Arct-Risk Final Report

Photo: Holt Hancock

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Main results from the research project "Risk governance of climate-related systemic risk in the Arctic" (Arct-Risk)

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ArctRisk
Risk governance of climate-related systemic risk in the Arctic

Introduction

This report represents the main findings from the research project Arct-Risk (Risk governance of climate-related systemic risk in the Arctic), conducted in the period 2021-24. The project was financed by the Norwegian Research Council's Polar Research Program (POLARPROG). The Norwegian University of Science and Technology (NTNU) had the project lead and carried out the project in co-operation with an interdisciplinary group from the University Center in Svalbard (UNIS), the University in Stavanger (UiS), NTNU Societal Research and SINTEF.

Longyearbyen with structural snow avalanche protection measures (Photo: E.Albrechtsen)

To understand and adapt to climate changes is one of the greatest challenges society is facing today. The main objective of Arct-Risk is to develop knowledge and tools that can help society understand and handle the effects of climate changes on social security

Structural protection measures at Sukkertoppen (Photo: E. Albrechtsen)

Management of snow avalanche risk in Longyearbyen, a town in the Arctic that is experiencing climate change faster than many other places in the world, has been the main case for the project. The project was conducted in collaboration with local actors: Longyearbyen Local Government, the Governor of Svalbard, Telenor Svalbard, Skred AS, the Norwegian Water Resources and Energy Directorate Region North, Arctic Safety Center (UNIS), and Nordkapp Municipality. This collaboration has been the foundation of the project's research methodology, involving close cooperation between researchers and users to identify challenges, develop and implement solutions and measures, and evaluate outcomes.

The following two pages summarize the project's main findings and key lessons from climate adaptation in Longyearbyen. Subsequently, there is a description of snow avalanche risk and risk management in Longyearbyen, as well as a brief outline of the theoretical framework and research method. This is followed by a part 2 of the report that includes 11 short chapters present the main results of the project with links to more information.

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Main Results

- Demonstration of the *use of climate prognosis and data in risk governance*, where an important result has been breaking down climate data with appropriate resolution with regard to geography and time. Another important research activity has been communicating knowledge about *how changes in climate and weather affect natural hazards and thus society* in a way that makes the knowledge applicable for decision-makers and planners (chapter 1)
- *Raising awareness of uncertainty in risk governance related to climate change* through identification of various sources of uncertainty in handling of natural hazards in Longyearbyen, and descriptions of how these uncertainties can be managed and communicated (chapter 2)
- Development of a model and checklist for *assessing uncertainty in avalanche forecasting* that makes forecasters aware of the strength of knowledge behind the forecast and signaling further investigations to reduce uncertainty can be conducted. The method for uncertainty assessment is based on an evaluation of the avalanche forecasting in Longyearbyen (chapter 3 and 4)
- Identification of *uncertainty connected to development of structural protection measures* in the process of establishing slush avalanche barriers in Vannledningsdalen, connected with both the process of planning and the engineering. The study shows a need for raising awareness on uncertainty in various processes, as well as an involving approach to handle and communicate uncertainty (chapter 5)
- Explanation of the significance of *local knowledge in avalanche warning systems*, and an understanding of various dimensions of local knowledge (chapter 6)
- Explanation of the significance of *considering tacit and relational knowledge in public acquisitions* like avalanche warning services (chapter 7)
- Understanding of how *shared risk understanding in situations of evacuation* can contribute to improved evacuation as a risk management measure against acute natural hazards. Particularly related to how different actors can communicate more effectively during evacuations through shared risk perception (chapter 8)
- Description of *how sensor technology can be used as part of systems for natural hazard warning systems,* such as snow avalanche warnings, through documented experiences in the development and use of sensor systems in Longyearbyen. Additionally, a risk-related discussion on the suitability of sensor-based warning systems compared to permanent physical measures (chapter 9)
- Understanding of *how municipalities can adapt to rapidly changing climate conditions through a combination of short-term preparedness and long-term planning*, including managing uncertainty and continuously updating risk assessment (chapter 10)
- Development of a *climate adaptation indicator* for raising awareness, evaluating and monitoring the work with climate adaptation at the local level (chapter 11)

Lessons learned from Longyearbyen

Five key findings from Arct-Risk for future climate adaptation

Longyearbyen is experiencing climate change faster than most other places in the world. Knowledge about how climate adaptation is planned and implemented in the town is therefore crucial for future climate adaptation both in Longyearbyen and elsewhere globally. The research results from Arct-Risk points to five main themes that are transferable to other locations:

1	**Climate forecasts and -data with appropriate resolution**. Climate forecasts must be broken down into suitable temporal and geographical units to make them applicable in risk assessments and planning efforts. In Arct-Risk, we have demonstrated this by decomposing climate data for Svalbard into units that made them useful in risk assessments, e.g. through scenarios for Longyearbyen over different time periods. Another significant result has been knowledge-based descriptions of how climate change impacts natural hazards and, in turn, society, in ways that make this information actionable for planners and decision-makers.
2	**Identification and management of uncertainty.** Climate adaptation involves measures to handle future climate-related natural events that is associated with uncertainty regarding frequency, location, and magnitude. In Arct-Risk, we have identified uncertainties in various phases of risk governance and how these uncertainties can be handled. Methods for identifying and handling uncertainty will enhance climate adaptation work and the handling of natural hazard events.
3	**The significance of local knowledge in different aspects of handling climate risk**. Utilizing local knowledge in various parts of climate adaptation and in systems for handling av natural hazard events will improve risk understanding and thereby greater ground for decision-making. In Arct-Risk we have research results which show the significance of 1) use of local knowledge to understand the climate changes and their impact on society, 2) local knowledge as one of the foundations for developing permanent mitigation measures, 3) local knowledge as information for warning systems (forecasters on the mainland need «eyes in town», but also linked to local knowledge and history about avalanches) and 4) local knowledge as a criterion of evaluation during contracting of critical societal functions.
4	**Sensor-based warning systems for handling natural hazards and climate change.** Over the past decade, sensor technology has been developed and implemented to measure snow depth as part of the avalanche warning system in Longyearbyen. In Arct-Risk, we've documented experiences with developing and using sensor-based warning systems as a flexible and cost-effective solution that can be implemented rapidly as an alternative before and during the establishment of permanent measures, as well as an alternative to permanent measures. Increased use of sensor-based warning systems can be expected in the future, making Longyearbyen's experience valuable for developing and deploying warning systems elsewhere.
5	**Indicators for evaluation of climate adaption**. In the project, we have developed a set of climate adaptation indicators in collaboration with Longyearbyen Local Government to provide local authorities with a status of the work with climate adaptation. Such systems for evaluating the status of climate adaptation work at local level are useful for raising awareness about and following up the systematic work with climate adaptation.

Content

Case: handling of climate changes and avalanche risk in Longyearbyen

Longyearbyen is located on what originally was a river delta, flanked by steep mountainsides on the east and west of Longyeardalen (valley), Adventsfjorden to the north, and glaciers to the south. At the center of the valley lies Longyear River, see picture below. Since its establishment in 1905, Longyearbyen has been exposed to various natural hazards: different types of avalanches, landslides, rockfalls, and flooding. With the significant climate changes in the Arctic, the Longyearbyen community faces new challenges in managing climate risks and ever-changing natural hazards.

Overview picture of Longyearbyen, taken from the North (Photo: Knut Øien)

The annual mean temperature in the Arctic has risen nearly four times faster than in the rest of the world since 1979 (Rantanen et al., 2022). No other place on Earth has experienced such a significant increase in annual average temperature as the part of the Arctic where Longyearbyen is located. Climate change brings, in addition to rising temperatures, more precipitation, both rain and snow. This is expected to cause change in several of the natural hazards present in Longyearbyen.

Excepted changes of climate and natural hazards in Longyearbyen from the periode 1971-2000 to the periode 2071-2100 (Norsk klimaservicesenter, 2022):

- increased air temperature
- increased annual precipitation
- more frequent and intense events with heavy rainfall
- destabilization of near-surface permafrost
- changes in glacier area and mass,
- increased frequency for many types of floods
- and increased frequency for many types of avalanches and landslides

For example, one can already today notice the increased temperature through a series of record-breaking summer temperatures that influence natural hazards and the community. An example of an event related to this occurred in summer 2020, when high temperatures led to melting and flooding in the then-operational coal mine, Mine 7. During the winter season, changes in weather conditions are noticeable through rain episodes and mild periods. One can see a pattern of more frequent slush avalanches in the middle of winter—an avalanche type primarily associated with late winter on Svalbard previously.

As these examples show, Longyearbyen is experiencing, already today, how climate change affects occurrence and circumstance around natural hazard in greater degree than most locations in the world. ***This makes research on the handling of climate change impact on social security in Longyearbyen very relevant, with a big potential for transfer of experience to locations which have not experiences climate change in the same respect.***

Risk Governance

Society and sociotechnical systems cannot be viewed independently of nature. Together, climate change, natural hazards, infrastructure, societal functions, and the population form what we can call climate-related systemic risk. This systemic risk must be assessed, handled, and communicated through collaboration among multiple actors. In ArctRisk, we have adopted an ***interdisciplinary*** and ***risk-scientific approach*** to study how various actors have collectively created and utilized knowledge to make decisions in handling the risks posed by natural hazards and climate change to the Longyearbyen community.

The risk-scientific approach is based on a framework for risk governance, see Figure 1. The framework has been used as a theoretical model in several of the research project's activities. We have used the term governance instead of management to highlight that there are multiple actors who together assess and manage risk. The model is based on the International Risk Governance Council (IRGC) model for risk governance (IRGC, 2017) and ISO 31000 Risk Management. Additionally, the model is inspired by the Intergovernmental Panel on Climate Change (IPCC) model for climate risk management (IPCC, 2018), which distinguishes between strategies for managing natural hazard events in a short-term perspective and strategies related to climate adaptation in a long-term perspective. This is illustrated through the two feedback arrows above and below the boxes in Figure 1

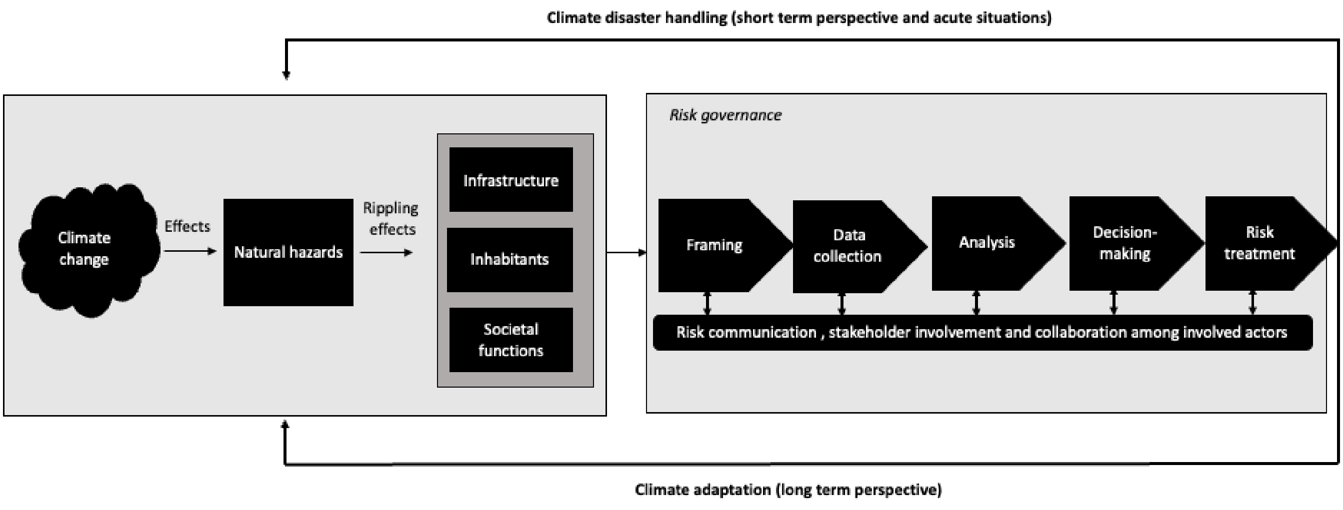

Figure 1: Risk governance framework

To the left in the figure is a box that shows how climate change, natural hazards, and key societal components together form a risk picture that must be managed through risk governance. Risk governance consists, as shown above, of six interrelated parts: delimitation/selection, information gathering, risk assessment, decision on measures, implementation of measures, and interaction/communication/participation.

