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Avalanches in the context of climate change in the northern regions

Lawinen und Klimawandel in Norwegen

Abstract:
Avalanches have caused more than 1500 deaths the past 150 years in Norway. Development in rural areas make us more vulnerable to geohazards. Climatic warming with increased frequency and strength of extreme weather events in the next 50 to 100 years may lead to an increase in the frequency of geohazard events. The snow avalanche hazard may decrease in near coastal regions due to increased elevation of the snow and tree line and a shortening of the snow season with less snow. In the coastal high mountain range and in the mountains of northern Norway, these effects have less importance. This will demand careful investigations of avalanche experts to avoid the use of avalanche-endangered areas.

Keywords: Avalanche, climatic change, Norway

Zusammenfassung:
In den letzten 150 Jahren wurden in Norwegen mehr als 1500 Lawinentote verzeichnet. Die Siedlungsentwicklungen im ländlichen Raum führen zu einer höheren Vulnerabilität gegenüber Naturgefahren. Die Zunahme von extremen Wetterereignissen in Frequenz und Stärke bedingt durch die Klimaerwärmung in den nächsten 50 – 100 Jahren, kann auch einen Anstieg der Häufigkeit von Naturgefahren bedeuten. Lawinengefährdungen werden in Küstenregionen aufgrund eines Anstiegs der Schneefallgrenze und der Waldgrenze und kürzerer Winter mit weniger Schnee, wahrscheinlich abnehmen. Im küstennahen Hochgebirge und in den nördlichen Bergregionen haben diese Effekte weniger Einfluss auf Lawinen. Um lawinengefährdete Gebiete zukünftig zu meiden, braucht es sorgfältige wissenschaftliche Untersuchungen von Experten und Expertinnen zum Thema Klimawandel und Lawinen.

Stichwörter: Lawinen, Klimawandel, Norwegen

Introduction

Climatic changes and related effects on avalanche activity is of great importance to people living in the mountainous districts of Norway. The current and future climate changes in Norway are described by several research projects, such as the "Klima 2100" report from the Norwegian Meteorological Institute (Hanssen-Bauer et al. 2015) and the research projects Geoextreme (Jaedicke et al., 2008) and InfraRisk (NGI 2009). These all show that changes in the climate are already present and are likely to increase by the end of the century. The weather is getting more unstable. We observe a general increase in precipitation amounts and intensity, shorter winter seasons and warmer winter temperatures. As a result, we also see a general rise of the tree line. We expect the climatic changes to reduce the number of avalanche situations, in particular along the coast and lower regions. In the coastal high mountain range, the avalanche activity may decline to a lesser degree. However, the projected climate changes in the complex topography in Norway may result in more variation than what the general picture shows. This article will not dispute the climatic scenarios; it will rather try to indicate some of the consequences related to avalanche activity that we must face in the years to come.

Avalanches in Norway

The *Geoextreme* project (Jaedicke et al., 2008) discussed avalanche activity related to a combination of different climatic parameters, which showed varying importance in different parts of Norway. The project aimed to find the key controls of avalanche activity. For snow avalanches, the picture varied through Norway. The major findings indicated the precipitation to be the most important single factor in the south of Norway and the wind to be the most important single factor in the north of Norway.

Changes in temperature

Temperature deviations from the reference period 1971–2000 in Norway from 1900 until 2014 (Figure 1) show a positive trend indicating generally warmer winters. The average global annual mean temperature in 2016 was approximately 1 °C above the 1951–80 average. The increase was highest towards the northern regions, with an anomaly of 22 °C in northern Norway (NOAA/NASA 2017). By this, 2016 turned out to be the warmest year on the NASA GISTEMP record, with significantly high temperature anomalies in the Arctic.

