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Potential dry slab avalanche trigger zones on wind-affected slopes in central Svalbard

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ABSTRACT

Experience suggests that shallow, steep zones on slopes are potential dry slab avalanche trigger points. However, a scientific understanding of this common knowledge is not well quantified due to the spatial variability of snowpack stability, which is governed by various internal and external processes. Currently, the best way to investigate these processes is through point stability testing on small slopes. We thus performed Compression and Extended Column Tests (CTs and ECTs) on three small, wind-affected alpine slopes in central Svalbard. While one study slope (Gangskaret) had smooth ground topography, the other two (Fardalen and Larsbreen) exhibited irregular, rugged ground topography. Our results show that weak layer reactivity was largely influenced by the ground topography, as snow depth is a function of terrain on wind-affected slopes. Slab thickness determines weak layer sensitivity where the ground topography is rugged. Thus, the most unstable spots on these slopes coincided with the shallower zones characteristic of steeper ground surfaces inclinations where the snowpack is thin and the weak layers are close to the surface. This was not as pronounced on slopes with smooth ground topography. However, as snowpack develops and thickens to a "snow depth threshold X", the ground irregularities are leveled out and their influence diminishes. Thus, knowing the terrain is crucial. Moreover, it is crucial to follow the seasonal snowpack development and extreme weather events that influence it. We found inverse relationships between stability and slab thickness for weak layers that developed early in the season. These early instabilities displayed discontinuity due to melt out over topographic highs during rain-on-snow events, but were left in a preserved state in topographic lows that became overlain by shielding refrozen meltform layers.

1. Introduction

About 250 people are killed by avalanches every year in Europe and North America (Etter et al., 2004; Schweizer, 2008). In about 90% of all accidents, the avalanche victims triggered the slab avalanche in which they were caught (McCammon and Haegeli, 2006). Clearly, an understanding of the snowpack processes involved in artificial slab avalanche release is crucial. Therefore, variability in snowpack stability should be studied, especially focusing on the cause of variability at various scales.

Slab avalanches release when a cohesive slab of snow detaches due to the fracture of a weak snow layer (Schweizer et al., 2003a). Fracture can be described as mixed-mode anticracking, which results in weak layer collapse (Heierli et al., 2008). The dominant limiting factor for weak layer fracture is the snow stratigraphy, where layers might not be continuous (Gauthier and Jamieson, 2010). Thus, it is important to understand how snow layers spatially interact with the terrain, as a means of interpreting weak layer depth and distribution. The spatial variability of the snow cover as a function of topography has been highlighted as a key zone of uncertainty (Haegeli and McClung, 2004). Schweizer et al. (2008) concluded that studying terrain-correlated patterns of weak layer formation is crucial. Furthermore, slab avalanche release is prone to areas of low stability, sometimes called deficit zones (Conway and Abrahamson, 1984). Such areas may be located on steep rollovers, around rock outcrops or topographic highs (Birkeland et al., 1995). Crown profiles and fracture lines often run along such features (Birkeland et al., 1995), as they interfere with snow stratigraphy. It is however, difficult to verify the existence of such zones on a slope, making the study of the spatial variability of snowpack stability highly challenging, yet relevant (Kronholm and Schweizer, 2003).

While the majority of snowpack stability studies are from the Alps and North America, our study is unique in that our field area is the High Arctic. Numerous studies have investigated variability in snowpack stability on different scales from slopes to mountain ranges, mainly using point stability tests. A comprehensive review of previous work is given by Schweizer et al. (2008). The authors identify external and internal causes during snow layer formation. While wind is the most important external factor (Sturm and Benson, 2004), terrain topography is the most important internal factor (Schweizer et al., 2008).

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Since terrain is relatively constant at the temporal scales of interest, it is likely the best tool for predicting slope-scale variability (Campbell and Jamieson, 2007). Regardless, the majority of studies have been carried out on sheltered slopes with minor wind influence and smooth ground topography. Only recently, Hendrikx et al. (2009) assessed changes in spatial variability over time on windy slopes. Guy and Birkeland (2013) introduced a spatial variability study from steep couloirs, showing a relationship between weak layer occurrence and wind direction as a function of topography.

In this study, we investigate the spatial variability of snowpack stability on three different, highly wind-affected slopes in central Svalbard. We hypothesize that snow stratigraphy and consequently weak layer formation is highly affected by wind loading, scouring, and redistribution. We further expect the continuity of the snow stratigraphy to be largely a product of the wind activity and the process of snowpack development around irregular ground topography. Therefore, the infill process of snow is influential in weak layer development, suggesting that shallow zones tend to correlate with lower stability and thus potential artificial trigger points.

