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Analyses of the Relation Between Spatial Snow Distribution and Terrain Characteristics

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ABSTRACT

A large amount of geo-referenced snow depth values were collected in the Aursunden catchment, Norway, using a georadar linked to a Differential Global Positioning System (DGPS). All data were imported to a Geographic Information System (GIS) and converted from point values to pixel values in a grid with 100 x 100 m cell size. The value for each pixel was calculated as the average of all snow depth point values inside the pixel. This conversion reduced the number of samples from 28,866 point values to 2602 pixel values for spring 1999 and from 33,652 point values to 2856 pixel values for spring 2000.

A digital elevation model (DEM) and a digital land-use map were used to identify the following five terrain characteristics, also as grid maps (layers) with pixel size 100 x 100 meters: elevation, aspect, slope, curvature, vegetation (forest or open field).

The five digital grid maps of the terrain characteristics and the two digital grid maps of the snow depth samples are the basis for all analyses presented in this work. The analyses have been made separately for the year 1999 and the year 2000. First, the five terrain maps have been reduced to the pixels which are common with the snow depth sample map. Analyses of correlation and regression were performed for snow depth versus aspect, slope, curvature and elevation. This was done separately for pixels in forest and pixels in open field.

At the 100 m grid scale the results did not show any strong correlation between the terrain characteristics and the snow depth. However, there was a difference in the correlation of aspect and elevation to snow depth and the correlation of slope and curvature to snow depth. The former ones have a correlation coefficient in the range of 0.092 to 0.389 and the latter ones in the range of 0.002 to 0.079. Thus, the impact of aspect and elevation on the snow depth was stronger than the impact of slope or curvature, at this scale.

Key words: Snowcover, snow depth, snow distribution, snow measurements, terrain analyses, georadar, regression analyses

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INTRODUCTION

The issue of the relationship between terrain characteristics and snow cover distribution is an important topic in hydrological modeling. Not only for the establishment of the models, as better information on the relationship will bring better understanding of the physical processes, but also for verification of hydrological models. One primary goal of knowledge about the terrain snow relationship is the creation of snowcover or snow depth maps for a given area such as a river basin. Distributing information, as snow cover, over space or time invariantly involves some sort of interpolation (Blöschl and Sivaplan, 1995). Traditional linear interpolation is often not sufficient since the nature of snowcover is too variable. Thus, in catchment hydrology, topography is widely used as a covariate because it is about the only information known in spatially distributed fashion (Fitzharris, 1975, as cited by Blöschl and Sivaplan, (1995)). The principle way of distributing snowcover information is to measure snow depth at certain places in the area, establish the relation between snow depth and terrain characteristics, and then assign snow depths to unmeasured places depending on their terrain characteristics.

The terrain snowpack relationship has been discussed in many previous publications. Already in 1970 the World Meteorological Organization (WMO, 1970) pronounced the importance of catchment topography for the design of snow courses and snow surveys in order to obtain good estimates of the snow depth. Evans et al. (1989) used slope, slope aspect (this is referred to as aspect in the presented paper) and vegetation as terrain characteristics. They found correlation between snow depth and aspect and a clear correlation between snow depth and vegetation. The results were not quantified in terms of correlation coefficients, but they described how many percent of a certain terrain variable was located in a certain snow water equivalent (SWE) interval. Hosang and Dettwiler (1991) used regression analyses combined with interpolation of the residuals (kriging) to quantify the relationship between elevation, presence or absence of forest and potential direct solar radiation and SWE. They found a linear relationship with R^2 = 0.66. Reuna (1994) described a system for creating a map of SWE for 70% of Finland. Snow measurements from 170 snow courses were used to calculate the SWE for each cell in a 10 x 10 km grid. During the calculation, correction coefficients were used to reflect the topographic factors of orographic slope effect and orographic coastal effect. Taylor (1996) looked at monthly precipitation as it is connected to elevation, aspect and slope, and stated the following: "For winter conditions the correlation between precipitation and elevation is generally weak for all aspects for individual Januarys between 1986 and 1990." He did not find a consistent relationship between monthly precipitation and slope, neither for summer nor for winter. Nevertheless, there was a correlation between elevation and precipitation. More recently Carroll and Cressie (1997) estimated the SWE using a geostatistical model and snow course, snow survey and remote telemetry (SNOTEL), and airborne snow data. In this research they developed a positive-definite spatial covariance function that allows incorporation of geomorphic site attributes when SWE estimates are obtained. They concluded that incorporating of, in that case, elevation, slope, and aspect made predictions of the SWE more precise. However, they also mentioned that the variables slope and aspect did not improve the modes substantially in all the cases. A rather high correlation between terrain character and snow depth was found by Forsythe (1997). He calculated an adjusted R^2 of 0.637 for the Marmot Creek Basin in Canada and an adjusted R^2 of 0.801 for the National Park Berchtesgaden in the German Alps. He connected snow depth from field surveys to elevation, angle of incidence, tree height and Landsat TM satellite data in the first case and to elevation and Normalized Difference Vegetation Index in the latter. Elder et al. (1998) made promising simulations with regression tree models. They showed that net radiation, elevation and slope could explain 60-70% of the variance in the snow depth measurements. A similar approach was made by Balk and Elder (2000). Net solar radiation, elevation, slope and vegetation cover type was used as independent variables in binary decision tree model. These models could explain 54-65% of the observed snow depth variance. Further they combined the decision tree models with geostatistical techniques, in this case kriging. The model was then able to explain 60-85% of the variance in the measured depth. Schmidt et al. (1998) investigated the sublimation of snowpacks in subalpine conifer forests. Based on modeling they estimated daily snowpack sublimation to be 20% greater on the south slopes than on the north slopes of the test basin.

