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AN ANALYSIS OF SNOW COVER PATTERNS IN A SMALL ALPINE CATCHMENT

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ABSTRACT

Snow cover patterns in a 9·4 km^2 basin in the Austrian Alps are examined during spring and summer 1989. Digital mono-plotting from oblique aerophotographs is used for mapping. On the basis of a square grid with 25 m spacing, snow cover as mapped during nine surveys is analysed as a function of elevation and slope. During winter conditions the snow cover is found to be much better related to these terrain features than during the late ablation period.

KEY WORDS Snow cover patterns Depletion patterns Photo interpretation Terrain effects

INTRODUCTION

Many studies on snowmelt runoff modelling (WMO, 1986; Braun, 1988) have shown that the use of runoff data alone for calibrating and testing models often is not sufficient. This is because of the large number of parameters used in these models. Recent trends, therefore, aim at introducing the spatial distribution of snow cover variables as additional information (Day *et al.*, 1990).

For example, Leavesley and Stannard (1990) reported on verifying a distributed snowmelt model by comparing the spatial and temporal variations of simulated and measured snow covered areas. The latter data were derived from satellite measurements. In alpine terrain, however, the use of satellite data is limited by two major factors. Firstly, high resolution images required in mountain areas still have low repetition rates (Rott, 1987). Secondly, cloud cover often impedes the identification of snow cover. For small to medium sized catchments, therefore, airborne and terrestrial mapping are of particular interest.

Most investigations on snow cover patterns in small basins are based on square ground elements of 5 to 50 m in size. Meier and Schädler (1979) analysed aerial photographs of a small lower alpine catchment and related the depletion patterns to variations in solar radiation receipt. On the basis of terrestrial photographs of one slope, Rychetnik (1984) investigated the relationship of snow cover patterns and avalanche activity. A study of Good and Martinec (1987), based on orthophotographs of an alpine valley, showed geometric features of the snow cover to be highly correlated with runoff.

In the context of snowmelt modelling, the relationship of the snow cover to terrain features is of great importance. However, there has been very little research on this problem. Rychetnik (1987) related the date of the disappearance of the snow cover to snow depths, elevations, slopes, and aspects. Elder *et al.* (1989) classified snow depths in an alpine catchment as a function of solar radiation, slope, and elevation. None of these studies, however, concerns snow cover patterns.

The objective of this study, therefore, is to map snow cover patterns and to analyse these patterns on the basis of terrain features.

STUDY SITE AND PERIOD

The study was conducted in the Längental catchment, Tirol, at 47° 12′N, 11°E in the Austrian Alps (Figure 1). The basin is 9·4 km^2 in area and elevations range from 1900 to 3050 m a.s.l. A broad range of

