IS ARCTIC SNOW DIFFERENT FROM ALPINE SNOW? FOLLOWING UP ON THE DISCUSSION IN REGARDS TO AVALANCHE FORECASTING

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ABSTRACT: A discussion at recent ISSWs elaborated on the question if Arctic snow is different from Alpine snow and in what way. Rather than using a physical snow pack model in regions close to the Arctic Circle and investigating its results in terms of snow properties and snow instability we like to focus here on practical examples of daily avalanche forecasting in regions closer to the North Pole such as Svalbard or Greenland. Those regions are meteorological dominantly affected by the North Atlantic Current that transports warm water masses to the North, which influences the avalanche climate. This and other obvious differences in Arctic climatic boundary conditions such as no or little solar radiation during winter months, lower sun angle in spring, stronger and longer lasting winds , and colder air temperatures result in different challenges for avalanche forecasters and different processes and avalanche problems have to be analyzed than in the Alps. Therefore we analyze typical avalanche events of the past with existing meteorological and snow pit data that represent such different processes of avalanche initiation. We focus on process understanding and how avalanche forecasters can address the challenges of Arctic snow pack properties.

KEYWORDS: avalanche forecasting, Arctic snow pack, process analysis.

1. INTRODUCTION

Following up on the discussion of last ISSW about differences from Arctic snow to Alpine snow, we like to address the topic from an avalanche forecasting point of you rather than a purely scientific. Rather than using a physical snow pack model in regions close to the Arctic Circle and investigating its results in terms of snow properties and snow instability that has been done by van Herwijnen et al. (2024), we like to investigate higher Arctic regions such as Svalbard, Van Mayen and Greenland, which were excluded from those analysis. In recent years several fatal avalanche accidents in such regions underline the necessity of a deeper understanding of how avalanches are initialized in the Arctic and what driving forces can be detected and measured. Examples of such recent fatal avalanche accidents are e.g. April 4th, 2026: A 17-year-old boy died after an avalanche struck a group of six snowmobilers near Qassi, south of Nuuk (Greenland); on January 30, 2021, a fatal avalanche on the remote Arctic volcanic island of Jan Mayen killed two civilian employees of the Norwegian Armed Forces and injured a third during a backcountry skiing leisure trip; May 2019 – Kamkrona, near Hornsund (Svalbard) Two Polish researchers from the Hornsund research station died after being caught in an avalanche while on a weekend ski trek over several mountains; on 20 February 2020, a local tour operator ran a snowmobile trip with 5 guests and 2 guides from Barentsburg toward the front of the Fridtjovbreen glacier. Two German tourists were killed in the avalanche that struck the group about 60 km west of Longyearbyen (Svalbard). The Avalanche warning service for Svalbard - the region around Longyearbyen in Svalbard is the only region in the higher Arctic with an operational avalanche service-:Varsom.no had rated avalanche risk in the area as "moderate" at the time. After the tragic avalanche accident 2015 in Longyearbyen, where 12 houses were destroyed and two people killed, and another one in 2017 from the same mountain, the Norwegian avalanche warning service increased its operational service to Svalbard. Still today little is known about Arctic snow pack conditions related to avalanche initiation in Svalbard. This is caused by limited avalanche research done in the past, we therefore like to add here to the discussion, also following up our paper from ISSW 2018, Prokop et al. (2018), on how to better forecast avalanches in the higher Arctic.

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2. SNOW CLIMATE

The difference between an Arctic and an Alpine snow pack is defined by the difference in the snow climate. Note that we discuss the Alpine snow pack as the snow pack in regions like the Alps in mid-latitudes and not as indication of an altitudinal

