Technical Note

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Spatio-temporal distribution of extreme weather events and natural hazards (snow avalanches and rockfalls) in Norway

Contents

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1 Background

The InfraRisk project is concerned with the impacts of extreme weather events (EWE) on the Norwegian transport infrastructure. Natural hazards triggered by EWE's are thereby of central concern. Transport routes running through or along steep terrain are frequently affected by natural hazards, predominantly by snow avalanches, rock falls, and debris flows.

The trigger mechanisms of these processes are not fully understood yet. It is generally assumed that the release of snow avalanches and rock falls is related to certain (extreme) weather events. The relation between snow avalanches and precipitation during winter is, to a certain extent, straight forward. The relation between individual climatic variables and rock falls is less obvious and strongly influenced by other relevant factors such as continuous weathering, freeze-thaw events and geological preconditions.

The present note reports about the analysis of how the distribution of rock falls and snow avalanches (stored in the national slide database, skrednett.no) is related to the spatio-temporal distribution of precipitation events and freeze-thaw events (as registered at meteorological stations).

2 Methods

The number of precipitation events with a magnitude of (a) more than 25 mm/day, and (b) more than 50 mm/day, and the number of freeze-thaw events documented at selected Norwegian meteorological stations were counted for each month in the period 1970-2008. As the meteorological stations differ regarding the parameters they record, two different sets of stations were used for the precipitation events and the freeze-thaw events. For the frequency analysis of the precipitation events 479 stations were available while for the freeze-thaw events only 112 stations could be used. Both sets were more or less uniformly distributed over Norway. Accordingly, the spatial resolution of the former parameter is higher than for the latter parameter. The monthly frequency of the precipitation and freeze-thaw events was related to the monthly frequency of documented rock fall and snow avalanche events. A number of 12 023 rock falls and 8 139 snow avalanches were available from the Norwegian slide database skrednett.no[1].

[1] http://www.skrednett.no/

3 Results

The average number of rock falls and snow avalanches per month is calculated from the available slide data and plotted against the average number of the defined weather events. Figure 1 shows the temporal distribution of rock falls over a year in relation to the monthly average frequency of precipitation events of more than 25 mm and of more than 50 mm. It becomes apparent that the months with higher precipitation event frequencies (peak in September to December) do not match the months with higher rock fall frequencies (peak in January to April). While the average number of events with more than 50 mm precipitation does not vary over the year, the number of events of more than 25 mm precipitation is highest in autumn and early winter (September-December).

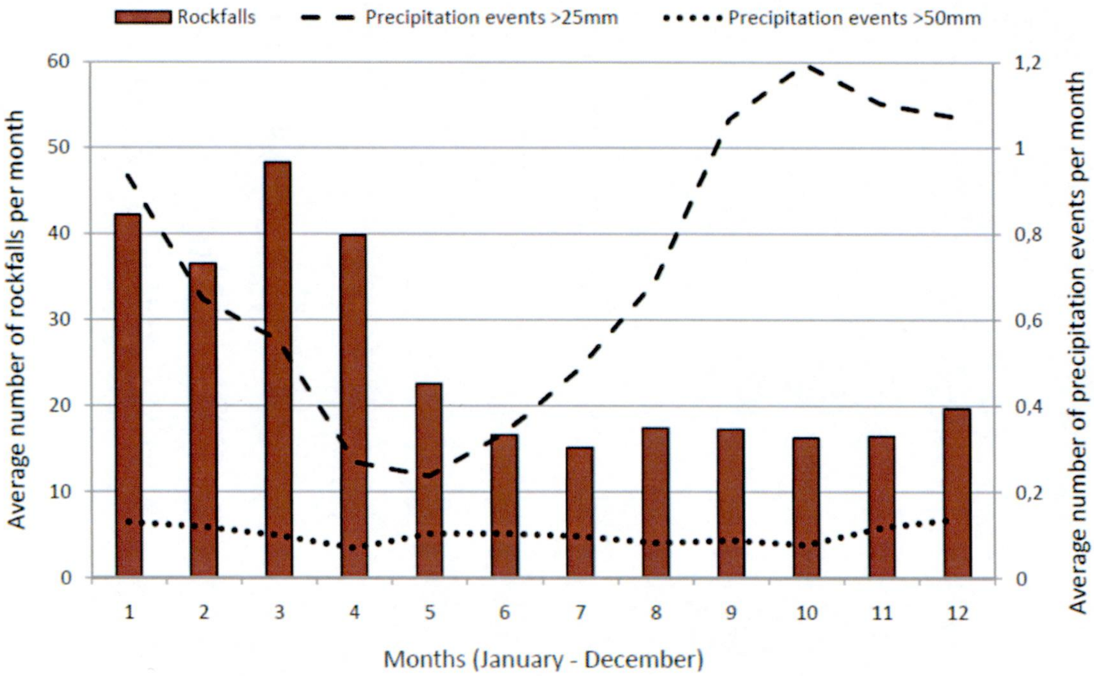

Figure 1: Average number of precipitation events per month related to the average number of rock falls for the period 1970-2008.

