COMPARISON AND CLASSIFICATION OF AN ARCTIC TRANSITIONAL SNOW CLIMATE IN TROMSØ, NORWAY

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ABSTRACT: Tromsø, Norway has a relatively mild climate and high precipitation levels compared to other locations at similar latitudes. Winter tourism in Tromsø has increased considerably in recent years, consequently also the skiing tourism. It is advertised that Tromsø has a mild coastal climate compared to other destinations at similar latitudes.

Existing snow climate classes separate snow covers into maritime, continental and transitional classes where persistent weak layers are rare in the maritime class. Rain and average air temperatures during the snow season are decisive factors for a snow pack to be classified as maritime or not.

In total 76 snow profiles from one coastal and one inland location during the winter season 2016-2017, in addition to meteorological data from 1957 to 2017, is the basis for classification of the snow cover climate in the Tromsø area in this study. An Arctic transitional snow climate was classified as having multiple rain-induced crusts during relatively warmer years and extensive depth hoar formation during relatively colder years, where the frequency of constructive metamorphism increased inland.

This type of snow cover classification is useful in many ways. Spatial comparison with other areas, both national and international, becomes possible. Temporal comparison, by making a description of the relationship between weak layers and climate, can be done. Also, it provides the Tromsø area with its own snow climate describing typical processes influencing snow and snow stability.

KEYWORDS: snow climatology, transitional snow climate, spatial variability, arctic snow climate.

1. INTRODUCTION

Snow avalanches, hereafter avalanches, represent a potentially fatal threat to people living nearby to and travelling in mountainous areas worldwide. The number of avalanche fatalities per year in Norway has varied between five and nine (Fitzharris and Bakkehøi, 1986; NGI 2016), depending on the time span calculated.

Snow climates are classified into a maritime and continental class with a transitional class in between (Roch, 1949; McClung & Schaerer, 2006). According to McClung & Schaerer (2006), persistent weak layers, weak snow layers that persists through weeks and months, are a characteristic for continental snow climates. Contrary, such layers are rare in maritime snow climates.

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2. PERSISTENT WEAK LAYERS IN A COASTAL CLIMATE

Tromsø is a city in Northern Norway situated among fjords and mountains at 69,5° north. The city has a relatively warm and wet climate despite its northern location (The Norwegian Meteorological institute, 2016). At the same time, persistent weak layers are regularly seen in the Tromsø area (The Norwegian Water Resources and Energy Directorate, 2016). With skiing tourism increasing (Hansen, 2015), there is a need for a clarification that the regular Tromsø snow cover does exhibit continental snow climate type characteristics.

Thus, this article aims to classify the snow climate in the Tromsø area by investigating spatial and temporal variance in the snow stratigraphy and stability from one maritime-like mountain and one more continental-like mountain nearby Tromsø. Respectively, the mountains were located approximately 25 km and 50 km away from open sea.

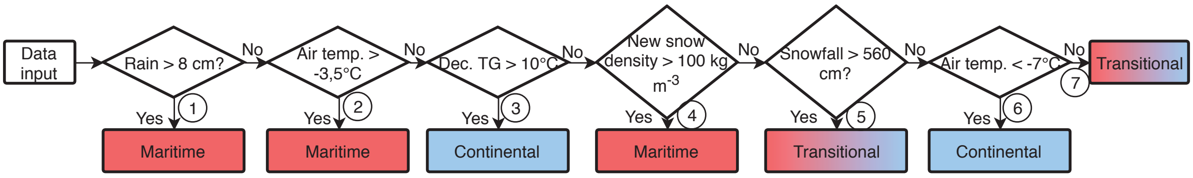

Figure 1: Flow chart describing a classification procedure for snow climates. Modified after Hägeli and McClung (2007) and Mock and Birkeland (2000). TH: temperature gradient, SWE: snow water equivalent.

3. METHODS

Through the winter season 2016–2017, 76 snow pits were dug at four different spots, two at each mountain. From the snow pits, snow stratigraphy, snow stability and snow density were logged after guidelines from the Canadian Avalanche Association (2014). All the acquired snow data was compiled in a spreadsheet, making it possible to investigate different snow properties at the different study plots. The acquired data were shared with the Norwegian Avalanche Forecasting Service through their crowd-sourcing service www.regobs.no

Interpolated weather data with 1 x 1 km resolution were obtained from the freely available emergency preparedness, monitoring and warning tool for floods, landslides and snow avalanches in Norway, www.xgeo.no. The dataset, with daily air temperatures and precipitation amounts during the 60 years from 1957 to 2017, was run through a flow chart (Figure 1) developed by Mock & Birkeland (2000) to distinguish snow climate regions in Western United States.

