

## GLOBAL WARMING REDUCES THE CONSEQUENCES OF SNOW-RELATED HAZARDS

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**ABSTRACT:** Most recent publications dealing with consequences related to avalanches and slushflows state that their impact on mankind will increase. That is a highly debatable statement. Milder weather, shorter winters, less snow and rise of snowline will mainly shift their potential problem away from populated areas and infrastructure. It is unlikely that expansion of settlement and/or human activity into these areas will outweigh the hazard reduction, mainly because other types of rapid mass movements will increase in those areas and in general. Surely are part of the Arctic and parts of cold continental and mountainous regions, subject to more snow and rain in winter due to the climatic change, and consequently to larger and more frequent avalanches and slushflows. It is, however, unlikely that the consequences to future activity in remote areas will exceed the reduction in consequences in more densely populated areas. Global warming reduces the impact by snow-related hazards on mankind, but the general hazard potential worldwide will most likely increase.

**KEYWORDS:** Global warming, avalanches, slushflows, consequences, mankind, demography

### 1. INTRODUCTION

Change in global weather patterns causes a shift in the potential of most natural hazards around the world. Most likely, the frequency and intensity of natural hazards will increase in some regions and decrease in others. From a human perspective, the consequences of some hazards will increase, and that of others will decrease.

When reading reports dealing with consequences of global warming, one might get the impression that all problems related to rapid mass movement in steep terrain will increase (Petkovic 2013, Relf et al. 2015). However, it is highly debatable whether increased cycling between rain and snow, shorter winters and a general rise of the snowline will increase the impact of avalanches and slushflows on mankind (Jaedicke et al. 2008).

Most of the Arctic and parts of the cold continental regions are obviously subject to more snow and rain in winter, and consequently to a higher potential of large avalanches and more frequent slushflows (Hansen et al. 2014, Hanssen-Bauer et al. 2015, Hestnes et al. 2016). The frequency and amount of precipitation may also increase in some mountainous regions throughout the world. It is, however, unlikely that these changes in mostly remote areas will exceed the reduction in consequences in more densely populated areas, even if one takes future migration into account.

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### 2. THE SNOW-RELATED HAZARDS

The genetics and occurrence of avalanches are extensively documented in the scientific literature and well known by the professional community (fig. 1). The genetics of slushflows is essentially different and more complex, but hardly discussed in scientific papers. The following summary should make up for a deficiency.



Figure 1: A slab avalanche has demolished a hut below a low hillside. (K Brattlien, NGI)

Slushflows – rapid mass movement of water-saturated snow – are normally released where a critical water pressure is attained in the snowpack due to rain and/or snowmelt. They are depending on a complex interaction between geomorphic factors, snowpack properties and the rate and duration of water supply. Slushflows released due to high cyclonic activity during autumn and winter, and intense snowmelt during spring break-up, occur seemingly at random, sometimes concentrated in regions of limited size. They occur in all countries and regions with permanent or seasonal



Figure 2: Unstable saturated snowpack. Snow depth 1.3-1.5 m. (E Hestnes, NGI)



Figure 3: Slushflow in motion. (A Ose, Ørsta)

snow cover (fig. 2-3) (Hestnes 1998, Hestnes and Bakkehøi 2004, Hestnes and Kristensen 2012, Onesti and Hestnes 1989).

Slushflows are often misclassified as avalanches or debris flows, despite their obvious differences in release mechanism and flow dynamics. Their genesis and behaviour is, however, to some extent comparable to that of debris flows (Norem 2014).

Regions exposed to cyclonic activity during autumn and winter are particularly prone to slushflows. They are often disregarded in hazard evaluation with dire consequences for both people and infrastructure (Abermann et al. 2017).

Slushflow releases during spring and summer break-up are especially frequent in Arctic, cold continental and mountainous regions throughout the world and some can become very large. Reported consequences of slushflows from these

sparsely populated regions are few, but certainly underreported.

The sparsity of information on slushflow occurrences is partly because the phenomenon does not have a unique term in national languages (Hestnes 1998, Onesti and Hestnes 1989). In the media and the literature, slushflows are often classified as wet snow avalanches, rain-on-snow events, floods, debris flows or described by names only known to the local population.

Slushflows often entrain varying quantities of mineralogical material, topsoil and trees. The deposits in those cases may look dark gray or black in melting periods. Such events are often misclassified as debris flows or earth slides (fig. 4-5). Occasionally, events of rapid mass movement involving snow might even be difficult to classify into a single category at all, when the flow pattern and the dominant character of the mass changes along the path (fig. 6).