https://doi.org/10.15788/1790099052

difference. While van Herwijnen et al. (2024) stressed “It’s still physics so no major differences” elaborating that regional differences in the Arctic can result in similar snow packs like in Alpine regions of the world, e.g. Eckerstorfer et al. already defined in 2011 the region around Longyearbyen as an ‘‘High Arctic maritime snow climate’’ as having a very thin and cold snowpack, a basal layer of depth hoar with wind slabs and ice layers on top. The snowpack lasts for 8–10 months of the year, at higher grounds for the whole year.” All of the regions we are addressing here are located at the coastline or in vicinity of the sea, as those areas are the only populated where human traffic occurs, so we support here the definition of an Arctic maritime snow climate. Van Herwijnen et al. (2024) concluded also: “Arctic snowpacks present unique challenges due to distinct boundary conditions, notably the absence of solar radiation during winter months and the frozen ground. These widely different boundary conditions affect internal snowpack processes with mostly unknown repercussions on snow stability” Here we like to add what the different boundary conditions cause and what the avalanche forecaster has to mind about.

Figure 1: Typical multilayered shallow Arctic snow pack, where snow drift accumulates enough snow to release a hard slab avalanche near Longyearbyen, Svalbard. Left: Several layers of wind drifted snow, Right: Hard slab avalanche release.

3. SOLAR RADIATION

The absence of solar radiation during winter month, a shorter period of day and night cycle and the presents of solar radiation during the whole day in the end of the winter season result in very different boundary conditions for an Arctic snow pack than an Alpine snow pack has. During the absence of solar radiation and therefore no influence on the snow pack stratigraphy and constant air temperatures during day and night, the avalanche forecaster can focus on the different storms affecting the region of interest, strong winds and other processes. When solar radiation occurs, quickly the time increases when the sun hits the snow every day, so the forecaster needs to adapt quickly as well, but rather cold air temperatures during this season make solar radiation to a minor contributor to snow instability. Challenging is the end of the winter season where solar radiation is present during the whole day and air temperatures approaching 0 C°, wet avalanche cycles occur very fast, as melt/freeze cycles do not occur anymore as air temperatures are constant above 0 C° and solar radiation is present during day and night. This also results in a phenomena that occurs only in the Arctic: Solar radiation triggered avalanches on northern exposed slopes. Here the low sun position close to the horizon results in a perpendicular angle of incident and accordingly the highest energy input for the snow pack possible (Fig. 2).

4. WIND

Of course there are regions with strong winds with an Alpine snow pack too, but overall the winds in Arctic regions have a different much stronger and more continous extend (Fig.3). This results usually in much harder snow packs, mostly non existent in Alpine regions other than in high altitudes and accordingly the occurance of hard slab avalanches. Such conditions, that pose risk due to their rare occurrence in Alpine regions even for experienced mountain guides e.g. tragic avalanche accident 1.4.2015, French Alps, 3350 m a.s.l. where 3 jung participans of a Austrian Alpine Club guided tour died, are very common in the Arctic. Hard slabs are predominant and little is known about the process of their initation so very difficult to forecast.

Figure 2: During the meteorological winter season (December till February) most of the time no solar radiation occurs. Left: Tragic avalanche event in Longyearbyen 2015, Right: The highest sun position at the horizon in the end of February near Longyearbyen, Svalbard

Related to wind cornice failures and associated cornice fall avalanches comprise e.g. nearly 50% of observed avalanche activity near Longyearbyen and endanger human life and infrastructure annually in most of the Arctic regions. As the very hard detached cornice blocks remained largely intact throughout the avalanching process and ran further than the main avalanche mass it is important to define cornice fall as an unique avalanche problem for Arctic regions and forecast them precisely (Hancock et al., 2018). Detailed studies about the initiation of cornice fall are missing but it can be concluded that such cornice fall avalanches occur when either mechanical pressure such as wind or additional snow fall acts on the cornice or rapid warming occurs (Hancock et al., 2020). At least a guideline for avalanche forecasters exist. In Alpine regions cornice fall is a neglectable issue, at least for avalanche forecaster, of course not for single mountaineers breaking such cornices.

Wind drifted snow is above all the main, or even single contributer to the occurrence of large catastrophic avalanches e.g. Longyearbyeb 2015. Most of the Arctic regions are comparable dry, with winter precipitation significant lower than in Alpine regions. Only snow fall and wind induced snow drift usually delivers enough snow accumulation for the initiation of large slab avalanches. So usually when strong winds and snow fall is forecasted the avalanche danger rises significantly. It is still difficult to forecast the amount of snow that is accumulated in such events, so measurements of the spatial snow depth distribution at important slopes are ideal for the forecaster (Prokop 2008, Prokop and Procter 2014, Hancock et al. 2020).

