BAVARIAN GLACIERS 1989/90–2006/07 (1:5,000)

(5 Glaciological Maps)

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The maps show the areal extent and the contour lines of the five existing glaciers in the Bavarian Alps, covering different time periods: Nördlicher Schneeferner 1999–2006 (Map 1), Südlicher Schneeferner 1999–2006 (Map 2), Höllentalferner 1999–2006 (Map 3), Blaueis 1989–2007 (Map 4), and Watzmanngletscher 1989–2007 (Map 5). Except for Höllentalferner, the ice thicknesses derived by radio echo sounding are also displayed. The three "-ferners" are located around Zugspitze in the Wetterstein group, whereas Blaueis and Watzmanngletscher are situated in the Berchtesgaden Alps.

Aerial images from the Bavarian State Office for Surveying and Geoinformation (LVG) in 1989 and 1999 were analyzed by photogrammetric processing on a ZEISS Planicomp P1 and subsequently digital elevation models (DEM) were generated using the HIFI software (Ebner et al. 1980). The images from Zugspitze, taken on 15 September 1999, showed almost snow-free glacier surfaces with good contrast. The Berchtesgaden Alps were captured on 5 July 1999, when both glaciers were still snow-covered. We assessed the thickness of the snow pack by comparing the elevations of flat rock areas between the 1989 and the 1999 stereo models. The results of 2 m for Blaueis and 2.5 m for Watzmanngletscher were subtracted from the glacierized area of the 1999 DEM, which was then regarded as the 1998 autumn surface. Since the snow cover in the Berchtesgaden Alps did not allow glacier boundaries to be detected, those from the previous survey in 1989 are included in maps 4 and 5.

An airborne laser scanning survey of the Wetterstein group was conducted by the LVG on several flight profiles during the first half of November 2006. According to snow observations of the skiing resort, a constant value of 0.75 m was subtracted from the original elevation. Recent glacier outlines have been retrieved from digital orthoimages taken in June 2006 by LVG.

While taking into consideration the scale of the images and local conditions on Bavarian glaciers, Finsterwalder and Rentsch (1973) estimated the mean vertical error of terrestrial and airborne photogrammetry to be within a range of few decimeters. The maximum error is 1 m (H. Rentsch, pers. comm. 2003). The accuracy of airborne laser scanning was tested by differential GPS profiling on Engabreen in Norway, where mean discrepancies of 0.1 ±0.1 m standard deviation were observed (Geist et al. 2005).

The parallel shifts in the contour lines outside the glacierized areas in maps 4 and 5 are artefacts from the reprojection of the 1999 elevation model from Gauss-Krüger into UTM coordinates.

In November 2006 (Nördlicher and Südlicher Schneeferner) and October 2007 (Watzmanngletscher and Blaueis), ice thicknesses were determined using a ground-penetrating radar system (GPR) with 200 MHz antennas. To locate the profiles, kinematic GPS tracking using a differential system was carried out. On the radargrams, the bedrock could for the most part be identified clearly. To convert time into depth, a mean radar wave velocity of 0.15 m ns^{-1} was assumed. In a Geographic Information System, point shapefiles containing ice thicknesses along the profiles have been created and the glacier outlines were determined on the 2006 orthoimages by LVG. In glacier parts without information on ice depth, some reasonable thickness estimates have been introduced, e.g. by extrapolating slopes of ice free surroundings, to avoid linear gradients and to create a concave shape of the bedrock. All points were then interpolated into a raster, using a spline function.

From 1989/90 to 2006/2007, all glaciers reduced their areal extent. The strongest relative reduction of -44 % was observed on Watzmanngletscher, which has lost all its protuberances and is restricted to its most central part (see Map 5). Given the fact that this glacier was considered as diminished in the 1940s and that it showed the largest mass and area gains from 1960 to 1980, Watzmanngletscher seems to be the most sensitive and vulnerable to climate fluctuations of all Bavarian glaciers. The changes in area, thickness and volume for the periods 1989/90 to 1998/99 and for 1999 to 2006 were presented by Hagg et al. (2008). Changes versus altitude for 20 m elevation bands can be found on www.bayerische-gletscher.de.

Nördlicher Schneeferner is by far the thickest glacier according to the radio sounding data, its maximum depth reaches approximately 50 m. The radio sounding of Höllentalferner yielded no results during the 2006 field campaign. A new survey showed that it has a maximum thickness comparable to Nördlicher Schneeferner, but a significantly lower mean thickness and volume (Hagg et al. 2012).

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