REPORT

Applied Avalanche Research in Norway AARN

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Project

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Summary

During the first year of the project period 2020-2022 of NGIs research project on Snow avalanches, Applied Avalanche Research in Norway (AARN), work was conducted in all three work packages (WP 1 – Avalanche formation and release, WP 2 – Avalanche dynamics, WP 3 – Avalanche interaction) and several cross-package topics. In addition, several significant upgrades were made to the research infrastructure at Fonnbu and Ryggfonn. During 2020, the results of the research activities have been published in peer-reviewed journals, summarised in technical notes, and presented online at national and international conferences and seminars. AARN personnel have been actively engaged in educational outreach activities, including as lecturers and student supervisors.

Contents

Review and reference page

1 Overview and administrative aspects

1.1 Project activities in 2020

Table 1 Summary of the AARN project activities in 2020, based on the project proposal. Note the research activities in most topics are ongoing.

WP 1 – Avalanche formation and release	• Access and validate different approaches for quantifying the spatial and temporal distribution of snow in steep terrain. • Collect data from partners and colleagues on the release volume of natural and artificially triggered avalanches. • Test and compare available wind and statistical models.
WP 2 – Avalanche dynamics	• 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. • Investigation of distributed observational methods – application of microsensors to provide information on avalanche motion and fluidization. • Evaluation of locations for experiments on small avalanches. • Avalanche experiments in Ryggfonn – continuation of long-term monitoring activities: weather, snowpack development, and avalanche activity. Specific topics: release probability, flow, impact forces, and effect of catching dam. • Collect existing observations and measurements of fluidisation mechanics of the avalanche head and find suitable equations for the description of this process • Develop improved models of erosion, entrainment, and deposition. • 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.
WP 3 – Avalanche interaction	• Identify and evaluate alternative avalanche mitigation measures. (i.e. those which are not widely applied at present). • Determine the vulnerability of typical Norwegian wood frame buildings as a function of avalanche pressure – analysis of historical avalanche disasters to improve estimates of the vulnerability of persons in buildings as a function of the degree of damage. • Methods for quantifying residual risk once mitigation measures are in place.
Research infrastructure resources (RIR)	• Stationing of a pulsed Doppler radar systems at Ryggfonn, in collaboration with BWF Innsbruck.

	• Installation of a GEODAR radar system, in collaboration with the University of Durham. • Establishment of new a time-lapse camera and two weather stations, one in the release area and one in the run-out area to improve snowpack monitoring. • Refurbishment of the existing data acquisition system at Ryggfonn. • Maintenance of the Fonnbu research station.
Cross-Package Topics (CPT)	• Opportunistic documentation of unique avalanche events. • Investigation of the role of forest effects in avalanche formation, movement, and interaction.

1.2 Involved personnel

The 26 individuals listed in Table 2 contributed to AARN activities in 2020.

Table 2 Contributors to AARN in 2020, listed alphabetically.

Researchers & scientific staff
Breien, Hedda
Domaas, Ulrik
Frauenfelder, Regula
Gauer, Peter
Gilbert, Graham
Gisnås, Kjersti
Glimsdal, Sylfest
Heyerdahl, Håkon
Høydal, Øyvind Armand
Issler, Dieter
Jaedicke, Christian
Kristensen, Krister
Langeland, Henrik
Liu, Zhongqiang
Mo, Katrine
Robinson, Kate
Salazar, Sean
Sandersen, Frode
Strout, James Michael
Technical staff
Lied, Erik
Smebye, Helge Christian
Sverdrup-Thygeson, Kjetil
Administrative staff
Haaland, Kirsten Helness
Johnsen, Maren Kristine
Nakken, Robert
Raddum, Ellen

1.3 Budget

Table 3 gives an overview of the planned and actual allocation of resources to the different work packages (including WP 0 – Project administration). Deviations from the planned allocation are presented below. In order to meet the project objectives and adapt to the changes in the work environment with the COVID-19 pandemic, a number of steps were implemented in AARN including increased frequency of digital project meetings and focusing on research activities which could be completed without travel.

