AN EXTREME SLUSH AND SLAB AVALANCHE EVENT IN HIGH ARCTIC MARITIME SVALBARD

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ABSTRACT:

Ten slush avalanches and 31 slab avalanches were observed and documented in a 16.8 km² large mountainous area, around Svalbard's main settlement Longyearbyen. All avalanches released within a 15 days period between 14 - 29 January 2010. Extreme meteorological conditions in the winter prior the avalanche events, caused the slush and slab avalanches. Regular field observations in the Longyearbyen area over the last 3 years, as well as literature on past slush flow avalanches and extensive avalanche activity suggest, that the January 2010 avalanche period can be classified as an extreme event both in magnitude and frequency. In this paper we explain the unique meteorological and snowpack conditions that favored the slush avalanche release as well as the connected slab avalanche event. In particular an extreme warm November 2009 to January 2010 period with a record amount of solid precipitation compared to the whole Svalbard meteorological record (1912-2010) are the key releasing meteorological factors for both extreme events. These meteorological conditions developed a soft, coarse grained snowpack that was isotherm at 0 ºC when both slush and slab avalanches slid on one of the several ice layers inside the snowpack after it got saturated with water.

1. INTRODUCTION AND SCOPE

In the 15 day long period 14-29 January 2010, first 10 slush avalanches and then subsequently 31 slab avalanches were observed in a 16.8 km² large mountainous area around Svalbard's main settlement Longyearbyen in central Spitsbergen (Figure 1), largely controlled by the extreme meteorological conditions. Frequent monitoring of the avalanche activity in this area in the period 2006-2010 (Eckerstorfer and Christiansen submitted c) as well as available literature on past slush and slab avalanche events suggest, that this slush and slab avalanche event can be classified as extreme events both in magnitude and frequency.

The purpose of this paper is to describe the unique meteorological and snowpack conditions prior to the slush and slab avalanche extreme event.

2. SNOW CLIMATE AND METEOROLOGY

The snow climate is maritime, characterized by a cold snowpack, consisting of a persistent weak depth hoar base with ice layers and wind slabs on top (Eckerstorfer and Christiansen, submitted b). The snowpack is on average thin due to an annual precipitation of only 200 mm w.e. at sea level, but snowdrifts occur in topographical lee sites. During winter, a seesaw pattern of cyclonic activity bringing warm and moist air to Svalbard and cold anticyclonic air masses from the north, result in large daily or weekly temperature variations (Dickson et al. 2000). Due to the maritime location, the area around Longyearbyen is rather warm, compared to other High Arctic locations, with a mean annual air temperature (MAAT) of -3.8 ºC in 2009 and a late 20th century MAAT of -5.8 ºC (1975-2000).

3. METHODS

In the snow season 2009-2010 (October – May) meteorological, snowpack and avalanche data were collected during 62 field days in the study area (Figure 1). Additionally, meteorological data from a meteorological station at sea level was used, from where an almost hundred year's long record (1912-2010) exists (met.no).

4. RESULTS

4.1 Meteorology

During the period October 2009 to January 2010 a record high amount of precipitation of 137.2

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mm was measured. In January 2010, 68.7 mm precipitation was recorded, which is 390 % more than the 1912-2010 average. The highest wind velocities in winter 2009/2010 were measured end of January 2010, when a blizzard with wind gusts of 31 m/s occurred. Along with this storm activity, air temperatures rapidly rose to close to or above 0 ºC. Several periods with air temperatures remaining above 0 ºC at least for a day were observed from October 2009 to January 2010, with the longest period between 15-19 January 2010 reaching maximum air temperatures of 3.5 ºC, 18 January 2010. These warm periods clearly also affected the monthly average air temperature. The October 2009 – January 2010 period had an average temperature of -4.6 ºC, which is significantly warmer than the normal period (1980-2010) average of -9.5 ºC (met.no), and the average for the entire 1912-2010 October-January record of -9.9 ºC (met.no).

4.2 Snowpack

The snowpack prior to the January 2010 extreme events consisted of a basal ice layer overlain by depth hoar and an up to 50 cm thick layer of wet grains, resulting from extensive warm periods in December 2009, that also created ice layers from rain on snow events. By mid January, the snowpack contained a lot of free water, weakening the snow crystal bonds above a prominent ice layer which was deposited in the beginning of November, found in the lower third of the snowpack. This ice layer is believed to be the bed surface layer on which the slush avalanches slid down. Evidence for this is that no sediment was observed in the avalanche debris, which would have been the case if the slush avalanches had slid down on the basal ice layer, since it is more irregular, especially on coarse grained talus slopes. The free water available in the snowpack from the 4 days thawing period (14-18 January 2010) saturated the snowpack down to the ice layer, which was impermeable for the water. Thus friction was reduced by the hydrostatic pressure, which reduced the shear strength at the interface and the slush avalanches released (McClung and Schaerer, 2006).