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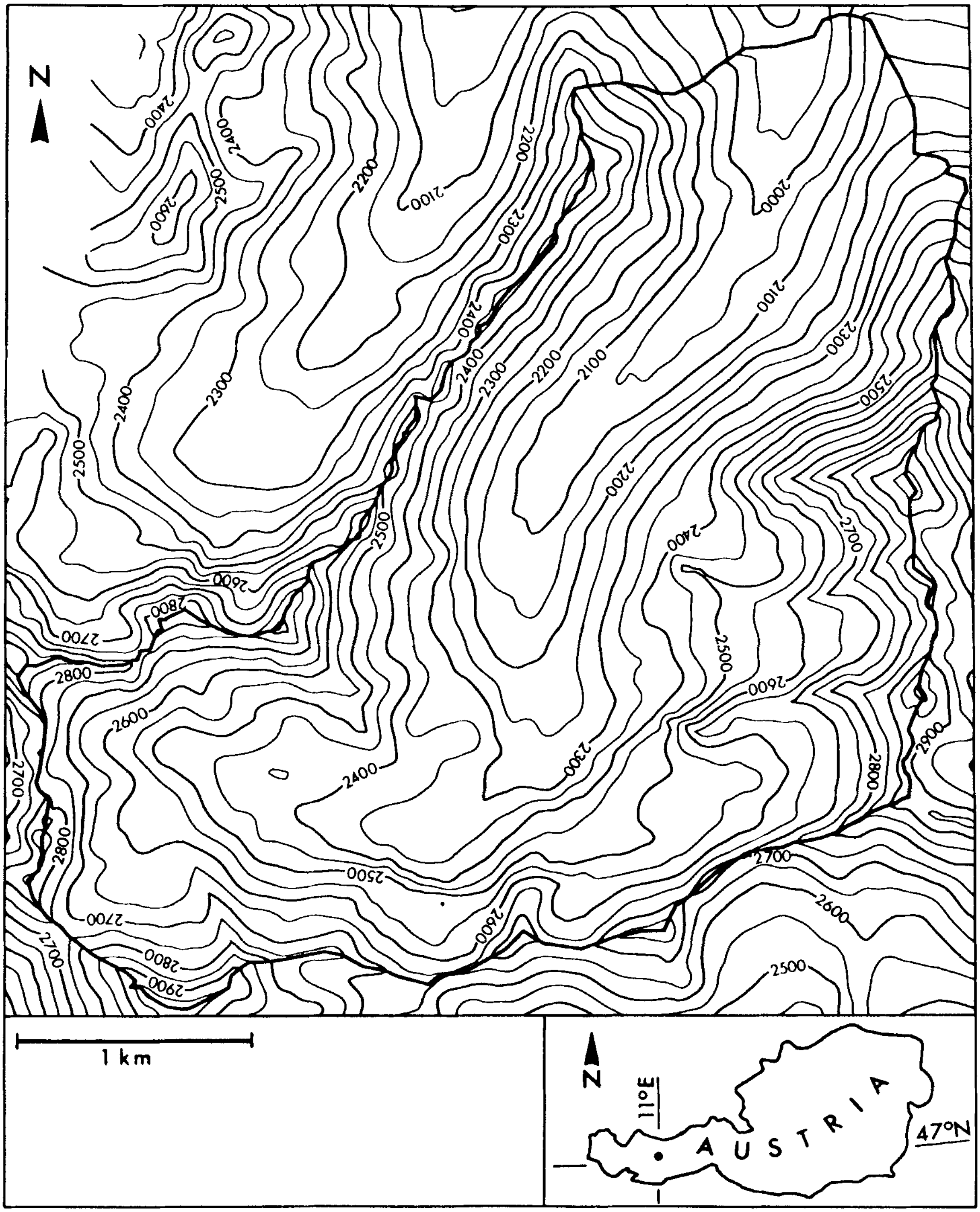

Figure 1. Map view of the Längental basin, Tirol; contour interval 50 m

slopes and aspects is represented. Figure 2 shows a frequency distribution of elevations and slopes on the basis of a 25 m grid. Topographically, the basin consists of two major units. The lower part comprises east and west facing slopes including talus fans with typical slopes of 35 to 40°. The upper part is open to the east. The southeast edge of the basin is formed by three prominent cirques.

Most of the catchment lies above the timber line. There are only a few scattered larches and cembra-pines. The flat areas are covered by alpine meadows. The annual precipitation averages about 1200 mm, 50 per cent of which falls as snow.

In the lower parts of the catchment the snow cover period typically lasts from November to May reaching maximum snow depths of about 150 cm in March. The upper parts of the basin are bare only for a few weeks in August or September and maximum annual snow depths are of the order of 400 cm. The snow distribution is typical of an alpine catchment. Redistribution caused by wind drift, avalanching, and sloughing substantially affects snow cover patterns. Factors affecting snow distribution in alpine terrain are discussed in some detail in Elder *et al.* (1989).

MAPPING OF SNOW COVER PATTERNS

Since the Längental catchment may be inaccessible for weeks due to avalanche hazard, the snow cover was mapped on the basis of aerial photographs. Surveys were conducted at intervals of one to two weeks depending on weather conditions. A Hasselblad 500 C/M non-metric but calibrated camera was used. Due to frequent cloud cover the flying height was generally limited to 3500 m, therefore, oblique photographs were made. A complete coverage of the catchment consisted of nine photographs per survey because of the complexity of the basin. For ease of interpretation, a fixed flying route was adhered to. An example of a photograph is given in Figure 3 which shows the upper part of the basin and views toward the west. For ease of comparison an arrow is given pointing to the same snow-free ridge in Figure 3 and in the following transformed pictures.

All photographs were printed, and ground control and tie points were identified. On the basis of aerial bundle triangulation (Kager, 1980) the external orientation elements for each photograph were determined.