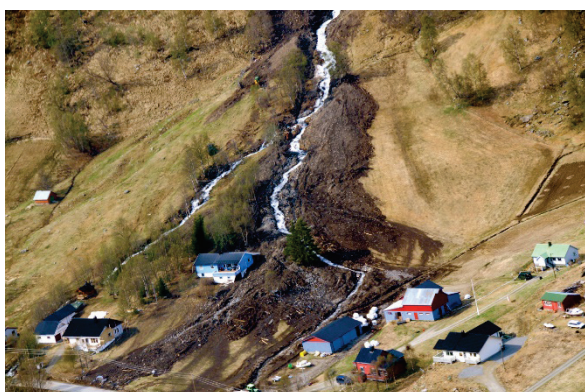


Figure 4: Dirty deposit of slush has reached a housing area far below the snowline. (Taurisano, NVE)



Figure 5: The vertical cut in the flank of this deposit shows that the masses consists of wet snow. (Frækaland, SVV)

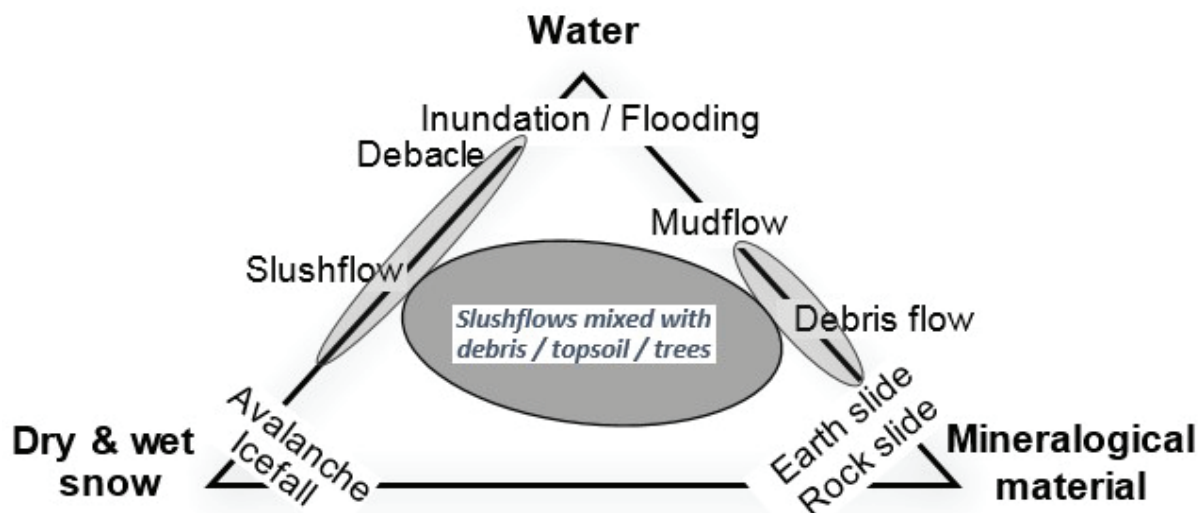


Figure 6: Classification of rapid mass movement.

### 3. CHANGING CONSEQUENCES TO HUMANITY

The occurrence and frequency of snow-related hazards varies widely throughout the world and changes are already being felt in regions affected by global warming. The question is how such changes may affect the consequences for humanity. The factors controlling release, frequency, size and runout, as well as land-use and migration, are keys to the future consequences. Experiences from mainland Norway and Norway's Arctic territories are the basis of our reflections (fig. 7).

In large parts of the cold continental and mountainous regions of the world, the snowline will progressively move to higher elevation due to rising temperature, the length of normal winter seasons will be shorter, and large parts of these regions will get less snow.

The tree line will creep uphill and reduce the potential size of starting zones and tracks where soil conditions are favourable and pasturing negligible. The general rise of the snowline will also reduce the potential runout of avalanches and slushflows, even though the starting zones remain the same. For example, will Central European countries experience a dramatic loss of their seasonal and permanent snow cover, and countries and regions worldwide may completely lose both snow and glaciers, including countries on the southern hemisphere (fig.8) (Schoeneich and de Jong 2009).

The massive impact of global warming in parts of the Arctic and in some continental regions have resulted in more snow by now, as well as slushflows in mid-winter due to heavy rain and snowmelt. This dramatic shift in weather patterns is expected to continue and to harm human activity in these regions. Fortunately, most of these regions are sparsely populated. However, the settlement of Longyearbyen in the Norwegian Arctic is already seriously affected by these changes (Hansen et al. 2014, Hestnes et al. 2016).

