REPORT

Applied Avalanche Research in Norway

RESEARCH PLAN 2020-2022

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NORWEGIAN GEOTECHNICAL INSTITUTE
NGI.NO

Project

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1 Introduction

Snow avalanches are a significant natural hazard and common phenomenon in Norway. Each year, avalanches result in fatalities, evacuations, and interruptions or damage to infrastructure networks such as roads, railways, and electrical transmission lines. Persistent avalanche hazard in steep terrain is a major factor considered during land-use planning and development. During the snow season, daily or weekly variations in the avalanche danger identified in regional and applied bulletins influence the operation of transportation networks.

Applied research on avalanches and their societal impacts has been conducted at the Norwegian Geotechnical Institute (NGI) since 1973. This research has been funded in part by an annual grant from the Norwegian parliament, administered by the Norwegian Water Resources and Energy Directorate (NVE – *Norges vassdrags- og energi-direktorat*). Recent research activities have improved our understanding of avalanche formation, movement, and impacts. Enhanced knowledge of the individual processes leading to avalanche initiation, avalanche dynamics, and avalanche impacts has been applied to developing tools to help predict avalanche occurrence, runout distance, and impact pressures. While much has been accomplished within the avalanche research community in recent years, many key questions remain.

This project plan: (1) presents the research goals for the 2020-2022 period, (2) outlines the projects organization – including potential for external collaboration, and (3) presents the work-package structure and specific research tasks to be undertaken by the applied avalanche research group at NGI over the next three years.

2 Project goals

Modern avalanche research addresses topics ranging from fracture mechanics to stress psychology. These different aspects of avalanches are studied by specialized international research groups.

The applied avalanche research team at NGI has traditionally concentrated on the topics of avalanche dynamics, forecasting, mitigation, and hazard zoning. The aim of the applied avalanche research group is to support the Norwegian society and conduct leading research projects to further the international understanding of avalanche processes. The unique full-scale test site at 'Ryggfonn' and the research station 'Fonnbu' are fundamental infrastructure for our field-based research. In recent years, we have developed a strong focus on modelling, analysis, and mapping to upscale field observations and achieve our societal mandate.

The overarching research goals for the period 2020–2022 are to:

- improve the understanding of how snow in steep terrain develops into avalanches,

- study and describe the moving snow masses in a flowing avalanche, and
- investigate the interaction of moving avalanches with vegetation, buildings, mitigation measures and infrastructure.

The societal goals are to:

- unite national and international resources for the best use of the Ryggfonn and Fonnbu research facilities,
- involve relevant users and practitioners in research activities,
- integrate avalanche research in other major national research projects, and
- contribute to the development of national standards for hazard assessment.

3 Project organization

3.1 Project leadership and project participants

The project is run by NGI, in close collaboration with the project administrator, NVE. The proposed project leader for the next three-year period is Dr. Christian Jaedicke, assisted by deputy leader Dr. Graham Gilbert. Each work package will be led by an NGI researcher who gathers and coaches a research group that can fulfil the specific tasks of the work package. The research group will consist of NGI personnel as well as researchers from our partner organisations. We aspire to involve external researchers in our work.

3.1.1 Post-doctoral researcher

We intend to hire a post-doctoral researcher to join our team and to work continuously within the project for a minimum of one year. We will consider both the possibility to look for candidates that can work on a task specified in this proposal, as well as the possibility for candidates to suggest their own unique research topics, as long as they align with other activities.

3.1.2 Steering group

The project is supervised by a steering committee, which follows the project and supports the project leadership during the project period. The steering group consists of the project leader, the head of the section for Avalanches and Rock Slides (Håkon Heyerdahl), the market-area director (Dominik Lang) and the NVE program responsible (Odd Are Jensen). The steering group will meet every six months.

3.1.3 Reference group

The task of the reference group is to position the avalanche research within a national and international context, to give advice and direction on research topics and to support cooperation between the project and other research groups. The reference group consists of snow and avalanche experts from national and international organisations.