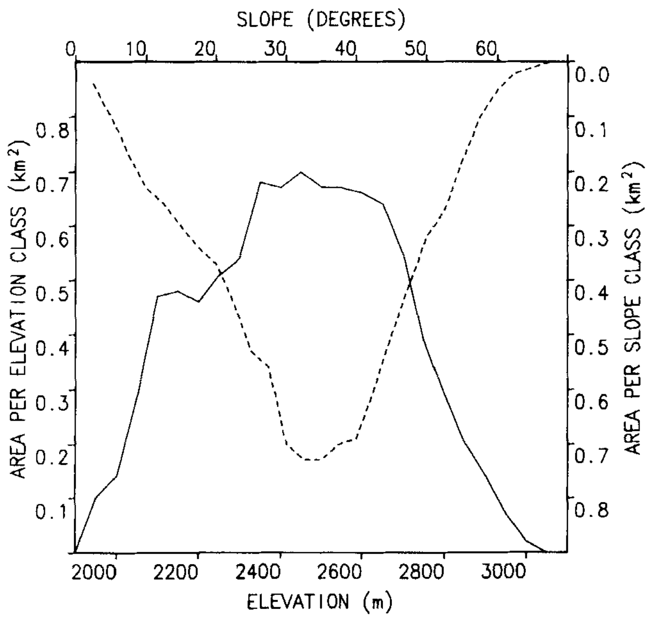

Figure 2. Distribution of the Längental catchment area as a function of elevation and slope. Elevation (full line) and slope (dashed line) in classes of 50 m and 2·5°, respectively

Figure 3. Aerial photograph of the upper part of the Längental basin, June 14, 1989. Thin lines represent snow boundaries as used for mapping and the thick line marks the section considered. Circles indicate ground control and tie points. By permission of BMLV, 13088/502-1.6/89

Automatic identification of snow cover patterns within the photograph is potentially inaccurate (Good and Martinec, 1987) because varying lighting conditions impede assigning fixed grey levels to snow covered or snow free areas. Therefore, an alternative approach was chosen. Within the prints, boundary lines of snow cover were identified, marked manually and subsequently digitized. Clearly, the determination of snow boundaries is scale dependent. Here, a scale matching that of the digital elevation model was chosen. Accordingly, snow patches of less than 10 m diameter were neglected.

The transformation of boundary lines from the photograph to the map scale was made on the basis of digital mono-plotting (Radwan and Makarovic, 1980; Hochstöger, 1989). At the map scale, individual