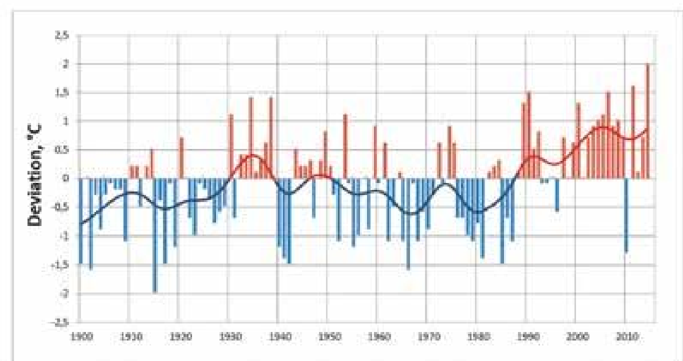

Fig. 1:
Annual temperature for Norway (1900–2014). The figure shows deviations in temperature (°C) from the average over the reference period 1971–2000 (Klima 2100, NCCS–report no 2/2015).

Abb. 1:
Jährliche Temperaturen für Norwegen (1900–2014). Das Diagramm zeigt die jährlichen Abweichungen (in °C) zum Mittelwert der Referenzperiode 1971–2000.

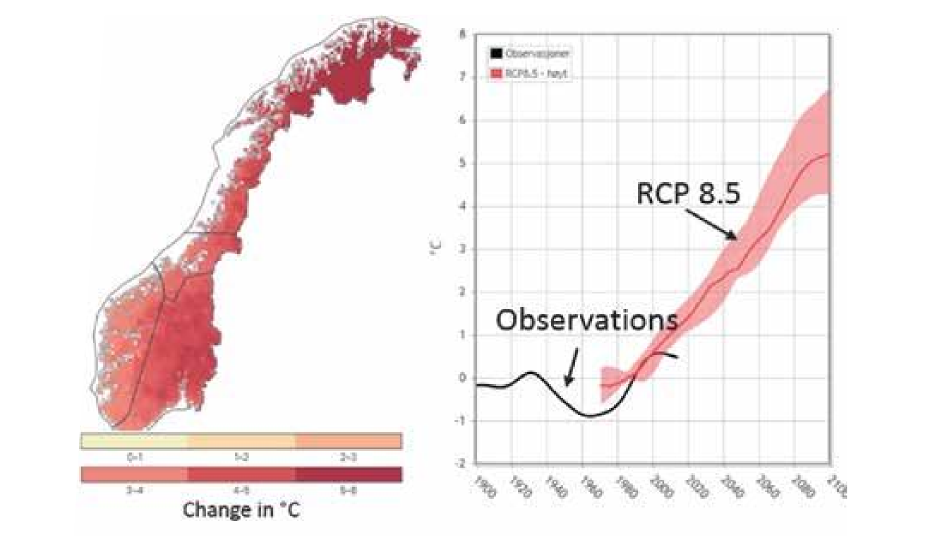

Fig. 2: Increase in winter temperature for the RCP 8.5 scenario.

Abb. 2: Zunahme der Temperaturen im Winter für das Szenario RCP 8.5.

The four Representative Concentration Pathways (RCPs) describe different possible climate futures in the year 2100 depending on the increase in radiative forcing due to greenhouse gas release to the atmosphere. RCP 8.5 is closest to the observed increase in CO_2, and indicates a 4–6 °C temperature increase by the end of the century (Figure 2).

Increases in temperature lead to a weakening of the polar vortex and an increase in the Rossby wave pattern with a slower eastward progression. A pattern with lower atmospheric pressure over the Arctic leads to stronger westerly winds in the upper atmosphere at northern latitudes (Francis and Vavrus, 2012).

For Norway, this may result in longer periods with cold or mild weather. This also implies that even if the climate gets warmer, long cold winter periods may still occur prior to situations with heavy snow precipitation. This may still cause classic avalanche situations for regional areas along the coast of Norway.

The monthly temperatures during winter in the period 1951–2015 for the western part of south Norway clearly show a warming climate. During the last 15 years there were only two "cold" winters having average monthly temperatures below 0 °C for 4–5 consecutive months. In comparison, for the whole period there was on average 3–5 years between every "cold" winter.

Three major avalanche events occurred in this period (Figure 3). The first in 1968 in Sæbø (Feb 19th), the second in 1979 in Ørsta (Feb 11th) and the third in 1993 in Odda (Jan 17th). Common for all these three situations was a cold early winter from October until the avalanche occurred. Due to a thin snow cover in the mountains during the cold early winter a weak layer with depth hoar developed near the ground. Heavy snowfall, strong winds and, for the Odda event mild weather, lead directly to the avalanche situations.