The temporal relationship of snow events of more than 25 mm and more than 50 mm is presented in Figure 2. Since snow avalanches are per definition associated with the presence of snow, the two variables show a clear dependency. Most of Norway is snow-free during the summer months. Therefore, no snow avalanches occur during that time. However, during winter and spring a time delay of one month is observable between the peak frequency of snow events >25 mm (December-February) and the peak in snow avalanche frequency (January-March).

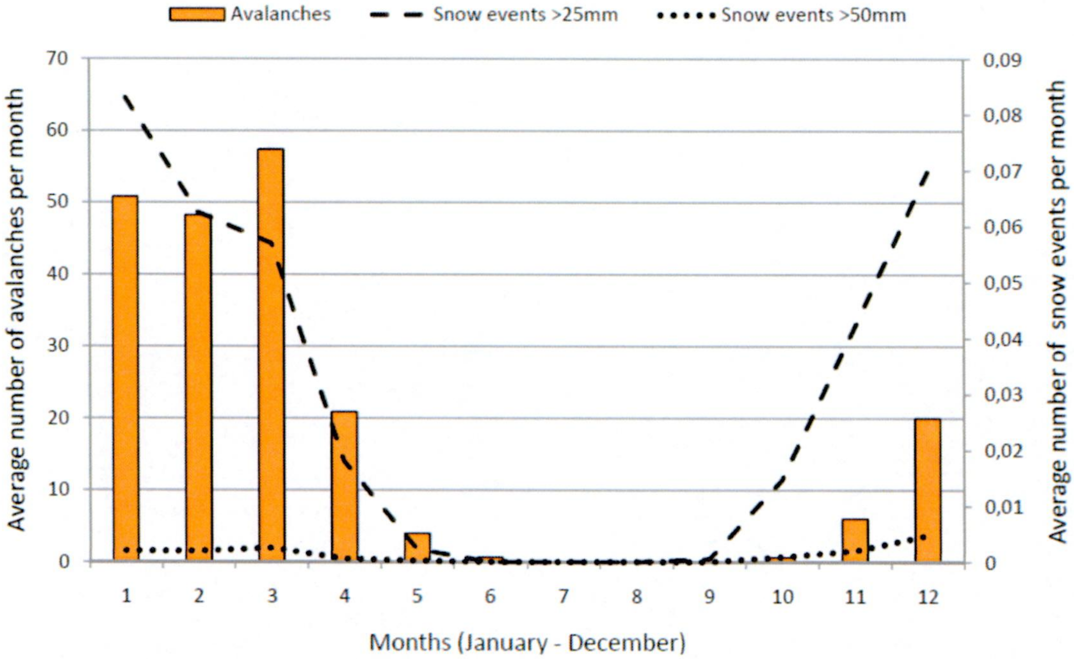

Figure 2: Average number of snow events per month related to the average number of snow avalanches for the period 1970-2008.

Figure 3 shows the temporal pattern of both rock falls and snow avalanches in relation to the frequency distribution of freeze-thaw events. In winter and spring (January-April) a higher average number of rock falls and snow avalanches coincide with a high frequency of freeze-thaw events. In autumn and early winter (October-December), however, this pattern is inexistent. While the frequency of freeze-thaw events is high, no enhanced rock fall and snow avalanche activity is observable.