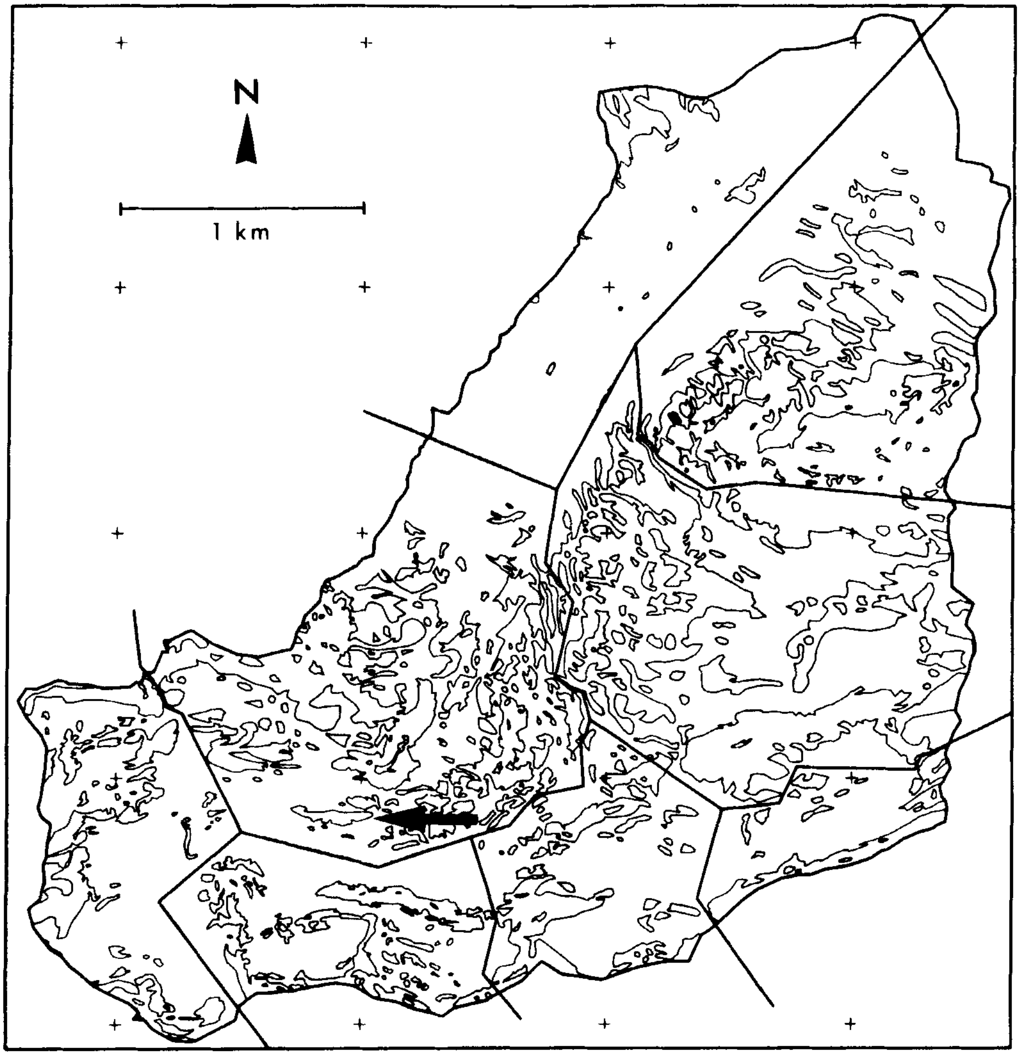

Figure 4. Map of snow boundaries (thin lines), June 14, 1989. Thick lines indicate the sections as mapped from individual photographs. The arrow corresponds to those in Figures 3 and 5

pictures derived from single photographs were linked in a graphic editor. Figure 4 shows an example of a map view of snow boundaries in the Längental basin.

Boundaries of snow patches were digitized counterclockwise and boundaries of bare areas were digitized clockwise. This allowed automatic discrimination between snow free and snow covered areas on the basis of vector data alone. The vector data were rasterized to yield 25 × 25 m square ground elements (groundels). A single element was allowed to be either snow covered or snow free. It was deemed to be snow covered when more than 50 per cent of its area was covered with snow as indicated by the map. Figure 5 presents a raster image of snow cover patterns of the upper part of the catchment. The arrow in the figure corresponds to those in Figures 3 and 4. Most obvious from Figure 5 is the gross simplification of the patterns as compared to the photograph (Figure 3).