Fig. 3: Photos from three major avalanche situations in Norway. a) Sæbø (1968, photo Aftenposten), b) Ørsta (1979, photo Karstein Lied) and c) Odda (1993, photo Eirik Brekke).

Abb. 3: Fotographien großer Lawinenereignisse in Norwegen. a) Sæbø (1968, Foto Aftenposten), b) Ørsta (1979, Foto Karstein Lied) and c) Odda (1993, Foto Eirik Brekke).

Changes in precipitation

The largest changes in precipitation by the end of the century will occur in autumn and winter. The winter precipitation for Norway is expected to increase by on average 17 % (RCP8.5), varying from 3 % to 26 % over Norway.

The climate projections show increases in both intensity and frequency of heavy precipitation events in all of Norway (Figure 4). «Heavy precipitation» is defined as daily precipitation exceeded approximately every second year in the period 1971–2000. The overall increase in frequency of heavy precipitation events during winter is predicted to be 143 % by the end of the century (RCP8.5; Figure 4, left), with largest increase in northern Norway. The relative change in precipitation intensity averaged for the whole country is between 12 % and 19 % for the 2 scenarios (Figure 4, right). The increase is predicted for the entire year in all regions, but with highest values during the summer season.

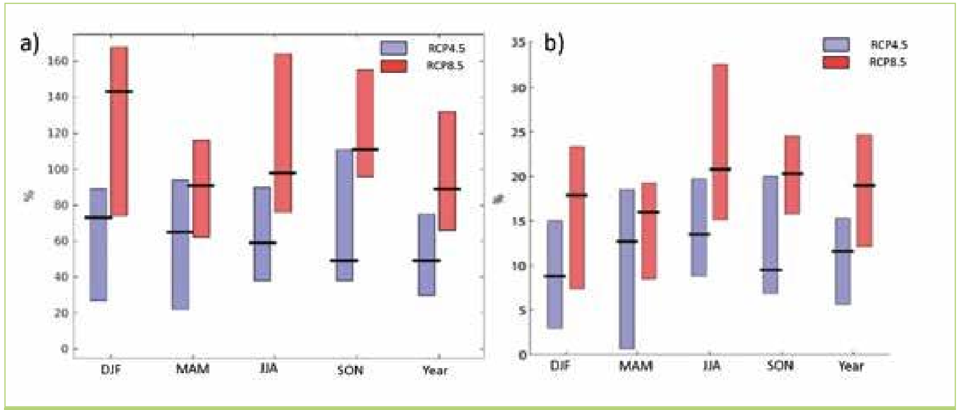

Fig. 4: Relative change (%) in the number of days with heavy precipitation (left) and intensity (right) from the 1971–2000 period to the 2071–2100 period for the scenarios RCP4.5 and RCP8.5. Median value (black line). Seasonal and annual values.

Abb. 4: Relative Änderungen (in %) der Tagesanzahl mit Starkniederschlägen (links) und der Niederschlagsintensität (rechts) zwischen den Zeiträumen 1971 – 2000 und 2071 – 2100 für die Szenarien RCP4.5 und RCP8.5. Die schwarzen Balken stellen den Median dar.

Forest growth and the effect on avalanche activity

Dense forest has a protective effect against avalanche release (Olschewski et al., 2012; Bebi et al., 2001). This is caused directly by the trees supporting the snow pack and reducing the formation of weak layers that may cause slab avalanches (Gubler and Rychetnik, 1991).

Forest can affect avalanches by reducing the velocity and runout lengths in the valley below, primarily when the forest covers the mountainside all the way up to the avalanche release area. In these cases, the avalanche has not yet reached a high velocity or a terminal velocity when it passes through the forest, and the forest may have some effect. When avalanches reach terminal velocity, experience shows that the forest below will have little or no effect, and the avalanches may clear away even fully-grown forests. This is demonstrated by several examples of previous avalanche incidents (Figure 5). Forests may stop small to medium size avalanches after they have cleared several hundred meters of fully-grown forest. However, there is limited knowledge on the effect of forest after the avalanche has been triggered (Anderson and McClung, 2012).