3.2 Field resources

For the understanding and quantification of avalanches processes, full-scale experiments on avalanche release, movement and effects are needed. There are two full-scale experimental sites for research on avalanches with size 3 or larger world-wide, one of which is the Norwegian test site at Ryggfonn in the Strynefjell mountains. The test site is supported by the nearby Fonnbu research station. Significant results have been obtained from field research at these two facilities. Therefore, one of the essential components of the project is the continued maintenance and operation of these two unique research facilities.

For the upcoming three years, we will change the way these research facilities are financed. Ryggfonn and Fonnbu will be accounted separately as “Research Infrastructure Resources” (RIR) for all costs, both incurred expenses and hours, that are needed to maintain and modernise the infrastructure. The RIR costs will be invoiced to the project. Hours spent on conducting research and investments in new instrumentation will be accounted for directly in the research project.

In this way we will 1) gain a better overview of the actual costs of maintaining the research infrastructure resources, 2) subsidize the operational costs by renting out the facilities to other projects and visiting researchers, and 3) improve management of necessary upgrades and investments. This shall also ensure a better continuity in the experiments that are required for avalanche research.

3.3 Research ideas and suggestions

To ensure wide acceptance of the NGI research activities, ideas and suggestions for research were collected in four stages, each targeting a different audience:

- During a two-day idea seminar at NGI, the snow avalanche research group evaluated the last three years of research, reviewed developments in international research, and identified the most urgent research questions for the subsequent three-year period;
- All members of the Norwegian Avalanche Association (Norskred) were invited to provide suggestions for the research activities;
- During the Nordic avalanche conference in Voss, in November 2019, participants were asked to contribute with their ideas;
- Feedback from the international research community was received to identify current knowledge gaps in avalanche research.

This preparational work resulted in a significant number of valuable ideas that were all considered for their potential to become a part of this research plan.

3.4 Work packages and tasks

The research activities are organised into four work packages (WP0 – WP3), each with specific tasks. This research plan provides an overview of the ideas for each work package. The level of detail in the work package descriptions will allow us to adapt the project in new directions and to pursue novel ideas as research progresses. For example, if one work package bears important new knowledge that calls for dissemination, it will be possible to allocate additional resources to this work package to publish the results. Significant avalanche events, or the possibility to conduct several experiments in Ryggfonn will be prioritised. Keeping a flexible project plan will allow us to embrace full experimental efforts at the site as soon as, and whenever, field conditions are identified as being favourable to carrying out experiments.

3.5 Cross-package topics

Some research topics and methods apply to more than one work package. We have therefore defined several cross-package topics. These are described in Section 9 below.

3.6 National collaboration

Avalanche research covers a wide field of expertise and involves different stakeholders from road authorities to land-use managers. We aim for increased interaction with different Norwegian stakeholders to adjust the research to their needs. We will be open to the following three types of collaboration.

- Research collaboration with:
  - companies and start-ups that require avalanche and snow research for developing new products and services,
  - universities and other research institutes that can contribute with expertise and students,
  - public agencies such as the Norwegian Public Roads Administration or NVE, and
  - large end users such as Statnett and Statkraft.
- Dissemination and discussion partners:
  - Organisations such as Norskred;
  - Local and national media;
  - Communities and counties;
  - Other organisations that have an interest in avalanche research.
- Supporting partners:
  - We will invite selected companies and organisations to support avalanche research with rebates, financial participation or in-kind contributions.

3.7 International collaboration

Due to the specialized nature of most research groups, international exchange of experiences, results and opinions is essential for progress in avalanche research. Currently, NGI maintains an extensive international network and is active in initiatives to increase the cooperation with colleagues in Iceland, Austria and Japan. We will increase international collaboration in the coming project period by:

- contributing to international meetings and conferences, including the European Geosciences Union (EGU) and the International Snow Science Workshop (ISSW),
- leading researcher mobility initiatives between institutions in Norway and abroad, and
- prioritizing joint scientific publications with international and domestic colleagues.

