Plate 3.10 Glacier Parameters and Their Changes, 1850–2000

Introduction

Inventories of glaciers in the Swiss Alps dating from around 1850, 1973 and around 2000 provide a comprehensive and unique compilation of data [5,6,7,8]. They have been used as a basis for the characterisation of ice-cover in Switzerland in the present plate, which also shows changes during glacier recession since the maximum extent reached in 1850.

The basic information and the glacier parameters derived from it have been stored and are available in analogue form (maps, fact-sheets, tables, aerial photos) as well as digital form (e.g. databases, satellite photos). The data can be statistically grouped and analysed according to spatial criteria (e.g. mountain groups) or for specific glaciological questions (e.g. type of glacier or exposition) [6].

The glacier inventories mentioned above present interesting aspects and possible applications in research and practical work:

- estimation of the extent and dynamics of glacier recession since 1850;
- application of estimation methods for modelling glacier behaviour (e.g. calculation of mass balance from changes in length) [1,2];
- basis for modelling glacier recession scenarios for the 21st century [5,6];
- criteria for selecting suitable glaciers for specific studies (e.g. so-called cold glaciers as climate and environment archives for ice drilling);
- recording and quantification of the available ice (water) reserves;
- identifying glaciers that are likely to break away and potentially dangerous pro-glacial lakes and hence early recognition of flooding and debris-flow hazards [3].

Ice-cover and types of glaciers

According to the data in the inventories there are around 2000 glaciers in the Swiss Alps today (cf. 1:1 100 000 map) [6]. They are concentrated in the central part of the Valais Alps (e.g. the Monte Rosa and Dent Blanche regions), the Bernese Alps (Finsteraarhorn, Jungfrau, Aletschhorn) and the Alps of Central Switzerland (Damma), and secondarily in the Alps of the southern Grisons (Bernina, Bergell). This asymmetrical spatial distribution illustrates the considerable local variations in climatic and topographical conditions.

The size distribution of the glaciers and thus the frequency of the four different types of glaciers are extremely irregular (fig. 1). In all mountain groups glacierets and névés (perennial snowbanks) (types C and D) are numerically predominant (fig. 2), while their contribution to total glacier area is of minor importance, however (fig. 3). Valley glaciers (type A) and mountain glaciers (type B) are far less frequent. The Grosser Aletsch, the largest glacier in the Alps, plays a special role in nearly all quantitative comparisons (cf. table 1).

Most of the glaciers in the Swiss Alps have a northern exposition (NW, N, NE) and are thus protected from direct radiation. In general, far fewer glaciers have a southern exposition (SE, S, SW) and are thus subjected to greater radiation. Under similar topographical conditions, these glaciers are in general considerably smaller than those on the northern slopes (fig. 4,5).

Glacier recession

Around 1850, glaciers in Switzerland covered a total area of 1800 km^2 (fig. 6). By the reference year of 1973, as a result of a temperature rise of around 1 °C, the total area had decreased by some 500 km^2 or 27 % to only 1300 km^2 [6]. Over the following years, up until the reference year of 2000, there was a further decrease of 250 km^2 [8]. In 2000 Swiss glaciers covered an area of

1050 km^2. As a result of the «century recession» the extent of glacierisation in Switzerland fell to 58 % between 1850 and 2000. Today 2.5 % of the country's total area is covered by glaciers.

Between 1850 and the inventory year of 1973 the volume of ice decreased by one third (35 km^3), namely from 110 km^3 to 75 km^3. Over the past three decades, with an accelerated rate of recession, a further 20–30 % of the volume has melted. In most regions far more than half the original volume in 1850 has been lost. The remaining volume of ice in the Swiss Alps in 2000 can therefore be estimated at 50 to 60 km^3, which represents a water equivalent of 45 to 55 km^3 (fig. 7).

The percentage of decrease in area and volume is inversely proportional to both the original figures (1850) and the regional degree of glacierisation. The percentage of loss among glaciers or glacierised regions that had less area and volume in 1850 (e.g. Lower Engadine, Basòdino, Grand Muveran) has been considerably lower than among larger glaciers and regions with more glaciers (e.g. Aletschhorn, Monte Rosa, Dent Blanche).

Position and rise of the equilibrium-line

The mean position of the equilibrium-line can be calculated from an assumed surface area ratio between the accumulation zone and the ablation zone of 2:1, and for this reason it is referred to as the 2:1 equilibrium-line. The altitude of the equilibrium-line varies within an extensive vertical altitude band (2300–3100 m) that thus covers a considerable temperature range. Basically this wide variation can be explained by spatial and climatic conditions. Furthermore, differences in exposition also play a role, resulting in a variation in the equilibrium-line of up to 300 m between north-facing and south-facing slopes.

An interpolated map of the trend surface of regional means shows that the equilibrium-line rises from the wet northern Alpine rim to the drier inner-Alpine regions. For example, the equilibrium-line is highest in the Monte Rosa, Aletschhorn and Bernina regions while the much wetter Tour Sallière, Grand Muveran, Gotthard, Flims–Pizol and Bergell have a lower equilibrium-line. This supraregional general trend, which is principally dependent on precipitation, is influenced by exposition, i.e. radiation, as well as other local factors such as wind-drift. In this respect, altitudes of the equilibrium-line in the reference year of 1973 are representative for the period 1960–1990 (fig. 8,9).