Comments on the deviations from the planned allocation:
WP 0: A significant proportion of the budget allocated to WP 0 went to reporting (337 kNOK) – both from the previous project period and during 2020, monthly

project meetings (286 kNOK), student supervision (81 kNOK), and planning of the seminars in March (cancelled due to covid) and september (total ca. 40 kNOK). The remaining 254 kNOK was used for project administration.

WP 1/WP 2: There less activity than anticipated in WP 1 during 2020, primarily due to the availability of personnel. The difference in financial resources was transferred to WP 2.

WP 3: Activities were increased in WP 3 to compensate for the lack of activities in other project sections. Specifically, we focused on developing the database for investigating the vulnerability of persons in structures (discussed below).

RIR: Several significant infrastructure upgrades were completed at Ryggfonn in 2020. These are discussed in greater detail below. These upgrades were partially financed by other means at NGI.

CPT: A few the cross-package topics (CPT) are opportunistic and require that personnel can travel (e.g. for documentation of unique avalanche events) – these opportunities were limited in 2020, particularly as the latter part of snow season (March – June) coincided with the onset of mobility restrictions in Norway. Other changes relate the availability of AARN personnel. Resources were redistributed to other activities.

Table 3 Budgeted allocation and actual use of resources per work package in 2020 (amounts in kNOK).

	WP 0 (Admin & reporting)	**WP 1**	**WP 2**	**WP 3**	**RIR**	**CPT**	**Total**
Allocated	200	600	750	400	850	1 200	4 000
Used	998	325	1 030	523	516	534	3 926
Difference	798	-275	280	123	-334	-666	-74

1.4 Dissemination

(Underlined names are participants in the AARN project)

Peer-reviewed publications

Gauer, P. (2020). Considerations on scaling behavior in avalanche flow: Implementation in a simple mass block model. *Cold Regions Science and Technology* **180**, 103165; doi: 10.1016/j.coldregions.- 2020.103165.

Grigorian, S. S. and Ostroumov, A. V. (2020). On a continuum model for avalanche flow and its simplified variants. Geosciences **10** (1), 35; doi:10.3390/geosciences10010035. Edited by D. Issler.

Issler, D. (2020). Comments on "On a continuum model for avalanche flow and its simplified variants" by S. S. Grigorian and A. V. Ostroumov. *Geosciences* **10** (3), 96; doi:10.3390/geosciences10030096.

Issler, D. (2020). The 2017 Rigopiano avalanche—dynamics inferred from field observations. *Geosciences* **10** (11), 466; doi: 10.3390/geosciences 10110466.

Nishimura, K., Barpi, F. and Issler, D. (submitted). On the Special Issue "Snow Avalanche Dynamics". Submitted to *Geosciences*.

Presentations at conferences, seminars and meetings

Gauer, P. (2020) Avalanche hazard assessment of Pollfjell, Lyngen, Vital Infrastruktur Arena (VIA) Temamøte: Ras- og skredsikring 21 and 28 October 2020 Webinar.

Pérez-Guillén, C., Tsunematsu, K., Nishimura, K., and Issler, D. (2020) Seismic localization and dynamical characterization of snow avalanches and slush flows of Mt. Fuji, Japan, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-13407, https://doi.org/10.5194/egusphere-egu2020-13407

Salazar, S., Smebye, H., Frauenfelder, R., Miller, F., Solbakken, E., Humstad, T., and McCormack, E. (2020) Airborne Structure-from-Motion modelling for avalanche and debris flow paths in steep terrain with limited ground control, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-20529, https://doi.org/10.5194/egusphere-egu2020-20529

Reports

McCormack, E., Frauenfelder, R., Salazar, S., Smebye, H., Humstad, T., Solbakken, E., (2020). "Photogrammetry and Drones for Avalanche Monitoring." Norwegian Public Roads Administration, Report 655.