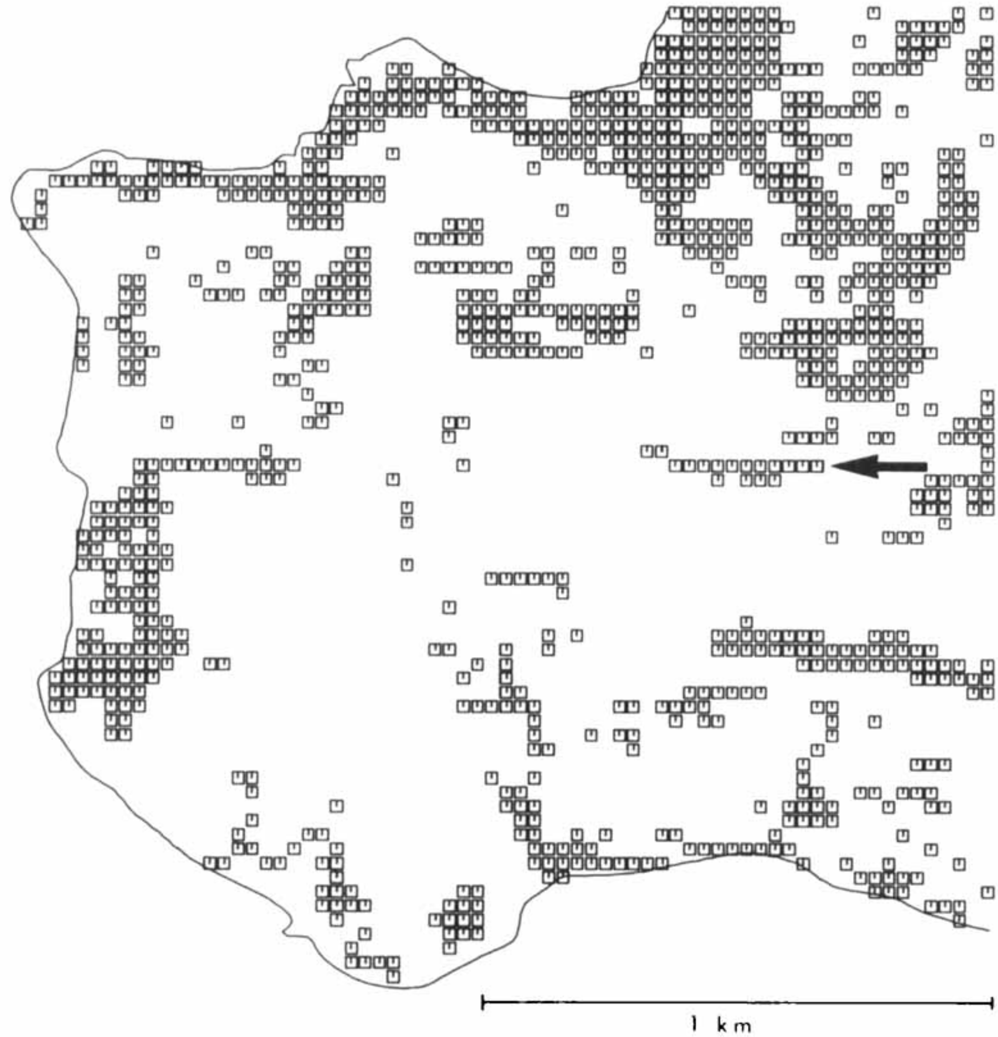

Figure 5. Snow cover patterns in the upper part of the Längental basin, June 14, 1989. Bare ground elements (25 × 25 m) are marked by squares

METHOD OF STATISTICAL ANALYSIS

For analysing snow cover patterns as a function of terrain features a digital terrain model with 25 m grid spacing and better than 2 m accuracy was employed. Its grid points were identical with the centres of the groundels. Parameters examined were elevation and slope. The slope of a grid element was calculated using the elevation of the four nearest grid points. Within the analysis, groundels were subdivided into classes of 50 m and 2·5°, respectively.

RESULTS

Figure 6 shows snow cover patterns as mapped during nine surveys from March to July 1989. The extent of the snow cover reached a maximum of 86 per cent on May 4 and subsequently decreased to 9 per cent on July 20. Snow cover patterns are quite complex. However, the basic features of the patterns remained constant