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Read more about the risk governance model here

A relatively new concept that has received much attention in risk research in recent years, but also in practice in several industries, is uncertainty. ISO 31000 defines uncertainty as a state where there is a lack of knowledge about an event, its consequences, or the likelihood of its occurrence. In the risk-based approach in Arct-Risk, we have conducted **research to raise awareness of what uncertainty can entail, as well as developed methods to identify and manage uncertainty.**

Snow avalanche risk mitigation in Longyearbyen

In ArctRisk, we have limited the research on risk governance to avalanche risk. However, the results of the projects are transferable to other natural hazard management in Longyearbyen, such as flood protection of the Longyear River and the systematic work on monitoring the active layer in the permafrost. Avalanches of various types are not new in Svalbard and Longyearbyen. Several small and large avalanches and slush flow avalanches have occurred in the mountains surrounding the town. Twice, avalanches in the town have claimed human lives. In 1953, a slush flow in Vannledningsdalen took three lives, and in December 2015, two people died when an avalanche from the mountainside of Sukkertoppen hit eleven of the town's houses. In February 2017, another avalanche occurred, this time from the top of Sukkertoppen. Avalanches from the top of Sukkertoppen were not new, but it was new that the avalanche reached all the way to the settlement, causing material damage but no loss of life.

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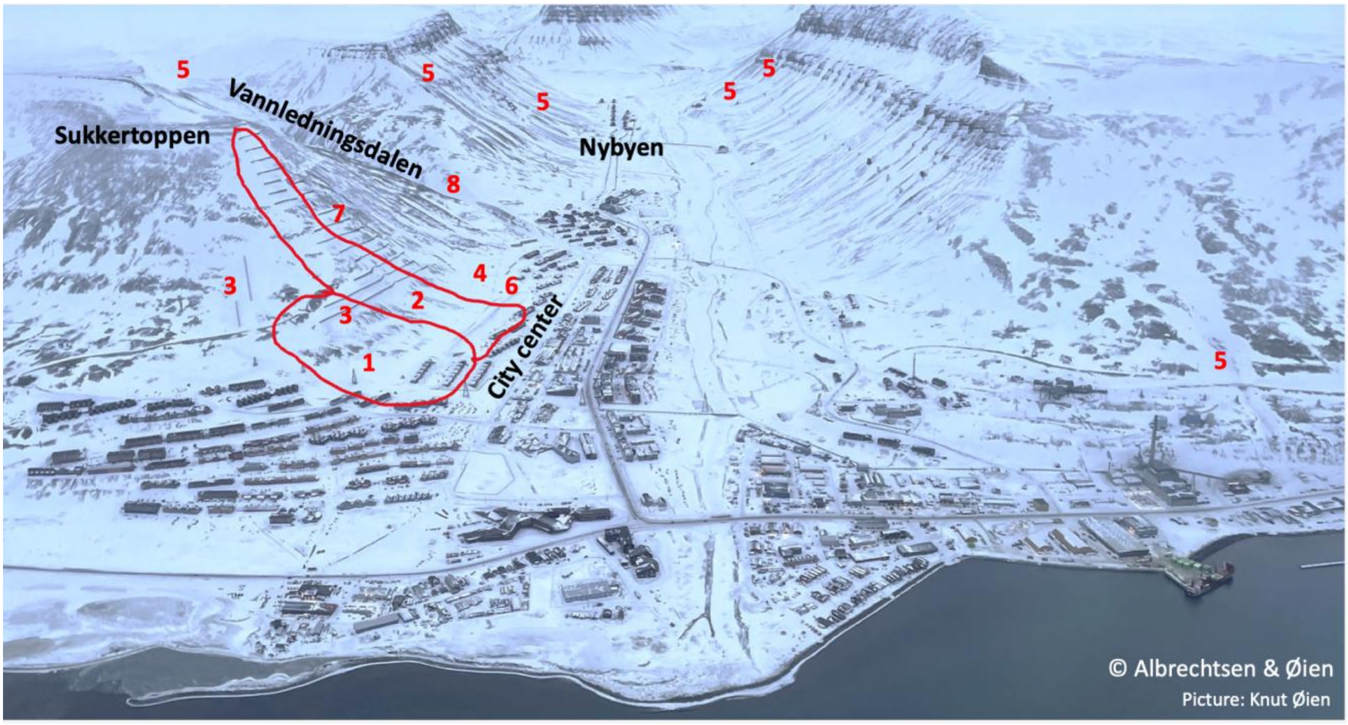
More on avalanche risk mitigation in Longyearbyen: Hancock et al (2024) and Albrechtsen et al (2024)

A common factor for the avalanches in 2015 and 2017 was abnormal and extreme weather conditions (DSB, 2015; Landrø et al., 2017). The day before the 2015 avalanche was characterized by strong winds from the east and heavy snowfall, in addition to a temperature increase from -12 to -2 degrees Celsius within 24 hours (Jonsson and Jaedicke, 2017). Before the 2017 avalanche, there was first a week of warm weather and heavy rain, followed by a week of cold weather, and in the days leading up to the avalanche, there was light snowfall and strong winds from the east (Jonsson and Jaedicke, 2017).

Before the 2015 avalanche, there was little systematic work on avalanche risk in the town, but as an immediate measure after the 2015 avalanche, a site-specific avalanche warning system was established (Hancock et al., 2024), which has continued every winter season since 2015 in the parts of the town not secured by physical measures. Planning and risk mapping to establish permanent measures began in 2016. The first permanent safety measures with snow fences and supporting structures were completed in 2018. Table 1 and Figure 2 on the next page provide an overview of the safety measures implemented since the 2015 avalanche.

Table 1 Chronological overview of avalanches and mitigation measures in Longyearbyen since 2015 (Albrechtsen et al., 2024)

No.	Year	Event/measure
1	Dec. 2015	Avalanche from Sukkertoppen hits buildings, 2 fatalities
-	2016-	Site-specific avalanche warning system established
2	Feb. 2017	Avalanche from Sukkertoppen hits buildings, no fatalities
3	2018	Completion of three supporting structures in the avalanche path of the 2015 avalanche, two snow fences, and a drainage ditch
4	2019-21	Relocation/removal of 140 housing units in avalanche zones, equivalent to 10% of the town
5	2019-	Stations with snow sensors established as part of the warning system, initially three sensors, later both five and six sensors in various locations
6	2022	Completion of a 400 m long and 5.5 m high catching dam
7	2022	Completion of a total of supporting structures in the avalanche path of the 2017 avalanche
8	2024	Completion of nets in Vannledningsdalen to manage slush flows



Figur 2: Overview of avalanches and mitigation measures in Longyearbyen (Albrechtsen et al.., 2024).

The avalanches in 2015 and 2017 has, in many ways, changed an entire town, including visible physical safety measures on the mountainside above the center. The permanent safety measures (snow fences, supporting structures, catching dam, and safety nets) secure the center of Longyearbyen. Other parts of the town are still in avalanche-prone zones: Nybyen, Sverdrupbyen/Huset (to the right of Nybyen in the picture above), and Skjæringa/Burmadalen (in the bottom right corner of the picture), as well as the road sections under Gruvefjellet and Platåfjellet (roads on both sides of the river from the center to Nybyen/Huset). For these zones, site-specific avalanche warning is still in place.

Avalanche Warning

Immediately after the 2015 avalanche, NVE established site-specific avalanche warning in Longyearbyen, initially by a consulting company contracted by NVE and later by NVE itself. Subsequently, avalanche warning in Longyearbyen has been carried out by several consulting companies contracted by NVE (Hancock et al., 2024). From 2024/25, it will be contracted by the Local Government, which has taken over responsibility for avalanche warning. The site-specific warning is performed daily, and in case of increased risk, a detailed avalanche warning is also issued. The warning is based on several information sources: weather forecasts, data from weather stations, webcams, data from snow sensors, and observations made by a local observation group. The warning then serves as input for decisions such as the evacuation of homes, which is carried out by the Governor in close cooperation with NVE.

Snow sensor Gruvefjellet. Photo: Eirik Albrechtsen

Snow sensor above Huset. Photo: Martin Indreiten

Since 2019, snow sensors have provided valuable input on snow depth for avalanche warning. The Arctic Safety Centre at UNIS, together with Telenor Svalbard, developed the sensors that were put into use. The first sensors were expensive, heavy, and power-consuming, while today's sensors are low-cost and energy-efficient. The snow sensor system in Longyearbyen and Honningsvåg has been an important part of one of the work packages in ArctRisk. **In ArctRisk, we have specifically researched uncertainty in avalanche warning, the role of local knowledge in warning systems, and how sensor technology can be used as part of warning systems.**

Supporting structures, catching dam and snow fences seen from the upper part of Sukkertoppen. Photo: Eirik Albrechtsen

Permanent measures

The permanent measures, that are clearly visible from town, prevent damage to infrastructure, buildings, and the population. Climate projections have been one of the knowledge bases in the development of the permanent measures and are thus a good example of risk governance of climate-related risk. **In ArctRisk, we have studied the development of permanent measures from a risk-scientific perspective, where the development of a knowledge base and the planning process in the Longyearbyen Local Council have been central.**

Research method

As described in the previous chapter, climate change and adaptation related to avalanches in Longyearbyen have been the main case in Arct-Risk. Longyearbyen has functioned as a "living lab" to:

- understand the impact of climate change on societal safety
- understand, develop, and test technological and organizational solutions for climate adaptation

Arct-Risk has been conducted as an interdisciplinary project combining theoretical backgrounds from safety science, engineering, meteorology, snow science, and sociology. An interdisciplinary approach has been important because successful risk management and adaptation to an uncertain future are not just about creating more scientific knowledge about the hazards themselves. Successful management and adaptation also require the ability and capacity to translate new knowledge about hazards and changes in hazard characteristics into action.

Data collection:

- Series of workshops with the local user group
- 38 interviews with various stakeholders related to avalanche management in Longyearbyen
- Observation studies of decision-making processes related to avalanche warnings
- Document studies
- Workshops with an international expert group
- Seminars/webinars to present and discuss results

Arct-Risk's methodological approach is inspired by action research, which is characterized by collaboration between researchers and users to define and solve problems, implement measures, and evaluate the measures. This approach has been successful for the knowledge created in the project. A success factor for this has been ***close cooperation with key stakeholders in Longyearbyen***: Longyearbyen Local Council, the Governor of Svalbard, NVE Region North, Arctic Safety Centre, and Telenor Svalbard. Representatives from these actors, along with representatives from Nordkapp Municipality, have formed a ***local user group***. Nordkapp Municipality has participated based on the use of snow sensors from UNIS. Evidence that this approach has worked can be found in ***various results that have been put into practice*** among these stakeholders, as described in the next chapter.