Figure 3: Wind packed snow and cornice growth during most of the winter season in Svalbard.

5. RAIN

Another important contributor to avalanche release in Arctic regions is rain fall. For some readers that might be surprising, but in warm regions of the Arctic, due to climate warming, the whole winter long

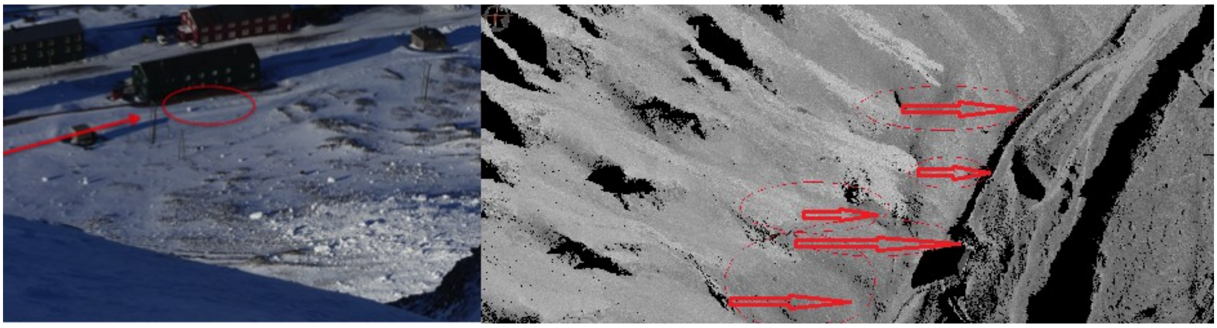

Figure 3: Cornice blocks have a significant longer run out distance than hard slab avalanches and endanger human life and infrastructure in the Arctic (Longyearbyen, Svalbard) Left: Cornice blocks reaching housing, Left: Longer cornice block run out measured by terrestrial laser scanning (Intensity image)

rain induced avalanches are increasingly happening. The same accounts for Alpine regions, however, due to the shallower multi layered snow pack that usually occurs in Arctic regions, avalanching occurs more immediate. Moreover it seems that when the snowpack is hard and rather cold, rain causes a fast change of snow pack properties and large avalanches occur (example pictures). Also the dynamics favor longer avalanche run out distances. Rain-on-snow (ROS) events and subsequent rain-induced wet-snow or slush avalanches are increasing on Svalbard. Rapid Arctic warming has caused more winter precipitation to fall as rain rather than snow, heavily destabilizing existing snowpack, triggering slush flows, and causing destructive mass movements around settlements like Longyearbyen Vickers et al. (2024).

6. AIR TEMPERATURES

As already mentioned in the paragraph about solar radiation, air temperature changes in time during one day and night cycle differs a lot in Arctic regions in comparison to Alpine regions. Air temperatures do not change much due to the lack of solar radiation (or very little solar radiation), or constant solar radiation in the late winter season. It can be quite boring for an avalanche forecaster during stable weather conditions, when no solar radiation exists and temperatures remain constant with no wind. However, changes in air temperatures driven by large weather systems occur in a larger extend than usually in Alpine regions. In particular in Svalbard, dominated by North Atlantic Current, 20 C° difference from one day to the other occur more frequent than in Alpine regions, so rather challenging. The Arctic climate is with no surprise mostly still much colder than where recreationists usually stay in Alpine regions, which favors the existence of hard slab avalanches, which are difficult to forecast.

7. PERMAFROST GROUND

While an avalanche forecaster in Alpine regions is often busy with warning about gliding snow avalanches, those are hindered in Arctic regions by the permafrost ground; gliding snow avalanches are nonexistent in Arctic regions. No liquid water content occurs in the interface of ground and snowpack and the shallow snowpack that transform fast to facets due to missing heavy snowfall events in the beginning of the season hinder glide avalanches to release.