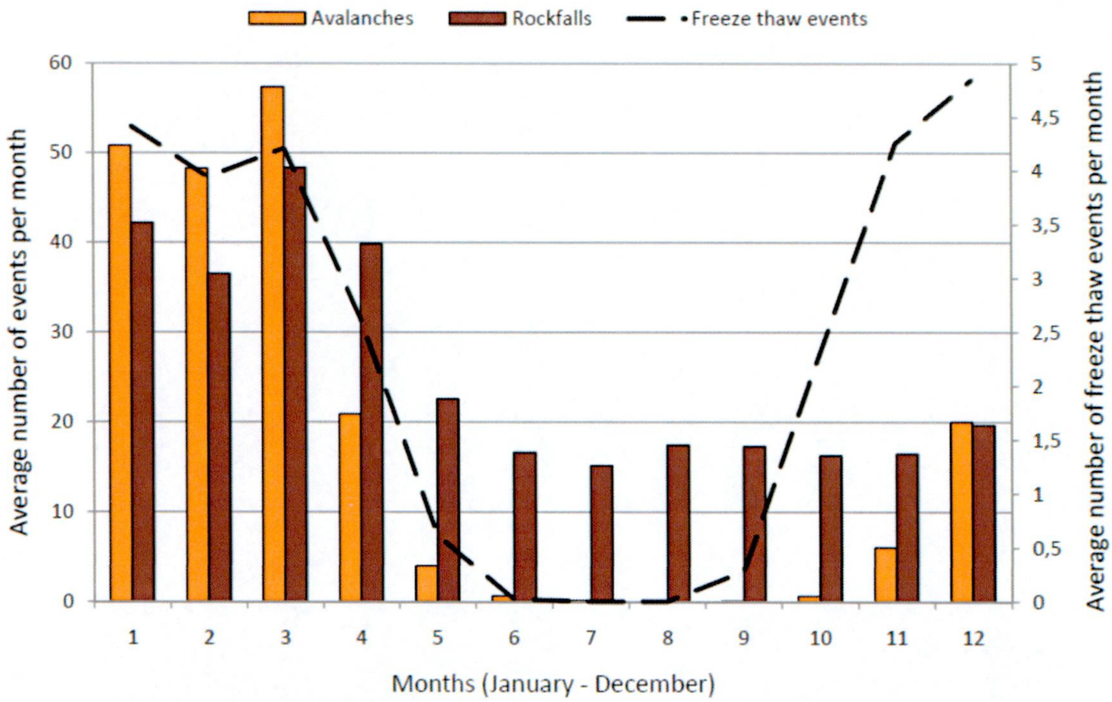

Figure 3: Average number of freeze-thaw events per month related to the average number of rock falls and snow avalanches for the period 1970-2008.

In a second analysis each location of a documented rock fall or snow avalanche was linked to the next meteorological station by using a Thiessen polygon interpolation (i.e., a station accounts for all those hazard locations that are closer to this station than to any other station). Figure 4 shows the spatial distribution of the rock fall events in relation to the recorded average annual frequency of precipitation events with more than 25 mm for each meteorological station (represented by Thiessen polygons). The rock fall frequency is generally higher in areas with a high precipitation event frequency. However, almost all of the areas with a high precipitation event frequency are also characterized by steep topography. The relation is, therefore, more complex.