The previous studies are a great improvement compared to simple extrapolation of snow survey data, but there are still some limitations. One is for example the availability of snow data. First, snow data were usually collected manually, which was very work intensive and time demanding. Thus, the amount of data was often limited with respect to extensive statistical analyses. Second, the exact location of each measurement was not necessarily known. Often, only the start and end of a snow course had a measured position. These facts aggravated analyses with a Geographical Information System (GIS). Especially important is the knowledge of snow depth and terrain characteristics at sufficiently many points in a catchment in order to perform robust statistical correlation and regression analyses. In the presented work, an approach is made to make such analyses, not on point value level, but with average values for 100 x 100 m grid cells (pixels).

STUDY AREA

The study area, Aursunden, is located in the mid-south of Norway close to the Swedish border (Lat. 62°41' N, Long. 11°48' E). It is a part of the Glomma river basin and has an area of 849 km^2. Elevation reaches from 690 to 1553 masl with a mean of 869 masl. Below the timberline (ca. 850 to 900 masl) the terrain is covered with birch forest. This comprises 31 % of the total catchment area. In general the terrain elevations increase towards the east, where mountains of alpine character are found. Approximately 12 % of the area is covered by lakes. The climate in this area is continental, which means cold winters and relatively warm summers. See Marchand and Killingtveit (1999) for more details on the catchment.

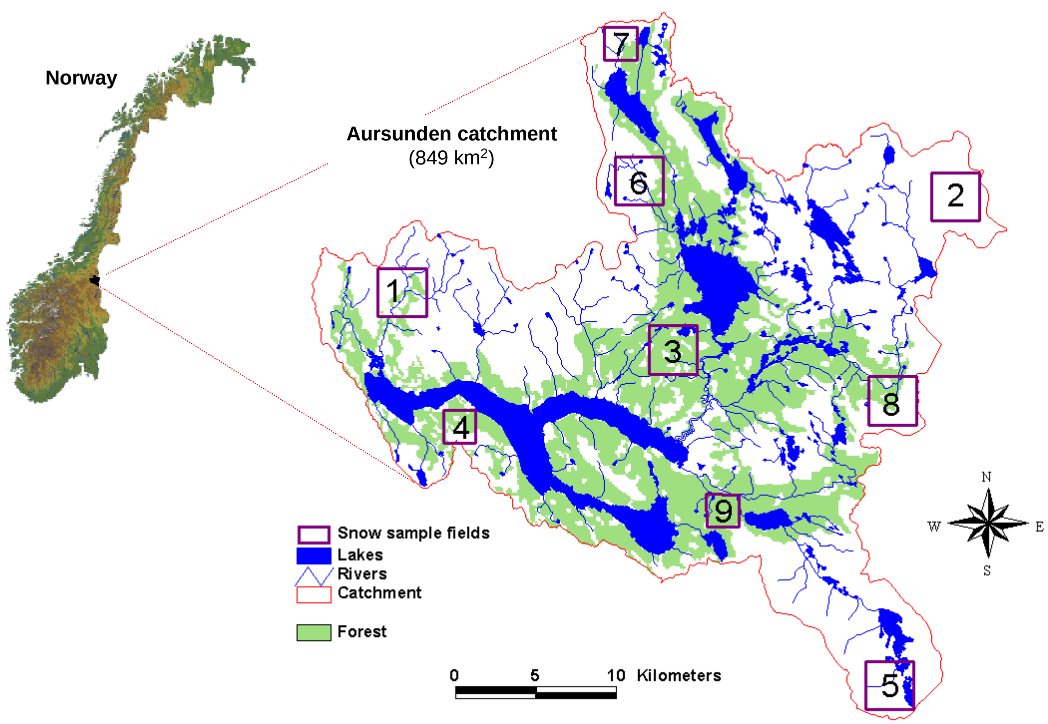

Figure 1 The Aursunden catchment. The nine “snow sample fields” are plotted according to the map scale. The smaller ones are 2x2 km and the bigger ones are 3x3 km.

TERRAIN PARAMETERS

The following five terrain parameters were considered: elevation, aspect, slope, curvature, vegetation (the two classes: forest or open field). A digital terrain model (DTM) and a land-use map were supplied by the Norwegian Mapping Authority (NGO). Thus, information about elevation and vegetation was directly available as digital 100x100 m grid layers (pixels), whereas grid layers for the parameters aspect, curvature and slope were generated from the elevation data. The GIS ArcView function “aGridCurvature” generated the curvature layer. Here the curvature of a surface was calculated on a cell-by-cell basis. For each cell, a fourth order polynomial was fitted to a surface composed of a 3x3 window. A positive curvature indicates that the surface is upwardly convex at that cell. The unit of curvature is 1/100 m. A negative curvature indicates that the surface is upwardly concave at that cell. A value of zero indicates that the surface is flat. Values of curvature are in the range –0.5 to 0.5 for a moderate relief and in the range of –4 to 4 for an extreme relief. The slope grid layer indicates the terrain slope in degrees from 0 to 90. More information on the ArcView functions used are found in the help system of ArcView or in the description given by Zevenbergen and Thorne (1987). Aspect is expressed in degrees from 0 to 359.9, measured clockwise from the north. To handle the circular character of the aspect when doing correlation analyses, values were converted from the circular scale (0-359.9) to a linear scale (0-180). This has been done by creating a linear measure from 180 to 0 for every degree (360 times), where 180 is expressing a certain degree and 0 is expressing the opposite side of the circle. The value of this new measure is decreasing equal from 180 to 0 without regard to moving clockwise or counterclockwise around the compass rose. A correlation analysis has been done for all 360 possibilities. The degree of aspect that gave the highest correlation value was than picked out, together with the appending values (0 to 180). This new scale is further called “ranked aspect”, and it belongs to a certain degree of aspect. For instance in Figure 2 a) the ranked aspect 230 is used. This means the aspect degree 230 gave the highest correlation to snow depth and equals now the value 180. The aspect degree 50, which is the counterpart of 230 on the compass rose, is equal to the value 0.