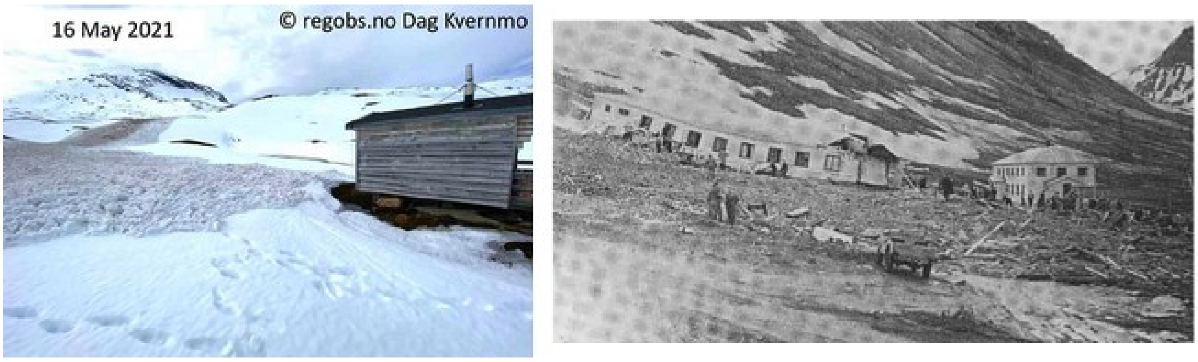

Figure 4: Sluhsflows present a significant hazard in the Arctic.: Right: Buildings in Haugen, Svalbard, that were destroyed by a slushflow in 1953 (Picture from UNIS 2006). Left: Slushflow observed near a cabin, note the shallow terrain and the long run out of the slushflow (Sund et al. 2024).

On the other hand an avalanche forecaster in the Arctic is busy with another type of avalanche release: Slush flows, which are nonexistent in most of Alpine regions. Slush-flows, i.e. the rapid mass movement of water-saturated snow, is confined primarily to Arctic and high sub-Arctic regions. Slush flows are most likely to occur when appropriate water input to snow- pack, suitable starting-zone conditions are available and drainage is missing due to permafrost ground (Onesti and Hestnes 1989). Dramatic slush-flow events have been damaged infrastructure (Fig. 4) in and mitigation strategies have been applied in Arctic regions (D'Amboise et al. 2024; Jonsson and Gauer, 2014)

8. SNOW STRATIGRAPHY

Depending on location there is of course a big variety in snow stratigraphy in Arctic snowpacks. In general, though, an Arctic snowpack is thin, predominantly consists of depth hoar and is heavily influenced by strong winds (Fig. 1). This results in several thin and hard layers containing small, by wind decomposed crystals on top, several wind or rain crusts and facets or depth hoar further down. Large dendrites and surface hoar at the snow surface are rather seldom. Overall a very different looking snow pit than in Alpine regions. Stability test usually initiate on the facets or depth hoar layers near the ground, however, due to the rather hard and multi layered snow pack above, the force needed to initiate fracture propagation can be large and the common procedures such as ECT tests are perhaps not the ideal way to predict hard slab avalanches. The use of physical snowpack models such as SNOWPACK (Van Herwijnen et al. 2024) is limited, as important Arctic weather processes are not covered in detail and reliable input data is needed (Praz 2018., Prokop et al. 2018)

9. CONCLUSIONS

Predicting avalanches in the last 20 years both in Alpine regions (European Alps) and in Arctic regions (Svalbard and Greenland) we summarize here some obvious differences between Arctic and Alpine snow in regard to avalanche release and snow stability. Forecasting avalanches in Arctic regions demand often a different approach to the topic than in Alpine regions. This summary is not meant to be complete and is biased by the experience made by the authors in the high Arctic regions and is rather descriptive than scientific. However, we like to add to the discussion and we think ISSW is the right platform to do so, as recent tragic avalanche accidents in the Arctic make better avalanche forecast needed as e.g. tourist activity increases in avalanche prone areas. Reliable data about snow conditions is often missing and rather non experienced forecaster struggle to warn precisely when it is needed. Even though most of the differences between Alpine and Arctic snow mentioned here seem perhaps obvious for some readers, we think more effort should be done in understanding processes of Arctic avalanche release than e.g. trying to describe an Arctic snow pack by modeling results of a not really suited physical snow pack model. In particular the lack of knowledge regarding the release of hard slab avalanches makes avalanche forecasting in Arctic regions difficult.