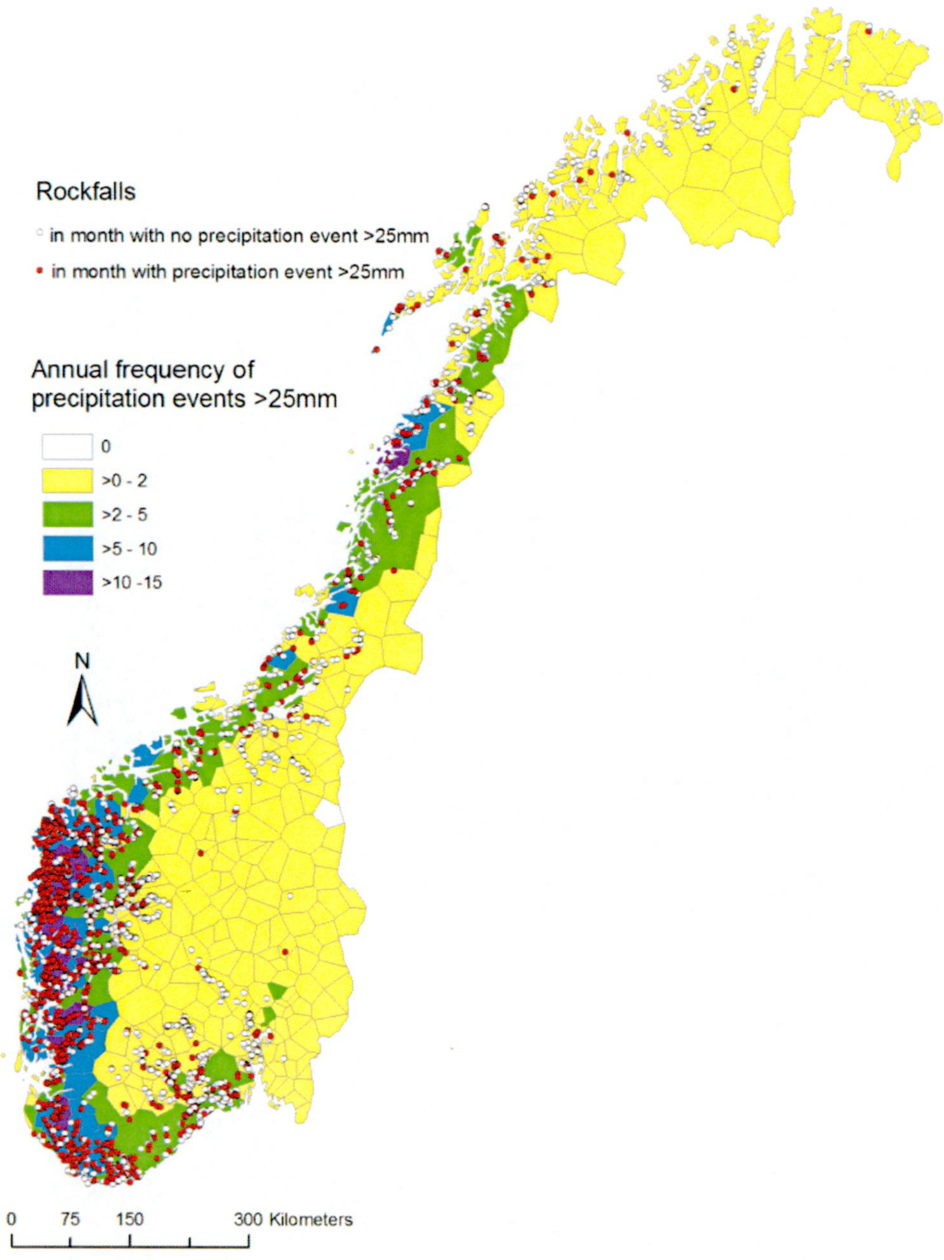

Figure 4: Spatial distribution of recorded rock falls related to the annual average frequency of precipitation events >25 mm at various meteorological stations, represented by the according Thiessen polygons.

In addition to the spatial joining of meteorological station and rock fall and snow avalanche events, a temporal join was conducted. This was done by cross-correlating the actual month when a rock fall or snow avalanche had occurred with the spatially correspondent information regarding the frequency of precipitation events or freeze-thaw events in the same month. Figure 5 shows the relative frequency of precipitation events in months with rock falls compared to the relative frequency of precipitation events without rock falls. The ratio presented in the upper part indicates that months with rock fall occurrences show generally a tendency to a disproportionately high frequency of precipitation events.