DATA COLLECTION METHODS

Certain locations for snow sampling were selected to yield a good representation of the entire basin. This was done by calculating basic statistical moments (min, max, mean, standard deviation) for the five terrain parameters with help of GIS, first for the entire catchment and than for the desired snow measuring locations. The two sets of statistical moments were compared and the snow sample locations in the GIS were adjusted until a good agreement between the two sets was achieved. This means for instance: if the entire catchment has a certain range of altitude with a certain mean, it was tried to cover the same range and obtain the same mean with the altitude of the snow sample locations. Or if the basin has 31 % forest area it was tried to place about 31 % of the snow sample location in the forest. This analysis resulted in nine “snow sample fields” that were located across the whole basin (see Figure 1).

Snow data were collected as part of the “New Generation Hydrological Models” project. A SIR 2 georadar (Geophysical Survey Systems Inc.) was connected to a Differential Global Positioning System (DGPS) receiver (Garmin GPS 12 with correction signal receiver from SEATEX). The radar sent pulses into the snow at one meter intervals. The reflections of each pulse were then stored for post processing. The DGPS receiver logged the position with an accuracy of 5 -10 m. Markers on the radar data (one for each position) made a link between certain radar pulses and the position. Since the position was logged with a two second time interval, the distance between consecutive snow depth values with positions was 5 to 12 m. This depended on the speed of the snowmobile which pulled the whole system. The sampling strategy was to measure first the snow depth along the borders of each snow sample field. The snow depth inside each field was measured by driving continuos lines in north-south and west-east directions. These lines were distributed as even as possible, however dense forest or steep slopes sometimes caused problems for keeping the lines straight. The even placement of the sample fields within the catchment covered snow depth variation in the macroscale. Meso- and microscale variations were considered by the measurement method inside the single snow sample fields, but microscale variations could not be analyzed in the 100 m grid (see also next section). For more information on these definitions of scale it is referred to Killingtveit and Sand (1990) or Pomeroy and Gray (1995). The computer program SIRDAS was used for analyzing the radar pulse reflections to detect the ground reflection and to calculate the snow depth from the travel time of the radar signal. The radar measured snow depth values were calibrated with manually measured snow depths (measured with a graduated rod). The result of the field measurements was snow depth point values with positions. The number of collected values was 28,866 in spring 1999 and 33,652 in spring 2000. A more detailed description of the measuring system, the survey strategy and the collected data can be found in Marchand et al. (2000). The used georadar itself, the measuring technique, and the accuracy compared to manual control measurements are described further in Sand and Bruland (1998), Killingtveit et al. (1998) and Bruland et al. (1999). Sand and Bruland (1998) used 6 control transects with a length between 620 and 1000 m. At these control sections they measured snow depth with a hand probe in a 5 m intervall and with the radar in a 0.25 m interval. The comparison between the hand measurements and radar measurements showed R^2 values ranging from 0.74 to 0.90. Killingtveit et al. (1998) measured 8 different snow courses both with the SIR-2 radar and by hand probing. Resulting correlation coefficient were in the range of 0.92 to 0.98 at seven courses and 0.77 at one of them. They concluded that the radar data were equally good as the manual measured data. In some cases they found that the radar measured snow depth was more relaiable than the hand probed one, this was especially the case at large snow depths (> 5 m) with ice layers. Bruland et al. (1999) found an R^2 value of 0.97 in his comparison between manual and radar measurements.

ANALYSIS

In order to use the snow data together with the terrain data, point snow depth values were converted to a grid cell resolution of 100 x 100 m by averaging the point data in a grid cell. This conversion reduced the number of samples to 2602 and 2856 pixel values for spring 1999 and spring 2000, respectively. Hence, five grid maps of the terrain characteristics and two grid maps of snow depth values, one for each year were developed. The following analyses were made for each of the two years.

The terrain maps were reduced according to the coverage of the snow depth map. Thus, only pixels with snow measurements were left on the grid layers. The terrain parameter vegetation was binary, forest and open field, and was therefore difficult to use in correlation analyses together with the other terrain characteristics. Thus, further analyses where made separately for forest areas and open fields. The regression and correlation analyses were performed between the snow depth layer as response and the following four layers as predictor variables: ranked aspect, slope, curvature and elevation. The first regression was linear (see Table 1). Then additional predictors were created by multiplication among the original predictors and use of power or log transformations. The objective of this was: 1) To find transformations that give a more linear relationship between the snow depth and the predictors. Blöschl (1999) commented the non-linearity as follows: "… probably all processes associated with the formation, redistribution and depletion of the snow pack are non-linear…". 2) to consider eventually occurring interaction between the predictors. The effect of interactions between predictors exists if the value for the slope coefficient for one predictor variable depends on the level of another predictor variable. It could for instance be the case that a certain aspect is more decisive for the snow depth at in pixels at high elevation compared to pixels at low elevation. This could be caused by wind impact, sublimation or other phenomena. Concerning dominant wind directions it is easy to imagine that for example terrain curvature is more relevant for snow depth in pixels that are located in wind exposed directions of aspect compared to pixels, which are located in the lee of a hill most of the time. Seyfried and Wilcox (1995) described a model which included the use of wind data. But wind was not incorporated in the presented regression model, thus the wind effect has to be considered indirectly in the equation. More detailed descriptions of wind impact and blowing snow modeling were for example given by Pomeroy and Gray (1995), Pomeroy and Li (1997), Pomeroy et al. (1997) and Liston and Sturm (1998).