3.8 Teaching and education

In Norway, there is high demand for avalanche expertise in the public, private, and education sectors. Currently, most education focuses on the planning and safety during recreation in avalanche terrain. Few opportunities are available to learn about the technical aspects of avalanches. For example, courses that teach the basics of snow and avalanche physics are uncommon, despite the knowledge being essential to training the next generation of avalanche experts. We will therefore promote such courses in cooperation with Norwegian educational institutions (such as the University Centre in Svalbard (UNIS), the University of Oslo (UiO) and national geohazard course etc.) and contribute with our expertise and results to courses and the education of MSc- and PhD-students.

4 WP 0 – Management and dissemination

WP 0 will focus on project management and dissemination and is the formal administration of the project and the reporting to NVE, the steering group and the reference group. All reports will be presented in English to increase the accessibility of the research results. To ensure dissemination to Norwegian stakeholders, we will additionally present major findings and results in Norwegian on the project website and during national seminars and conferences. This will help to maintain and further develop a Norwegian vocabulary of avalanche- and snow-related terms.

Tasks

T0.1 Project administration **2020–2022**

Focus on project management, budget administration, and resource allocation. Monthly meetings in the project group to follow up on project developments.

T0.2 Steering committee and reference group **2020–2022**

The project steering committee will meet every six months to discuss recent progress. Progress will be summarized in a report and meetings will be called by the project leader at NGI.

The reference group will meet annually. We will include at least two international representatives, if possible. A kick-off meeting will be planned in the first half of 2020 and a final assembly and public seminar will take place in autumn 2022.

T0.3 Reporting 2020–2022

We propose three levels of progress reporting:

- Biannual progress reports in July of each year, in advance of the steering committee meetings.
- Annual progress reports at the start of each calendar year (January) to provide a summary of activities during the previous year.
- A final project report will be delivered at the end of 2022. This will include a list of publications, dissemination efforts, and educational activities.

T0.4 Conferences and publications 2020–2022

Support (direct costs and hours) for the participation in relevant national and international meetings and conferences as well as financial support to cover publication fees. Additional support from internal and NFR mobility funds and publication funds will be applied for where applicable.

T0.5 Dissemination 2020–2022

WP 0 will coordinate dissemination activities, including:

- Presentations at seminars and conferences within Norway, including snøskredkonferansen, Norsk rasforum, and NVE's fagdag. This will ensure that Norwegian stakeholders are informed of the research results;
- Presentation of major findings on the project website;
- Presentation at major international conferences;
- Publication in peer-reviewed journals;
- Contributions to education by involvement in university courses.

T0.6 Project plan 2023–2025 2022

The new project plan for the subsequent three-year period will be developed in autumn 2022 and will be based on the results from the current period as well as relevant developments in national and international research.

Timeline and deliverables in WP 0

D0.01	Progress report month 6	2020-07
D0.02	Progress report month 12	2021-01
D0.03	Progress report month 18	2022-07
D0.04	Progress report month 24	2022-01
D0.05	Progress report month 30	2022-07
D0.06	Final report for three-year period 2020–2022	2023-01
D0.07	Final assembly and public seminar	2022-11
D0.08	Project plan 2023–2025	2022-12

5 WP 1 – Avalanche formation and release

5.1 Variable size of release areas and volumes

For the dynamic modelling of avalanche velocities and run-out lengths, the initial snow volume plays an important role. The fracture depth and extent of the release area is different for each event. These variables can be quantified and assigned probabilities. We will use results from recent studies on fracture mechanics, the spatial variability of weak layer distribution and geostatistical modelling to address the variability of snow depth, stability and the extent of release areas to achieve a probability distribution function for release of a given volume of snow.

T1.1 Literature review 2020

Search and review relevant literature to access and validate different approaches for quantifying the spatial and temporal distribution of snow in steep terrain. The outcome will be a literature review that can be used in a future publication and report.

T1.2 Collection of data for statistical analysis 2020

We aim to collect data from partners and colleagues on the release volume of natural and artificially triggered avalanches. Additional data such as detailed digital elevation models (DEMs) and weather and climate information will be collected and stored in a database for geostatistical modelling (T1.3).

T1.3 Geostatistical modelling of avalanche release volumes 2021

To achieve T1.3, methods and findings from T1.1 will be used with the prepared data (T1.2) to identify a statistical method to retrieve release volumes and release area extent from readily available data such as terrain features and climatological data.