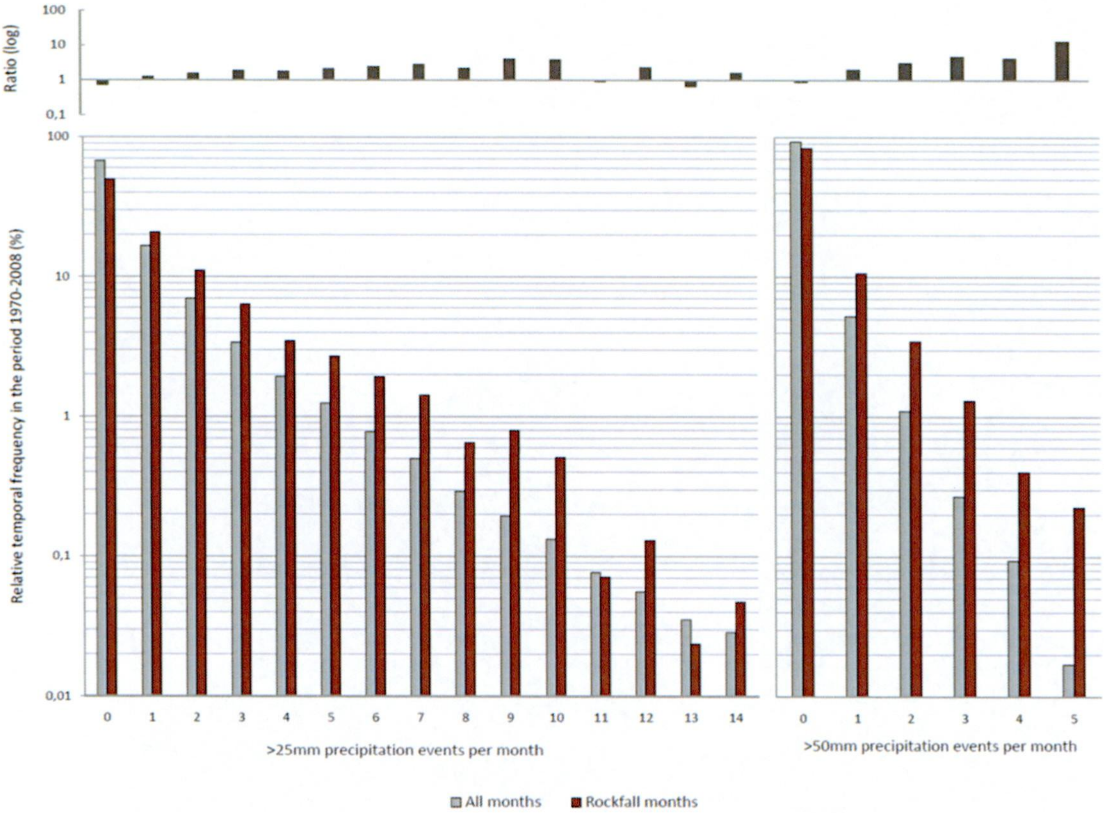

Figure 5: Temporal cross-correlation of months with rock fall occurrence to the corresponding frequency of precipitation events >25 mm (left) and >50 mm (right) in the same month. The ratio in the upper part of the figure indicates whether or not months with rock fall occurrences show a tendency to a disproportionately high frequency of precipitation events.

The spatial join of snow avalanche events and snow events with more than 25 mm is represented in Figure 6. The locations of snow avalanches along the west coast of Norway correspond quite well with a higher frequency of snow events recorded by the meteorological stations. The snow avalanche locations in the northern part of the country are generally characterized by a lower number of snow events per year.