2. Study area and sites

2.1. Study area

Longyearbyen, Svalbard's main settlement, is located in the center of the main island Spitsbergen at 78°N, 15°E (Fig. 1). The region around the settlement consists of deglaciated U-shaped valleys and small cirque glaciers, underlain by continuous permafrost (Humlum et al., 2003). Mountains display generally a plateau shape, where the southeasterly prevailing winter wind direction (Christiansen et al., 2013) forms cornices on the leeward edges. Cornice falls are the most commonly observed avalanche type, exceeding 50% of the avalanche activity (Eckerstorfer and Christiansen, 2011c). Slab avalanches constitute 32% of the total, typically releasing in avalanche cycles as direct action avalanches induced by passing low-pressure systems (Eckerstorfer and Christiansen, 2011b). These lows bring warm and moist air to Svalbard, resulting in large air temperature fluctuations and mid-winter rain events. As a consequence, ice layers are characteristic of the maritime influenced snow climate in the Longyearbyen area (Eckerstorfer and

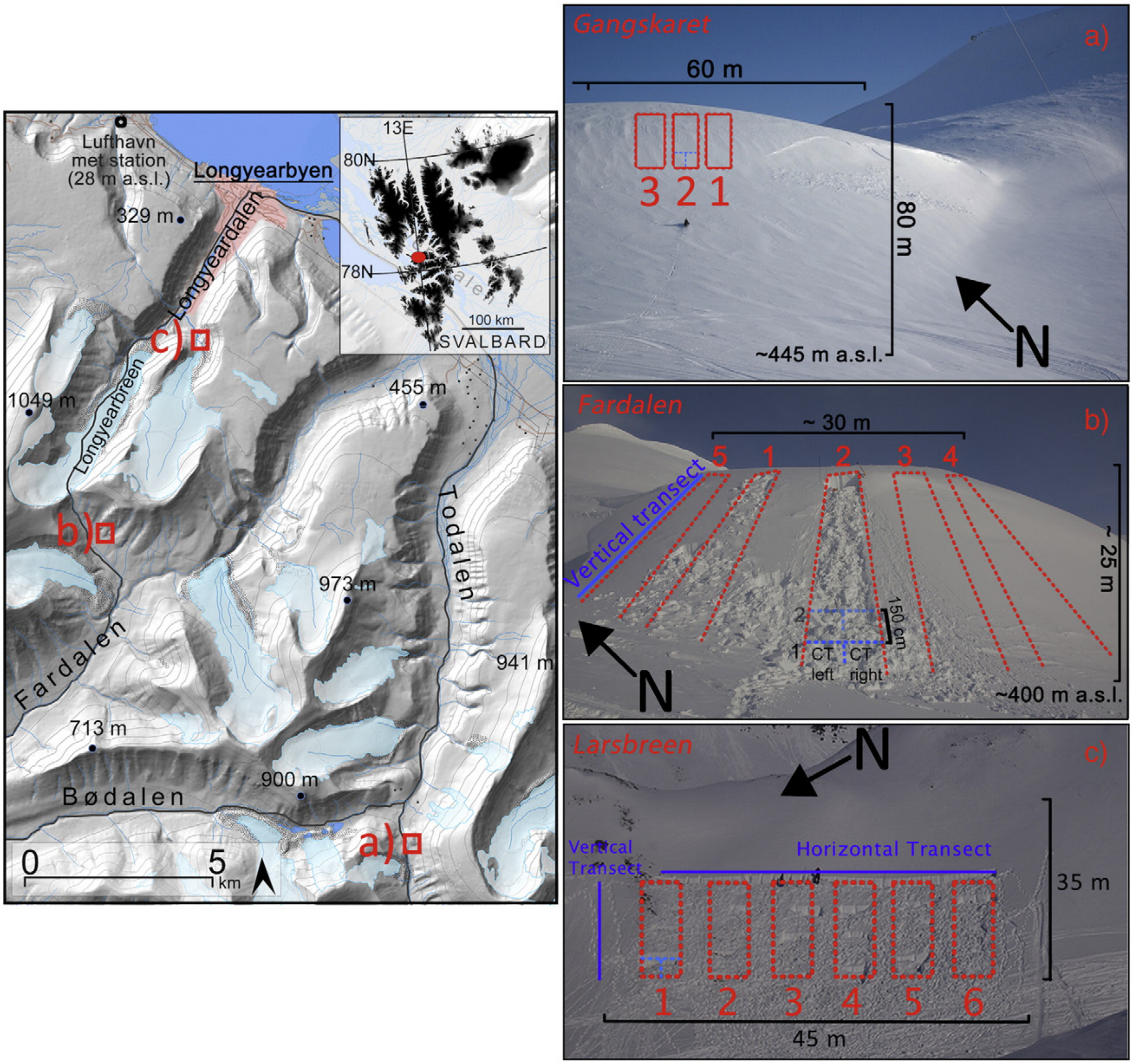

Fig. 1. Study area and sites. The topographic map shows the area around Svalbard's main settlement Longyearbyen. The inset map shows the location of Longyearbyen marked with a red dot. The three study slopes are marked by red squares. a) Gangskaret study slope, b) Fardalen study slope and c) Larsbreen study slope. Note that the picture of Gangskaret was taken before fieldwork, since afterwards visibility did not allow for a picture. Note also, that the trenches are numbered according to the sequence of excavation.