5.2 Effects of wind and weather on the snowpack properties

Wind is one of the main agents controlling snow redistribution and avalanches. Generally, we assume that areas in the lee of the major wind direction accumulate more snow than adjacent slopes and are more likely to produce avalanches. Field experience and local wind modelling in alpine terrain has shown that this assumption is often wrong. We aim to use high resolution wind modelling and statistical models to estimate the local snow accumulation in avalanche release zones given a certain amount of precipitation in the studied area. We will also investigate if recent developments in drone technologies and remote sensing techniques can be used to validate the model results. For instance, we will investigate whether repeated drone surveys using high-resolution optical payloads and real-time kinematic navigation could be used to create snow distribution maps in selected areas.

T1.4 Modelling of wind fields and snow transportation 2020

Available wind and statistical models will be tested and compared. Computational and labour efficiency will be considered with respect to the achieved results.

T1.5 Snow distribution probability maps 2021

Results from T1.4 will be used to produce maps that present the probability for accumulating above-average snow amounts in the terrain. This work will focus on larger areas, rather than individual slopes and release areas. These maps can be validated using field surveys and remote sensing tools identified above.

5.3 Simple probabilistic release models

By combining the results from work package modules 5.1 and 5.2, we will establish a probabilistic description of the expected release volume and release area extent in different release zones.

T1.6 Probabilistic release model 2022

Presentation of a feasible workflow to quantify the probability distribution functions for release volumes and events as needed for the input to dynamic avalanche models.

Timeline and deliverables for WP 1

D1.1	Literature review on publications useful in geostatistical modelling of possible release volumes	2020-10
D1.2	Probability distribution functions for release volumes with given return periods	2021-05
D1.3	Probabilistic snow distribution maps	2021-12
D1.4	Probabilistic release model	2022-05

6 WP 2 – Avalanche dynamics

Advancements in modelling and instrumentation technology can give new insights into avalanches and avalanche dynamics. Through collaboration with the University of Nagoya and the Snow and Ice Research Centre (SIRC) at the Japanese National Research Centre for Earth Science and Disaster Resilience (NIED), experiments with small avalanches have been carried out during the past few winters in Niseko, Japan. Using the results of these tests and suggestions from NGI, a prototype of a novel mobile instrument for measuring the profiles of velocity and total as well pore pressure has been developed. WP 2 will integrate recent developments in avalanche process studies into new models and evaluate the potential of instrumentation and drone technology for improving our understanding of avalanche dynamics.

Full-scale experiments at Ryggfonn continue to be the centre of this project. If the monitoring of the conditions in the release area can be improved, more potentially favourable situations for field campaigns can be recognized in advance. At the same time, improved radar equipment will greatly increase the information extracted from spontaneous avalanche events.

Many of the persisting knowledge gaps in avalanche science can be summarized by the question, "Why are some avalanches extremely mobile?" To answer this question, the data from avalanche experiments need to be analysed more deeply than before and inform the development of process models, for the fluidization of the head region of avalanches and for erosion, entrainment and deposition of snow along the trajectory of an avalanche. Finally, to make these insights useful in practice, they need to be moulded into mathematical equations that describe avalanche motion in sufficient detail yet can be applied in hazard-mapping work by practitioners. The model has to be able to describe density changes corresponding to three main flow regimes (including the powder-snow cloud) and the exchange of mass and thermal energy between the snow cover and the flow.

6.1 New instrumentation for avalanche dynamics research

T2.1 Improved radar systems **2020**

Our partner BFW Innsbruck will contribute to the experiments by stationing one of their pulsed Doppler radar systems at Ryggfonn. This will allow continuous monitoring of the slope and the study of velocities and internal structures of both spontaneous and artificially released avalanches. We will establish the necessary infrastructure for permanent installation of the instrument.

In addition, the GEODAR radar system, developed by British researchers, has provided insight into the motion of the entire avalanche at the Swiss test site Vallée de la Sionne with unprecedented detail. We aim to install a similar system at Ryggfonn, either by purchasing one such instrument or collaborating with the University of Durham.