From workshop about uncertainty with participation from the local user group, November 2022 (Photo: Eirik Albrechtsen)

Impact

- One of the partners in Arct-Risk, Skred AS, uses an uncertainty checklist for avalanche warning (Chapter 4) developed in collaboration between the research group and Skred AS as a background document when conducting avalanche warnings.
- Longyearbyen Local Government has gained increased awareness of the status of climate adaptation work through our collaboration on the development of climate adaptation indicators (Chapter 11).
- The project, together with Longyearbyen Local Council, organized a "climate café" on June 6, 2023, with good participation from the residents of Longyearbyen. Arct-Risk contributed with meeting facilitation, a presentation on climate change, and a presentation on climate adaptation indicators. A good forum for sharing knowledge about climate change and adaptation.
- Dissemination of knowledge about climate change in Svalbard to various stakeholders, as well as making this knowledge available through webinar recordings, podcast episodes, and a user-friendly report.
- General awareness-raising about uncertainty in risk governance in the project's user group and through various communications about what uncertainty can be and how it can be managed in avalanche warning/mitigation in different forums.
- One of the project members has co-authored a chapter on Svalbard in the new "Climate in Norway Report" to be published by the Norwegian Water Resources and Energy Directorate in 2025
- The project has contributed climate data to the Governor of Svalbard's Risk and vulnerabilty analysis 2022.
- Project members participated in the implementation of the mining compancy Store Norske's climate risk assessment 2022, including the development of climate change scenarios based on our knowledge of climate forecasts and data.
- Educating tomorrow's experts: application of research results in master's courses at the Arctic Safety Centre, UNIS. In addition, 12 master's theses (completed by 17 students) have been written in connection with Arct-Risk. See Chapter 13.
- Arct-Risk is described in the Norwegian government’s white paper No. 26 (2023-24), "The Svalbard White Paper," as a good example of a research project in Longyearbyen with direct relevance to Svalbard, and where the results have been applied locally.

«Climate café» i collaboration with the Longyearbyen Local Government, June 2023. (photo: Albrechtsen)

PART 2

Summary of main findings

Foto: Holt Hancock

ArctRisk

Risk governance of climate-related systemic risk in the Arctic

1 Climate changes at Svalbard

Background

The climate in Arctic regions is changing rapidly. According to Rantanen et al. (2022), the annual mean temperature in the Arctic has increased almost four times faster than the rest of the world since 1979. The exact figures of change vary between time periods, seasons, and regions within the Arctic, but all studies indicate that climate changes are greater in the Arctic than in other parts of the world. This strong warming of the Arctic compared to the rest of the world is called "Arctic amplification." Generally, the warming of the Arctic is strongest in winter and especially in the European part of the Arctic, i.e., the areas around Svalbard. This rapid regional warming is largely due to the melting of sea ice. In the summer, less sea ice means less reflection of solar radiation, and thus more heat ends up in the ocean. In winter, there is no solar radiation and thus not the same effect, but less sea ice will lead to increased heat loss from the ocean (the sea ice acts as an insulating "blanket"), which in turn warms the atmosphere. In this way, the loss of sea ice contributes to Arctic amplification, and this is particularly evident around Svalbard.

Purpose

Research activities to:

- understand observed climate changes in Svalbard and extreme weather events in Longyearbyen
- increase knowledge about expected climate changes in Longyearbyen
- apply climate forecasts in risk assessments
- disseminate knowledge about climate change to various stakeholders

Results

Observed climate changes at Svalbard today:

- Increased annual temperatures have been documented at measurement stations on the west coast of Svalbard and in Longyearbyen from 1980 to the present. This increase is especially noticeable in winter.
- Increased precipitation at measurement stations on the west coast of Svalbard and in Longyearbyen.
- More of the precipitation today compared to the 1970s falls as rain instead of snow at measurement stations on the west coast of Svalbard and in Longyearbyen. This is especially true for the winter season.

Expected climate changes at Svalbard

Global climate models are run with relatively coarse grids of 100-150 km. To better understand regional and local changes, these models need to be downscaled, which is done, for example, through the international CORDEX (Coordinated Regional Climate Downscaling Experiment) initiative. To study future climate changes in Svalbard, we used data from the Arctic part of CORDEX (Arctic CORDEX). This is the same data used in the "Climate in Svalbard 2100" climate report from the Norwegian Climate Service Center (NCCS), but we have looked at this data with higher temporal resolution than NCCS, by dividing it into 5-year periods up to the year 2100. We have focused especially on temperature and precipitation conditions for Longyearbyen in winter (when climate changes are strongest). Figure 3 shows the results for the distribution of temperature. A clear warming trend is seen over the studied period (for December-February), and at the same time, the number of extremely cold days decreases over time.

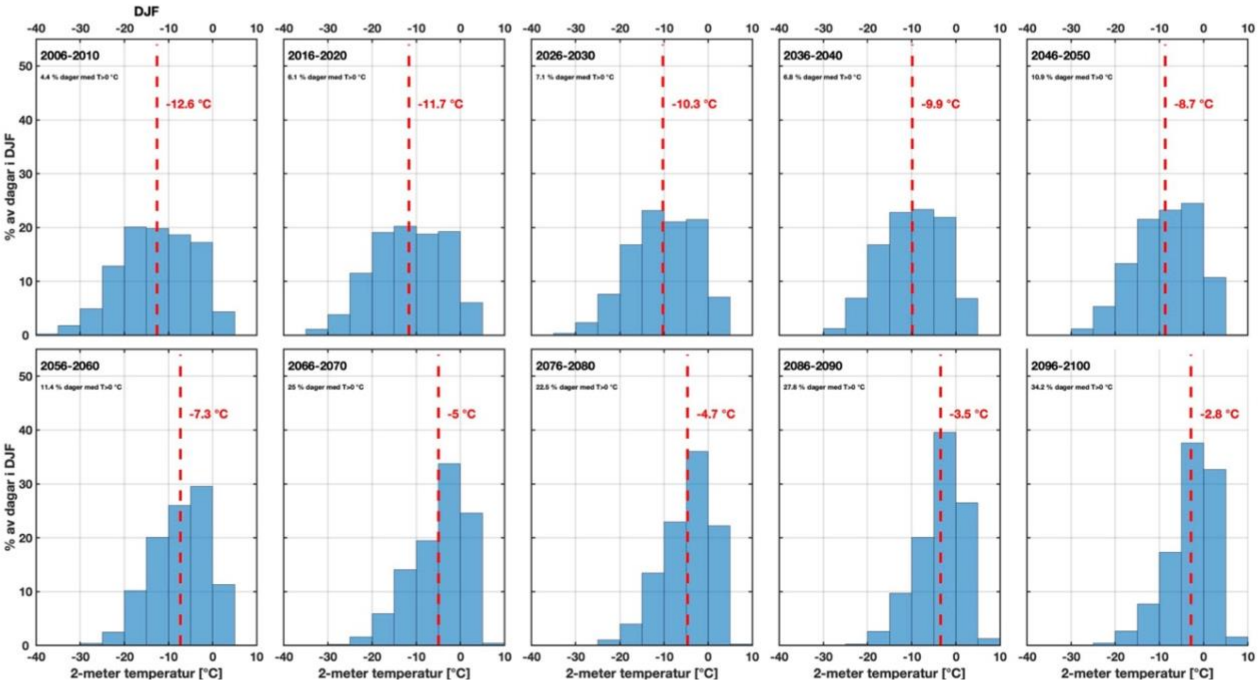


Figure 3 Distribution of temperatures in the winter season in 5-year periods from 2006 to 2100. The figure shows changes in variability, average winter temperature (red, dotted line), and % of days with temperatures above 0°C (text in the upper left corner).

Lesson learned

Climate change affects the Longyearbyen community through changes in natural hazards surrounding the town: avalanches, landslides, rockfalls, floods, and erosion, which in turn can impact infrastructure and functions in the town. More natural hazard events are likely in a warmer and wetter climate. Knowledge about climate change and its impact on the local community is therefore necessary to understand and manage the risks associated with these changes.

For use in risk assessments, it is useful to have climate forecasts with high (fine-grained) geographical resolution and short time periods. Today, many climate forecasts are described for large geographical areas and over a long time perspective up to the year 2100. In 2022, Arct-Risk collaborated with Store Norske on their climate risk assessment. An important contribution from Arct-Risk was to establish scenarios for climate change in Longyearbyen for short, medium, and long term, which were used to identify events and analyze the risks associated with them.

Table 2: Climate Scenarios for Longyearbyen for Use in Risk Assessment

Scenario 1: short term (0-5 years)	Scenario 2: medium term (6-25 years)	Scenario 3: long term (25-50 years)
- Climate change will continue, and warmer and wetter weather is expected. - There will still be sea ice around the archipelago in winter, but with great variation from year to year. - Increased glacier melting will continue. - Likely to continue with more frequent heat records. - Snow seasons will be shorter, but we may experience increased snowfall during certain storms. - Moving towards a "Tromsø-light" climate in terms of precipitation. - Extreme scenario: although the climate will generally become warmer and wetter, there will still be rare winters without rain on snow. These "old-fashioned Svalbard winters" will have a probability of 1/50 years and 1/100 years.	- The climate will continue to change and become more like the climate in Tromsø. - Spring will change the least, and there will still be ice around the archipelago, but the ice will not be stable and will come and go. - There will be great variation from year to year. - It is likely that we will experience the first completely ice-free summer in the Arctic, meaning we will only have one-year ice that is not as resistant to storms and warm ocean water. - Winter temperatures between -10 and -5 °C will become common, while temperatures below -15 °C will become extremely rare. Long cold periods will disappear or become extremely rare. - Extreme scenario: although the climate will generally become warmer and wetter, there will still be rare winters with rain. In these extreme scenarios, there will be at least 5 days of rain in the winter season, with a probability of 1/50 years and 1/100 years.	- Climate changes in all seasons. - Extreme years may have an average temperature above zero degrees, and the snow cover will no longer be continuous. - There will be more melt-freeze cycles throughout the winter, which will become an annual phenomenon. - Winter temperatures will vary between -20 and +10 degrees, with an increasing number of days with temperatures between 0 and 5 degrees. - Extreme scenario: Precipitation amounts equivalent to today's Tromsø or a place in Rogaland. Under such conditions, a single warm precipitation event could cause all the snow to melt.

Why is this a lesson for managing climate change?

Since climate change has already affected the Longyearbyen community to a much greater extent than mainland Norway, all results from Arct-Risk will provide valuable insights for preparing and understanding future climate adaptation on the mainland. Specifically, from the activities Arct-Risk has had on weather and climate, one lesson is that breaking down climate forecasts into appropriate time and geographical units is beneficial. For conducting risk and vulnerability analyses (ROS), it is advantageous to use a shorter time frame rather than looking, for example, all the way to 2100. The latest versions of the Governor's ROS analysis both utilized insights on climate projections from Arct-Risk in their assessments of natural hazards. We contributed to developing scenarios for Store Norske's climate risk assessment in 2022. Additionally, Arct-Risk has contributed knowledge to a new Svalbard chapter in NVE's new climate report coming in 2025.