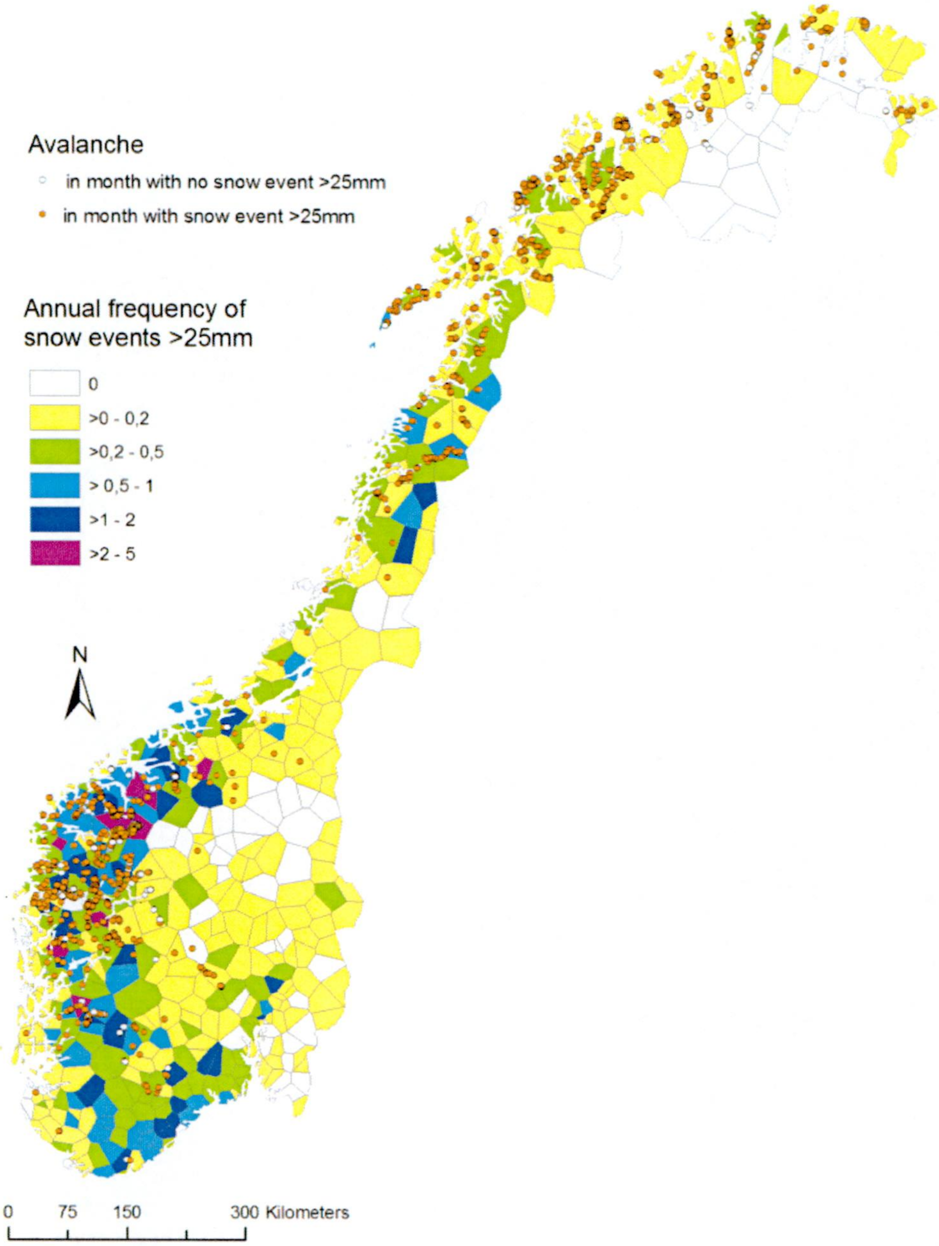

Figure 6: Spatial distribution of recorded snow avalanches related to the annual average frequency of snow events >25 mm at various meteorological stations, represented by the according Thiessen polygons.

The temporal correlation between months with snow avalanches and the corresponding number of snow events in that month reveals, however, that snow avalanche months are strongly related to months with a higher frequency of snow events (Figure 7).

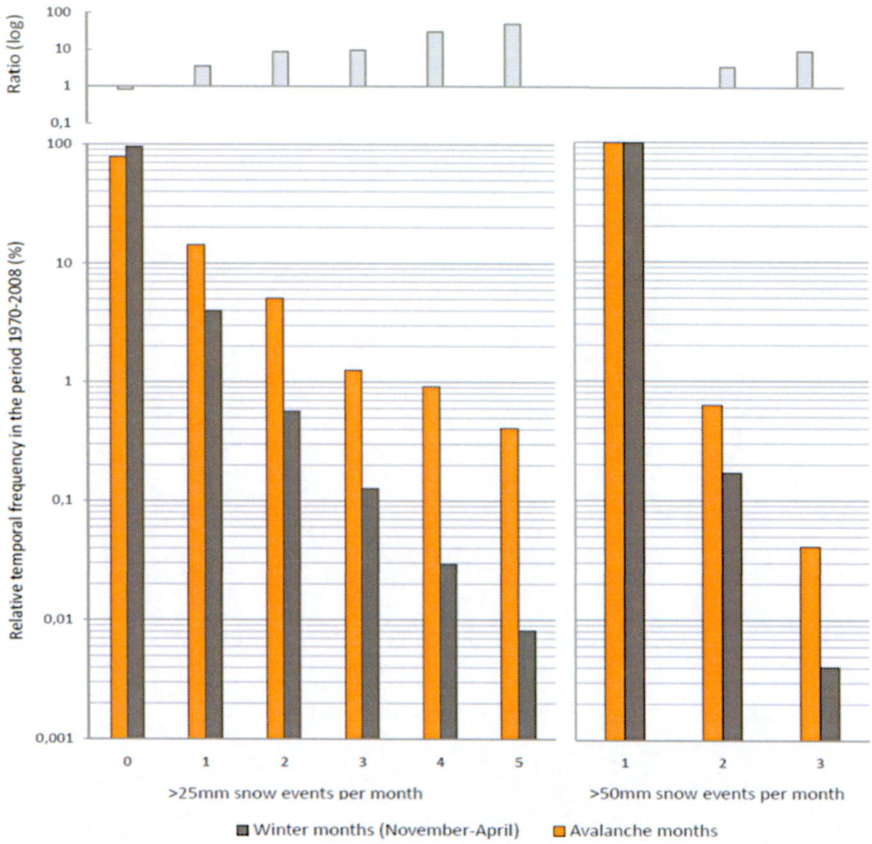

Figure 7: Temporal cross-correlation of months with snow avalanche occurrence to the corresponding frequency of snow events >25 mm (left) and >50 mm (right) in the same month. The ratio in the upper part of the figure indicates whether or not months with snow avalanche occurrences show a tendency to a disproportionately high frequency of snow events.

The spatial distribution of rock falls and snow avalanches related to the annual average frequency of freeze-thaw events does not show a clear relation (Figure 8). Areas with a high freeze-thaw activity do not always correspond to higher numbers of rock falls and snow avalanches. This is, for example, the case in southern Norway.