Analyses of the best subset were used to eliminate needless predictors. Analyses of significance at the 5 % level were made for both regression equations and predictor variables. Insignificant variables were removed from the best subset models. The remaining subsets and the used transformations can be found in Table 2. Scatter plots of snow depth against the four original predictors were made to visualize their interrelation (Figure 2 and Figure 4 to 6). Pearson correlation coefficient was calculated as a measure of the linear correlation. To give visual a impression of the relation of snow depth and aspect (not ranked this time), snow depths inside each interval of 10 degrees of aspect were averaged and the results were plotted as rose diagrams (Figure 3).

RESULTS AND DISCUSSION

The main outputs from the analyses were regression equations and correlation coefficients. The correlation matrices showed low correlation between snow depth and terrain characteristics. Highest correlation was found between snow depth and elevation in 1999. The coefficient is 0.352 in forest and 0.389 in open field. Both are significant at the 5 % level. Other significant correlations were found between snow depth and ranked aspect in the forest as well as in open fields. However the correlation coefficients were low. All correlation coefficients are given in Figure 2, 4, 5 and 6. Many of the coefficients indicate no correlation. This means; either the relationship between snow depth and the terrain characteristics is not linear, or it does not exist at all at the 100 m grid cell level. Correlation is discussed further in the following sections. The best subset regression analyses of statistical models with the four predictors ranked aspect, slope, curvature and elevation showed that not all predictors were significant in all the models. The predictor curvature was not significant (5 % level) in the forest in both years. This result seems to be logical since the wind, which redistributes snow from terrain elevations to depressions, has only minor impact in the forest. Ranked aspect was not significant in open fields in 1999, whereas slope and curvature were not significant in open fields in 2000. These results does not show a certain systematic. It was expected that at least ranked aspect and curvature should be important for the snow depth. The problem to indicate this might lie in the relatively large grid size of 100 m. The insignificance of the predictor variable slope could be connected to the disability to measure the snow depth in really steep slopes, when using a snowmobile. The steepest slope measured was 23.6° (according to the 100 m DEM). Blöschl et al. (1991) used a model with constant relation between snow depth and slopes from 0 to 10 °s and a linear relation for slopes from 11 to 60°. Terrain with slopes over 60° was assumed to be snow free. This indicates that slopes in the range from 0 to 23°, which were analyzed in this study, were somewhere in the transition where the correlation starts. This could explain the low correlation coefficients. Additionally the micro scale variations at measured steeper slopes will disappear when averaging to the 100 m grid.

The linear regression equations resulting from the best subset analysis and after removing insignificant predictors are given in Table 1. All equations were significant at the 5 % level.

Table 1 Linear regression equations for snow depth (SD) with 4 predictors: ranked aspect (RA), slope (S), curvature (C), elevation (E)

$SD_{1999\ forest}$	=	-146.6 + 0.037 RA - 0.61 S + 0.2863 E	R^2_{adj} = 13.0 %
$SD_{1999\ open\ field}$	=	- 68.9 - 1.34 S - 21.9 C + 0.1899 E	R^2_{adj} = 15.6 %
$SD_{2000\ forest}$	=	-177.0 + 0.209 RA - 2.00 S + 0.3860 E	R^2_{adj} = 7.3 %
$SD_{2000\ open\ field}$	=	19.6 + 0.617 RA + 0.0807 E	R^2_{adj} = 5.3 %

The linear regression equations explained only some of the variations in the data set, nevertheless they were significant at the 5 % level. In 1999, the adjusted R^2 was 13.0 % in forest and 15.6 % in open field. In 2000, it was even lower with only 7.3 % in forest and 5.3 % in open field. Table 2 shows regression equations after transformation of some predictors and performing best subset analyses. Predictors that were not significant at the 5 % level were removed from the best subsets. All remaining equations were significant at the 5 % level.

Table 2 Non-linear regression equations for snow depth (SD) with some transformed predictors: ranked aspect (RA), slope (S), curvature (C), elevation (E)

$SD_{1999\ forest}$	=	$-78.5 - 8.68\ S + 2.6 \ln RA -7.1 \ln S + 0.0001780\ E^2 + 42.3\sqrt{S}$	R^2_{adj} = 15.4 %
$SD_{1999\ open\ field}$	=	$-214.2 + 11.281\ S + 0.272\ E - 0.042\ RA \times S - 0.014\ S \times E - 0.023\ C \times E +13.4 \ln RA + 2.5 \ln S$	R^2_{adj} = 20.1 %
$SD_{2000\ forest}$	=	$108.0 - 3.727\ RA + 81.11\ S - 0.345\ RA \times C + 0.004939\ RA \times E - 0.07457\ S \times E + 75.9 \ln S + 0.0002817\ E^2 - 178.8\sqrt{S}$	R^2_{adj} = 12.3 %
$SD_{2000\ open\ field}$	=	$36.3 + 20.93\ S + 0.1275\ E + 0.000974\ RA \times E - 0.02445\ S \times E - 54.3 \ln RA + 47.8 \ln S$	R^2_{adj} = 8.3 %

The transformation and combination of predictor variables improved the adjusted R^2 for 1999 to 15.4 % in forest and 20.1 % in open field. For 2000 it gave 12.3 % in forest and 8.3 % in open field, this means still a low explanation of the observed variations. This is a small improvement and the transformed equations explain still little of the variations in the snow depth. However, the change is significant. It indicates either that there is some interaction effect among the predictor variables which is considered by multiplying variables or it could be caused by better linearity between snow depth and the transformed variables.