Widespread occurrences of both avalanches and slushflows with extensive impact on human activity and infrastructure are rare. Such critical slushflow cycles have occurred only four times in northern and three times in southern Norway during the last one hundred years. Only one of these situations occurred due to intense snowmelt in spring. The other extraordinary situations occurred when extreme rainfall in mid-winter fell on a homogeneous coarse-grained snowpack developed over a long period with cold weather and persistent snow down to sea level (Hestnes et al. 2012).

Catastrophic avalanche cycles have a close to similar frequency in Norway and mainly registered in the same winters as the extensive slushflow periods. Contemporary events have occurred in periods of coarse-grained snowpacks and heavy precipitation. However, the avalanches have been released at different locations and higher elevations. Moreover, widespread occurrences of avalanches have occurred prior to extensive slushflow cycles in the same winter.

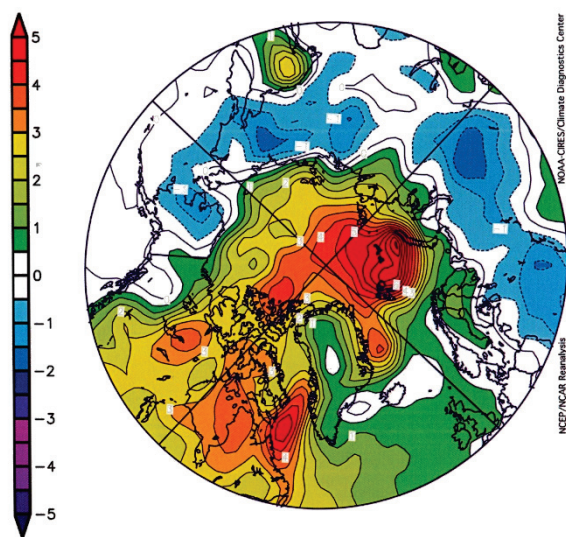


Figure 7: Warming of the Arctic is changing continuously (NOAA-CIRES/Climate Diagnostics Center).

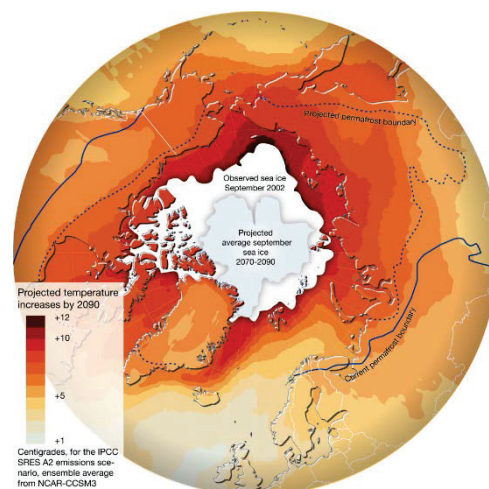


Figure 8: Projected temperature increase in the arctic for the period 2070 – 2090. (Data in the map are from NCAR and ACIA.)

Meteorological statistics from regions affected by cyclonic activity already shows a tendency towards more frequent cycling between rain and snow during the winter season. These oscillations cause more frequent slushflows of small volumes and limited consequences early in the winter season, but generally strengthen the winter snowpacks with hard crusts and icy layers, thereby reducing both the number of larger slushflows and avalanches in general. The statistics thereby indicate that extreme rainfall on homogeneous coarse-grained snowpacks will become rarer and their consequences will decrease.

#### 4. SUMMARY

For the Globe as a whole, there is a clear warming trend, but there are striking regional variations, with a few areas even showing a slight cooling, as well as unexpected changes of the global weather systems. In most places, winter temperatures are rising more rapidly than summer temperatures.

The occurrence of heavy rain-on-snow during winter will dramatically increase the potential of slushflows in parts of the Arctic and cold continental regions, while more snow and strong winds will increase the size and frequency of avalanches. Limited human activities in these areas limits the negative consequences of these changes.

Outside these regions, milder weather, shorter winters with less snow and rising snowlines will reduce the potential consequences of both slushflows and avalanches. Therefore, areas like the Alps and other populated mountain regions will

have a decreased risk due to avalanches and slushflows.

The potential hazard of slushflows and avalanches will shift away from populated regions. It is unlikely that expansion of settlements and/or human activity into areas with decreasing hazard will outweigh the hazard reduction. Other types of rapid mass movements will increase in the same populated areas. Consequently, global warming altogether reduces the impact of slushflows and avalanches on humans, while the total risk due to rapid mass movements will most likely increase.

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