Plate 3.6 Variation of the Snow Line

Introduction

According to [7] the snow cover is «a thin, thermally insulating, extensive but temporary layer on earth's surface reflecting radiation to an extreme degree. It is an important phenomenon in relation to winter tourism (glide layer), agriculture (insulation), water management (temporary reservoir), avalanches, glaciers, permafrost and climate». The fact that in the Grisons around two-thirds of the income from tourism accrues during the winter season, which is strongly oriented towards skiing [6], illustrates the economic importance of snow cover. It also plays a major role in the hydrological cycle, as demonstrated by the example of runoff regimen shown in map 5.2. Since snow is often around melting point at the latitude of Switzerland, it is very sensitive to temperature changes and is therefore an excellent indicator of climatic change [7].

Observation of snow cover

Weather and earth observation satellites offer a comprehensive view of snow cover that complements the point measurements made by the areal snow measuring network (cf. map 3.1). Orbiting weather satellites fly over the same area quite frequently. Data produced by American NOAA (National Oceanic and Atmospheric Administration) satellites with a 12-hour frequency was used for the described investigations. Thanks to the high repetition rate of the data, at least one cloud-free image is normally obtained per week, even during cloudy periods. With the wide-angle AVHRR (Advanced Very High Resolution Radiometer) scanner installed in the NOAA satellite it is possible to obtain images of areas covering up to 2000 • 5000 km^2. The spatial resolution (1 • 1 km^2) and spectral bands (0.55–0.68 μm, 0.73–1.1 μm, 3.55–3.75 μm and 11.5–12.5 μm) of the AVHRR scanner are ideally suited for mapping snow cover [4]. The NOAA-AVHRR data is readily obtainable using the receiving equipment and data storage system of the Department of Geography of the Bern University [2].

Maps of snow cover accumulation and ablation

Snow cover maps can be drawn up on the basis of satellite data using digital image-processing and geographical information systems (GIS) [3]. By superimposing snow cover maps for different points in time it is possible to monitor the accumulation and ablation of snow cover at any given location. The four 1:1 100 000 Atlas maps illustrate the general development of the snow cover over the winters of 1983/84 and 1992/93. Short-term changes, i.e. the formation of a temporary snow cover that melted after only a few days are not considered. In order to make the maps more accurately comparable, equal or at least similar data was used for each period, depending on cloud cover. By means of the time-series represented in figure 1, the two winters in question can be compared against the long-term record. In winter 1983/84 the accumulation and ablation of the snow cover occurred on average around one to two weeks later than the long-term mean, but the period with permanent snow cover was average or above average in length. As the maps indicate, almost the whole of Switzerland was under snow at the beginning of March 1984. The winter of 1992/93 was characterised by a short period of permanent snow cover and, in comparison with long-term data, very early ablation. Large areas of the midlands had no snow at all. This winter was in fact typical of the short winters with little snow that Switzerland experienced more frequently at the end of the 1980s and the beginning of the 1990s.

For any given altitude it is possible to set up simple regression models to describe the mean dates for accumulation and ablation. The following formulae can be used for the northern side of the Alps:

$E = -0.0386 \cdot \text{altitude} + 140.89$ $r^2 = 0.78$, $n = 31$

$A = 0.0752 \cdot \text{altitude} + 128.89$ $r^2 = 0.88$, $n = 31$

where

E:	mean accumulation date [number of days after 1st September]
A:	mean ablation date [number of days after 1st September]
altitude:	altitude above sea level [m]
r^2:	explained variance
n:	number of samples

Long-term changes in snow cover

Temporal changes in the extent of snow cover are excellent indicators of climatic change. For this reason the time-series of terrestrial data available in Switzerland have been evaluated for long-term trends. Figure 1 shows some typical examples. Normally two stations at different altitudes (approximately 1100 m to 1500 m and 1700 m to 2000 m above sea level) were selected per FISAR region (Swiss Federal Institute for Snow and Avalanche Research, cf. map 3.3); in addition, data from one very high station (Weissfluhjoch) and one low station (Interlaken) was also included. Each winter there may occur a succession of periods with permanent snow cover separated by snow-free periods. The diagrams in figure 1 show each the longest period of permanent snow cover. The relevant data is based on the winter reports published by FISAR [5]. According to the diagrams there is no indication of any obvious long-term trends in accumulation or ablation, or indeed in the duration of the snow cover. Furthermore, a comparison between various stations reveals that the annual variation in accumulation and ablation decreases with increasing altitude. In this connection the 100-day rule that is very important for tourism is referred to. According to this rule, a given skiing area can be considered reliable if there are at least 100 days between mid-December and mid-April when the snow cover is sufficient for skiing [1]. Skiing areas at 1800 m and above are quite reliable, while between 1000 m and 1800 m the conditions may vary from year to year, depending on aspect, distance from the crest of the Alps and various other factors [1].