The slush avalanches released in all slope aspects (Figure 1) in the period 14-18 January 2010. All slush avalanches started approximately on a slope inclination between 50º and 30º, and ran down out to flat terrain in some cases. All slush avalanches were confined to gullies or narrow valleys, cut by river erosion (Figure 1). Once the slush avalanches left the narrow gullies, they strictly followed the slope morphology and stopped and deposited the wet snow on the lower slopes. This flow behavior indicates a certain fluid to granular solid behavior, as found by Jaedicke et al. (2008) in their chute experiments on slush flow dynamics. The slush avalanches that ran onto talus fans, either followed the steepest parts of the fan, or followed debris flow track depressions and accumulated a debris tongue at the lower part. All slush avalanche debris were bordered by up to 1.5 m high levees, extending from the rare end of the debris to the debris tongue in the front.

The 31 slab avalanches all released in the blizzard 26-29 January following the warm event, and this event is in magnitude the largest one observed so far in central Svalbard (Eckerstorfer and Christiansen, submitted c). Most slab avalanches released on slopes facing NNE to S as well as W, since the major two valley systems Todalen and Longyeardalen – Fardalen are tending almost N-S (Figure 1). Four of the 31 slabs were “D4-R5” avalanches, according to the classification system by Greene et al. (2004). All slab avalanches slid on the same ice layer as the slush avalanches. Between 22 – 26 January 2010 air temperatures remained close to and above 0 ºC, and rain saturated the already wet snowpack even more. The slab avalanches released, presumably due to water lubrication of the ice layer that formed the sliding surface, and by loading of solid precipitation and thus an increase in stress on the snowpack (McClung and Schaerer 2006). Therefore it is clear that the slab avalanches were wet slab avalanches. By beginning of February, air temperatures started to drop rapidly and as many slopes slid during the extreme slab avalanche event and the snowpack got hard and packed, with only little avalanche activity observed for the rest of the snow season 2009-2010. This is completely different to the avalanche observations in the period 2006-2009 (Eckerstorfer and Christiansen submitted c) where only two slush avalanches were observed and most avalanches occurred mainly in the end of the season in April and May.

5. DISCUSSION AND CONCLUSION

Ten slush avalanches occurred between 14-18 January 2010, followed by 31 wet slab avalanches occurring between 26-29 January 2010. They all released in a 16.8 km^2 large mountainous area around Svalbard’s main settlement Longyearbyen, but this event was not confined to this area and was seen to have occurred also in neighboring areas of Svalbard. Both avalanche events are extreme in their magnitude, and here we presented the meteorological and snowpack conditions that lead especially to the slush avalanche event. This is interesting since not many studies focuses on mid winter slush avalanches, releasing during rain on snow events, which might occur more often in a wetter and warmer climate especially in maritime High Arctic locations such as Svalbard. The wet slab avalanche event was briefly presented because it was the highest magnitude avalanche event so far observed in the Longyearbyen area, and is closely associated with the slush avalanche events in terms of the meteorology and snowpack characteristics causing the event.

The slush avalanches are comparable to past observed slush avalanches worldwide (Nobles 1966, Onesti 1985, Hestnes and Sandersen 1987, Onesti and Hestnes 1989, Furdada et al. 1999) in terms of the topography of the release zone, the morphology of the track as well as their flow behavior. Crucial factors like snowpack conditions favoring and meteorological conditions releasing slush avalanches are also comparable to past studies. But we hereby want to emphasize, that especially the snowpack development, determined by the meteorological situation though the entire winter until the slush avalanche event is a key factor. If there is no ice layer blocking the snowpack, even in continuous permafrost areas like the Longyearbyen area, water runoff through open spaces on coarse grained talus slopes might decrease the probability of a slush avalanche release. If the snowpack in general is hard and cold sometimes before air temperatures significantly rise, water would not as easily penetrate and saturate the snowpack, as it does in a softer coarser grained snowpack. Therefore the timing of the slush avalanche event in mid winter depended on unique meteorological and snowpack conditions, much more than slush avalanches that release during spring melting.

The slush avalanches from January 2010 released when a low pressure system caused a 4 day thawing period, with constant positive air temperatures reaching a maximum of 3.5ºC, and 34 mm of rain fell up to almost 1000 m a.s.l. These low pressure systems typically occur in winter in Svalbard, and in this case caused also the wet slab avalanche event in end of January, when a blizzard hit Longyearbyen. The already wet and coarse-grained snowpack made it easy for more water to percolate through the snow, lubricating the ice layer on which the slush avalanches slid. Consequently 31 wet slab avalanches released due to the overburden pressure by more snow loading in a few days.