More information

Wickström, S & Jonassen, M (2023) «Klimaendringer på Svalbard nå og i fremtiden» Report (in Norwegian)

Wickström, S. (2022) "Arktisk meteorologi og klima» Webinar (in Norwegian)

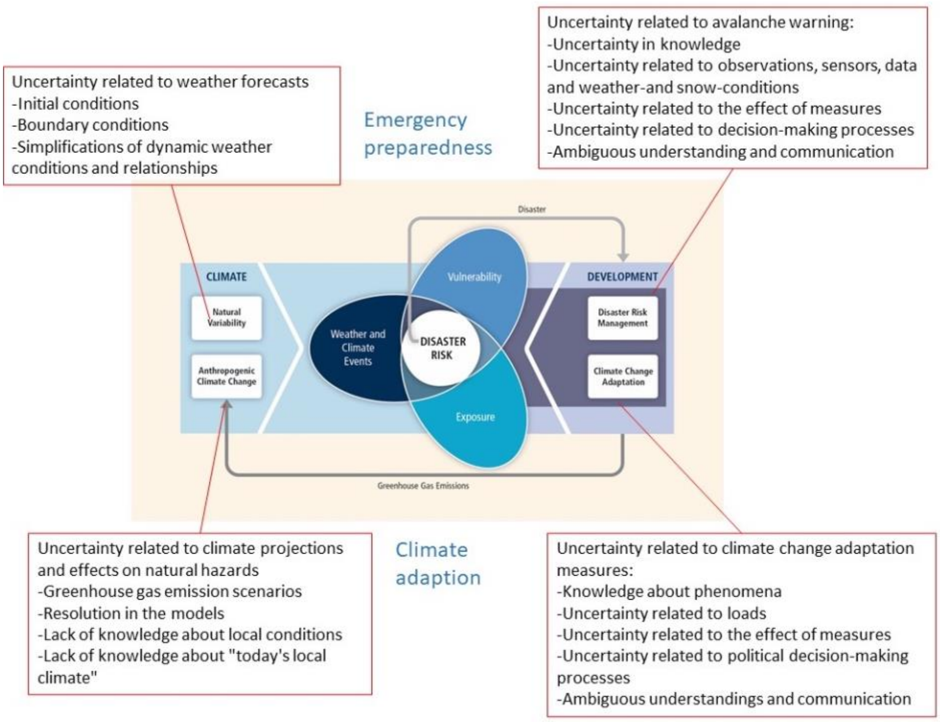
2 Uncertainty regarding risk management, natural hazards and societal security

Background

Since the turn of the millennium, there has been increased attention on expressing risk by using uncertainty as one of the parameters. For example, ISO 31000 "Risk Management" defines risk as "the effect of uncertainty on objectives," where uncertainty is a state where there is a lack of information, lack of understanding, or knowledge about an event, its consequence, or the likelihood of its occurrence. November 1-3, 2022, Arct-Risk organized a workshop on uncertainty related to risk management, climate change, natural hazards, and societal safety. The purpose of the workshop was to create and share knowledge about uncertainty related to risk management, natural hazards, and societal safety. The workshop had physical and digital participation from Icelandic Met, Longyearbyen Local Governement, The Norwegian Meteroligical Office, Nordkapp Municipality, Norwegian Climate Service Center, The Norwegian Water Resources and Energy Directorate, Skred AS, Norwegian Public Roads Administration, Telenor Svalbard, NTNU, NTNU Social Research, SINTEF, UiS, and UNIS.

Main Sources of Uncertainty Regarding the Management of Natural Hazards in Longyearbyen

Figure 4 shows the uncertainties identified and discussed in the workshop based on the IPCC (2012) conceptual framework for climate risk. The text boxes above the figure show uncertainties related to the short-term management of natural hazard events. These are related to weather forecasts and avalanche warnings. The text boxes below the figure show uncertainties related to the long-term management of risk (climate adaptation). These are related to climate forecasts and climate adaptation measures. These uncertainties will, in turn, affect knowledge related to natural hazards and how natural hazards, in turn, affect societal safety.



Figur 4: Overview of sources of uncertainty

Management and Communication of Uncertainty

Based on presentations and discussions in the workshop, the management of uncertainty can be categorized into four main types:

1. *Highlighting and raising awareness of uncertainty to decision-makers and other stakeholders:* Highlighting uncertainty leads to awareness of uncertainty among those who create decision-making bases, decision-makers, and other stakeholders. One way to highlight uncertainties is to categorize the sources of uncertainty, which can be done in various ways. An example is categorization according to climate conditions, natural hazards, society, and risk-reducing measures. Three ways to communicate uncertainty are: 1) specify uncertainty, 2) explain uncertainty, and 3) summarize uncertainty.
2. *Gathering more knowledge:* Several suggestions were discussed in the workshop to reduce uncertainty by gathering more and better knowledge. For example, by involving local actors to contribute input to more tailored climate profiles and facilitating more data collection related to natural hazards in Longyearbyen, also by including this in the Local Council's plans. It was further pointed out that access to all background documents, such as more detailed climate profiles, is an important source to increase knowledge strength for the development of climate adaptation measures.
3. *Precautionary strategy:* The workshop provided two examples of precautionary strategies to manage uncertainty. Uncertainty in the climate profiles' distributions on climate emission projections has been politically managed at the national level by choosing the "worst-case" scenario with the highest emissions (RCP 8.5) from the international climate report from IPCC. Thus, a precautionary strategy has been adopted that accounts for the worst possible outcome. In the design of the safety measures in Vannledningsdalen, uncertainty about how a future climate affects the measure has largely been managed by designing the net constructions with conservative design values. Additionally, it is recommended to follow up on assumptions made for the measures after they are implemented.
4. *Communication of uncertainty between experts and decision-makers and between decision-makers and affected persons*: Communication of uncertainty both between experts and decision-makers and between decision-makers and affected persons was also discussed in the workshop. For example, experiences from the landslide event presented at the workshop showed the benefits of being open about the knowledge base on which evacuation decisions were made. The example shows that in communication with those affected, it was useful to be specific about the information one had.

Lesson learned

The topic of uncertainty has been a recurring theme in Arct-Risk. The studies demonstrate that better understanding, mapping, and communication of uncertainty can improve society's ability to manage risks related to climate change and natural hazards. What are the key lessons from these activities?

- *Uncertainty can be reduced and managed* by systematically mapping the sources of uncertainty (such as the checklists for avalanche warning), using multiple data sources and model runs to improve forecasts (e.g., ensemble forecasts in weather prediction), and/or designing measures with safety margins (such as the safety nets in Vannledningsdalen).
- *Local knowledge is essential* in both avalanche warning and climate adaptation. Uncertainty can be reduced with input from local actors to improve the relevance and accuracy of measures. This applies to observations, assessments of measures, and communication with the local population.
- *Communication of uncertainty is key to building trust*. Experiences from studied evacuation situations in the project show that clear communication about both risk and uncertainty strengthens understanding and acceptance among those affected.

- *Need for continuous learning and adjustme*nt. The climate profiles and projects in Vannledningsdalen illustrate how measures must be based on updated knowledge and adjusted as more information becomes available.
- *Common language and tools strengthen the decision-making basis.* The use of standardized methods, such as the risk matrix and checklists, makes it easier to communicate complex issues across disciplines and between experts and decision-makers.

Why is this a lesson for managing climate change?

Future climate changes will be associated with a high degree of uncertainty – we know that the climate is changing but not how. More natural hazard events are likely to occur in the future, but we do not know how often they will happen and which events will occur. And we do not know what the consequences of such events will be. Identifying and managing uncertainty is therefore essential in systematic risk governance related to climate adaptation and the management of natural hazard events.

Further reading

Albrechtsen, E., Holen, S. and Wickström, S. (2023) Usikkerhet knyttet til risikostyring, naturfarer og samfunnssikkerhet. Workshop report (In Norwegian)

Albrechtsen, E. and Holen, S (2023) Identifying and managing uncertainty in governance of climate-related risk: Lessons from an Arctic society. Presented at ESREL 2023

Photo: Holt Hancock

3 Evaluation of local snow avalanche forecasting in Longyearbyen

Background

After the fatal avalanche accident in 2015, local avalanche warning was introduced in Longyearbyen. This warning was initially carried out by the Norwegian Water Resource and Energy Directorate (NVE). In 2017, another avalanche occurred in almost the same location, and after reviewing this accident, it was concluded that there was inadequate handling of uncertainty. From 2019, Skred AS took over the local avalanche warning in Longyearbyen and was responsible for it during the avalanche season 2020-2021, when the Arct-Risk project started working on evaluating the local avalanche warning. The evaluation also partly covered the avalanche season 2021-2022.


Photo: Martin Indreiten

Two types of local warnings are prepared for Longyearbyen: a daily warning and a detailed warning. The daily warning is prepared from November 1 to May 31. A detailed warning is prepared based on an assessment of the need for it in the daily warning. If temporary measures (yellow warning) or evacuation (red warning) are recommended, the Governor convenes an assessment meeting where measures are decided. Longyearbyen Local Council, NVE, and the avalanche warning service (which was then Skred AS) also participate in this meeting.

The evaluation was carried out in close collaboration with a local user group consisting of Longyearbyen Local Council (LL), the Governor of Svalbard (SMS), Telenor Svalbard AS, Nordkapp Municipality, Skred AS, the Norwegian Water Resources and Energy Directorate Region North (NVE), and the Arctic Safety Centre at UNIS. This particularly involved those responsible for the local warning (NVE and LL), those who prepare the local warning (Skred AS), contributors to the local warning (UNIS and Telenor), and users/decision-makers (SMS). Skred AS carried out the warning service on behalf of NVE, while UNIS conducted observations on behalf of LL. Additionally, UNIS collected data, such as snow depth measurements, via sensors developed in collaboration with Telenor. The sensor technology is described in more detail in a separate sub-project.

Objective

The main purpose of the evaluation of the local avalanche warning in Longyearbyen was to contribute to the best possible quality of avalanche warning, including highlighting uncertainty, as a basis for decision-making on measures. The focus was on the preparation and use of the local warning (now referred to as site-specific warning or site-specific avalanche path warning), and possible improvements, especially related to content and structure.

Practical improvement suggestions for the local warnings (daily warning and detailed warning) were based on a risk-scientific perspective, including the design of risk matrices and the communication of risk and uncertainty, without delving into the avalanche-specific aspects, such as snow cover profiles and the structure of the snow cover.

Results

The main result is a list of improvement suggestions related to:

- Uncertainty in detailed warnings
- Uncertainty in daily warnings
- The matrices in daily and detailed warnings
- The background documents
- Detailed warnings in general
- Daily warnings in general

About half of the improvement suggestions were aimed at better handling of uncertainty in the warnings. An overview of contributions to uncertainty in the various steps of the risk governance framework is shown in the figure below.