Robinson, K., Liu, Z. and Issler, D. Vulnerability of structures and persons in buildings. NGI Technical Note 20200017-03-TN

Gauer, P., Aalerud, A.H. and Body, N.S. Avalanche observations versus numerical avalanche model: Simple test of model performance. NGI Technical Note 20200017-04-TN

Gauer, P. and Langeland, H. WP 2 – Full-scale experiments at Ryggfonn: Ryggfonn avalanche observations 2019/2020. NGI Technical Note 20200017-05-TN

1.5 Teaching and student supervision

In 2020, AARN researchers participated in teaching activities at the University Centre in Svalbard (UNIS), University of Oslo (UiO), and University of Tromsø (UiT).

Four master students contributed to AARN activities and were supervised by project researchers in 2020: Ole Kanstad (UiO, completed June 2020), Kristian Ask (NTNU, completed June 2020), Brage Storebakken (UiO, started end of 2020), and Elise Nilsens (UiO, started end of 2020).

2 WP 1 – Avalanche formation and release

2.1 Simple probabilistic release models

Work on a simple probabilistic release model for avalanche Hazard Mapping (Gauer 2018a), was taken up again. The model involves meteorological data from SeNorge, and includes parameters such as HS, HNW, RR, SWE, TA. The model now includes an extended forest parametrization that also accounts for interception. Verification of the model is on-going and will be a central topic in 2021.

3 WP 2 – Avalanche dynamics

3.1 New instrumentation for avalanche dynamics research

Several new technologies and instruments were explored with the goal of better understanding of avalanche formation and dynamics. Among the technologies that were evaluated for monitoring of natural and artificial avalanche releases, were a fully autonomous, pulsed Doppler radar system (further described in Section 6.1), low-cost, distributed geophone sensors, and aerial survey methods.

3.1.1 Aerial survey methods to derive snow distribution

Towards the goal of rapid snow distribution measurements as input for future roadside avalanche hazard assessment and design of mitigation measures, unmanned aircraft systems (UAS, or drones) were among the technologies that were explored. Specifically, continuous snow cover mapping and drone-based roadside inspection of snow-loaded areas of interest (i.e. on avalanche paths), were investigated. Low-cost, consumer-grade drones were utilized with a direct georeferencing survey technique. The main advantage of the direct georeferencing methodology was to perform a survey rapidly without the need for extensive ground control. Compared to conventional drone-mapping techniques, which require well-distributed and independently surveyed ground control points for referencing drone image products, the direct georeferencing method minimised survey time and reduced exposure of field personnel.

To validate the aforementioned methodology, two field investigations were performed over Sætreskarsfjellet, in Grasdalen, as depicted in Figure 1. One UAS survey was performed to establish a snow-free baseline and a second UAS survey was performed to provide a comparison with snow cover. In both cases, a terrain-following flight plan was utilized. The aerial survey images were processed using a Structure-from-Motion processing workflow to derive high-resolution, three-dimensional surface models. The difference between the surface models was used to estimate snow depth across the entire surface of the surveyed area. A snow depth probe was deployed in the field at the time of survey to provide ground validation for comparison of the drone-derived snow depths.