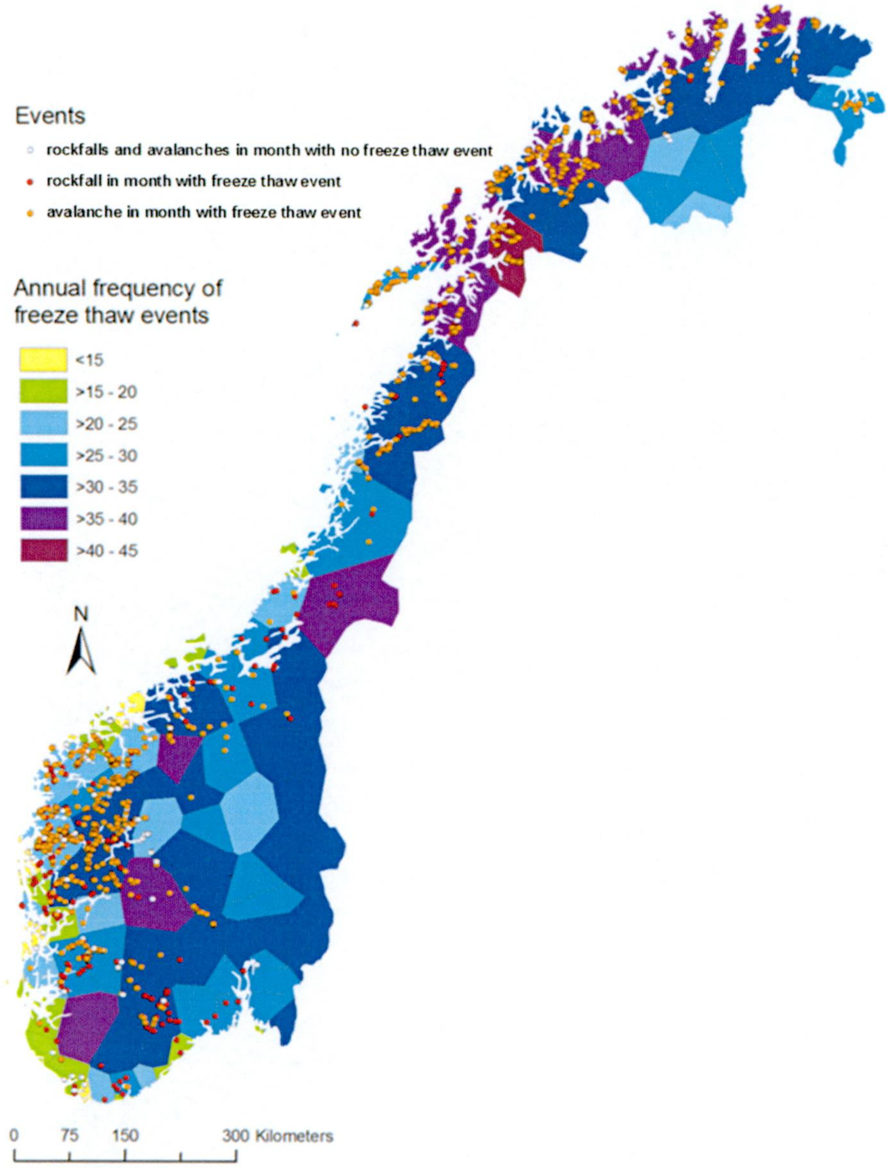

Figure 8: Spatial distribution of recorded rock falls and snow avalanches related to the annual average frequency of freeze-thaw events at various meteorological stations, represented by the according Thiessen polygons.

Figure 9 shows, however, that a higher frequency of freeze-thaw events is very often related to the months where snow avalanches occur. However, the dependency between a higher frequency of freeze-thaw events and the occurrence of rock falls is much weaker.