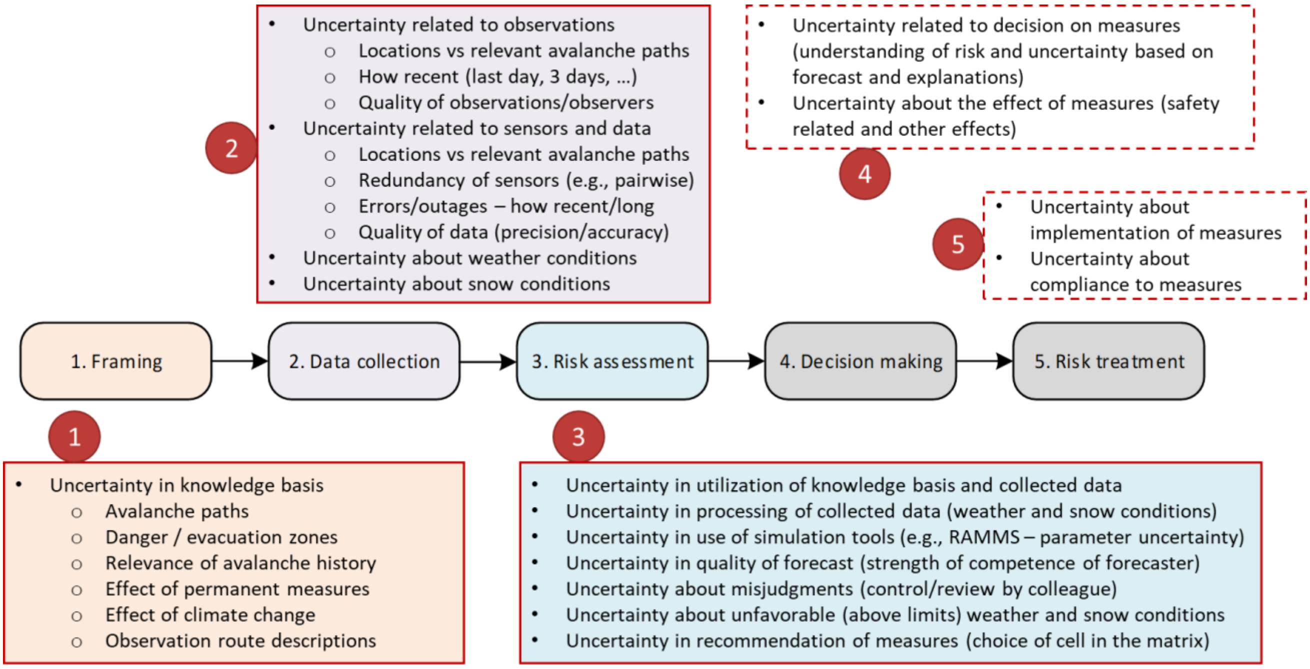


Figure 5: Uncertainty in avalanche forecasting

Lessons learned

The main conclusion was that the local avalanche warning system worked well and was perceived as appropriate. There was close and good cooperation between observers and forecasters, and information from observations was often directly reflected in the warnings to a much greater extent than in the regional warning. However, there is room for improvement in the local warning system. One of the challenges that was specifically addressed was the handling of uncertainty, partly due to the recommendation from NVE (after the avalanche accident in 2017) that the local warning system should take more account of uncertainty in the warnings. The work on handling uncertainty was continued in Arct-Risk through the development of an uncertainty checklist, as described in the next chapter.

The improvement suggestions were primarily aimed at the avalanche warning system in Longyearbyen, but many of the suggestions are generalizable and can be used in other local warnings. The report can also be used by NVE in the preparation of a general guideline for local warnings (site-specific warnings) in Norway.

Why is this a lesson for handling climate change?

Avalanche warnings are primarily weather-affected, and to a lesser extent – or more slowly – affected by changes in the climate, but there are some aspects that are important in terms of handling climate change. In the conclusions after the evaluation of the avalanche accident in 2017, NVE states, among other things: "To capture most dangerous situations, it is important to account for uncertainty. The climate is changing, and previous snow and avalanche history does not necessarily provide a complete picture of the current situation." Previous snow and avalanche history is included in a foundational document prepared by NVE, as a basis for selecting which avalanche paths should be covered by the avalanche warning system. This will gradually change over time due to climate change, and also as permanent measures are introduced for some of the avalanche paths. It is therefore important that possible changes in avalanche paths and types of avalanches (e.g., slush avalanches) are considered in the regular (annual) update of the foundational document. Observations and sensor technology must be adapted accordingly, for example, sensor technology suitable for slush avalanches.

Further reading

Øien K. & Albrechtsen E (2022) . Lokalt snøskredvarsel for Longyearbyen. Evaluering av nåværende system. SINTEF rapport 2022:01035. (In Norwegian)

Øien, K., H. Hancock, Indreiten, M. & Albrechtsen (2022). Evaluation of a Local Avalanche Forecasting System in Svalbard, Presented at ESREL 2022

4 Uncertainty checklist for avalanche forecasting

Background

The work on an uncertainty checklist builds on the evaluation of the local avalanche warning system in Longyearbyen and improvement suggestions aimed at better handling of uncertainty in the warnings. In the evaluation after the avalanche accident in 2017, the Norwegian Water Resource and Energy Directorate (NVE) directly points out the need for such a checklist: "The local warning must more clearly communicate the uncertainty in the assessments and the underlying data. A checklist should be introduced to highlight uncertainty."

Purpose

The main purpose of the uncertainty assessment is to make avalanche forecasters aware of weak knowledge in the warning and, based on this, consider further investigations to reduce the uncertainty, as well as to communicate this to decision-makers. A robust decision requires that decision-makers understand the uncertainties.

Results

The results consist of an uncertainty model and an uncertainty checklist. These are accompanied by guidance on definitions/explanations of each uncertainty factor and guidance on how to assess both individual uncertainty factors and the overall aggregated uncertainty. The uncertainty model and the uncertainty checklist with an example of use are shown below.

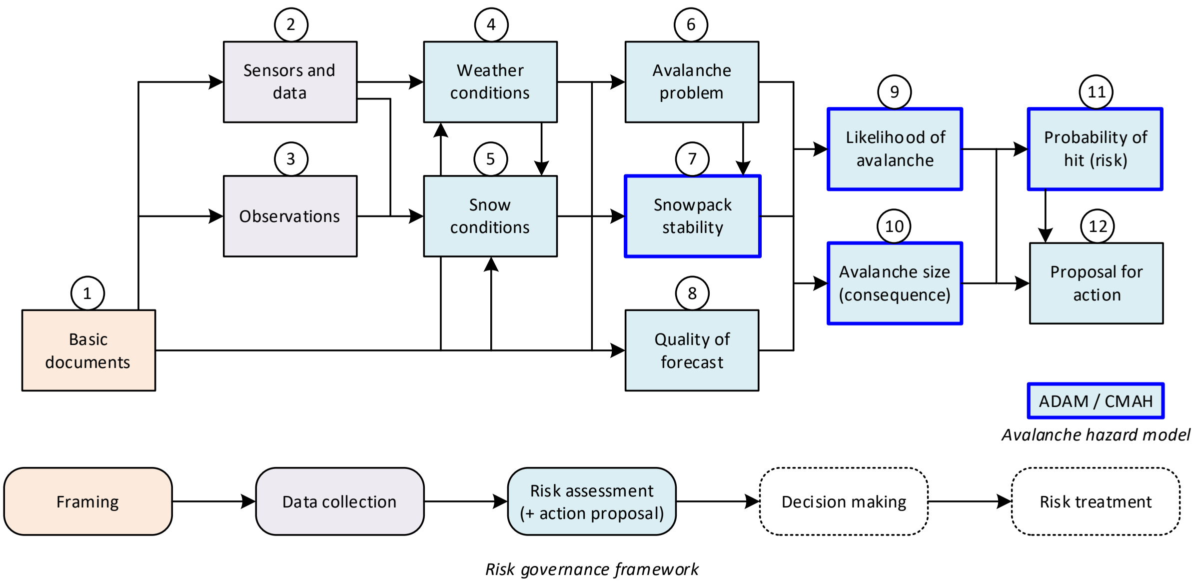


Figure 6 Uncertainty model for avalnche forecasting

The model consists of 12 uncertainty factors or sources, linked to the relevant steps in the risk governance framework, and boxes with thick blue borders indicate which factors are based on avalanche hazard models. The numbering follows the workflow of the avalanche forecasters.

The 12 uncertainty factors/sources from the uncertainty model are listed chronologically from top to bottom according to the workflow in avalanche warning, and they are grouped according to the first three phases of the risk governance framework. Each uncertainty factor is then assessed as low, medium, or high uncertainty by the forecasters. Factors with medium or high uncertainty must be specified (shown in blue text in the last column for the example in the figure). Finally, an overall uncertainty is indicated based on the assessments of the individual factors, both descriptively and by indicating low, medium, or high overall uncertainty. The uncertainty checklist therefore seeks to clarify what we know and what we do not know, and to what extent.

Uncertainty assessment				
UNCERTAINTY - Total assessment	**Low**	**Medium**	**High**	
The uncertainty in the warning is high due to a lack of observations and data, including snow depth. Uncertain avalanche size.			X	
FACTORS/SOURCES TO UNCERTAINTY	**Low**	**Medium**	**High**	**Specification (for Medium and High uncertainty)**
UNCERTAINTY IN KNOWLEDGE BASIS				
1. Basic documents		X		*Uncertainty about basic information on which wind directions that give large snow accumulation*
UNCERTAINTY IN COLLECTED INFORMATION				
2. Sensors and data			X	*Uncertain snow depth as the snow depth sensors are out of order*
3. Observations			X	*Few available observations (only blurred images)*
UNCERTAINTY IN ASSESSMENTS				
4. Weather conditions - nowcast and forecast	X			
5. Snow conditions - nowcast and forecast		X		*Uncertainty about which layer the avalanche loosens*
6. Avalanche problem - nowcast and forecast	X			
7. Snowpack stability - nowcast and forecast	X			
8. Quality of forecast	X			
9. Likelihood of avalanche	X			
10. Avalanche size (consequence)			X	*Uncertainty about avalanche size and runout length*
11. Probability of hit (risk)	X			
12. Proposal for action	X			

Figure 7. Example of filled out checklist

Lesson learned

We have developed an uncertainty checklist based on an uncertainty model, which is theoretically based on a risk governance framework, avalanche hazard models, and workflows for avalanche forecasters. To make it practically applicable, the scope of the assessment is balanced against the total time and effort required to provide an avalanche warning. It is also included in the avalanche warning template to make the uncertainty assessment efficient.

Some adjustments were made before testing, while the initial testing did not reveal any additional need to add or remove uncertainty factors. Further use may, however, lead to further adjustments, including guidance on definitions and evaluations, to make the uncertainty assessment less influenced by the subjective perception of each forecaster.

The checklist adds value to the forecasters in terms of awareness and reminder of the individual uncertainty factors that must be considered during the preparation of the avalanche warning, as confirmed during the initial test period. The checklist is also assumed to add value to risk owners in the form of more robust decisions.A major challenge in implementing the uncertainty checklist is the lack of incentives for the providers of warning services when price is the only criterion used to differentiate the providers.

Why is this a lesson for handling climate change?

Regarding the handling of climate change, the first uncertainty factor/source is particularly important, i.e., whether the foundational information is sufficiently updated concerning possible new avalanche paths and forms of avalanches, such as slush avalanches. Slush avalanches in winter are expected to increase as a result of climate change.

Further reading

Øien K, Albrechtsen E, Kronholm K, Nordbrøden H, Hancock H and Indreiten M.(2023) Uncertainty assessment and communication in site-specific avalanche warning – a model and a checklist. Presented at the *International Snow Science Workshops (ISSW) 2023*.

5 Uncertainty related to development of permanent mitigation measures

Background

While climate change affects the environment on a global scale, the consequences will be felt locally. To manage these changes, it is necessary to implement climate adaptation measures at the local level. Planning and implementing climate adaptation requires knowledge on multiple levels, including technical and social aspects. Uncertainty is an inherent part of such processes and must be considered when developing climate adaptation strategies. In Longyearbyen, climate change is noticeable with altered conditions for avalanches, and one of the climate adaptation measures is the construction of structural barriers for avalanches.

Purpose

The aim of the study is to identify how uncertainty is managed in the process of implementing an avalanche barriers in Vannledningsdalen, a side valley running out in the centre of Longyearbyen. In recent years, conditions for slush avalanches in this valley have changed, and previous preventive measures by removing snow can no longer be used. Therefore, it has been deemed necessary to prevent slush avalanches with protective nets. The study focuses on the planning process led by Longyearbyen Local Government and carried out in collaboration with NVE and the consulting group that designed the avalanche barriers, and is based on both document studies and interviews.

