SITE SPECIFIC AVALANCHE WARNING FOR SETTLEMENTS IN NORTHERN NORWAY: TWENTY YEARS OF THE NORTHERN NORWAY AVALANCHE SURVEILLANCE PROGRAM

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ABSTRACT: Northern Norway experienced an intensely snow rich winter in 1997 when settled snow heights reached a record 240 cm at the weather station in Tromsø on April 29th. Numerous avalanches, settlement evacuations, and two fatalities in a destroyed house in the settlement of Breivikeidet left the public exhausted at the end of the winter. The chaotic response to avalanche events during the season demonstrated the need for local and regional authorities to adopt a more proactive and coordinated approach to manage avalanche risk. Hazard mapping was initialized to gain an overview over the exposed settlements and to pinpoint the buildings at risk. At the same time, an avalanche warning service (Northern Norway Avalanche Surveillance; '*Nordnorsk skredovervåkning'*, NNSO) was established in the winter 2002/2003 by initiative of Tromsø municipality, the Norwegian Geotechnical Institute (NGI) in cooperation with Tromsø police office and the County Governor in Troms. Several other municipalities joined the initiative, and an inter-municipal organization led by Tromsø municipality was formed. At maximum, 16 municipalities encompassing 41 settlements from North Cape to Lofoten, a distance of 600 km, were covered by the warning system. The Meteorological Institute in Tromsø provided weather surveillance and NGI in Oslo supplied avalanche expertise. Meteorologists in Tromsø used threshold criteria in snowfall and winds to alert the avalanche forecasters in Oslo to provide an avalanche hazard assessment. The expert assessment relied heavily on local observers who assisted with daily snow height and new snow measurements and supply of profound knowledge of each settlement's avalanche history and local climate. If necessary, evacuations were enforced by the police, assisted by the municipalities. The system provided systematic risk management and a sense of safety for over 20 years. The simple setup of the system showed excellent performance over many years at minimal costs. In recent years, new methods, updated hazard maps, dataflow and establishment of regional avalanche warning have warranted revisions to the established system. After the resignation of Tromsø municipality as the project coordinator (2022), today only six municipalities remain in the system under the lead of Kåfjord municipality. They have applied for a regional research project to support the further development of the NNSO as they consider the system vital for the safety of their inhabitants. This project exemplifies how remote, resource-limited communities can develop simple and cost-efficient site-specific avalanche warning services.

KEYWORDS: Avalanche warning, settlements, risk management, municipalities.

1. INTRODUCTION

Northern Norway, consisting of Nordland, Troms and Finnmark counties, is dominated by mountainous terrain and deep fjords extending from the coast and inland (Figure 1). Over 15% of the land area is classified as avalanche release areas (steeper than 30 degrees) in Troms and 3% in Finnmark ("Høydedata," 2024). The climate in the area is dominated by the close vicinity to the Arctic Ocean. In winter, temperatures are usually close to zero degrees Celsius in coastal areas and rain can be expected at any point during the avalanche season due to the maritime climate conditions. Precipitation ranges from 750 mm annually along the coast at sea level to 1000 – 1500 mm at higher elevations. Valleys and fjords, shielded from the coastal weather, can receive as little as 300 – 600 mm annually. Further inland

