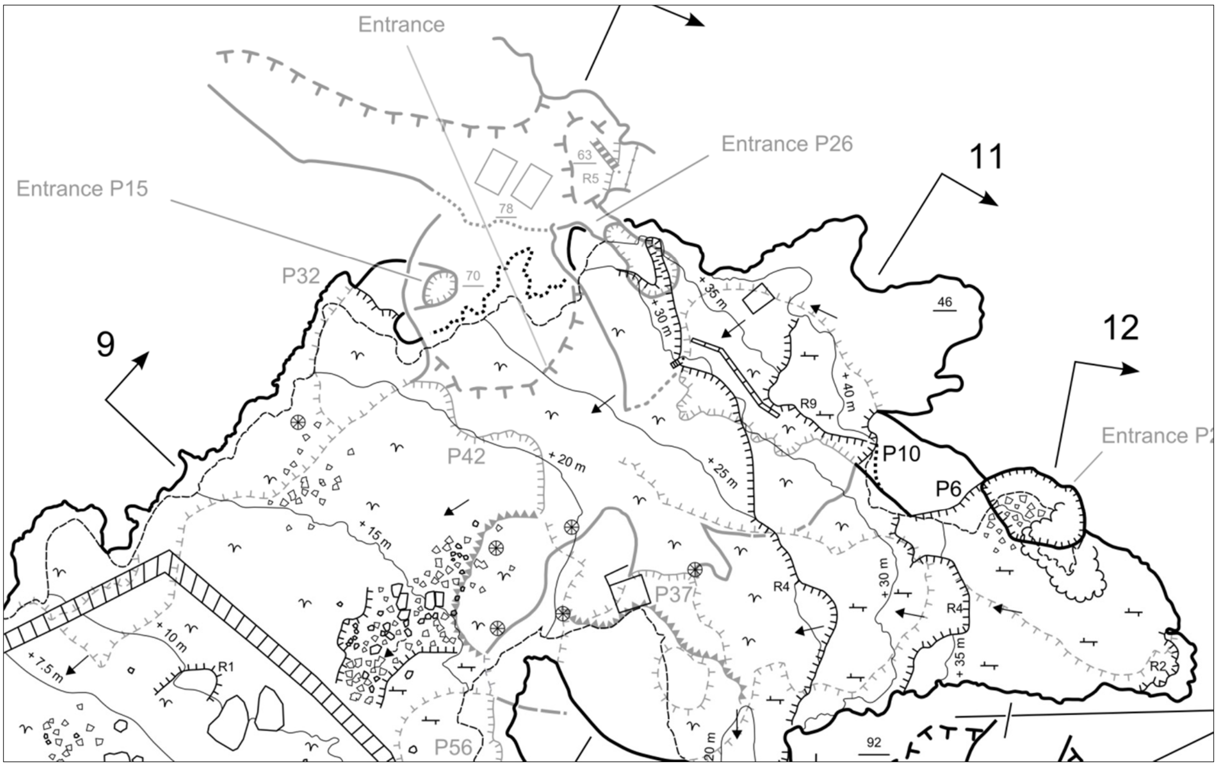

Figure 6: Detail of Figure 5 Courtesy Guy van Rentergem, Deinze, Belgium.

4. RESUMÉ

Since the beginning of structured cartography "surveying and mapping" have always been practiced jointly: one could and cannot exist without the other. In order to exactly depict a part of our world – be it remote high-altitude glaciers or subterraneous cavities, first it has to be surveyed. Since the advent of 360° laser-scanners and their capability to deliver three-dimensional point clouds of cave-walls, instead of the "classical" planimetric cave mapping with only few complementary individual cross-sections the truly three-dimensional data acquisition and visualization is *the* means of choice.
In the future the measuring and recording of shapes and volumes of high-mountain ice streams as well as of cave systems will certainly gain importance for various applications, foremost for hydrological and tourism aspects (cf. Buchroithner & Gaisecker 2009).

5. ACKNOWLEDGEMENTS

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