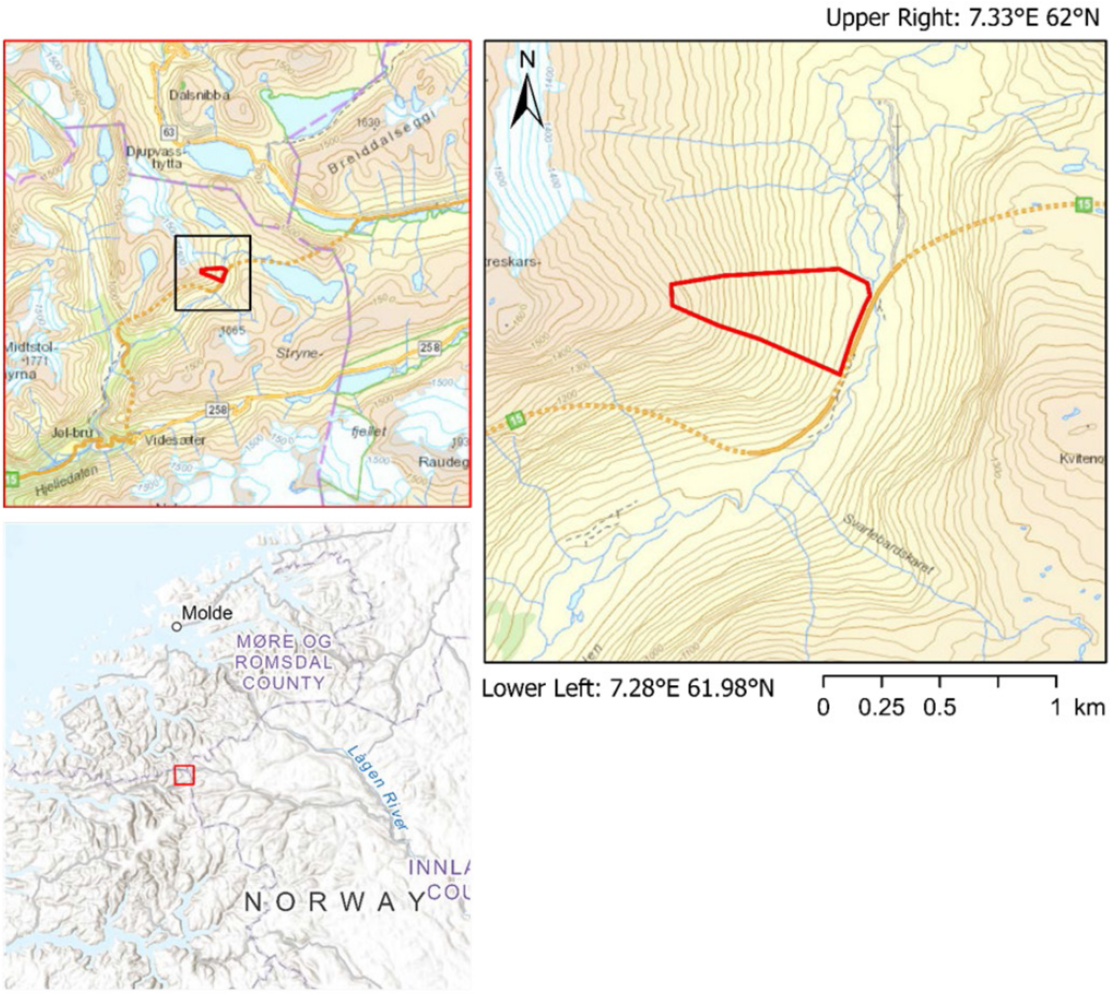


Figure 1 UAS survey area on Sætreskarsfjellet in Grasdalen, Vestland county (source data: Geodata AS, Kartverket; figure reproduced from McCormack et al., 2020)

Challenges related to hardware and software capabilities, as well as the lack of reliable 4G network coverage, were encountered during testing of the direct georeferencing method. To overcome these limitations, the survey area was divided into two parts (as depicted in Figure 2) and a portable base station was deployed to assist in the collection of relative real-time kinematic data. The challenges encountered were representative for data collection campaigns in remote and mountainous terrain.