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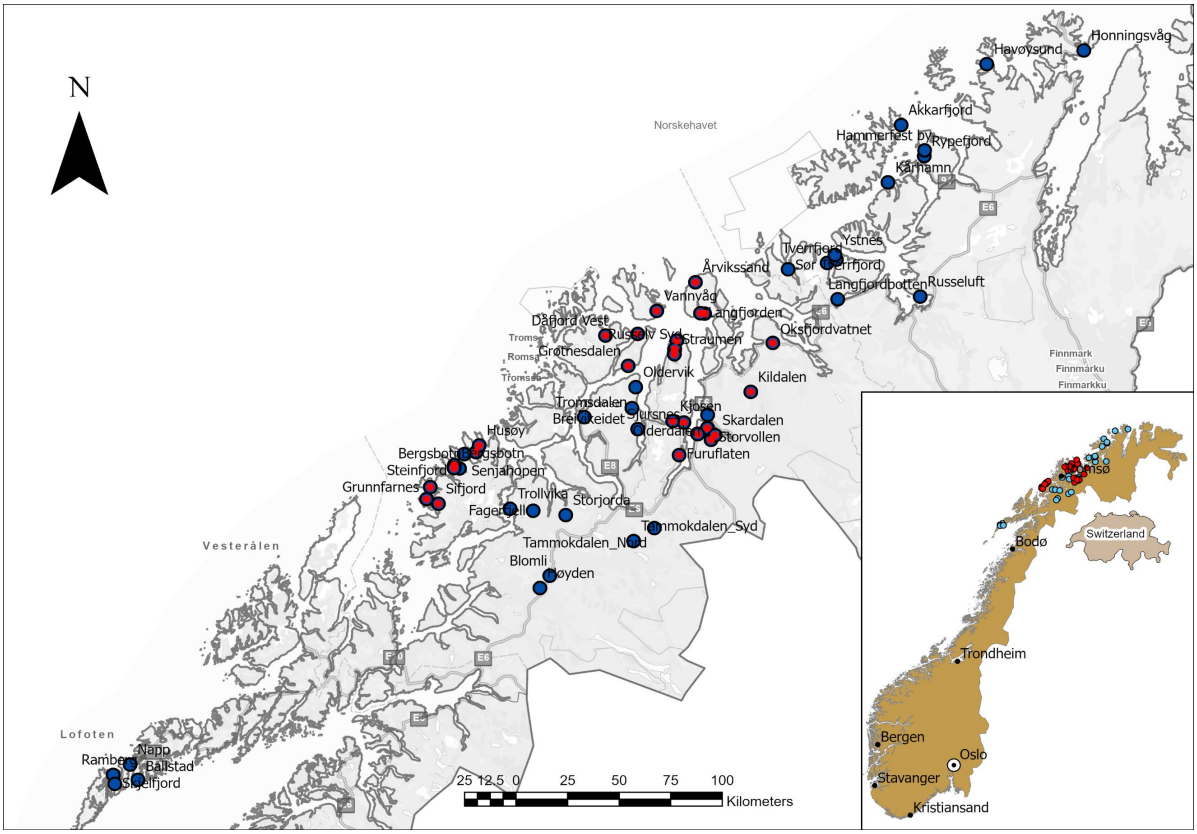

Figure 1: Overview of the areas that were included in the Northern Norway Avalanche Surveillance in the years 2002 – 2024. Active areas in the season 2023/2024 are marked with red points. The outline of Switzerland is shown for comparison.

and to the north, both temperatures and precipitation are lower. The lowest temperatures and precipitation values are observed in the continental parts of Finnmark (Norwegian Meteorological Institute, 2024). Here, the relatively flat topography yields only isolated avalanche terrain. A special phenomenon of the climate in this region are so called polar lows: small, rapidly-developing low pressure systems that can lead to high wind velocities and intensive snow showers (Noer et al., 2011). In several cases, polar lows have dumped a meter of snow within hours with a very high spatial variability. Until recently, weather prediction models had limited possibilities to resolve these systems. Modern models especially tuned for the Arctic front are better suited for the purpose and unpleasant surprises are now increasingly limited.

Humans have settled and lived in the area since the ice age (Stagg, 1952). The locations of the settlements along the coast were chosen based on the available resources of fishing, good harbors, reindeer herding and, in later centuries, trade and farming. Natural hazards, such as avalanches, landslides, rockfall, and tsunamis likely also factored into the selection and survival of settlement locations. As the number of inhabitants increased dramatically following the second world war (“Statistics Norway,” 2024), more hazard exposed terrain was taken into use, increasing the total number of buildings in avalanche exposed areas.