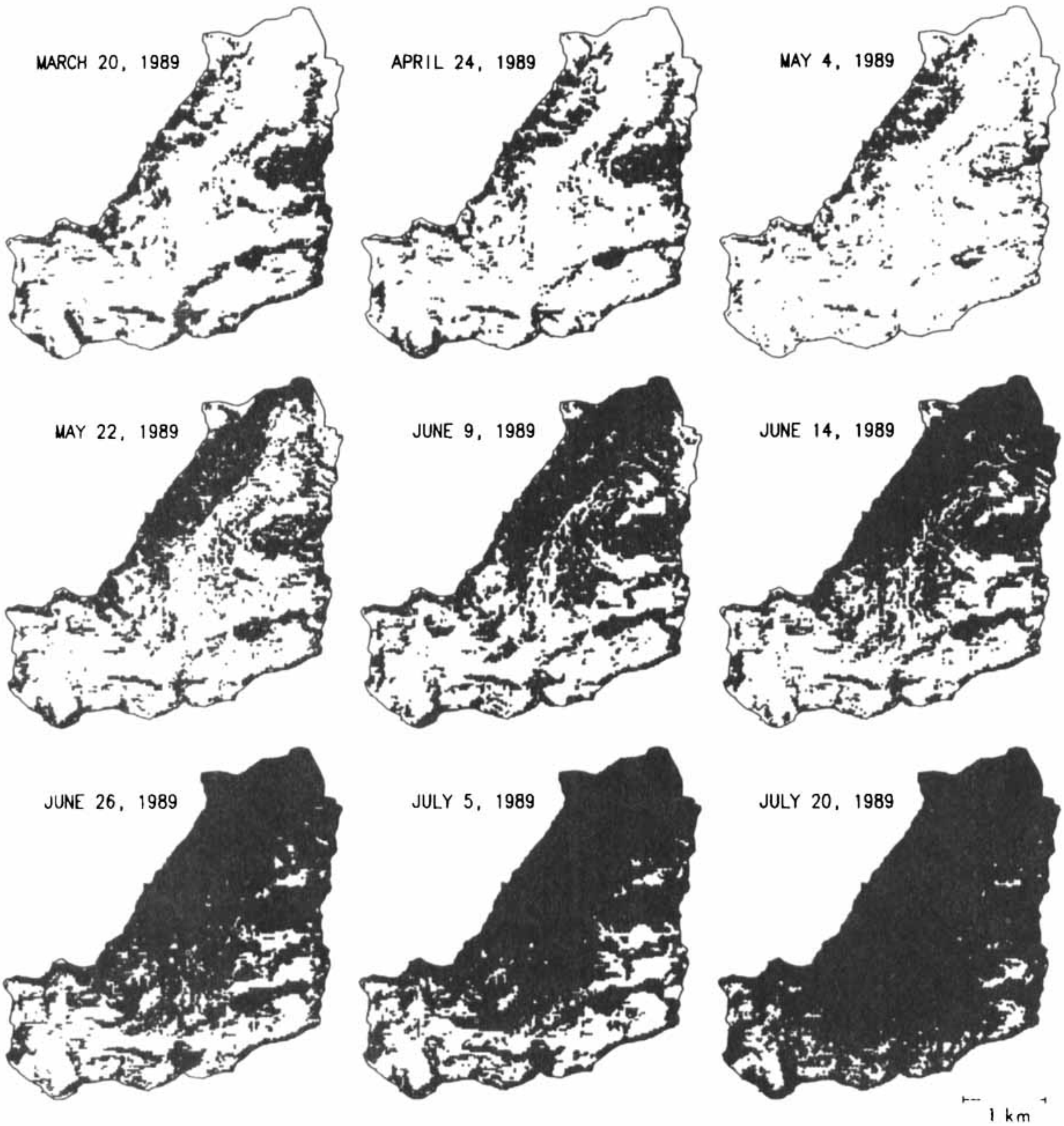

Figure 6. Snow cover patterns as mapped from nine surveys in March to July, 1989. White areas are snow covered and dark areas are bare

throughout the ablation period. Most striking are those in the southeast corner of the catchment as a consequence of three cirques (see Figure 1).

Figure 7 presents an analysis of snow cover as a function of elevation. During the surveys in March, April, and on May 4 the basin was heavily snow covered up to elevations of 2700 m. Subsequently, the snow cover gradually dissipated with more intense melting at lower elevations. This is most conspicuous at the altitude related to a snow cover of 50 per cent. On May 22 this level was at 2000 m and subsequently increased to

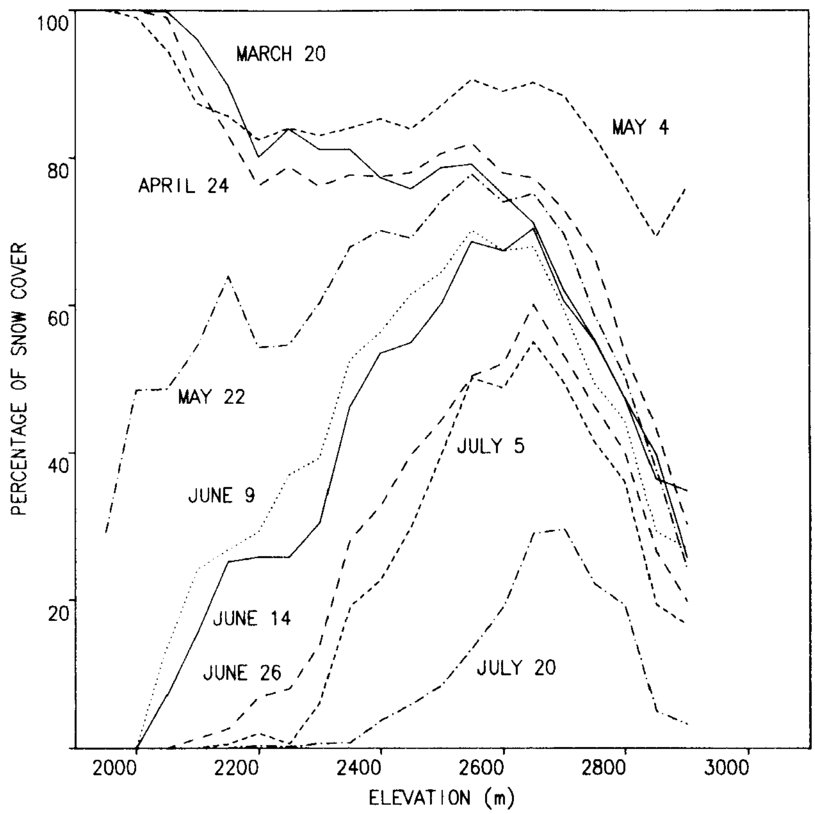

Figure 7. Percentage of snow cover in the Längental basin for nine surveys in 1989 as a function of elevation

2300 m on June 9 and 2600 m on June 26. During all surveys snow cover decreased with increasing elevation at altitudes higher than 2700 m.

Figure 8 summarizes an analysis of snow cover as a function of slope. Areas inclined less than 35° exhibited a complete snow cover during the surveys in March, April, and May 4. Graphs related to subsequent surveys show a shape similar to those in late winter indicating melting in all slope classes. Slopes steeper than 60° were virtually never snow covered. However, this is not true on May 4 which significantly deviates from the other surveys.