While a flow chart, shown in Figure 1, was used to identify snow climates, snow data was included in the results and discussion to be able to compare and discuss the avalanche winter regime (Hägeli, 2007).

4. THE ARCTIC TRANSITIONAL SNOW CLIMATE IN TROMSØ

4.1 Snow climate from meteorological data

The resulting snow climate classifications after the flow chart of Mock and Birkeland is shown in Figure 2. At the coastal and continental study plot, 34 and 41 out of 60 winters were classified continental, respectively. Nearly all of these winters were classified continental from the measured December snow temperature gradient (Dec TG).

In winters when the inland location was classified as continental and the coastal location was not, the inland location was only slightly beyond the threshold for being classified as continental in decision point 3 in the flow chart.

18 and 13 out of 60 winters were classified as maritime at the coastal and inland study plot, respectively. At each of the study plots, ten of the maritime winters had an average new snow density of more than 100 kg m^{-3}. Both study plots had more than 8 cm of rain in three winters.

Eight winters at the coastal study plot and six winters at the inland study plot were classified as transitional. All of these winters were classified as transitional since they passed all the way through the flow chart. In the two differing winters, the inland plot was classified as continental due to Dec TG above 10°C m^{-1}.

Average meteorological data from the 60 investigated years are shown in Table 1. The average winter in that period was in both study plots classified as continental.

Table 1: Average meteorological data from the 60 winter seasons 1957–1958 to 2016–2017 at a maritime and continental study plot. The blue shaded cells represent a continental classification.

Location	*Rain (mm)*	*Air temp (°C)*	*Dec. snow TG (°C/m)*	*New snow density (kg/m)*	*Snowfall (cm)*
Coastal	28,2	-5,1	13,9	99,4	346,7
Inland	24,5	-5,8	19,3	94,8	310,9

4.2 Avalanche problems

The most important avalanche problem was logged from every snow profile, presented in Figure 3.

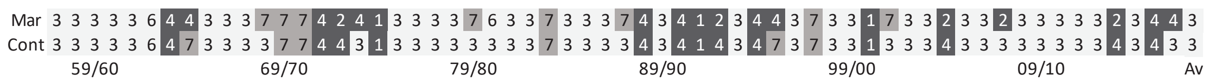

Figure 2: Snow climates from the winter seasons 1957–1958 to 2016–2017. Dark shade: maritime. Intermediate shade: transitional. Light shade: continental. The average row is based on average meteorological data from 1957–2017.

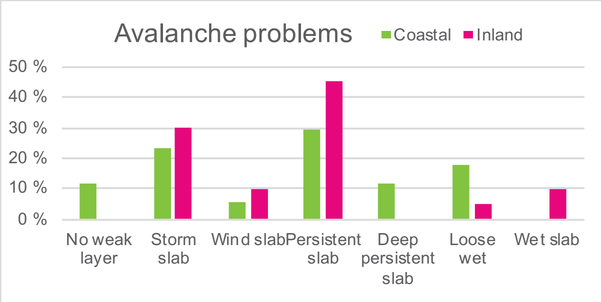

Figure 3: Avalanche problems registered during the 2016–2017 winter season.

The most frequent avalanche problem at each study plot was «persistent slab»; 29 % and 45 % at the coastal and inland study plot, respectively. The second most occurring avalanche problem, also at both study plots, was «storm slab». Storm slab occurred 24 % and 30 % at the coastal and inland study plot, respectively.

The largest differences between the coastal and inland study plot were observed for the avalanche problems «persistent slab» and «loose wet». Persistent slab was observed 15 percent points more often at the inland location than at the coastal location. Loose wet was observed 12 percent points more often at the coastal location than at the inland location.

«No weak layer» and «deep persistent slab» were observed in 12 % of the snow profiles at the coastal location, while never observed at the inland location. «Wet slab» was registered in 10 % of the snow profiles at the inland location, while never observed at the coastal location.

5. DISCUSSION

Firstly, the role the polar night plays for the snow temperature gradients during winter onset will be discussed. Secondly, two case examples from a relatively warm and a relatively cold winter day will be used as to discuss differences between coastal and inland locations in the Tromsø area.

5.1 *Polar night and snow cover thickness*

A December snow temperature gradient above 10°C m^{-1} occurred in 60 % and 72 % of all the 60 winters at the coastal and inland study plot, respectively. Seventeen and seven percent of these winters were classified as maritime due to either rain or high average air temperatures. This suggests that cold air temperatures on thin snow covers play a major role for the stability of a typical Tromsø snow cover. The observation of frequent presence of persistent weak layers as the major avalanche problem supports the argument.

The polar night causes negligible solar insolation during the typical months of winter onset. Simultaneously in the same months, clear skies allow strong outgoing radiation from the snow cover favoring strong snow temperature gradients.