Several fatal avalanche accidents in settlements (e.g. Hammerfest 1950, four fatalities, the winter 1955/1956 with 21 fatalities only in March) during the post-war era led to some early mitigation measures, but inhabitants generally chose to vacate these locations instead of investing in mitigation.

The avalanche research group at the Norwegian Geotechnical Institute (NGI) was established in 1973. When deciding in which institution to locate the research, the Norwegian Parliament also decided that the operational avalanche warning for the country should be part of the Norwegian Meteorological Institute. While NGI worked with research on avalanche warning and assisted with warnings for selected areas, the Meteorological Institute issued avalanche warnings at danger levels four and five – levels that would have consequences for infrastructure and settlements (Meteorologisk Institutt, 2006).

With this operational context, Northern Norway entered the winter of 1996/1997 and experienced an exceptional amount of snow and a high number of avalanches.

The objective of this paper is to briefly describe the situation during the winter 1996/1997 and the resulting initiative to provide a site-specific avalanche warning system for the exposed settlements in the region.

2. THE WINTER 1996/1997

The winter 1996/1997 led to a record 240 cm of snow on the ground in Tromsø city, with considerably more in the region's mountains (Ryvold, 1997). The entire region fought the continued heavy snowfall and maintenance of public life and services became difficult. Several severe storms led to numerous avalanches, road closures and isolating settlements across the region. On January 10th, 1997 one house was destroyed by an avalanche close to Breivikeidet (Figure 2) with two fatalities. Several other locations (Vannvåg, Breivikeidet, Oldervik and Lakselvdal) had to subsequently be evacuated in a rather hasty action. Roads were already closed and evacuation had to be done by snowmobile or boat in severe weather (Wessel-Hansen, 2017). In total, 355 avalanches are registered from this winter in the region (The Norwegian Water Resources and Energy Directorate, 2024), of which only one resulted in damage to buildings (the avalanche in Breivikeidet). The reporting and documentation of avalanche events at that time was sparse and incomplete. Most likely many more events would have been registered with today's reporting standards (Jaedicke et al., 2009).

Figure 2: The accidents at Breivikeidet 10.01.1997 lead to two fatalities (Photo www.nordlys.no)

3. NORTHERN NORWAY AVALANCHE SURVEILLANCE PROGRAM

3.1 Beginning

After the winter 1996/1997 the head of municipal preparedness in Tromsø worked together with NGI on an approach for avalanche warning for the exposed settlements in Tromsø municipality. In the coming five-year period, this cooperation was intensified and formalized. With the experience of the 1996/1997 winter fresh in mind, the Tromsø police department was highly supportive of the initiative and pointed out that additional municipalities had avalanche exposed settlements. The interest in cooperation increased and the new county governor from Troms County worked actively to extend the service to other municipalities with exposed settlements.

According to the Norwegian law on municipal preparedness, the municipalities are responsible for the safety of their inhabitants and need to be prepared to manage any crisis situation for their population (Justis- og beredskapsdepartementet, 2011). The Police Act (Justis- og beredskapsdepartementet, 1995) states that evacuations can only be ordered and enforced by the police. Municipalities in Northern Norway are large in area but small in population; many encompass only some hundred persons. The events of winter 1996/1997 pointed out the need to join efforts to increase the populations' avalanche safety. Tromsø municipality, in which the Breivikeidet accident had taken two lives, and which is the largest municipality in Northern Norway, showed solidarity with the smaller municipalities and took the lead in an inter-municipal project to provide an avalanche warning system for the settlements. Each of the involved municipalities were obliged to identify the settlements and houses to be included in the project. In some areas these decisions were based on existing hazard maps, in other areas a need for new maps resulted in extensive mapping work in summer 1997 and 1998.

One crucial detail in the first development of the early warning service was to obtain lists of inhabitants in the exposed houses, their ages and their needs in the event of an evacuation. These lists of inhabitants are invaluable for the police and proved to be crucial for effective and safe evacuation efforts. During the evacuations in January 1997, two whole settlements were evacuated even when only a handful of houses were actually threatened by the avalanche hazard. The lack of inhabitant lists in that situation led to unnecessary evacuation of a large number of people and safe houses could not be used for local resettlement. Instead, everyone was evacuated from the settlements.