Aspect

Among the first results were the dominant degrees of aspect (maximum correlation). For year 1999, the aspect with the highest correlation to snow depth is almost equal in forest (230 degrees) and in open field (231 degrees), i.e. roughly southwest. Even as the highest correlation, the correlation coefficient of 0.092 and 0.102 respectively, indicate a low correlation. The main wind direction during the winter 1998/1999 was south. In year 2000, the correlation is more significant. The coefficients were 0.165 in forest and 0.211 in open field. However, in this year there is a bigger difference between forest and open field, concerning aspect degree for maximum correlation. The highest correlation value was found at 158 degrees in the forest and at 177 degrees in open field, i.e. south-southeast and almost south. This result also fits well with field observations that showed massive snowdrifts (3 to 8 m) towards southeast and south. Strong winds from the northwest were dominating during snowfall in this winter. The prominent wind direction was south-southeast in 2000, but this wind direction does normally not bring much precipitation in the Aursunden region.

Figure 2 gives a graphical illustration for the relationship between snow depth and ranked aspect. Values for the Pearson correlation coefficient are included in the figure to describe the linear relationship between the two variables.

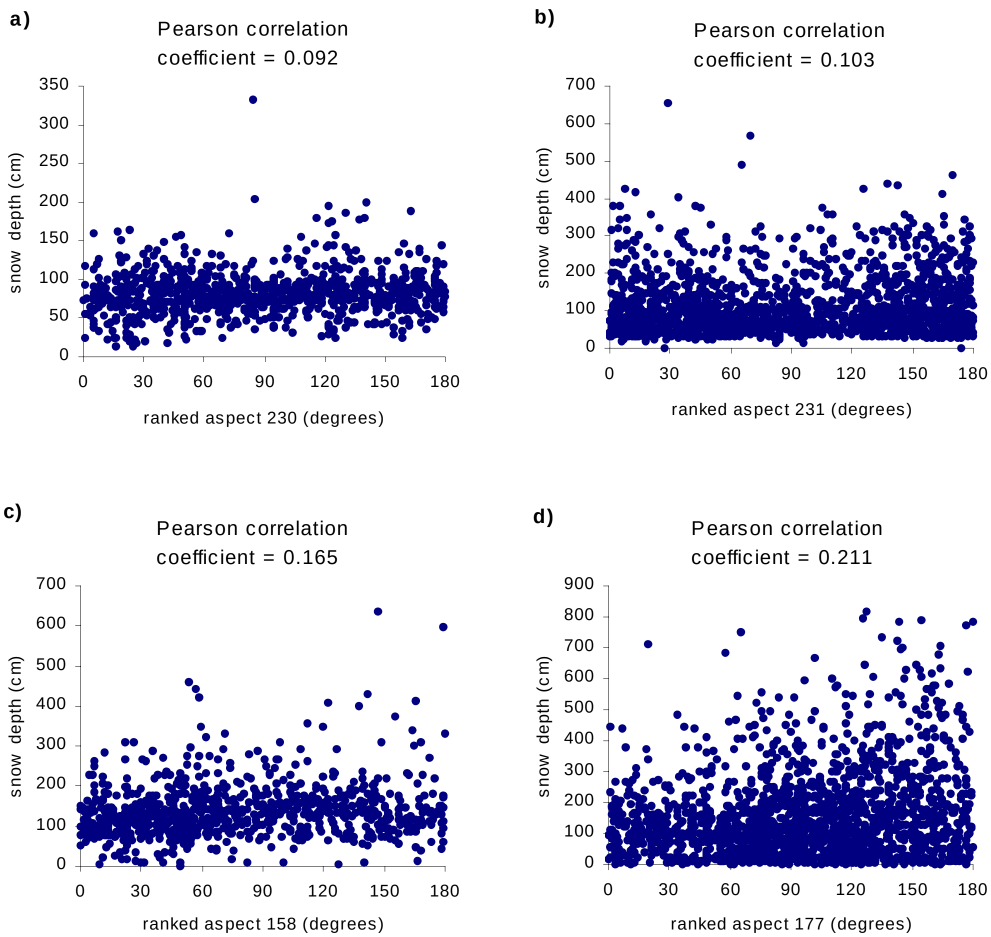

Figure 2 Relation of snow depth to ranked aspect; a) in forest, year 1999, b) in open field, year 1999, c) in forest, year 2000, d) in open field, year 2000

The scatter plots of snow depth against ranked aspect (Figure 2) show only small variations between the two years and the two terrain types. In all of the four plots, the relation could be characterized as close to linear. This is especially clear in the forest but less clear in the open field. In forest, the aspect seems to have little influence on snow depth since the slope of the trend line is almost flat. Nevertheless, the correlation coefficients of 0.092 and 0.165 with P-values of 0.006 and 0.000 respectively indicate a significant but far from strong linear relationship. In open fields, the slope of the trend line is steeper and correlation coefficients of 0.103 and 0.211 with significant P-values (0.000 for both) confirm the linear relationship.