There are also other radar systems that may be used for monitoring of avalanche dynamics, including ground-based, polarimetric, K-band, real aperture radar and airborne, L-band, synthetic aperture radar systems.

T2.2 Distributed observational methods **2020-2021**

New technology, based on the concept of the internet of things can provide interesting new opportunities for avalanche research. For example, distributed networks of seismic instruments can give information on the location of avalanche release and runout in a larger area. This has been tested in the Mount Fuji area and could be interesting in areas with critical infrastructure such as Rv15. Microsensors, distributed by drone or helicopter in the snowpack of the avalanche release zone could provide interesting data on avalanche motion and fluidization.

T2.3 Instrumentation for experiments on small avalanches 2020-2022

Techniques for safely and effectively releasing small avalanches will be devised and tested. A variety of measurement devices will be evaluated, ranging from portable Doppler radar and lidar scanners to drones equipped with optical sensors and thermal infrared cameras to tracers in the snowcover and accelerometers that may be carried by avalancheflows. A novel portable measurement wall with velocity, total-pressure and pore-pressure sensors developed at SIRC in collaboration with NGI will be improved.

This task will be carried out in close collaboration with our partners SIRC and BFW Innsbruck. The latter have some potentially suitable small avalanche paths in the immediate vicinity of Innsbruck and also portable Doppler radar systems.

6.2 Avalanche experiments

Experiments on artificially released avalanches at Ryggfonn will be the main focus of this task group. In addition, we will assess the feasibility of experiments applying mobile measurement devices on small avalanches in Grasdalen or another suitable location in Norway as well as in Innsbruck. This option will be compared to the alternative of stepping up NGI's participation in the experiments at Niseko.

T2.4 Avalanche experiments in Ryggfonn 2020–2022

The weather and snow-cover development in Grasdalen is continuously monitored with weather stations and video cameras at different locations, to recognize promising situations in advance. The experiments will follow the same script as in the past, guaranteeing a high standard of safety and maximum information gain from successful releases.

The experiments in Ryggfonn are also open to other institutions that wish to collaborate with NGI on snow avalanche dynamics. Currently, the Norwegian Public Roads Administration (NPRA) and the BFW are partners in the experiments. NPRA is particularly interested in pressure conditions and the danger to cars behind a terrain trap (dam) or depressions, while BFW contributes through speed measurements with its Doppler radar.

Representatives from BFW Innsbruck and SVV are invited to participate in the campaigns, other interested parties can also apply to join.

Major research questions involve:

- avalanche release: probability of natural release depending on the environmental conditions
- avalanche flow depending on the snowpack properties
- avalanche impact forces
- effect of the avalanche catching dam in the run-out area.

Obtained test results are checked, analyzed and archived in a form suitable for further use in the research. What aspects of data are analyzed in detail largely depends on the data quality and the characteristics of the triggered avalanche.

Data analysis also includes the cross-comparison of the data obtained at Ryggfonn with suitable data from other full-scale or laboratory experiments. This cross-comparison between different avalanche paths (test sites) and experiments is necessary to uncover scaling relations, e.g., due to different drop heights or due to differences in the steepness of the paths.

T2.5 Experiments on small avalanches 2020–2022

Based on experience from the Niseko experiments, the prospects and costs for improving the measurement equipment and the experimental procedures will be critically assessed. In addition, a variety of locations will be evaluated in 2020. If the results are positive, first experiments will be attempted in the winter 2021 in collaboration with our partners in Austria and Japan.

6.3 Reasons for extreme avalanche runouts

Extreme avalanche runouts are often observed in situations where snow properties and temperature conditions are ideal for the avalanche movement. Invariably, the front of such avalanches seems to have much lower density and higher velocity than the slower core following it and entrainment of cold snow appears to be a necessary condition. It is currently unclear which role the intermittency observed in some recent experiments plays in this context and where it originates from.

T2.6 Fluidisation mechanics 2020-2021

One of the theories advanced to explain extreme avalanche run-outs is fluidisation of the avalanche head due to air escaping from the failed snow cover underneath the flow, which reduces the friction significantly. We aim to collect all knowledge from observations and measurements and to find suitable equations for the description of this process.