Increases in growth season and higher annual temperatures (+ 4 – 6 °C) will raise the upper elevation limit for potential forest growth by approximately 400 – 500 m compared to today (assuming a lapse rate of approximately 1 °C/100 m). As a result, also many of the lower areas close to the coast may become covered by forest (Figure 6). The higher parts of the coastal mountain range will still be above the tree line in the future (Figure 7). Most of the eastern parts of southern Norway will have potential for forest growth, with the exception of isolated mountain areas, such as the Rondane mountain massif.

The increased forest growth in the coastal areas will reduce the number of potential release areas for snow avalanches. However, in some parts of the mountains we do not expect forest growth, even though the climatic conditions are sufficient:

- In steep release areas with bare rock faces.
- Avalanche tracks where frequent avalanches occur will keep the forest away unless the frequency decreases to less than 30 – 50 year return period.
- Wind exposed areas will keep the forest away, amplified by the projected increase in intensity and frequency of strong winds.

In addition, forest diseases, cutting and fires may alter the situation rapidly.

Fig. 5: Pictures show the 1995 Drevja avalanche that took out the forest also along the flat valley bottom.

Abb. 5: Bilder der Drevja Lavine 1995 mit Zerstörungen der Waldflächen bis hinab auf den flachen Talboden.

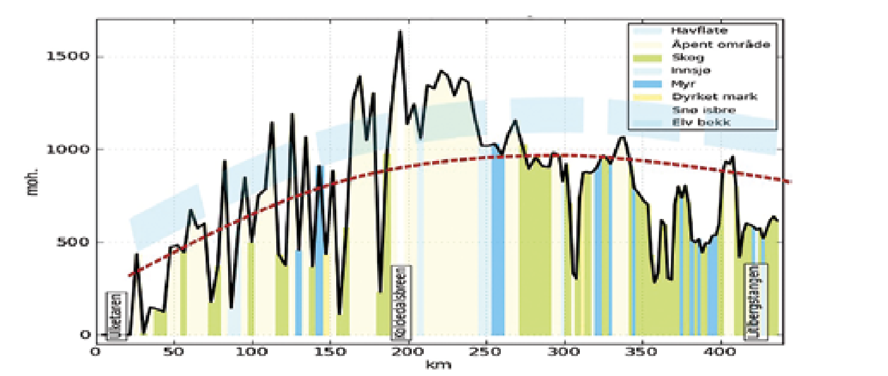

Fig. 6: West to East cross section in southern Norway (north of Bergen). Black line represents topography, red dotted line represents today's tree line, and blue dotted line represents the possible tree line in 100 years. Source: Norwegian Mapping Authority.

Abb. 6: Profillinie Südnorwegen (nördlich von Bergen) von West nach Ost. Die schwarze Line stellt das Gelände dar, die gestrichelte Linie die heutige Baumgrenze und die dicke blau gestrichelte Linie die mögliche Baumgrenze in 100 Jahren.

Fig. 7: The coastal mountain range. The forest may reach the avalanche release areas seen on the left part of the photo, but not to the right where the mountains are steep with bare rock faces.

Abb. 7: Küstengebirgsregion. Der Wald könnte bis zu den Lawinenanbruchgebieten in der linken Seite des Bildes hinaufreichen. Dies ist für den steilen, kahlen Gebirgsteil auf der rechten Bildseite nicht möglich.

Shorter winters and less snow – fewer avalanche situations?

The projected rise in annual temperatures combined with changes in precipitation will highly affect the snow cover, but with large variations over Norway. In many areas the increasing temperatures will result in reduced snow amounts, shortened winter seasons and a rise of the snow line. In the coastal areas, winters may become entirely snow free, or have only discontinuous snow cover during the winter months.