In the Längental catchment elevation and slope are not independent variables as there is a tendency towards steeper slopes at higher elevations. Therefore, the relation of snow cover to elevation and slope is examined simultaneously. Figure 9 shows an example of late winter conditions. During this survey the snow cover appears to be closely related to the terrain features. This relation is represented by a snow cover near unity at elevations lower than 2700 m and inclined less than 35° and an abrupt decrease above these limits. Figure 10 gives an example of the late ablation period. The distribution deviates substantially from that of the winter conditions. As expected from Figure 7 and Figure 8 the snow cover increased with increasing elevation and decreasing slope. However, no unique relationship to terrain parameters is apparent.

DISCUSSION

An analysis of all surveys yielded steep slopes to be generally snow free. Obviously, this may be attributed to sloughing, avalanching, and the combined effect of gravitation and wind. Regarding the threshold slope angle, one survey (May 4) deviates from the previous ones. It is believed that the difference is related to

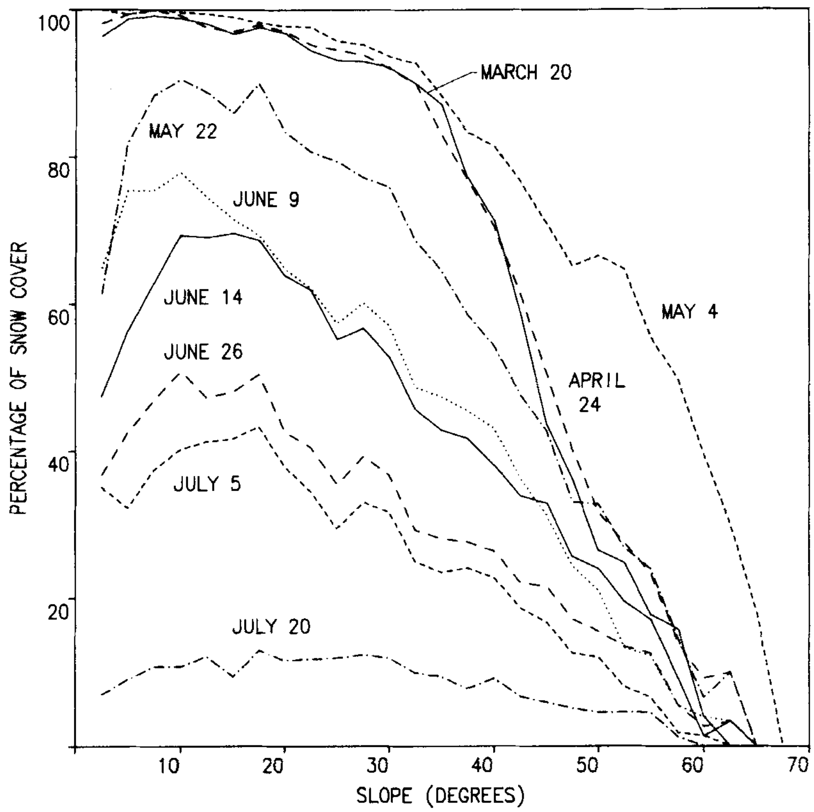

Figure 8. Percentage of snow cover in the Längental basin for nine surveys in 1989 as a function of slope

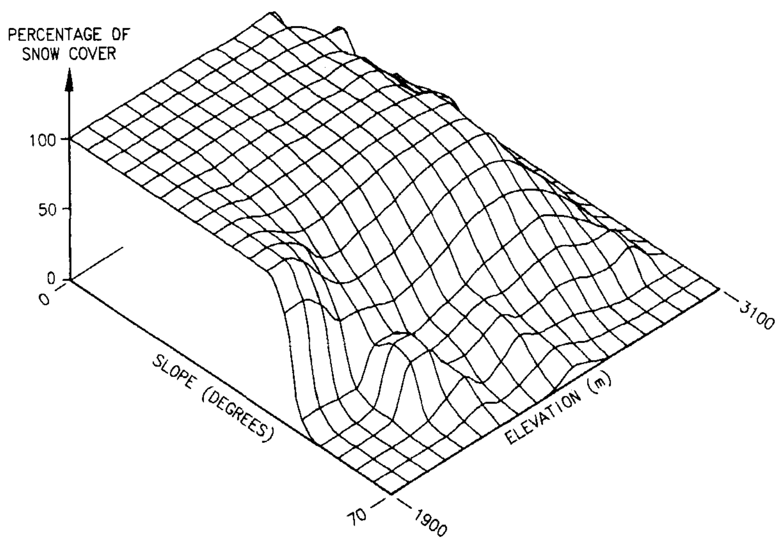

Figure 9. Percentage of snow cover in the Längental basin as a function of elevation and slope, April 24, 1989