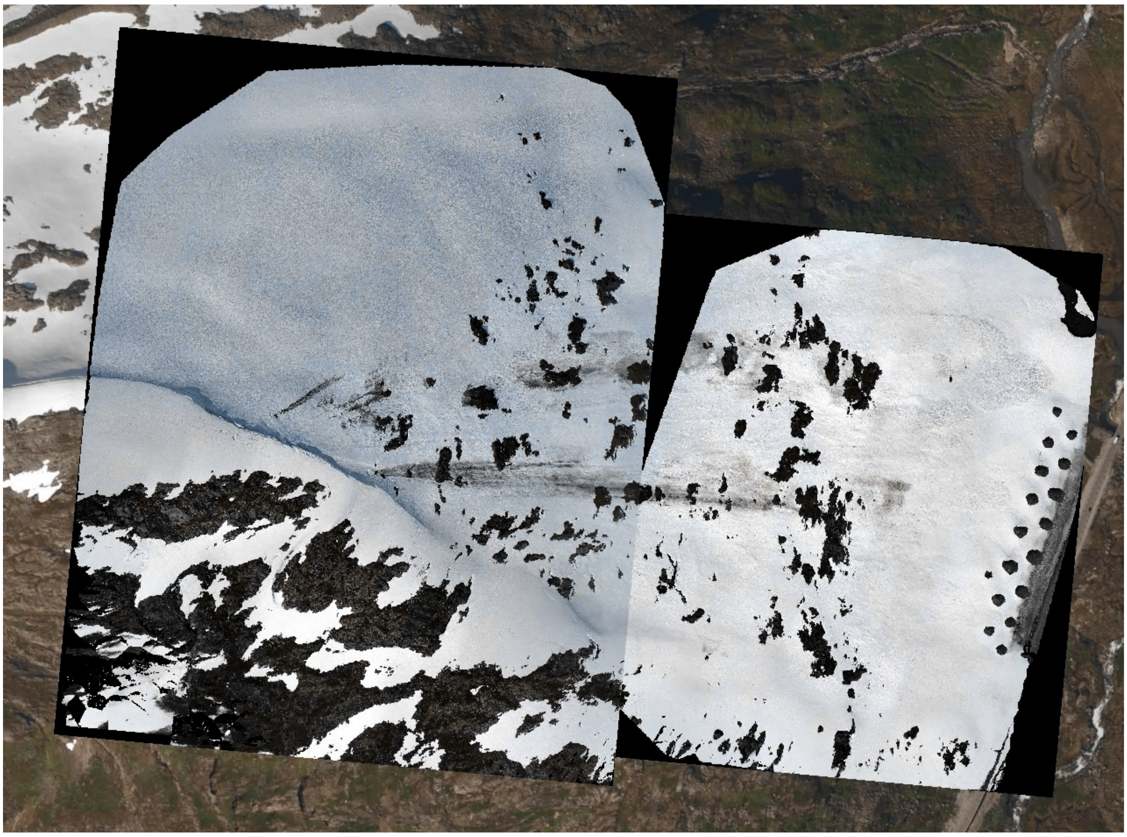


Figure 2 High-resolution orthomosaic derived from drone imagery over Sætreskarsfjellet in Grasdalen, Vestland county (source data: Kartverket).

A comparison of the snow-depth values, as obtained from snow probe measurements and from drone-based Structure-from-Motion modelling, revealed that the reliability of depth measurements was variable. While the measurements were in poor agreement (as depicted in Figure 3a) in the release area, the measurements at the base of the runout area were generally in good agreement (as depicted in Figure 3b). Factors that could have influenced the accuracy of the comparison include measurement error in the field, uncertainty in the terrain model differencing technique, and a limited number of samples. The potential for rapid, drone-based snow mapping was demonstrated and will be further explored in 2021.