The meteorological extreme events that occurred in January 2010 were in comparison to the almost 100 year long meteorological record in Longyearbyen exceptional in terms of longer than 1 day periods with air temperatures above 0 ºC and record solid precipitation. Both are crucial factors for the release of the slush and the slab avalanche events. Further studies should therefore aim to compare the meteorological situation of the January 2010 extreme events with the whole 1912-2010 meteorological record to determine past potential for likewise avalanche extreme events. These results can then be used to determine the return periods for such events, an important factor in avalanche forecasting.

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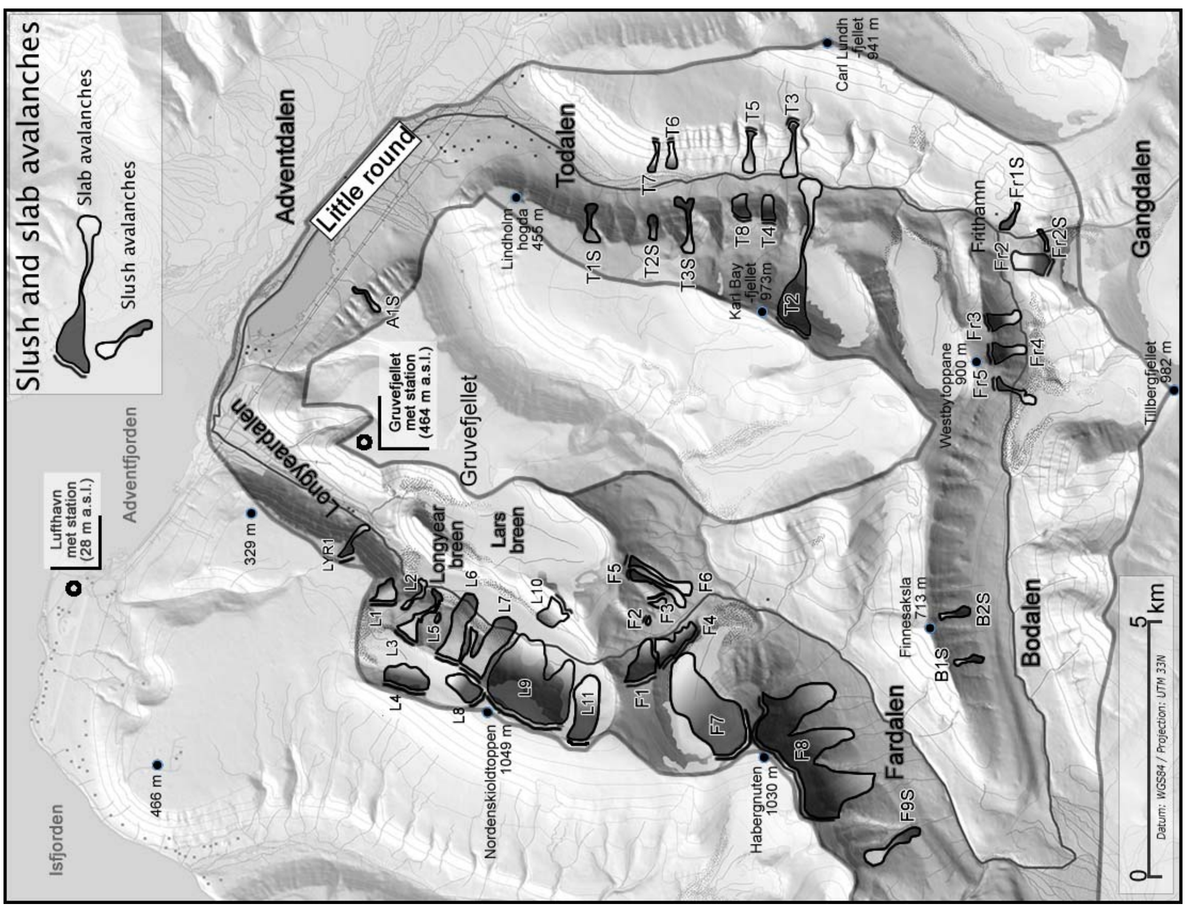

Figure 1: Topographic map of the study area, containing the snowmobile track (gray line). All slush avalanches (marked with "S" in the name) that released in the period 14-18 January 2010 and all slab avalanches (black line indicates the crown location) that released in the period 26-29 January 2010 are visualized.