T2.7 Erosion, entrainment and deposition 2020-2011

Entrainment was found to be a significant contributor to size and run out of avalanches. Our work in the project period 2017–2019 has laid the foundation for improved models of erosion and entrainment that need to be developed into practically applicable equations and tested against measurements. Entrainment of warm snow from deeper layers has been recognized to significantly alter the rheology of the flow—an effect that should be reflected in the model equations. Recent work also suggests that deposition at the tail of avalanches should be considered. This is not only a prerequisite for realistic modelling of the deposit distribution, which is important in dam design, but also determines whether an avalanche will starve in the track or grow into an extreme event.

The new equations need to be implemented in a 3-dimensional numerical framework to calculate the avalanche movement along a 3-dimensional avalanche path. We will use the most modern tools for the implementation and acquire assistance from other numerically advanced applications developed for the studies in hydrodynamics.

T2.8 Powder snow cloud 2020-2011

The powder part of avalanches can be destructive in the front of the avalanche. The destructive forces and run-out are not quantifiable by existing models. We aim to establish suitable equations that describe the powder-snow cloud as a separate layer so that it first can be tested as a stand-alone model and later be incorporated into a new multi-layer model.

6.4 Mathematical equations of an improved avalanche model

It is difficult to simplify avalanche dynamics into a set of equations. Current models for avalanche dynamics employ assumptions such as a constant snow density for the dense part of the avalanche mass and average the flow velocity over the depth of the flow. Several known processes in the avalanche movement are not captured by these simplifications. Recent investigations have improved the mathematical description of the internal processes occurring during an avalanche. We aim to combine these recent advancements in a new avalanche dynamics model.

T2.9 Mathematical equations 2021–2022

Several concepts of describing avalanche flow have been presented during the last decades. Some do not capture the physics and observations good enough, others are difficult to solve numerically and need high computational efforts to reach satisfactory results. Computer power has increased significantly, and more complicated models of avalanche flow can now be revaluated to be used in a new model.

T2.10 Proof-of-concept implementation 2022

To study the behaviour of the system of equations developed in T2.9 in a simplified setting, a multi-layer block model is written in a scripting language like Python or Matlab. It is anticipated to combine features of NGI's two-flow-regime block model B2FR and of the Kulikovskiy–Sveshnikova powder-snow avalanche model.

Timeline and deliverables for WP 2

D2.1	Annual reports or publications on avalanche experiments and analyses and interpretation of experimental data	2020-12
D2.2		2021-12
D2.3		2022-12
D2.4	Annual reports or publications on theoretical and numerical modelling work	2020-12
D2.5		2021-12
D2.6		2022-12
D2.7	Description of new instrumentation in Ryggfonn	2021
D2.8	New numerical model for avalanche flow	2022
D2.9	Open access to experimental data from Ryggfonn and Fonnbu	2021

7 WP 3 – Avalanche interaction

WP 3 aims to improve our understanding of the effect of terrain on the flow and direction of avalanches, the forces of avalanches on structures in the avalanche path, and the effects on buildings and other infrastructure in the run-out zone. One of the major aims of this research is to identify pressure criteria that can be included in a future version of the Planning and Construction code and in TEK.

T3.1 Alternative mitigation measures 2020–2022

A small number of mitigation measures such as supporting structures and retention dams are well known and used in many applications world-wide. Other solutions made of steel sheet pile walls, cross laminated timber or guiding dams made of snow have been suggested, but not considered from a theoretical point of view. Questions such as "Which forces can be expected and handled by such constructions?", "Where would they be applicable?", etc. need to be addressed.

In general terms, avalanche mitigation measures are usually an intervention into the environment, that often are experienced as aesthetically or visually adverse. We aim to identify new solutions and develop a framework that allows to design this kind of innovative mitigation measures.

T3.2 Vulnerability of structures and persons in buildings 2020–2022

When a building or structure is hit by an avalanche the type of avalanche, flow height, density and velocity are decisive for the forces on the object in the path. The object itself, its construction, and strength decide on the type and degree of the damage to the structure.