The vicinity to open ocean and open fjords allows for strong winds in the area. The eroding effect of the wind causes the snow pack to be scoured and thin in many slopes during winter and winter onset. This effect also amplifies the snow temperature gradients in an already thin snow pack under clear skies.

5.2 *Case example 1 — Maritime like winters*

From the idea that relatively warmer winters comprise of more warmer days and relatively colder winters comprise of more colder days, one warm and one cold day has been used to visualize temperature differences and to discuss those implications for the snow cover properties.

Figure 4 shows that during relatively warm winter days, the air temperatures differ to a small degree throughout the Tromsø region. The colder, blue, areas are in higher elevations, while the low-altitude areas in the whole region have relatively similar temperatures.

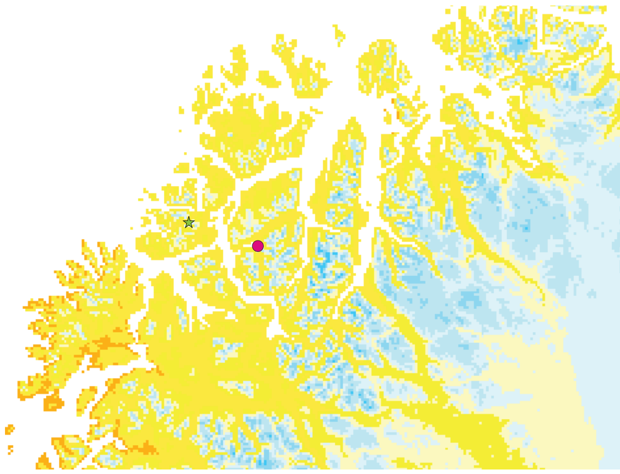

Figure 4: Case example of air temperatures during a relatively warm winter day in the Troms region. The yellow colors represent temperatures above 0°C, while blue represent colder than 0°C. Green star = coastal study plot. Pink circle = inland study plot.

Relatively warm winter air masses need to be transported with the wind from the south. Thus, it will in many cases be raining during warm winter days in Tromsø, which again causes formation of ice layers. As the subsequent air temperatures cool, strong snow temperature gradients adjacent to the ice layers form, allowing persistent weak snow crystals to grow. Thus, persistent weak layers around ice layers are susceptible to be important weak layers during maritime type winters.

5.3 *Case example 2 — Continental like winters*

Figure 5 shows that during relatively colder winter days, there is an apparent west-east air temperature gradient that differs to a greater degree throughout the Tromsø region, with much colder air temperatures inland. The temperatures vary less with altitude, even though some cold and heavy air sinks down into inland valleys.

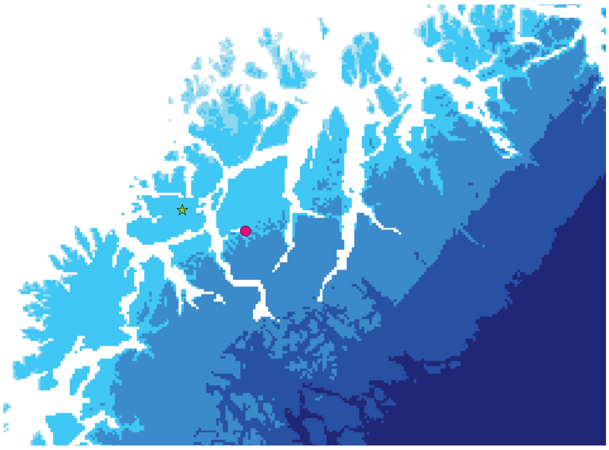

Figure 5: Case example of air temperatures during a relatively cold winter day in the Troms region. Lightest blue: -3°C to -5°C. Darker shades: colder in 5°C intervals. Green star = coastal study plot. Pink circle = inland study plot.

During periods with high pressure ridges over Northern Norway, clear skies and cold temperatures dominate, while low pressure systems from the south are kept away from the region. The cold air temperatures in the inland plateaus in the east fall down into the lower valleys towards west. At the same time, the ocean heats up the most coastal regions.

6. CONCLUSION

Following Mock and Birkelands flow chart, both studied locations are classified as continental during the investigated 60-year period. However, comparing snow data from the study plots during the winter season 2016-2017 to other winter avalanches regimes described by Hägeli and McClung (2007) reveals that the snow cover in Tromsø was more similar to a maritime-like regime and a transitional-like regime in southwestern Canada.

During a regular winter, rain occurs occasionally in the Tromsø region. Hence, characterizing the region as continental would be misleading.

Due to the opposing forces from the cold inland plateaus in the east and the warm low-pressure systems in the west, it is possible to describe the region between the two as a transition zone. In addition, the low insolation during Tromsø's arctic location makes it possible to suggest the name Arctic Transitional snow climate to describe the regular snow cover in the area.

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