After five years of developments, negotiations and adjustments the official service was launched in autumn 2002. Twelve municipalities in Troms County, under the coordination of Tromsø municipality, entered into the project under the name Northern Norway Avalanche Surveillance; Nordnorsk skredovervåkning, NNSO. Project partners included the 12 municipalities, the Tromsø police department, NGI, the Meteorological Institute and

the county governor in Troms. The group of municipalities was later expanded to new members in Finnmark and Nordland Counties.

From the start, the early warning service was established as a temporary effort to increase societal safety and was only to be operational until physical mitigation was installed to provide more permanent protection of the exposed settlements.

3.2 *Warning service data and procedures*

In each of the included settlements, a snow observer and a local "person of knowledge" were appointed to provide daily reports on new snow and total snow height. The person of knowledge, with their extensive local knowledge, would serve as a discussion partner for NGI in conditions which required avalanche assessments. They also provided information for the inhabitant lists and kept an eye on the people present in the area in a given avalanche situation. Every morning, the Meteorological Institute in Tromsø used these data and the results from meteorological weather models to examine predefined weather thresholds (Table 1) for the coming 24 hours. If the thresholds could be exceeded for any of the observation points due to the wind and precipitation forecast within 24h, the meteorologist on duty would have to contact NGI for an avalanche hazard assessment. For assessing the 72h precipitation one would use 24h+24h observed new snow height plus the 24h forecasted precipitation.

Table 1: Weather criteria used for alerting NGI for an avalanche hazard assessment

When the air temperature at sea level is ≥ +3 °C the last 12 hours, the snowpack is considered stable for the type of avalanches that can reach the settlements. Do NOT call NGI.			
When air temperatures are < +3 °C applies: NGI is to be contacted if the following precipitation/snow height values are reached at any of the observation stations in the surveillance region:			
Wind	**Precip. last 24 h**	**Precip. last 72 h**	**Precip. last 120 h**
< 20 m/s	>30 mm	>50 mm	>80 mm
> 20 m/s	>20 mm	>35 mm	>50 mm
Wind in m/s and precipitation in mm water equivalent or cm snow height. Wind velocities refer to average wind at two following observations at the stations Innhesten, Njunis, Kjølen or Himmeltind.			

When the criteria listed in Table 1 were exceeded, the Meteorological Institute would call the avalanche experts on duty at NGI and discuss the situation. NGI would then begin gathering information from all possible sources including weather stations, road reports and personal contacts to persons of knowledge in the settlements, snowplow drivers and others. The list of resources was constantly changing through the years as also other resources like webcams and official Varsom.no snow observers (Engeset et al., 2018) allowed more and more insight in recent years.

In addition, assessments could be triggered directly by the police and the municipalities, especially in cases when large avalanches in the vicinity of settlements were observed. The police were also obliged to report avalanche activity directly to NGI.

The resulting site-specific avalanche hazard assessment provided by NGI included:

1) Description of the request from the Meteorological Institute
2) List of the municipalities in focus
3) Description of the avalanche situation
4) Assessment of the probability of large avalanches that can reach settlements under surveillance.

An avalanche danger level according to the European avalanche danger scale was provided together with recommendations for mitigation measures.

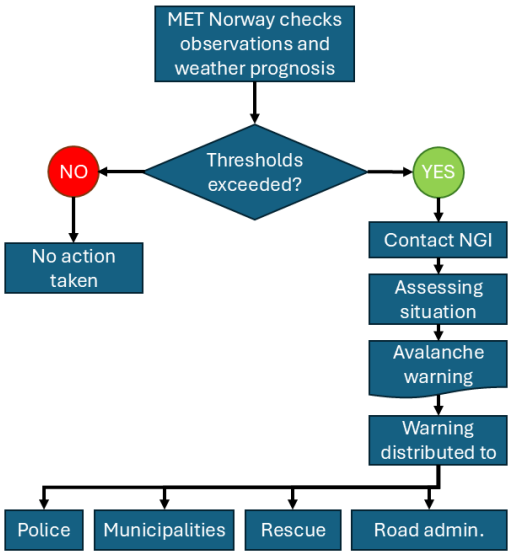

Figure 3: Flow chart showing the steps for assessment of the avalanche situation when the weather criteria were exceeded.