Results

Several sources of uncertainty have been identified at various stages of the process. These relate to, for example, the lack of inclusion of local knowledge and the population's expectations, design solutions that have not previously been used for slush avalanches, and impact assessments. The different actors in the process relate to the uncertainties in different ways. Although the authorities implicitly include uncertainty in the documentation, there is little explicit discussion of uncertainty in the documentation of the planning process. The consultants discuss uncertainty more explicitly in the design analyses. For the consultants, scientific uncertainties are the focus, while the authorities mention political decisions as the most important.

Lessons learned

The uncertainties identified in the study indicate a need for a more open discussions about uncertainty and lack of knowledge. A more open approach to including uncertainties could help identify more targeted strategies to manage them. Solutions for discussing uncertainties across disciplines are also necessary, although this is not an easy process. The study also finds that social aspects, such as citizen participation, are lacking.

Why is this a lesson for handling climate change?

In the future, it will be necessary to implement climate adaptation measures for various natural hazards such as floods and landslides, and uncertainties will be part of these climate adaptation processes. Becoming more comfortable with discussing uncertainties can be a tool for finding better solutions in future climate adaptation processes.

Further reading

Albrechtsen, E., & Holen, S. (2023). Identifying and Managing Uncertainty in Governance of Climate-Related Risk: Lessons From an Arctic Society. *Presented at ESREL 2023*

Holen, S. (in review) Climate adaptation and risk governance: a qualitative study on uncertainty during implementation of physical avalanche barriers in Longyearbyen

6 The significance of local knowledge in avalanche warning systems

Background

Climate change is altering the nature around us and the hazards it represents. Avalanches occur in new places and in new forms compared to what was common before. This means that assessing avalanche danger requires more than generic knowledge; it also requires knowledge about avalanches that can be contextualized with knowledge about local conditions. In avalanche research, there is a need for more understanding of how observers and forecasters use local knowledge in their warning work.

Purpose

The study aimed to enhance the understanding of the types and how local knowledge is applied when observers and forecasters work to understand avalanche risk in specific environments. The study focuses on sense-making and how local observers and forecaster work to make sense of various forms of information and data. We ask questions about what the ingredients of local knowledge are concerning avalanche warning and what role local knowledge plays in sensemaking.

Results

We use perspectives from the literature on sensemaking, sensework, and tacit knowledge to analyze and conceptualize the working methods and interpretation methods of observers and forecasters, and we do this in a way that allows for generalization beyond the specific cases in Longyearbyen.

Avalanche-related knowledge is closely linked to the observers' experiences with and exploration of the local geography and topography, not only in a professional context; observers are often outdoor enthusiasts who hike, ski, or guide others in the local area, thereby gaining valuable experience about local geography and topography. This is applied in avalanche forecasting work.

We have identified three different dimensions of local knowledge:

- situated, social knowledge (e.g., created in social interaction with other observers)
- embodied knowledge (e.g., 'feel for snow')
- synthetic knowledge (knowledge creation supported by sensor-based technology)

These dimensions of knowledge have implications for the development and operation of avalanche warning systems.

Lessons learned

The research results are not only significant for those who design avalanche warning systems and their organization, but also – and primarily – for people living in avalanche-prone areas. Avalanche warning depends not only on the quality of the warning itself, but also on the trust between the local population and the observers. Trust in risk assessments is strengthened by transparency in methodology and knowledge base, and the research results contribute to this.

It is also possible to draw lessons for purchasers of warning services. Their challenges are discussed in the next chapter

Why is this a lesson for handling climate change?

With climate change, we expect warmer, wetter, and wilder weather, which will increase the need for avalanche warnings in many places, including areas that have not previously been prone to avalanches. This also means that there will be a need for more avalanche observers in the future. The results of this study will, among other things, be significant for the quality of recruitment and training of observers.

Further reading

Johannessen, S., & Haavik, T. K. (2024). The role of local knowledge in snow observation and applied snow avalanche forecasting in Longyearbyen, Svalbard. Cognition, Technology & Work, 26(3), 417-433.

Foto: Martin Indreiten

7 The significance of considering tacit and relational knowledge in public acquisition of forecasting services

Background

The Norwegian public Procurement Act aims to promote the efficient use of society's resources while ensuring that public entities act with integrity so that the public has confidence that procurements are conducted in a socially beneficial manner. To ensure fair competition and to avoid favoring certain providers, the law places restrictions on public purchasers' interaction with providers, involvement in the service provider's work, and flexibility regarding contract adjustments after a tender competition is won. Furthermore, the law aims to prevent favoritism by stipulating that professional relationships developed between purchasers and providers during a contract period should not be considered in the competitive renewal of the contract. The Procurement Act generally also applies to safety-critical infrastructure, and thus includes the procurement of services related to avalanche warning.

Purpose

In this work, we explore the potential consequences of procurement regulations on service quality. We aim to highlight the importance of tacit knowledge developed through professional experience and relationship-building during the contract period, and how the procurement law affects the ability to emphasize such tacit knowledge in competitions. The avalanche warning system in Longyearbyen is a case in the study.

Results

The study identifies and describes various forms of knowledge that is applied within the framework of an avalanche forecasting service.

- *Situational knowledge among local observers* includes both individual expertise and knowledge developed through education and experience, as well as knowledge situated in the professional-social community developed among local observers.
- *Professional knowledge* includes generic and specific knowledge, organizational structures and routines, and the service provider.
- *Relational knowledge,* which concerns knowledge situated in the relationship between the forecaster and the local observers.

Lessons learned

Particularly, relational knowledge is difficult to manage within the framework of the procurement regulations. This is tacit and largely invisible knowledge in the context of contracts, and might thus being lost with each new contract round. This is not the intention of the regulations, but nevertheless a consequence of the tendency to 'commodify' services, i.e., specifying services as consisting of standardized and delimited tasks. The tacit knowledge we have described in this study resembles some of the characteristics associated with High-Reliability Organizations in the safety literature, and thus points to challenges in contracting for high reliability.

Why is this a lesson for handling climate change?

With climate change, we expect warmer, wetter, and wilder weather, which will increase the need for avalanche warnings in many places, including areas that have not previously been prone to avalanches. To ensure good avalanche forecasting services, it is important to ensure the best possible management of knowledge acquired through practice and interaction in such work.

Further reading

Størkersen, K. V., Haavik, T. K., Almklov, P. G., Gauteplass, A. Å., & Jore, S. H. (2024). Unprocurable essentialities: Situational and relational knowledge in publicly procured security services. Safety Science, 178, 106605.

Photo: Holt Hancock

8 Co-creation of risk in evacuation settings

Background

Climate changes lead to significant changes in temperature, precipitation patterns, sea levels, and the frequency of natural hazards and extreme weather. This challenges the safety of critical functions, infrastructures, and the lives and health of residents in vulnerable communities. Several northern and Arctic communities are now facing risks they have not previously experienced and must deal with recurring hazards such as rockslides, tsunamis, and avalanches. Among these, Karrat Fjord in Greenland, Rauma and Honningsvåg in Norway, and Longyearbyen in Svalbard have experienced an increase in hazards such as rockslides, debris flows, landslides, avalanches, and landslide-triggered tsunamis. Repeated evacuations and sometimes permanent relocations have therefore been necessary risk management measures to maintain community safety in these communities studied in this comparative case study.

Purpose

With an increased likelihood of higher consequences from natural hazards, the need for monitoring will also increase. Evacuation, as an organizational temporary risk mitigation measure against acute natural hazards such as landslides, rockfalls, floods, and the consequences of extreme weather, will become more common in several communities in the future. The project has looked at evacuation to understand how effective risk management can be achieved through risk co-creation, where authorities, experts, and residents collaborate to develop a common understanding of risk. By studying the decision-making and opinion-forming process that leads to evacuation, we aimed to understand how different actors—especially authorities, experts, and residents—can communicate more effectively to reduce tensions and build trust. This work is an important part of the decision-making process to achieve an often lacking common understanding of local ownership and socio-material belonging.

Results

The study indicates that successful evacuation patterns depend on risk co-creation processes where all involved actors are active in decision-making and communication processes. Furthermore, the willingness to recognize and integrate the local anchoring and social investments of the various local actors was crucial for establishing good relationships between authorities, experts, and the affected residents. Continuous communication was also particularly important for maintaining the patience of residents who, due to the nature of the risk, were evacuated over longer and multiple periods with high uncertainty. The communication processes also led to increased trust between the parties as the actors gained ownership of the hazard, but also of the potential consequences

Lessons learned

The findings highlight the importance of risk co-creation involving a shared understanding of the socio-material costs of risk. It is not just about understanding the immediate danger, but also how the risk imposes other costs on the local community. This approach led to the development of a generic model for risk co-creation that emphasizes the dichotomy between scientific and local knowledge, as well as past and future knowledge. Awareness of this can strengthen risk management by providing legitimacy and social acceptance for evacuation decisions

Why is this a lesson for handling climate change?

The model will be particularly important in a future characterized by an increase in climate-related risks, where more and more communities will be exposed to more frequent and intense natural events. Continuous communication and relationship-building will be especially important for risk management in situations where permanent technical measures cannot be implemented. The findings suggest that risk co-creation can enhance residents' evacuation capacity and reduce conflict. Results also highlight the need for similar dialogical communication processes in other communities experiencing, and likely to experience, natural hazards. This is especially relevant in communities with weak knowledge strength about hazard development and high local socio-material investment. This research thus emphasizes the importance of developing and adapting communication strategies as part of risk-based climate adaptation.

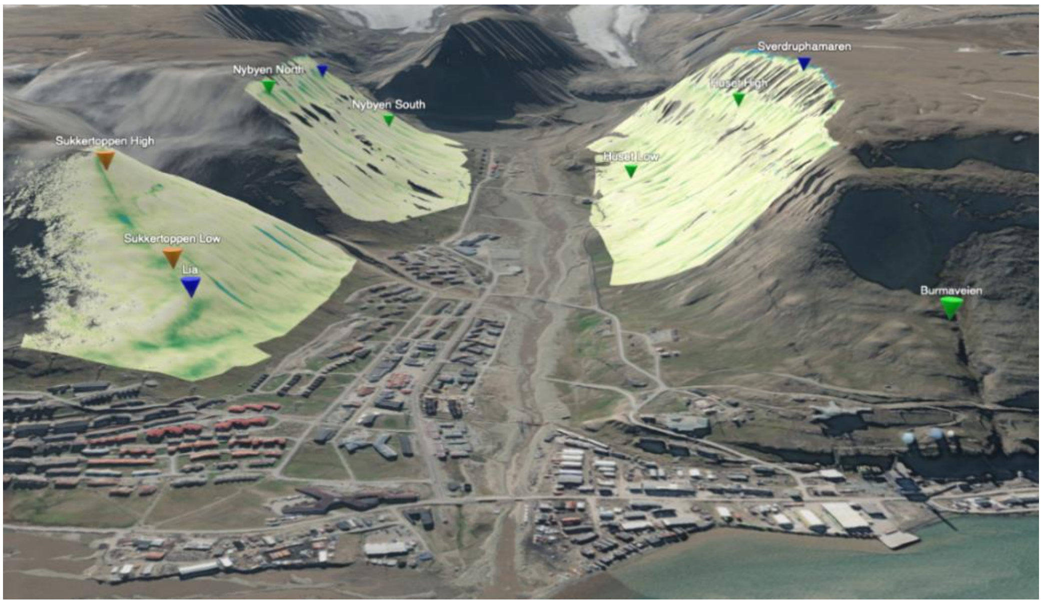
Further reading

Johannessen, S. et al. (2025) Co-creation of risk in evacuation settings: A risk governance approach to natural hazards risks. Safety Science

9 Sensors as a risk managment tool

Background

A central part of the local warning system established in Longyearbyen after the avalanches in 2015 and 2017 has been ultrasonic sensors to measure snow depth. The sensors measure snow depth in terrain that is difficult to access during the winter season and do not expose observers to avalanche risk during measurements. Before the winter of 2017/18, three sensor stations were established to measure snow depth: one in Lia above the center, one above Nybyen, and one above Huset (dark blue markings in the image below). Before the 2021/22 season, the original sensors were replaced with three pairs of sensors (six in total) in the same areas as the first sensors (green markings). The two sensors in Sukkertoppen (orange markings) have been removed today since permanent safety measures have been established there. Before the 22/23 season, a sensor was established above Burmaveien (green marking). Since the first sensors in 2017, there has also been technological development with lower costs and low power consumption, enabling the monitoring of natural hazards in an affordable and flexible way.



