Plate 3.7 Variations in Length and Mass of Glaciers

Introduction

It was towards the end of the Ice Age, around 11 000 years ago, that the Aletsch glacier last extended as far as Brig in the Rhone valley. Within only a few hundred years, the glaciers receded from the main Alpine valleys to the head of the lateral valleys, where their length and mass have fluctuated throughout historical times. Archeological evidence such as the mummified body found in the Similaun glacier in Ötztal (Austria) reveals that around 5000 years ago the Alpine glaciers were as small as they are today. Remains of trees from Roman times indicate that the snout of the Grosse Aletsch glacier was further back 2000 years ago than at its present 20th century minimum (cf. map 3.8). During the «Little Ice Age», after the late Middle Ages, the glaciers advanced and deposited moraines which in general marked the limits of their glacial forefields. The last time they extended as far was around 1850. The Trient glacier had already reached this most recent maximum in 1845, whereas the Unteraar glacier attained it only in 1870. The subsequent general shrinking of the Alpine glaciers has been measured annually since 1880, or in one case 1874, through the measurement network described in the map 3.1. Map 3.7 shows the main results of these observations. It can be seen that the general pattern of shrinkage has been more or less regular, although there have been some quite distinctive exceptions. The measurement series give only a partial picture. The whole phenomenon can be recognised in the field, however, from differences in plant species and soil characteristics within and outside the glacial forefields. These differences are also shown in the national maps. On this basis, the total variation in length has been quantified and the measurement series compared to the maximum as a reference value. In many cases it is not known exactly in which year a glacier reached its maximum length and mass, although this mostly occurred in the decade between 1850 and 1860. Geodetic values for several years and some reconstructed annual values have been added to the series of figures concerning variations in mass. Comprehensive information concerning the longest and most complete measurement series has been published in [1,2].

Variations in length

The map and table show overall ablation since the last maximum for all the glaciers covered by the measurement network. Those included in the current network are classified according to the way they behave. The main characteristics of the five different types (A, P, R, S, T) are given in table 2. As in any classification, the final decision is sometimes a matter of discretion. Figure 1 shows variations in length for six glaciers in each of the categories A, P, R and T based on the cumulative curves used as a principal criterion for classification. It can generally be seen that the variations in length of types A, R and T are mainly due to the movement of the ice at the snout of the glacier. In the case of type P, however, the variations in length have mostly been caused by ablation and accumulation, which are generally responsible for the balance of the mass. These four types demonstrate more or less normal behaviour, which for various reasons is abnormal in the case of type S [11]. Types A and T are opposites in that the one comprises large, flat glaciers and the other medium-sized, steep glaciers, which also react differently to climatic change. In the case of the Trient glacier (type T) variations in length immediately followed variations in mass. With the Grosse Aletsch glacier (type A) variations in length were observed around thirty to forty years later than in the Trient. In various aspects type R represents an intermediate category between types A and T. According to [7], the change in length since 1850 of an average Swiss glacier can be summarised as follows: around 1850 the average length was 1.41 km, which decreased to 0.92 km by 1974, i.e. by approximately 35 %. The percentage of retreat was thus slightly more significant than the relative loss in area (27 %) and mass (31 %).

Retreat of the Trient glacier

With the exception of 1993, the variation in the length of the Trient glacier has been measured in the field every year since 1878. Since 1956 the positions of the glacier snout have been plotted (fig. 3), and the longitudinal profile has been recorded for certain years (fig. 4). Figure 2 shows the degree of variation in the snout compared with the whole glacier. In figure 3 the positions of the snout are superimposed on an orthophoto. The bare area in the glacial forefield lies within the limits of the terminal moraine deposited when the glacier advanced in 1987 and the area of new woodland below the glacier has developed since the advance in 1920. Figure 4 shows the well known, typical phenomenon of the snout of an advancing glacier arching up steeply and that of a receding glacier flattening out into a wedge shape.