Overall, the equilibrium-line rose by around 100 m between 1850 and 1973 (fig. 10). This gives a general idea of the reaction of glaciers to the climatic change that started in the middle of the 19th century. The spatial variation in the rise of the equilibrium-line indicates a slight drop in precipitation since 1850 in the central Alps and along the southern rim (e.g. Monte Rosa, Aletschhorn, Bernina), i.e. in areas where the glaciers are generally at high altitudes.

The proportional area elevation distribution of the glaciers has been calculated at fixed altitude intervals using the newly available digital glacier outlines and a digital elevation model, and the results are compared for 1850/1973 and 1973/2000 (fig. 11). Both graphs show clearly that the greatest absolute decreases in area have occurred at altitudes where glaciation is at a maximum, while the most marked relative change has occurred at the lowest altitudes.

Changes in glacier area

The highly individual reaction of glaciers can be seen clearly in figures 12, 13 and 14. Despite the considerable scatter among glacierets and névés, it is immediately obvious that the relative change in glacier area for the periods 1850–1973 and 1973–2000 is inversely proportional to glacier size. For example, the percentage loss among valley glaciers was the lowest (10–20 %) while the figure for névés was the highest (20–100 %). Several hundred glacierets and névés have totally disappeared since 1850.

Methodology

In 1850, 1973 and 2000 glacier surface area and other principal characteristics (fig. 15,16) were determined in different ways. In order to elucidate the glacier maximum in 1850 original topographical maps were evaluated and partly completed through field observations for recording moraines (fig. 17) [5,6]. The 1973 inventory is based on special aerial photos that were used for recording glaciers visually; their outlines were then added by hand to 1:25 000 maps (fig. 17) [7]. The new Swiss Glacier Inventory (SGI 2000) was drawn up using satellite data (Landsat Thematic Mapper) and automatic mapping of glacier surfaces (fig. 18) [8]. The principal glacier parameters (e.g. slope, exposition, altitude of equilibrium-line) were obtained with the help of a GIS and a digital elevation model. Thanks to the cutting-edge methods used and the resulting possibilities for analysis and visualisation, this new inventory opens new perspectives [4,8,9]. Since it has not yet been completed, not all the desired data were available for the present plate. For this reason, the situation as per 1973 is shown in figures 2 and 3, which was in any case still applicable around 2000 in relation to the subjects of the figures.

Conclusion

The analysis of glaciers presented in this plate underlines their importance as sensitive climatic indicators. Their usefulness as models for early recognition of an acceleration in trends such as changes in the water balance, in potential natural hazards or in the landscape means that the glaciers in the Swiss Alps are key indicators for assessing current climate change as well as that expected in the 21st century [2].

References

[1] **Haeberli, W., Hoelzle, M. (1995):** Application of inventory data for estimating characteristics of and regional climate-change effects on mountain glaciers: a pilot study with the European Alps. In: Annals of Glaciology 21:206–212, Cambridge.

[2] **Haeberli, W., Maisch, M., Paul, F. (2002):** Mountain glaciers in global climate-related observation networks. In: Bulletin WMO, Vol. 51, No. 1:18–25, Genève.

[3] **Huggel, C. (2004):** Assessment of Glacial Hazards based on Remote Sensing and GIS modeling. PhD Thesis, Department of Geography, University of Zurich, Physische Geographie Vol. 44, Zürich.

[4] **Kääb, A. et al. (2002):** The new remote sensing derived Swiss glacier inventory: II. Results. In: Annals of Glaciology 34:362–366, Cambridge.

[5] **Maisch, M. (1992):** Die Gletscher Graubündens. Rekonstruktion und Auswertung der Gletscher und deren Veränderungen seit dem Hochstand von 1850 in Gebiet der östlichen Schweizer Alpen. Teile A und B, Physische Geographie Vol. 33, Zürich.

[6] **Maisch, M. et al. (2000):** Die Gletscher der Schweizer Alpen. Gletscherhochstand 1850, Aktuelle Vergletscherung, Gletscherschwund-Szenarien. Schlussbericht NFP 31, Zürich.

[7] **Müller, F., Caflisch, T., Müller, G. (1976):** Firn und Eis der Schweizer Alpen – Gletscher-inventar. ETH-Zürich, Publ. Nrn. 57 und 57a, Zürich.

[8] **Paul, F. (2004):** The new Swiss glacier inventory 2000 – Application of Remote Sensing and GIS. PhD Thesis, Department of Geography, University of Zurich, Zürich.

[9] **Paul, F. et al. (2002):** The new remote sensing derived Swiss glacier inventory: I. Methods. In: Annals of Glaciology 34:355–361, Cambridge.

[10] **Wipf, A. (1999):** Die Gletscher der Berner, Waadtländer und nördlichen Walliser Alpen. Eine regionale Studie über die Vergletscherung im Zeitraum «Vergangenheit» (Hochstand von 1850), «Gegenwart» (Ausdehnung im Jahr 1973) und «Zukunft» (Gletscherschwund-Szenarien 21. Jhdt.). Dissertation Geographisches Institut der Universität Zürich, Physische Geographie Vol. 40, Zürich.

---

[11] **Quellen Fig. 17:** Original-Messtischblatt Nr. 495 Zermatt (Ausschnitt) © Bundesamt für Landestopographie; Luftbild vom 7. September 1973, Gletscherinventar 1973, ETH Zürich; Photo: M. Maisch.