On average, large parts of Norway were covered by snow half of the year over the period 1971 – 2000, typically from November to May/June. The length of the snow-covered period will be reduced dramatically, particularly along the coast (Figure 8). This is mainly due to the general temperature increase, but is also related to warmer sea currents. The report *„Klima 2100"* (Hanssen-Bauer et al. 2015) shows that coastal areas with less than 100 days of snow cover today may see a reductions of between 50 to 100 days. With the RCP 8.5 scenario, large areas along the west coast may remain snow free all year in the future. Other

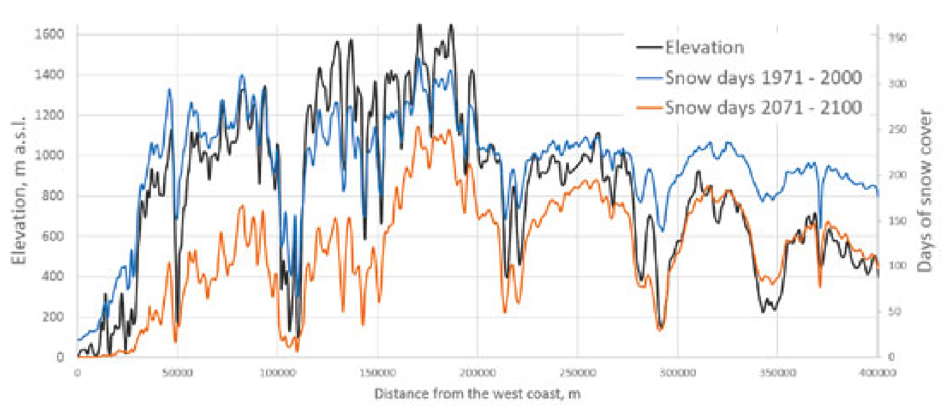

Fig. 8: West to East cross section in southern Norway. Number of snow days with snow cover in the reference period 1971 – 2000 and estimated for the 2071 – 2100 period.

Abb. 8: Profillinie durch Südnorwegen von West nach Ost. Anzahl der Schneetage mit Schneebedeckung für die Referenzperiode 1971 – 2000 sowie die Schätzung für die Jahre 2071 – 2100.

areas will have a snow season lasting only half the number of days compared to today, and large areas on the west coast will have less than three weeks of snow. The high mountain areas further east and away from the coast may still have similar number of snow covered days as today. In general, the reduced amounts of snow will significantly shorten the snow season in large parts of Norway, to a high degree in populated areas.

There has been an increase in the annual maximum snow depths in the high mountain and eastern parts of southern Norway, along with a decline along the coast and lowland during the last 50-year period (Figure 9, Dyrrdal et al., 2012). For the high mountains in southern Norway, observations show a 23 % increase in maximum snow depths.

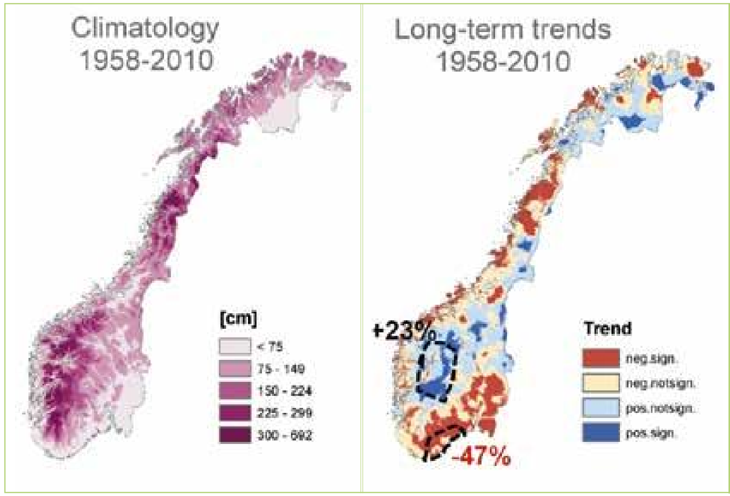

Fig. 9:
Maximum snow depths in Norway over the period 1958 – 2010 (left) with trends (right) (Dyrrdal et al, 2012).

Abb. 9:
Maximale Schneehöhen in Norwegen im Zeitraum 1958 – 2010 (links) und relativer Trend (rechts).