ACKNOWLEDGEMENTS

We thank numerous funding agencies for their financial support for research in the Arctic e.g. in Svalbard and Greenland in the last 20 years, in particular Institut polaire français Paul-Émile Victor (IPEV)

REFERENCES

D'Amboise, C., Hansen, V., Hendrikx, J., and L. Vick, 2024. Motivation for slushflow classification. In Proceedings of the International Snow Science Workshop ISSW in Tromso 2024 (pp. 759 - 765).

Eckerstorfer, M., and H. Christiansen, 2011. The ''High Arctic Maritime Snow Climate'' in Central Svalbard. Arctic, Antarctic, and Alpine Research, Vol. 43, No. 1, 2011, pp. 11–21. DOI: 10.1657/1938-4246-43.1.11.

Hancock, H., Eckerstorfer, M., Prokop, A., Hendrikx, J., 2020. Quantifying seasonal cornice dynamics using a terrestrial laser scanner in Svalbard, Norway. Nat. Hazards Earth Syst. Sci. 20, 603–623. https://doi.org/10.5194/nhess-20-603-2020

Hancock, H., Prokop, A., Eckerstorfer, M., Hendrikx, J., 2018. Combining high spatial resolution snow mapping and meteorological analyses to improve forecasting of destructive avalanches in Longyearbyen, Svalbard, Cold Regions Science and Technology, Volume 154, 2018, Pages 120-132.

Jonsson, A. and Gauer, P.2014: Optimizing mitigation measures against slush flows by means of numerical modelling – a case study Longyearbyen, Svalbard, in: Proceedings of INTERPRAEVENT-2014 in the Pacific Rim – Natural Disaster Mitigation to Establish Society with the Resilience, 25–28 November 2014, Nara, Japan, 224–225, 2014.

Onesti, L.J., and E. Hestnes, 1989. Slush-flow questionnaire. Ann. Glaciol., 13 (1989), pp. 226-230

Praz., M., 2018. Modeling the Arctic snowpack properties in Svalbard using SNOWPACK. Master thesis, UNIS, The University Center in Svalbard.

Prokop, A., 2008. Assessing the applicability of terrestrial laser scanning for spatial snow depth measurements. Cold Regions Science and Technology 54, 155–163. https://doi.org/10.1016/j.coldregions.2008.07.002

Prokop, A., Hancock, H., Praz, M., Jahn, E., 2018. Slope scale avalanche forecasting in the arctic (Svalbard). In Proceedings of the International Snow Science Workshop ISSW in Innsbruck 2018 (pp. 1035-1039).

Prokop, A., and E. S. Procter, 2016. A new methodology for planning snow drift fences in alpine terrain, Cold Regions Science and Technology, Volume 132, 2016, Pages 33-43.

Sund, M. and Gronsten, H. A. and Seljesaeter, S. 2024. A regional early warning for slushflow hazard. Natural Hazards and Earth System Sciences. Volume 24, issue 4, NHESS, 24, 1185–1201, 2024.

Van Herwijnen, A., Muccioli, M., Wever, N., Saiet, E., Mayer, S., Pugno, N., 2024. Is Arctic snow different from Alpine snow? Delving into the complexities of snow cover properties and snow instability. In Proceedings of the International Snow Science Workshop ISSW in Tromso 2024 (pp. 401–408).

Vickers, H., Grahn, J., Malnes, E., and P. Mooney, 2024. A climatology of rain on snow events in Svalbard and their implications for avalanche hazard. In Proceedings of the International Snow Science Workshop ISSW in Tromso, Norway 2024 (pp. 1284-1291).