Oversikt over sensorer i Longyearbyen.

Purpose

- Establish best practices for developing sensor systems for measuring snow depth as part of risk management/avalanche warning.
- Explain why the use of sensor systems is a valuable contribution to climate adaptation.

The basis for the research has been the development and use of the snow depth measurement system in Longyearbyen and Honningsvåg over five winter seasons, from a "proof-of-concept" test of the technology in 2017 to a robust system for measuring snow depth as an important part of avalanche warning today.

Results

Sensors for monitoring snow depth in both Longyearbyen and Honningsvåg are used as one of the inputs in local avalanche warnings. The sensors provide knowledge about snow conditions that is not available in other ways and, together with observations of the snow cover (see chapter 5), are important local inputs for daily and detailed avalanche warnings for decision-making on measures. Experiences from Longyearbyen show that the sensors provide good indications of changes in the snow cover and thus also significant changes in the risk picture.

Best practices for using sensor technology in natural hazard management

Best practices for using sensor technology, based on experiences with the development and use of ultrasonic sensors for measuring snow depth in Longyearbyen and Honningsvåg:

- *Sensor technology adapted to the natural hazard:* Selected sensors must measure key physical parameters for the specific natural hazard. The development of the sensor system should include the best available sensor technology, while considering resource constraints related to available labor and financial resources in implementation, operation, and maintenance.
- "*Low cost, low power":* Low-cost sensor concepts enable the installation of more sensors. This means that large areas can be covered by the sensor system and allows for the installation of sensors in exposed locations where sensors may also be damaged. Low-power sensors reduce maintenance time and costs, enable placement in locations with limited access or power supply, and contribute to better data delivery.
- *Risk-informed placement of sensors:* The placement of sensors plays a critical role in the overall performance of a sensor system. A risk-informed approach in the planning phase will enhance the quality of the sensor system. Using various sources of knowledge will provide a solid basis for decisions about sensor placement. These sources of knowledge include local knowledge of past natural hazard events, local knowledge of access to locations, and data from satellite, drone, lidar, and TLS (terrestrial laser scanning) systems.
- *Redundancy and reliability:* The sensor system must account for unforeseen and challenging circumstances through redundancy (e.g., multiple sensors collecting the same information), plans for both systematic maintenance and sudden repairs, and secure and reliable data processing/storage.
- *Flexibility*: The system should be designed to facilitate adaptation to changes in the risk picture and/or the adoption of new sensor technologies. Flexibility will increase the system's lifespan and robustness by allowing adaptation to new sensor technologies or integrating sensors that measure another parameter if there are changes in the natural hazard being monitored. An example of such flexibility is the use of sensor technology to measure water saturation in snow for monitoring slush flow hazards. In light of climate change, such flexibility is important.

Lidar scanning, Vannledningsdalen. (Photo: Martin Indreiten, 2022)

Installation of snow sensor at Gruvefjellet (Photo: H.Hancock)

Risk-scientific comaprison of permanent measures and organizational measures

In one of the research activities, we conducted a risk-scientific comparison of permanent safety measures (support structures, snow fences, catch dams, relocation of buildings) and organizational measures (warning systems based on sensor technology) using criteria for barrier performance. The results of the comparison:

- *Permanent measures are reliable and effective for the risk scenarios they are designed for,* but may be less suitable for changing and uncertain conditions as a result of climate change.
- *Organizational measures represent a flexible, cost-effective, and sustainable approach to risk management.* With the impact of climate change on natural hazards and society, organizational measures based on sensor technology should be an important approach, as they can provide flexibility and adaptability to the dynamic and complex picture of natural hazards.

Our assessment is based on limited experience. Therefore, more long-term research is required to evaluate the effectiveness of the various measures in Longyearbyen. Our approach provides a good framework for such an analysis to cover different effects.


Photo: Holt Hancock


Photo: Martin Indreiten

Lessons learned

There is much to suggest a movement towards increased use of sensors for monitoring various types of natural hazards in different contexts. Documenting the history of the development and use of snow sensors for risk management in Longyearbyen is therefore important experience for future systems that rely on sensors.

Why is this a lesson for handling climate change?

The research on organizational measures in Longyearbyen provides valuable knowledge that can be linked to several key proposals in The Norwegian Government’s white paper (St.meld 27, 2023-24) on flood and avalanche prevention:

- "The government has started the work of reviewing safety requirements against natural hazards in the building regulations. Considering climate change in spatial planning is crucial to reducing the consequences of floods and avalanches. To meet the challenges, the government will consider allowing measures other than permanent, physical safety measures." In Arct-Risk, we have generated knowledge about the development and use of warning systems with regard to the use of sensor technology, handling uncertainty (chapter 3), risk communication and evacuation (chapter 7), the importance of local knowledge (chapter 5), and established a safety framework for comparing permanent and organizational measures.

- "The government wants risk-based warning of natural hazards to be used to a greater extent" - In the project, we have documented experiences on how various sources of knowledge can be used to prioritize where and how sensors for avalanche warnings are established.
- The government emphasizes that "an important overarching principle is that preventive measures should be prioritized based on socio-economic profitability. Measures implemented should have greater benefits than costs." In Arct-Risk, we have documented how low-cost technology can be used as an important and effective element in warning systems.

Further reading

Hancock, H., Jenssen, E., Indreiten, M., Albrechtsen, E. (2023) "Sensors as a risk management tool - Measuring snow to help manage avalanche risks in Longyearbyen" Report

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10 Long-term climate adaptations and transferability to municipalities

Background

An important part of managing changing climate risks will be the long-term climate adaptation we undertake to ensure the ability to handle climate-related events, such as natural hazards and extreme weather, does not exceed our capacity to manage them. Based on Longyearbyen's handling of avalanche risk, we examined how long-term challenges are addressed. Experiences from here can help prepare the mainland for the challenges they may face in this work.

Photo: Eirik Albrechtsen

Purpose

The purpose of this study was to explore whether the municipal framework facilitates climate adaptation and how climate risk management can be implemented within it. The research aims to understand how short-term preparedness for natural hazards and long-term climate adaptation are managed at the local level, as in Longyearbyen, which faces faster climate changes than many other places in the world.

As mentioned, climate changes are occurring faster around the Svalbard archipelago than anywhere else. Longyearbyen is therefore already dealing with changes that the Norwegian mainland and other places will have to face in the future. Necessity has meant that Longyearbyen has gained a lot of experience in a short time with both short-term and long-term measures to manage climate risk. Since Longyearbyen largely operates within the same planning system as mainland municipalities, their experiences in managing climate risk will be valuable for preparing for the future.

Results

The results show that there is a dissonance between short-term preparedness for natural hazards and the long-term timeline for climate change and the resulting climate risk. This incompatibility can be attributed to uncertainty and a lack of guidelines on how to handle this uncertainty in emergency preparedness and climate adaptation work within local authorities. Informants indicate that there are challenges related to translating climate forecasts into concrete measures, and that it is necessary to make long-term climate challenges more manageable within the existing planning horizons at the municipal level

Lessons learned

To make the best use of available resources, local coordination, mobilization, and knowledge acquisition are required, which can be challenging in terms of capacity and economy for an average mainland municipality. In the current system, municipalities must be willing and able to bear these costs to have sufficient knowledge of what they need help with. This is not always possible or realistic when the risks are not perceived as immediate and imminent.

The importance of having a living document for Risk and Vulnerability Analysis (ROS) that continuously assesses and updates information on climate risk also emerges. It also underscores the need for clear goals and guidelines to help municipalities navigate the uncertainty associated with climate risk and adaptation. Local knowledge and experience, such as that in Longyearbyen, can be a valuable resource for other municipalities facing similar challenges.

Why is this a lesson for handling climate change?

This research is particularly relevant for addressing climate change because it highlights how municipalities can adapt to rapidly changing climate conditions through a combination of short-term preparedness and long-term planning. It also shows how to manage uncertainty and lack of guidelines by building on local experience and continuously updating risk analyses. However, it is important to note that achieving this is very costly in terms of effort and capacity, as well as financial resources, because it largely has to happen as a result of political will rather than as a process outcome.

Further reading

Andreassen, Stina (2024) Climate risk management at the local level: experiences from Longyearbyen. Proceeding of INTERPRAEVENT 2024

11 Climate adaptation indicators for measuring climate adaptation efforts

Background

Requirements for climate adaptation are included in the national planning guidelines for climate and energy planning and climate adaptation, which state: "Planning shall also contribute to preparing and adapting society to climate change (climate adaptation)." Municipalities are the frontline in climate adaptation work, including responsibility for public safety and emergency preparedness according to the Norwegian Civil Protection Act.

The need for climate adaptation is particularly great in Svalbard and Longyearbyen. As shown in the chapter on climate change in Svalbard, there is no other place on Earth where temperatures are rising faster than in Svalbard. In Longyearbyen, the annual average temperature has increased by over 4 degrees Celsius since 1991, and new heat records are constantly being set.

Purpose

Based on the requirements and needs, the purpose has been to highlight and answer the following questions: What are the effects of climate change in Longyearbyen? What is Longyearbyen local government (LL) doing to adapt Longyearbyen to climate change? How to measure LL's climate adaptation efforts?

Measuring climate adaptation capacity – the degree of climate resilience – is illustrated in the figure below. Just as dandelion children are adaptable (resilient), society must be climate resilient.

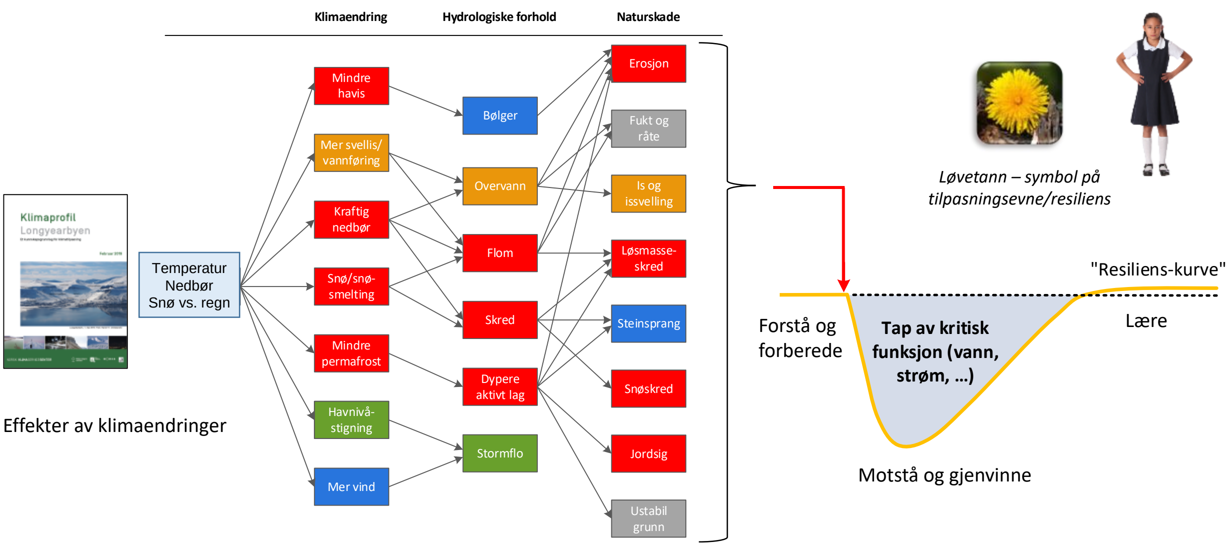

Figure 8. Measuring the ability to adapt to climate changes – degree of climate resilience

Based on the climate profile for Longyearbyen, an indicator-based tool has been established that can provide information on the status and progress of climate adaptation efforts in Longyearbyen. This is directly in line with the main goal of the Arct-Risk project to develop knowledge and tools to understand and manage the effects of climate change on public safety.