Variations in mass

Variations in mass are determined using the procedures described in map 3.1. Figure 5 shows the mass balance data for four glaciers. The column diagram gives annual values. In the case of the Rhone glacier the cumulative curve, partly determined by mean values over several years, goes back as far as the maximum observed in 1856. In the other cases the cumulative curve has sometimes been extrapolated in a linear fashion. The cumulative curve for the Silvretta glacier is calculated from a mean value for the period 1938–1959 and annual values from 1959 onwards. For the Limmern glacier, annual stake network values for 1947 to 1985 have been used, the remainder being reconstructed from measurements taken regularly on the Claridenfirn since 1914 [9,10]. In the case of the Rhone glacier, values for the periods 1856–1874 and 1874–1881 have been determined geodetically [8]. Annual values for 1882 to 1913 and 1978 to 1982 have been obtained from the gauge network, the remainder reconstructed using annual precipitation values and summer temperatures provided by the climatological stations in Andermatt and Reckingen [5,9]. The annual values for the glaciers in the Aletsch area have been calculated from the water balance for the Massa catchment (fig. 10). As spatial means they cover all the glaciers in the area studied [4,9].

All measurement series show a predomination of years with a negative balance for the mass. Between 1850 and 1973 the overall glacier volume shrank from 107 km^3 to 74 km^3 [7]. A common pattern in the temporal distribution of annual values can be seen in the frequency of years with a positive balance around 1920 and 1980 and years with a negative balance around 1950. In several years the balance for individual glaciers shows strong differences and even sharply contrasting values resulting from varying spatial precipitation patterns. This can also be seen in the cumulative curves: around 1920 the Rhone glacier grew more markedly than the Limmern or the Aletsch glaciers. The opposite is true for 1980.

Variations in mass of the Gries glacier

Since 1923 the mass balance of the Gries glacier has been recorded over intervals of several years using geodetic methods, and since 1961 annual stake network [3,6]. Figure 6 shows the thickness of the glacier between 1986 and 1991, the surface having dropped by an average of 1.4 m per year. Figure 7 shows the mass balance of the year with maximum loss and with maximum gain during the period 1961 to 1985, as well as for the year when no change in the overall mass was observed. The lines of equal variation in mass reveal the spatial differences in mass balance. The equilibrium line roughly corresponds to the snow line at the end of the snow melt period. The variations in the equilibrium line depend on altitude and other characteristics of the surface of the glacier (e.g. slope, exposure, curvature, albedo). The correlation between changes in mass balance and altitude is shown in the diagram by the regression curve calculated from all values for each year. This curve varies from year to year depending on meteorological conditions. For the mass balance of a glacier, a major factor determining accumulation is the precipitation regime, whereas ablation is principally affected by the temperature regime.

Glacial shrinkage in the Aletsch area

Since 1850 the area covered by glaciers in the Massa catchment has shrunk from 148 km^2 to 127 km^2 (fig. 8). It currently represents 33 glaciers, of which the three largest are included in the measurement network.

The reduction in mass can easily be seen from the bare moraine ridges flanking the glaciers. Figure 9 shows a comparison between two cross-sections through the surface of the glacier. It appears from the Konkordia profile that the level of the glacier has dropped by around 100 m since 1850. Radar soundings made in spring 1995 revealed that the glacier bed in the outflow area of Konkordiaplatz is 600 m below the surface. Drillings carried out in summer 1990 in the middle of Konkordiaplatz reached the glacier bed at a depth of 900 m. It was already suspected from seismic studies carried out in 1929 and 1958 that the floor of the valley is very deep at this point. The Aletschwald profile shows that the surface of the glacier, which has dropped by around 300 m since 1850, is now only 50 to 60 m higher than the end of the glacier. At the end of the Ice Age the surface of the glacier in this part of the valley was around 600 m higher, i.e. the valley was more or less entirely filled with ice.

Changes in the depth of the ice in the firn area and at the snout have been recorded annually since 1945 by surveying surface profiles. Between 1927 and 1944 they were determined using topographical maps. During the growth period around 1980 (cf. fig. 5) the depth of the ice at the highest point of the snout increased for a time, while at the end of the snout it decreased steadily and progressively (cf. fig. 9).

Water balance in the Aletsch catchment

The water balance in the catchment above the Massa gauging station has been calculated using a balance model based on precipitation and runoff data [4,10]. Figure 10 shows the mean annual pattern for the period 1931 to 1990, based on daily means. Precipitation is more or less equally distributed over the whole year. Low winter and high summer discharge values are typical of a glacial regime (cf. map 5.2). The volume of water stored in the snow cover increases steadily throughout the winter and in summer it decreases in an irregular daily pattern, depending on changes in temperature which affect melting and thus river flow.

Particular features of the time series 1901 to 1995 include high precipitation figures around 1980 and extremely high runoff figures for 1947. The periodically changing runoff pattern (an increase up to 1950 and from 1980 onwards, with a decrease in between) contrasts with the evolution of stored water quantities.

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