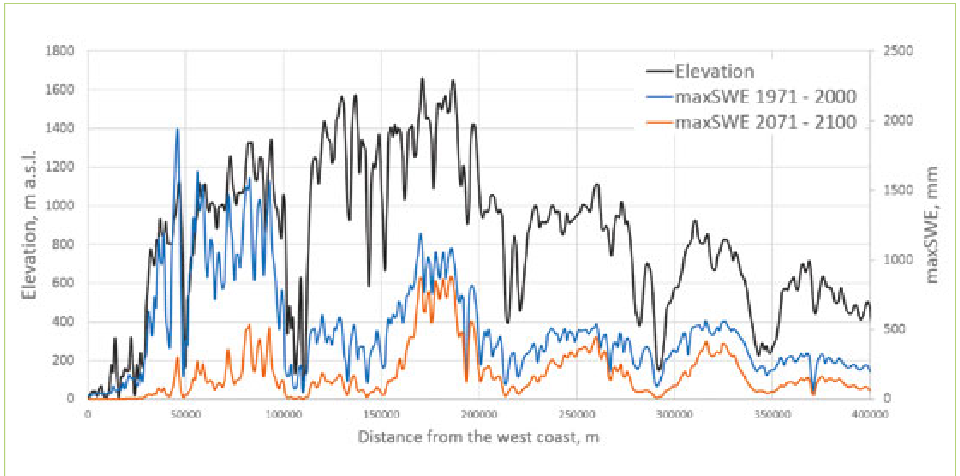

Fig. 10: West to east cross-section in southern Norway (black line). Annual maximum snow amount (SWE, mm) during winter in the normal period 1971 – 2000 and scenario for the 2071 – 2100 period.

Abb. 10: Profillinie Südnorwegen von West nach Ost (schwarze Linie). Jährliche maximale Schneehöhen im Winter für den Zeitraum 1971 – 2000 (blau) und für das Szenario für die Jahre 2071 – 2100 (orange).

The climatic change with a high temperature increase may give a large reduction in snow amount along the coast of Norway, while in other areas the increased precipitation amounts will even out the effect of the temperature increase. Figure 10 shows a cross section in southern Norway, where the most significant reduction is predicted for the west coast and in the western mountain range. The high mountain areas further east and away from the coast may still receive similar snow amounts as today.

The reduced snow amounts indicate a reduction of avalanche situations during winter. The effect is most pronounced along the coast and the coastal mountain range, and less in the high mountains further east. On the west coast some areas will not receive snow in the future, and thus not be at risk for snow avalanches. In high mountain areas above the 0 °C-isotherm we may experience a higher possibility for avalanche activity in the future, due to larger snow depths and more intense snow fall events.

Consequences

Based on the climate projections for the scenarios RCP 4.5 and RCP 8.5 for Norway, we expect shorter winters with less snow and higher temperatures towards the end of the century. Strong winds may occur more often and increase in intensity. Mild weather with rain will occur more often during the winter.

This may reduce the potential for avalanches in many areas, with some areas being out of risk due to absence of snow. Dry snow avalanches may occur more seldom and primarily in mid winter (December – February) due to lower snow heights and a warmer snowpack.

However, the projected increase in strong wind intensity along with increase in precipitation intensity may still create major avalanche situations. Additionally, the high mountain areas where there is a projected increase in snow amounts may experience increased rather than reduced avalanche danger. We may also experience an increase in wet snow avalanches and slush flow activity. Roads close to mountainsides and hydroelectric power lines may be more exposed due to increase in these natural hazards. Work on mountain facilities in avalanche-endangered terrain (with hazard warning) will have to shut down more frequent due to two different weather types:

- More often mild weather situations in winter months causing wet avalanches
- More frequent situations during midwinter with strong winds causing dry avalanche situations

An example of this was seen in 2015, when NGI conducted avalanche hazard warning for an entrepreneur working on the Styggevassdammen facility. A north-facing mountainside produced numerous wet snow avalanche situations during the winter and continued doing so until early summer (Figure 11). The amount of wet avalanche activity was much higher than expected for this area, and caused challenges for the entrepreneur work.

Fig. 11: Wet avalanche in Sprongdalen, Styggevassdammen 16th June 2015.

Abb. 11: Nassschneelawine in Sprongdalen, Styggevassdammen am 16. Juni 2015.

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