Figure 3 illustrates the snow depth at different directions on the compass rose. Again, the two years as well as forest and open field were separated.

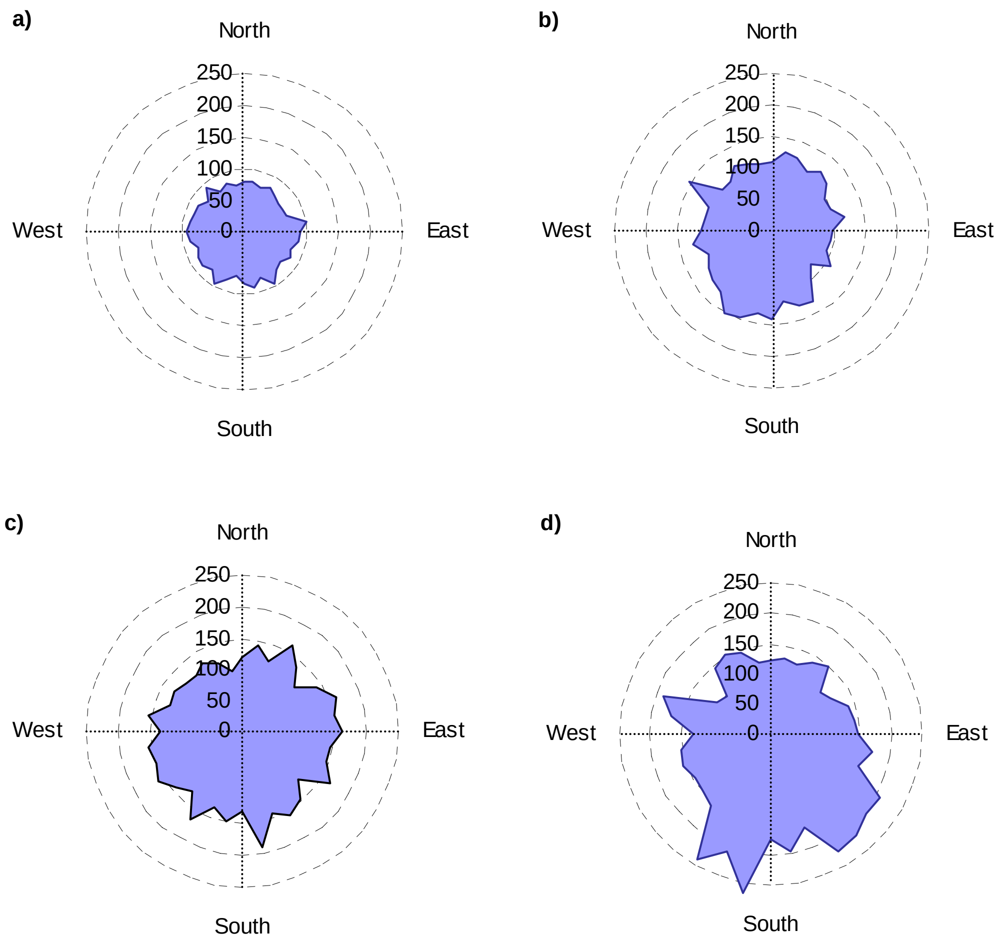

Figure 3 Snow depth (cm) at different directions of aspect (snow depths of all pixels inside intervals of 10 degrees of aspect were averaged); a) in forest, year 1999, b) in open field, year 1999, c) in forest, year 2000, d) in open field, year 2000

The rose diagrams in Figure 3 show different results for year 1999 and year 2000. In 1999 in forest, the snow depth was almost equally deep in all directions. In open field in the same year the snow pack was slightly deeper on the south slopes. The distribution in 2000 was more uneven. Both in forest and in open field was a clear tendency for deeper snow towards east and southeast slopes. This was most pronounced in the open field.

Slope

The variation in snow depth with slope is illustrated in Figure 4. Values for the Pearson correlation coefficient are included in the figure to describe the linear relationship between the two variables.