Results

There are several levels of results. An important outcome of the work is the development of a method for establishing indicators for measuring climate adaptation – the Climate Adaptation Indicators Method (CLAIM). Next, the set of indicators – the indicator tool – constitutes a main result, and finally, we have the results that the use of the tool provides in terms of status, trend, etc., for the climate adaptation work.

The method (CLAIM) is illustrated in the figure below (the climate change figure in step 3 is shown in the previous figure.

Trinn	Kort beskrivelse	Nivå i modellen
Definer omfanget av vurderingen		
1	Velg område	Nivå 1
2	Velg infrastrukturer og samfunnsfunksjoner	Nivå 2
3	Velg aktuelle klimarelaterte naturfarer/naturskader	Nivå 3
Etabler forhold og indikatorer for alle faser		
4	Vurder hver fase for hver klimarelaterte naturfare/naturskade	Nivå 4
5	Velg forhold for hver fase	Nivå 5
6	Velg indikatorer for hvert forhold	Nivå 6
Forbered og utfør målingene og beregningene		
7	Fastsett grenseverdiene for hver indikator, angi vekter og velg ansvarlig rolle	6
8	Angi måleverdier for indikatorene (utfør målingen)	6
9	Gjennomfør beregningene (skår og resiliensnivå)	1-6
Presenter resultatene		
10	Presenter resultatene (status og utvikling)	1-6

Figure 9 Method for developing the indicator

Central to the method are phases, conditions, and indicators (steps 4-6). Phases, conditions, and the number of indicators per condition are indicated in the table below

Fase		Forhold		Antall
1	Forstå risikoene	1.1	Kunnskap om klimatilpasningsutfordringer	7
2	Forberede/forutse	2.1	Ansvarliggjøring og involvering	6
		2.2	Forankring i planverk og reguleringer	9
		2.3	Inkludering av klimatilpasning i behandling og vurdering av plansaker og investeringsprosjekter	2
		2.4	Overvåking av bygninger og infrastruktur	3
3	Absorbere/motstå	3.1	Plassering av bygg i forhold til klimautsatte områder	17
		3.2	Krav til bygninger (klimarelatert)	1
		3.3	Plassering og redundans av veiinfrastruktur i forhold til klimautsatte områder	13
		3.4	Plassering av infrastruktur under og oppå bakken	2
		3.5	Redundans i strømforsyning	1
		3.6	Vann og avløp, og overvann (bl.a. vannkvalitet og håndtering av overvann)	3
		3.7	Redundans i vannforsyning	1
		3.8	Vedlikehold (for å opprettholde god standard og robusthet mot klimarelaterte hendelser)	5
		3.9	Ressurser til klimatilpasningstiltak	2
4	Respondere/gjenvinne	4.1	Beredskapsplaner	2
		4.2	Beredskapsøvelser og reelle hendelser	2
		4.3	Tilgjengelighet av strøm, vann og avløp, veier og fibernett	6
		4.4	Tilgjengelighet av andre kritiske/viktige funksjoner	7
		4.5	Ressurser for å håndtere klimarelaterte hendelser	5
5	Tilpasse/lære	5.1	Læring etter klimarelaterte hendelser (egne eller andres)	2
		5.2	Tilpassing etter hendelser	1
		5.3	Nye løsninger	1
	5	**22**		**98**

Figure 10 . Phases and conditions

Status is measured/assessed for each indicator with score values, which are then aggregated (through weighting) via conditions to phases and overall. An example of result presentation with test values (fictitious values) is shown in the table below. Here, results are shown per condition. In addition, results are provided per indicator, per condition, and overall, both as status and as trend, when measurements are taken regularly (typically annually).

Fase		Forhold		E	D	C	B	A	Skår
1	Forstå risikoene	1.1	Kunnskap om klimatilpasningsutfordringer						1,79
2	Forberede/forutse	2.1	Ansvarliggjøring og involvering						1,08
		2.2	Forankring i planverk og reguleringer						2,17
		2.3	Inkludering av klimatilpasning i behandling og vurdering av plansaker og investerings						2
		2.4	Overvåking av bygninger og infrastruktur						1,5
3	Absorbere/motstå	3.1	Plassering av bygg i forhold til klimautsatte områder						1,79
		3.2	Krav til bygninger (klimarelatert)						0,5
		3.3	Plassering og redundans av veiinfrastruktur i forhold til klimautsatte områder						1,35
		3.4	Plassering av infrastruktur under og oppå bakken						2
		3.5	Redundans i strømforsyning						0
		3.6	Vann og avløp, og overvann (bl.a. vannkvalitet og håndtering av overvann)						2,17
		3.7	Redundans i vannforsyning						0,5
		3.8	Vedlikehold (for å opprettholde god standard og robusthet mot klimarelaterte hende						1,5
		3.9	Ressurser til klimatilpasningstiltak						2,5
4	Respondere/gjenvinne	4.1	Beredskapsplaner						2,5
		4.2	Beredskapsøvelser og reelle hendelser						1,25
		4.3	Tilgjengelighet av strøm, vann og avløp, veier og fibernett						4,17
		4.4	Tilgjengelighet av andre kritiske/viktige funksjoner						2,21
		4.5	Ressurser for å håndtere klimarelaterte hendelser						2,2
5	Tilpasse/lære	5.1	Læring etter klimarelaterte hendelser (egne eller andres)						2
		5.2	Tilpassing etter hendelser						1,5
		5.3	Nye løsninger						2,5

Figur 11. Presentation of results of the assessment per condition

The preliminary results were presented to the residents of Longyearbyen during a climate café held on June 6, 2023. Some work remains to be completed by the Longyearbyen local government.

Lessons learned

The method raises awareness of the effects of climate change and what is important for adapting to climate change, and the measurements show "where the shoe pinches," i.e., where the need for effort in climate adaptation work is greatest (for example, building requirements, redundancy in power supply, and redundancy in water supply, as illustrated in the table above). The trend from repeated measurements shows the results of the climate adaptation efforts.

Based on the results, Longyearbyen local government (LL) can conduct an evaluation of the climate adaptation work and report this to local authorities, who can then report to central authorities. The evaluation, and its political processing, provide a basis and further guidelines for the climate adaptation work in LL.

Why is this a lesson for managing climate change?

Managing climate change requires knowledge of the effects and status of the condition so that one knows where they stand in the climate adaptation work. The climate adaptation indicators provide such a status.

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Øien K. og Albrechtsen E. *Klimatilpasning i Longyearbyen. Måling av klimatilpasningsinnsats med resiliensindikatorer*. SINTEF rapport 2024:01195. In Norwegian

12 Education of tomorrow's experts

12 master theses (17 students)

- Keng He, Martin (2021) Usikkerhetens innvirkning på håndtering av naturfarer. En kvalitativ casestudie av skredvarsling i Norge In Norwegian
- Espeland Aakre, Sebastian (2022) Communicating climate-related hazard risks in a changing world: A case study of risk communication in Longyearbyen
- Derås, Emilie Torsdatter , Johnsen, Kaja og Kverneland, Vilde (2022) Klimatilpasning i norske lokalsamfunn In Norwegian
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- Bolkan, Ida og Djupvik Grindheim, K. (2023). En analyse av risikokommunikasjon og befolkningens risikopersepsjon i Longyearbyen: En Mixed Methods Case Studie av flom som en klimarisiko. In Norwegian
- Mauseth Jakobsen, Frida og Rasmussen, Nora Kristine. (2023) Klimaendringenes påvirkning på veitransportsystemene i Vest-Finnmark: En kvalitativ case In Norwegian
- Radlwimmer, Antonia (2023) Measuring and modelling precipitation to improve natural hazard management in Longyearbyen.
- Hov Andreassen, Stina Marie & Øien Røisgård, Håvard (2023) Klimatilpasning i Longyearbyen. Erfaringer og overføringsverdi til fastlandet for et sikkert samfunn. In Norwegian
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- Thomae, S. (2024) Local weather variability in Longyearbyen and surroundings, Svalbard. (Bachelor thesis)
- Andreassen, Silje Maya (2004) Klimaprognoser i helhetlige risiko- og Sårbarhetsanalyser. Hvilke utfordringer møter kommuner når klimaprognoser skal benyttes i de helhetlige risiko- og sårbarhetsanalysene? In Norwegian

Master coursce at UNIS: AS-304 Risk handling in the Arctic operational context

During the project period, activities and results from Arct-Risk have been used in the master's teaching at the Arctic Safety Center. From being part of individual courses in 2021 to 2024, where an entire 10-credit course, AS-304 'Risk handling in the Arctic operational context,' is mainly based solely on the research results from Arct-Risk

From teaching on barrier theory and avalnche mitigation measures at Varden, August 2022. (Photo: Martin Indreiten)

13 Overview of all publications

Journal articles

Johannessen, S,, Hancock, H., Wickström, S., Albrechtsen, E. (2024) Risk governance of climate-related hazards in Longyearbyen, Svalbard: A review of risk governance approaches and knowledge gaps. Climate Risk Management, vol 43 (100585)

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Størkersen, K.V., Haavik, T.K., Almklov, P.G, Gauteplass, A.Å., Jore, S.H., (2024).Unprocurable essentialities: Situational and relational knowledge in publicly procured security services. Safety Science, vol 178, 106605.

Conference papers

Antonsen, S, Haavik, T., Kruke, B.I. og Johannessen, S. (2022) "Living near natural hazards in the age of climate change – the relationship between expert and local knowledge in risk governance" I Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022)

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Johannessen, S.A. (2022) "Potential Time Related Impacts of Turn-Over on Knowledge Continuity as Risk Perception in Longyearbyen, Svalbard" I Proceedings of the 32nd European Safety and Reliability Conference (ESREL 2022)

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Hancock, H., Indreiten, M., Jaedicke, C (2024), Avalanche risk management in Longyearbyen, ISSW2024

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Grindheim, K.D., Bolkan, I., Kruke, B.I. (2024) Flood Risk Communication And Perception In Longyearbyen. Proceedings of the 34th European Safety and Reliability Conference (ESREL 2024)

Albrechtsen, E. Indreiten, M, Hancock, H. (2024) Snow avalanche risk mitigation in the age of climate change in Longyerbyen. Proceeding of INTERPRAEVENT 2024

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Indreiten, M & Albrechtsen, E. (2021) "Handling uncertainty - a way to improve risk management in local avalanche warning systems". Paper presented at the *Arctic Safety Conference* in Longyearbyen, Norway, 09-11 November 2021

Keng He, M. & Albrechtsen, E. (2021) "Uncertainty in risk-informed decision-making processes in snow avalanche risk management in the Arctic". Paper presented at the Arctic Safety Conference in Longyearbyen, Norway, 09-11 November 2021

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