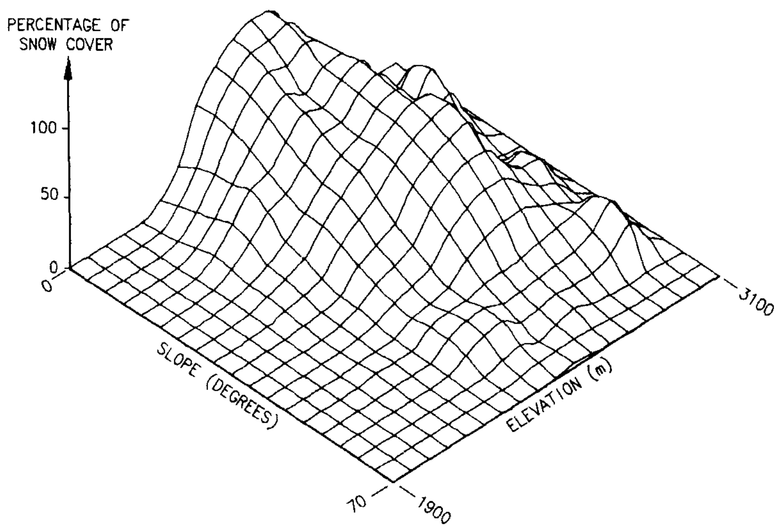

Figure 10. Percentage of snow cover in the Längental basin as a function of elevation and slope, June 26, 1989

changing consistency of falling snow over the ablation period. Typically, snow flakes are dry and fine in winter whereas they are large and heavier later in the season. Hence, in the latter case snow tends to adhere more readily to steep rocks. Similar to the effect of slope, areas at high elevations generally were snow free. This is probably due to the enhanced exposure to wind as compared to lower elevations.

In contrast to the winter conditions, a weak relationship of snow cover to terrain features was found for the ablation period. This is not surprising. Rychetnik (1987) only explained a small portion of the spatial variations in the date of disappearance of the snow cover by terrain features. He found maximum seasonal snow depths to be a better index. Similarly, Elder *et al.* (1989) detected a weak relationship of snow depths with elevations and slopes. The correlation was improved by including spatially distributed estimates of solar radiation.

Clearly, the influence of factors not directly related to the terrain becomes more dominant in the late ablation season. These factors include snowmelt and the more complex phenomena of wind drift and avalanching. Elder *et al.* (1989) suggested the inclusion of terrain curvature into the analysis, positive and negative values representing gullies and ridges, respectively. This parameter may assist in indexing the contrasting effects of wind drift. When examining maps of curvature of the Längental catchment it was noticed that there was, indeed, a tendency for less snow on ridges and more snow in gullies.

Though being beyond the scope of this paper another point appears to be worth addressing, that of the effect of solar radiation on snow cover patterns. The sequence of snow cover patterns presented in Figure 6 strongly suggests an early disappearance of snow on the southeast facing slopes. An analysis of snow cover for slopes of various aspects, which is described in more detail in Kirnbauer *et al.* (1991), offers evidence of this effect. For example, on March 20 north and south facing slopes exhibited a very similar snow cover distribution while later in the season this was not the case. For example, on July 5 the analysis (Kirnbauer *et al.*, 1991) indicates 80 per cent snow cover on the north facing slopes of the upper portion of the basin while the south facing slopes at the same altitudes showed a snow cover of less than 40 per cent.

Simulating spatially distributed snowmelt in the Längental catchment allows a more implicit assessment of snow cover as related to various effects including solar radiation receipt, albedo, and the distribution of snow water equivalent. Results of such work are reported in Blöschl *et al.* (1991) indicating that snow cover patterns are, indeed, a valuable means for evaluating a distributed snowmelt model.

CONCLUSIONS

The analysis showed that snow cover patterns in the Längental catchment are quite complex. However, the basic structure remains similar throughout the snowmelt season due to topographic effects. For winter conditions the snow cover of individual ground elements appears to be closely related to terrain features. Specifically, this relation is represented by a snow cover near unity at elevations lower than 2700 m and slopes less inclined than 35° and an abrupt decrease above these limits. This distribution may be traced back to the effects of sloughing, avalanching, and wind drift. During the late ablation period the relation to terrain is less pronounced. Snow cover is found to increase with increasing elevation and decreasing slope. Areas steeper than 60° were virtually never snow covered. The influence of factors not directly related to the terrain, such as melting, becomes more dominant in the late ablation period. Though attempts at correlating snow cover and terrain features are encouraging, the extreme complexity of redistribution processes certainly will limit the accuracy of predicting the snow cover distribution.

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