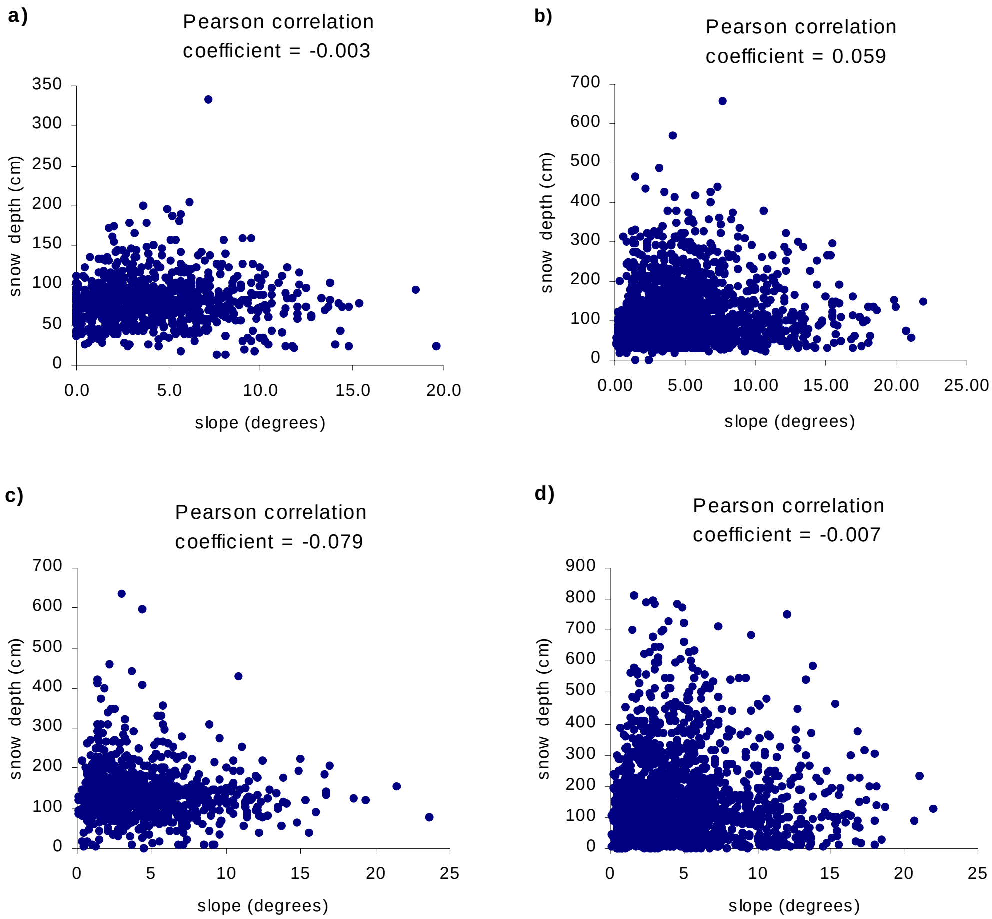

Figure 4 Relation of snow depth to slope; a) in forest, year 1999, b) in open field, year 1999, c) in forest, year 2000, d) in open field, year 2000

The scatter plots of snow depth against slope (Figure 4) show little linearity. This may explain the small values of the correlation coefficients. For the forest in 1999 and for the open fields in 2000 there were no significant correlations, whereas in 1999 in open field and 2000 in forest the correlation was significant, but low.

Curvature

The main results concerning the terrain parameter curvature are illustration in Figure 5. Values for the Pearson correlation coefficient are included in the figure to describe the linear relationship between the two variables.

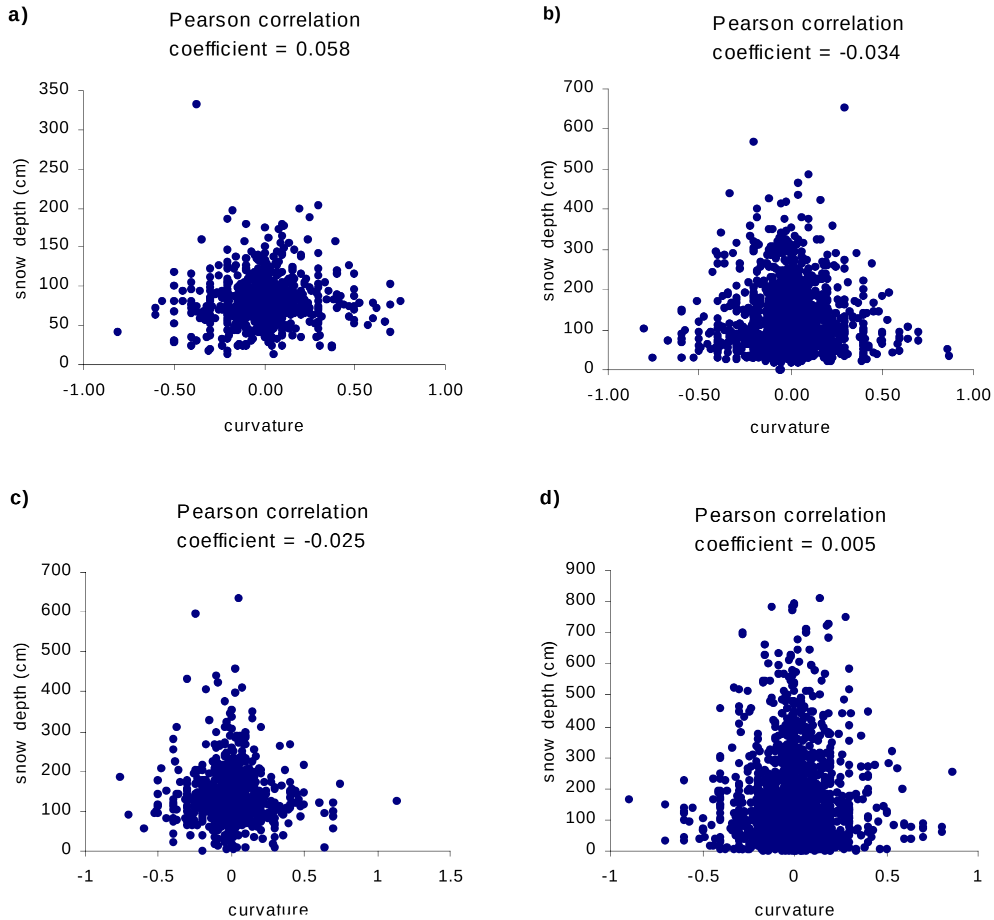

Figure 5 Relation of snow depth to curvature; a) in forest, year 1999, b) in open field, year 1999, c) in forest, year 2000, d) in open field, year 2000

The plots of snow depth against curvature (Figure 5) indicate deep snow packs mainly in flat terrain (values close to zero). The plots do not indicate a big difference in snow depth between concave and convex terrain. This is similar in all of the four plots. Correlation coefficients are low (-0.034 to 0.058).