The assessment was sent to the police in Troms (Tromsø) and Finnmark (Alta), first by FAX, later by e-mail and SMS, followed by a phone call to ensure reception and understanding of the message. Figure 3 illustrates a flow chart for the procedures of the service.

In situations with a high probability that avalanches could reach the included settlements, the police would enforce an evacuation while the affected municipalities would provide support and alternative accommodation for the evacuated persons.

3.3 *Operation*

The early warning service for the municipalities was typically provided for the period between December 1st and May 15th. Observers and local

"persons of knowledge" had to come into action each autumn with the aim of getting the whole system up and running in advance of the Christmas Holidays. In spring, the service was terminated in a mutual agreement between the involved partners, according to the weather and snow situation. As soon as no snow was left in the lowlands at the buildings, the service stopped since wet snow avalanches are not considered to be a problem in this context.

Tromsø municipality supported the administration of the early warning service with a 10% position for the 20 years from 2002 – 2021 until Tromsø decided to leave the project and pursue their own avalanche warning service.

During these 20 years, between 12 to 48 assessments were issued each winter, most of which concluded with a low probability for avalanches that can reach the settlements (Figure 4). Medium or high probability assessments would lead to possible evacuations. There is no full record of evacuations, but media reports indicate approximately 2-3 evacuations on average every year, mostly in Hammerfest, Honningsvåg, Oldervik and Breivikeidet.

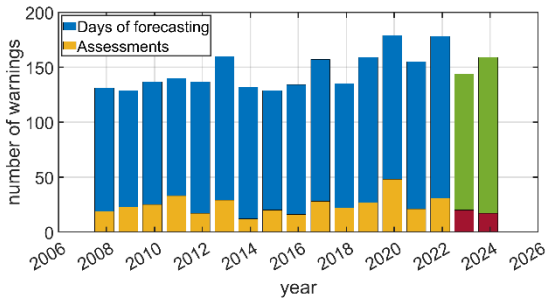

Figure 4: Number of days with forecasting and number of issued assessments during the years with continuous records in the project. The last two bars refer to the period with a reduced number of municipalities after 2022.

3.4 Further development

After the project became operational in 2002, the preparedness officer for the counties of Finnmark and Nordland urged other municipalities to join the NNSO. Some settlements were also withdrawn from the service due to abandonment of at-risk locations or construction of physical mitigation. In 2007, the National Public Road Administration joined the project group and two years later the Norwegian Red Cross joined as a resource for observations and during evacuations. From the season 2012/2013, The Norwegian Water Resources and Energy Directorate (NVE) has supported the NNSO with a grant that should cover approximately 50% of the costs. In 2013, the regional avalanche warning service Varsom.no started to issue regional avalanche warnings on a daily basis (Engeset, 2013). This improved the overall understanding of the regional avalanche situation and introduced formalized avalanche and snow observations that provided a significantly higher density of observations and insight into the snow and avalanche conditions in Northern Norway. Meanwhile, technical tools and open data access have changed the methodology and routines both at NGI and the Meteorological Institute. In the peak season of 2021/2022, sixteen municipalities and 41 settlements were covered by NNSO.