We aim to determine the vulnerability of typical Norwegian wood frame buildings as a function of avalanche pressure by finite-element calculations and/or laboratory tests. Furthermore, information on historical avalanche disasters will be analysed to improve the preliminary estimates of the vulnerability of persons in buildings as a function of the degree of damage of the building.

T3.3 Residual risk 2020–2022

Norwegian hazard maps usually merge all rapid mass movements into one hazard zone. The theoretical background for this method has never been developed. We aim to establish a simple theoretical framework that allows to argue for an applicable method in practical mapping projects. The same methods will be applied to study the effect of mitigation measures such as supporting structures and retention dams on the hazard zone and how to quantify the residual risk after mitigation is in place.

Timeline and deliverables for WP 3

D3.1	Catalogue of alternative mitigation measures including guidelines for their design	2022-05
D3.2	Assessment of the vulnerability of Norwegian buildings and suggestions for pressure criteria	2020-12
D3.3	Theoretical framework for assessment of several hazards in one hazard zone and for the residual risk after mitigation measures	2021-07

8 Research infrastructure resources (RIR)

8.1 Full-scale avalanche test-site Ryggfonn

A main challenge for avalanche research is to obtain a comprehensive understanding of the different flow regimes (dense, fluidized, or suspension flow) and of the involved physical processes. To obtain the necessary understanding, a combination of different measurements and observations is desirable to gain a broad and consistent picture of the avalanche flow. The complexity and variety of avalanche motion requires a combination of small-scale experiments (detailed investigations, statistics), large-scale tests (detailed investigation), and field observations (diversity, statistics). Cross-comparison between different avalanche paths (test sites) is necessary to uncover scaling relations, i.e. to identify differences in avalanche behavior arising from variations in total length or slope along avalanche paths.

Field observations and full-scale tests under controlled conditions are still necessary for the mentioned reasons and as a basis for statistical analysis.

The task RIR 'Full-scale avalanche test-site Ryggfonn' includes the operation and maintenance of the test site. as well as measurement campaigns at Ryggfonn every year (which are largely dependent on the weather and snow conditions).

The avalanche experiments need to be seen in close connection with the snow monitoring at the Fonnbu station.

A continued upgrade of the Ryggfonn avalanche full-scale research site will ensure that the facility can provide up-to-date data needed for the development of a thorough understanding of avalanche dynamics.

The following instrumental additions are planned in the coming period:

- Establishment of a time-lapse camera at the top of Sætreskarsfjellet (point 1452 m a.s.l.) to record activity in the avalanche track at Ryggfonn.
- Install two weather stations in the release area and in the run-out area to improved snowpack monitoring.
- Installation of an autonomous pulsed Doppler radar system surveying the track up-hill from the valley bottom. This will be done in cooperation with the

Austrian Institute for Natural Hazards at the BFW (Bundesforschungszentrum für Wald)

- Refurbishment of the outdated data acquisition system. This will also include an updating of the software.
- In addition, defective sensors will be replaced if necessary.

Deliverables

D2.1	Annual operation and maintenance of the test site. Feasible upgrades of instrumentation.	2020-12
D2.2		2021-12
D2.3		2022-12

8.2 Research station Fonnbu

The RIR Fonnbu is a unique platform for research in the Norwegian alpine environment. While the station has been used intensively for snow and avalanche research, its use for other research fields, such as mountain ecology and geological processes, could be of interest. Fonnbu offers all facilities for this kind of research and will be available for research projects, courses and other research and education-related activities.

The task RIR Fonnbu includes the operation and maintenance of the research station. A new weather station was established in 2019 and we will work to improve the accessibility of the data for the meteorological institute and general public.

9 Cross-package topics (CPTs)

9.1 Climate and climate change

Results presented in the Klima2100 report by the Norwegian Climate Data Centre show that the number of days with snow cover decreases significantly. Also, the number of days with snow precipitation will decrease. On the other hand, single events with intensive snow precipitation can increase in number and intensity, especially in the release areas of large avalanche tracks. We aim to study the effect of these changes on the extent of hazard zones that were established in the current climate.