Elevation

The relationship between snow depth and elevation is shown in Figure 6. Values for the Pearson correlation coefficient are included in the figure to describe the linear relationship between the two variables.

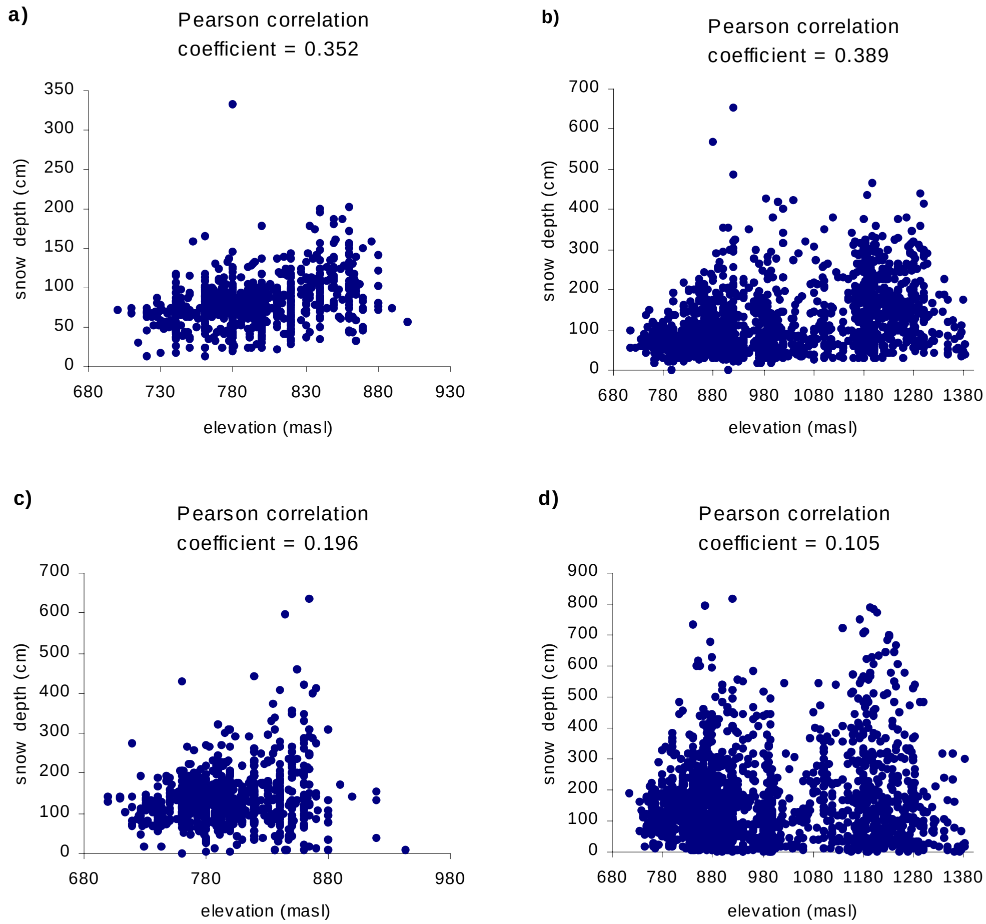

Figure 6 Relation of snow depth to elevation; a) in forest, year 1999, b) in open field, year 1999, c) in forest, year 2000, d) in open field, year 2000

The scatter plots for snow depth against elevation (Figure 6) was described as linear with a positive slope, i.e. snow depth is increasing at higher elevations. This also conforms to the commonly used rule of increasing precipitation at increasing elevations. The linearity was clearer in the forest than in open field. Correlation coefficients are varying between 0.105 and 0.389, these values are much higher than the ones from the other terrain parameters. This result also agrees with findings in previous studies, e.g. Forsythe (1997).

CONCLUSION

The performed data analyses on the 100 m grid scale did not indicate any strong correlation or regression between the snow depth and four terrain parameters (aspect, slope, curvature and elevation) in the two terrain types forest and open field. The highest correlation was found for elevation. In addition, ranked aspect had significant correlation both in 1999 and 2000 in both terrain types.

Even if the correlation is weak and the degree of explanation of the regression equation is low, both are still significant. However, it would not be very satisfying to predict the snow depth in pixels without measurements with such a low degree of explanation. One possibility for further improvements would be similar analyses with a different grid size as smaller pixels could lead to a better correlation. The problem for doing so is the limited availability of high resolution DEMs in Norway, especially for rural regions. Thus the 100 m grid is at present the most realistic alternative for operational use in hydrological models. This is of course incongruent with the fact that model and measurement grid should be consistent with the nature of the response variability (Seyfried and Wilcox, 1995). Concerning snow, a high variability is found already far below the distance of 100 m. On the other hand it could be a possibility to increase the grid cell size with the objective of finding a minimum grid cell size at which the snow depth is independent from the terrain parameters, or at least only depends on one or two. This was apparently already partly the case at the 100 m grid cell level since correlation was very low as well as the degree of explanation by the regression equations. Recently Cline et al. (1998), Woo (1998) and Blöschl (1999) assessed the issue of scaling in snow hydrology. When increasing the distribution of snow depth inside a terrain independent pixel could be expressed by a statistical probability distribution function. It is the challenge for further investigations to find proper functions. Examples for this approach were for instance found in Killingtveit and Sand (1990), Donald et al. (1995), Liston (1999), Luce et al. (1999) and Marchand and Killingtveit (1999).

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