3.5 Evaluation

Waaler (Waaler, 2015) studied the organizational structure of the NNSO by interviewing stakeholders and reviewing the warning service against the backdrop of legal requirements of the municipalities and other inter-municipal projects. The results show that NNSO was a highly unique organization that included municipal, national and private partners. The partner municipalities transferred authority and trust to the coordinating municipality Tromsø. The project was therefore highly centralized and characterized by close teamwork between the Meteorological Institute, NGI and Tromsø municipality. The NVE evaluation in 2021 (NVE, 2021) was initiated based on a dialogue with Tromsø municipality about the possibilities of further improving the early warning system and a request for higher grants from NVE to cover increasing costs associated with the service. Interviews were conducted with some of the involved stakeholders, but major actors in the NNSO (e.g. Troms Police and the Meteorological Institute) were not considered in the evaluation. The evaluation concluded that NNSO is highly valued and considered mandatory for the safety of the exposed settlements. It pointed out many aspects of the service that ought to be improved, such as education of observers, increase of competency in the municipalities, in addition to new and improved modelling of avalanche run out scenarios, hazard mapping approaches and routines. Most of these points were highlighted earlier in Tromsø municipality's application for more financial support for the service.

3.6 Situation today

Following the NVE evaluation, Tromsø municipality left the project and Kåfjord took on the coordination with four other municipalities. After a fatal avalanches on Reinøya in 2023 (NVE, 2023), Karlsøy municipality joined and six municipalities are currently covered by the avalanche warning service. Tromsø and Honningsvåg have established independent systems. The situation in the other former member municipalities is unknown,

even though the number of exposed buildings there remains unchanged. Adjustments have been made in the warning service to meet the requirements of the European recommendations for site-specific avalanche forecasting (EAWS, The European Avalanche Warning Services, 2022). New hazard maps, financed by NVE, are available for many of the exposed areas and finally a complete GIS based overview of all included buildings was established for all six municipalities in spring 2024.

4. DISCUSSION

The avalanche warning service for avalanche exposed settlements in Northern Norway was established based on the experiences from winter 1996/1997 when no effective avalanche warning for infrastructure or settlements existed. Due to financial constraints of the small municipalities in Northern Norway, the warning service was developed with the idea that anything is better than nothing. Cooperation and solidarity between municipalities fostered a joint effort for the benefit of all involved municipalities. The system was designed to be simple, cheap and effective with a long list of possible improvements. One of the key weaknesses was the dependency on the local experience of NGI's avalanche experts. Many of the team that started the service in 2002 had detailed local knowledge of the terrain, climate and avalanche history from many years of field work in the region. With retirement of the original experts, a new generation of avalanche experts came in, but the project did not have the financial resources for site visits or to use modern modelling tools for the avalanche paths. The projects depended also highly on key persons in the municipalities, police and county governor. Even with the limited resources, the service was still developing from year to year, introducing new communication and GIS technologies to enable the new avalanche experts to keep track of the snow and avalanche situation in the North. The introduction of the regional avalanche warning service Varsom.no changed the boundary conditions significantly in 2013, but it was quite obvious for the municipalities and the police that the regional warnings did not provide sufficient information for the initialization of evacuations in the exposed settlements.

The findings from the NVE evaluation (NVE, 2021) show a clear way into the future for the NNSO with a list of recommendations for improvements of the service, many of which were suggested frequently already from the start of the service.

5. CONCLUSION

The described avalanche warning service for exposed settlements in Northern Norway is a low-budget solution that has improved the safety of the inhabitants significantly. Close cooperation between municipal, national and private actors delivered a systematic and satisfying solution for the problem at hand. The service developed continuously and included up to 16 municipalities in three counties. Involvement of local expertise and experience in the settlements lead to high local engagement and acceptance among the people living in the avalanche exposed areas. For the economic resources invested, the outcome for the municipalities and police was highly beneficial. The service can be significantly improved with investments in both local competency, technical solutions, mapping, etc. In the process of doing so, one must balance such investments with the actual needs and financial resources of the municipalities. Originally, the avalanche warning service was meant as a temporary mitigation measure until permanent physical mitigation is installed. Over 20 years later, only few settlements are protected by permanent mitigation and a site-specific avalanche warning service, such as NNSO, remains the best solution to increase the safety of the inhabitants of the exposed settlements.

ACKNOWLEDGEMENT

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