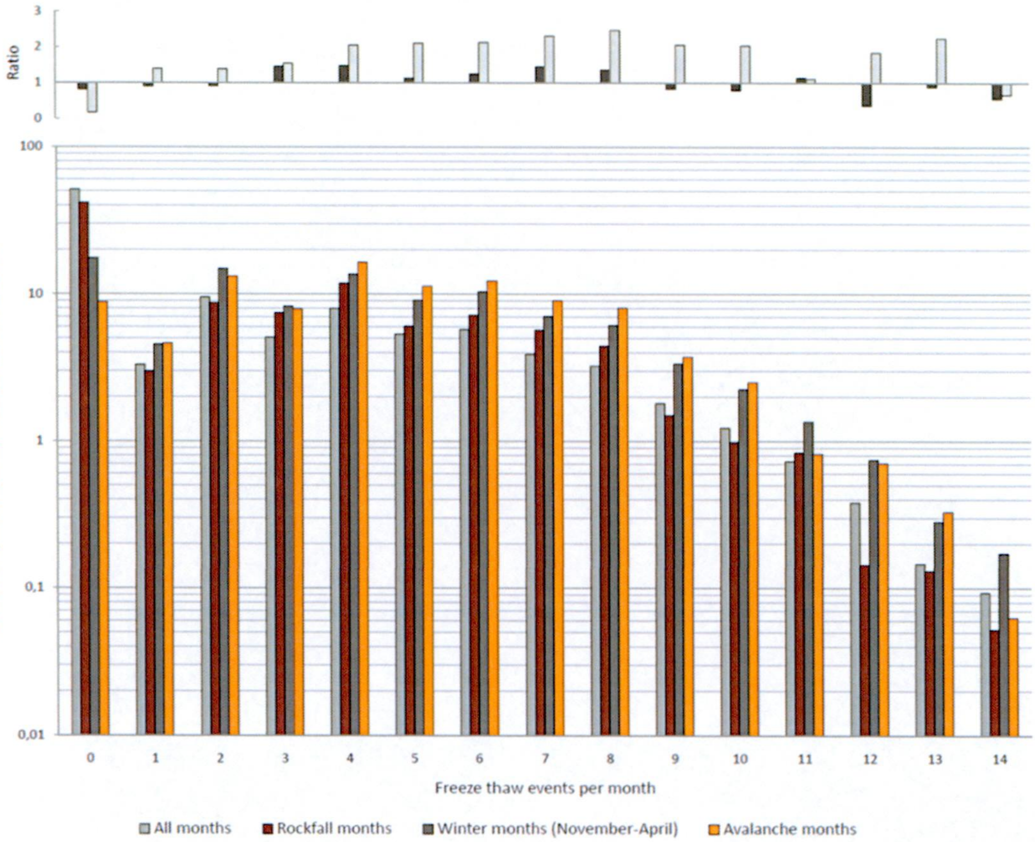

Figure 9: Temporal cross-correlation of months with rock fall or snow avalanche occurrence to the corresponding frequency of freeze-thaw events in the same month. The ratio in the upper part of the figure indicates whether or not months with snow avalanche occurrences show a tendency to a disproportionately high frequency of snow events.

Our analyses have some limitation, the main ones being:(a) the spatial connection between hazard location and the next meteorological station is merely based on distances (which can be as large as 200 km) and do not account for topographic or climatic patterns; (b) the temporal resolution of our analyses is restricted to one month. This renders it difficult to link the actual date of a rock fall or snow avalanche to the exact date of a registered precipitation event or freeze-thaw event.

4 Conclusion

Both rock falls and snow avalanches show interdependencies with the spatial and temporal distribution of precipitation events and freeze-thaw events. For snow avalanches the signal is strong and a clear relation with snow events and freeze-thaw events can be seen. For rock fall the distribution pattern shows less agreement with the temporal and spatial occurrences of precipitation events and freeze-thaw events.

Rock falls do not correlate with the general temporal pattern of precipitation events. While the frequency of rock falls is highest during late winter and spring, the frequency of precipitation events is highest in autumn and early winter. However, those months with rock fall occurrence show generally a disproportionately higher frequency of precipitation events than the normal distribution would suggests. The relation between the occurrence of rock falls and the occurrence of freeze-thaw events is less evident. Still, rock fall frequency and freeze-thaw event frequency coincide quite well during spring. It seems likely that the frequent freeze-thaw events during winter time cause a constant weakening of the bedrock, while precipitation events act as immediate triggers for rock falls.

Snow avalanches are dependent on the existence of snow. Each snow event increases the total amount of snow potentially available for snow avalanches. However, the early months of the winter (November and December) are not characterized by an increased snow avalanche activity as the snowpack is still not well established and usually quite thin. Towards the end of the winter, the number of snow avalanches increases due to a more complex snow pack and the existence of potential shear planes and week layers in the snow. The complex sequence of new snow, wind and freeze-thaw events decide in combination on the number of natural avalanches. Thus, it is to conclude that single occurrences of snow or freeze-thaw events only trigger a limited number of avalanches immediately. However, the summation of several events over the course of a winter build the complex snowpack and subsequently lead to failure.