Variations in snow line and snow cover

Changes in snow line and snow cover in selected large river basins were extrapolated from the four snow cover accumulation and ablation maps for the winters of 1983/84 and 1992/93 (fig. 2 and 3). The resulting diagrams clearly show once again the differences between the two winters. In 1992/93 the snow line was generally higher than in 1983/84. Owing to an anticyclone over Switzerland between December 1992 and February 1993 the snow line remained more or less unchanged during that period. At the beginning of March 1993 the snow line descended temporarily to between 500 m and 1000 m, but with relatively high temperatures it quickly retreated to higher altitudes once more. As already mentioned, in winter 1983/84 the mean dates of accumulation and ablation were later than the long-term mean. Otherwise, variations in snow line correspond quite closely to the mean patterns obtained using the regression models.

The differing movement of the snow line in the two winters studied here is also clear from the diagrams describing the degree of snow cover. The considerable differences at the beginning of the ablation phase in March, in particular in the Aare, Reuss and Ticino river basins, are especially noticeable.

A snowmelt runoff model

One way in which the data presented here can be usefully applied is in the field of water management, for setting up models of, and predicting, snowmelt runoff. By way of example, the Snowmelt Runoff Model (SRM) is briefly outlined [8]. The SRM is based on the so-called degree-day method; input parameters include daily values for snow cover, temperature and precipitation. Information concerning snow cover is obtained from satellites. As the example given in figure 4 illustrates, the catchment area is divided into altitude zones and the snowmelt runoff is calculated for each zone separately. Figure 5 shows the result of a model-based calculation for the Rhine basin as far as Felsberg. In order to compare the results of such a calculation with measured runoff, the latter must – for the influence of hydroelectric power stations – be adjusted to natural runoff.

Fig. 4
Dissolvimento della neve per diverse zone d'altezza
Ablation at various altitudes
Rhein, Felsberg 1984

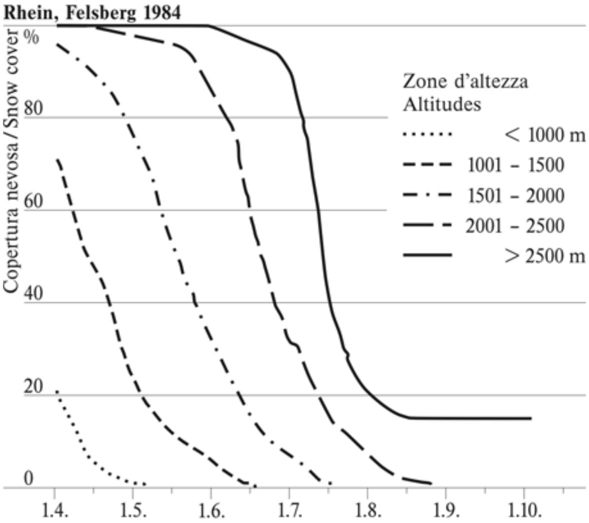
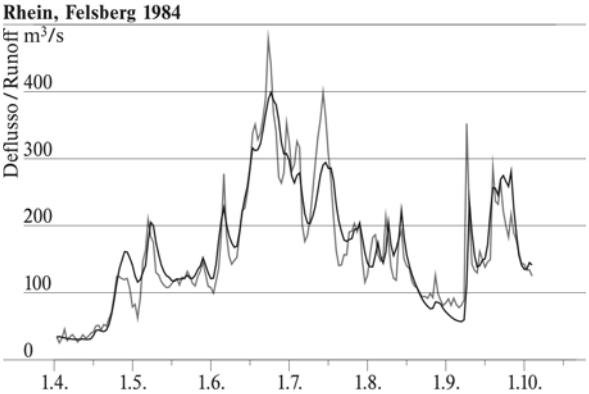


Fig. 5
Modello fusione-deflusso
Model for snow melt runoff
Rhein, Felsberg 1984



—— Valori misurati / Measured values
—— Valori del modello / Values obtained via model

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