9.2 Avalanche observations and monitoring

Avalanche events with exceptional run out length, avalanches in new locations or avalanches that lead to damages on buildings and infrastructure are of significant interest for several aspects of avalanche research. We will therefore continue the adhoc activity to visit and document unique avalanche events. Such information forms the basis for model validation and other research activities.

9.3 Quantitative risk assessment

The Norwegian building code defines the acceptable risk from avalanches in three hazard classes (1-3) with nominal annual probability 1/100, 1/1000 and 1/5000. These classes are used in hazard mapping for new areal planning. For the assessment of quantitative risk of avalanches reaching existing settlements only limited methods are developed. Many questions remain open and we aim to combine results from several work packages to develop a consistent method that can serve as a model for such hazard assessments.

9.4 Forest effects

Forests plays a major role in avalanche formation, movement and interaction. This topic will therefore be considered and discussed in all three work packages. The following processes will be studied in the cross-package topic:

- In the *release zone…*
    - Anchoring effect of forest
    - Changes of snow properties due to forest and vegetation (radiation and other effects)
    - Effects on loading (interception of precipitation in the crowns of trees)
- In the *avalanche path…*
    - Breaking effect of forest on flowing avalanches
- In the *avalanche run-out zone…*
    - Forces that are needed to destroy forest of different age and composition
    - Estimates of the extra damaging effect of tree debris hitting man-made structures

9.5 Dissemination

A central way of communicating our research results to colleagues around the world is through papers in peer-reviewed journals. Part of the funds allocated to this CPT will be used to support the writing of high-quality papers. Additional funding will be made available from NGI's general research budget on request.

We will select the most relevant conferences and symposia each year and send delegates who will give talks or present posters. Among these meetings may be the following:

- International Snow Science Workshops 2020 (Canada) and 2022 (USA)
- INTERPRAEVENT 2021 (Bergen)
- Nordisk snøskredkonferanse 2021
- Possibly EGU (Vienna) or AGU (San Francisco)

Our work will be presented on the NGI website, on national and international seminars and meetings. We aim to publish several peer-reviewed papers of our work and supervise several graduate students.

In addition, we will present our work on the NGI website and explore ways of communicating avalanche science and its practical applications to non-scientific audiences. Discussions have started with a film producer about a documentary on avalanches and avalanche research including experiments at Ryggfonn. We also consider initiating creation of an illustrated children's book involving snow avalanches as a central element of the story line. Adaptation of the highly entertaining yet physics-based life show "Nadaranger" (from the Japanese word "nadare" meaning "snow avalanche" and "ranger") of our Japanese partners at NIED may be an interesting and engaging way of reaching secondary-school students.

Within the three-year period, we will work for establishing a Norwegian avalanche course for professionals that will give the possibility for dissemination of research and experience.

10 Budget

Annual fixed costs in kNOK:

Ryggfonn maintenance and upgrade	500
Post-doctoral fellow	1,000
Ryggfonn campaign(s)	appr. 250–500

The remaining annual budget of approximately 2000–2250 kNOK will be allocated at the beginning of each project year based on task progress, available personnel resources and possibly new opportunities that have arisen since the completion of the present document.

Note that the post-doctoral fellow will only be selected during 2020 and their main work topic is not determined yet but will depend on the qualifications and interests of the successful candidate. The preliminary budget for 2020 is therefore set up without regard to this position. If the fellow starts his/her term at some point in 2020, the budget needs to be adjusted accordingly.

Table 1: Preliminary project budget for 2020

Module	Topic	Preliminary allocation 2020 (kNOK)
WP 0	Project administration	200
WP 1	Avalanche release	600
WP 2	Avalanche movement	750
WP 3	Avalanche interaction	400
CPT 1	Climate and climate change	–
CPT 2	Avalanche observations and monitoring	400
CPT 3	Quantitative risk assessment	200
CPT 4	Forest effects	200
CPT 5	Dissemination	400
RIR 1	Maintenance and upgrade Ryggfonn	500
RIR 2	Maintenance Fonnbu	100
RIR 3	Measurement campaigns Ryggfonn	250
Sum		**4000**

Kontroll- og referanseside/ Review and reference page

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