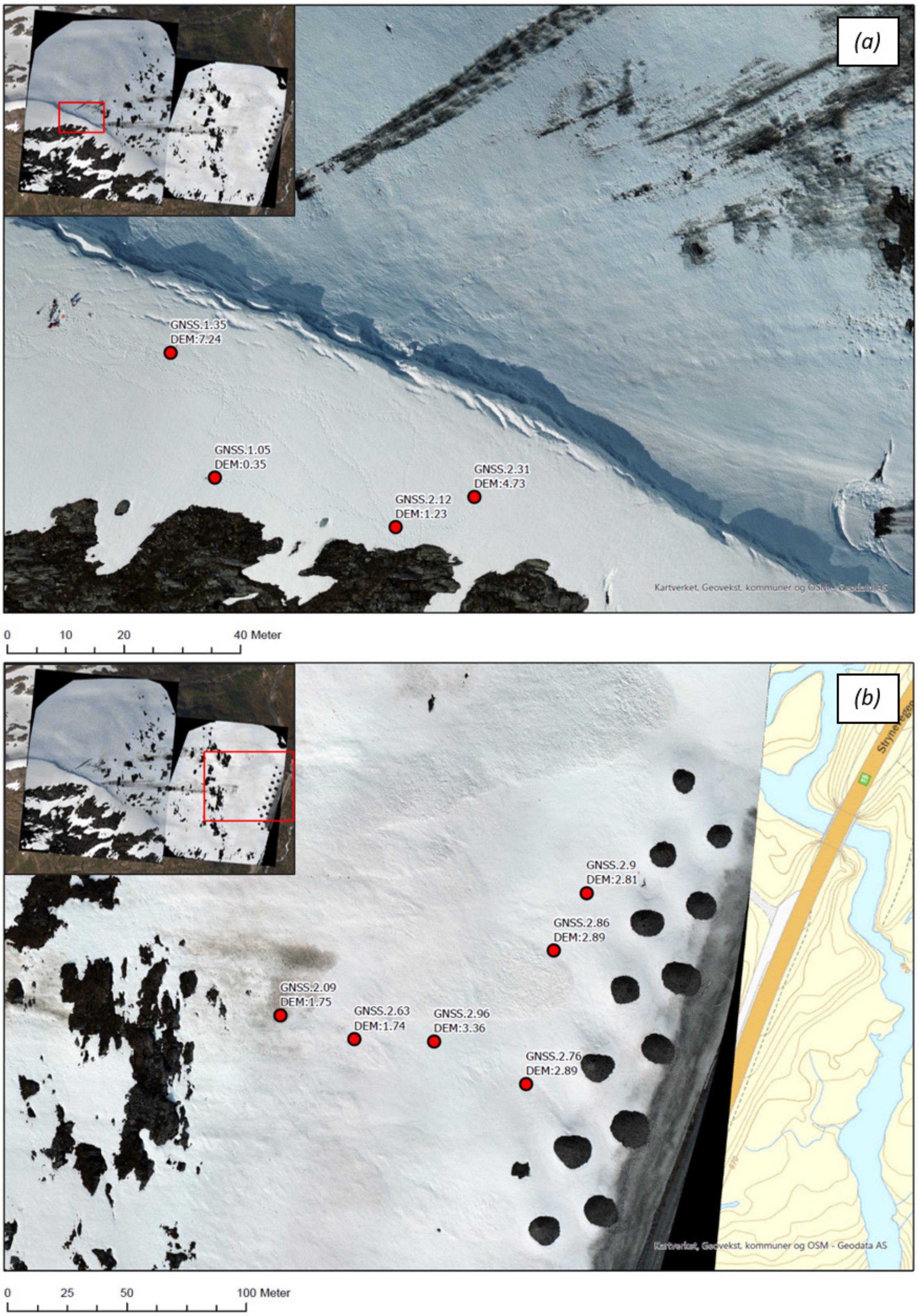


Figure 3 Ground control points (indicated in red), labelled with estimated snow depth according to snow probe ("GNSS") and drone survey ("DEM"), in the a) release area and b) runout area.

3.2 Avalanche experiments

Ten natural avalanches of size 2 and 3 on the EAWS scale occurred during the 2019/2020 winter season in Ryggfonn. The avalanches released between the end of December and early April. Due to regional travel restrictions related to the Covid-19 pandemic, it was not possible to launch a field campaign in 2020. Nonetheless, the instrumentation natural releases provided some pressure data and rough estimates on local velocities. These events also confirmed that it is desirable to have an autonomous RADAR system at the site to obtain velocity data and a system of time-lapse cameras to obtain continuous information about the conditions before and after natural releases. Although field observations were carried out on few occasions after an event, the gained information was limited by weather constraints (e.g. poor visibility). A summary of these avalanches is reported in 20200017-05-TN.

3.3 Reasons for extreme avalanche runouts

Extending the consideration on the scaling behaviour of avalanches flow (Gauer, 2018b), simple mass block simulations were run, revealing once again the importance of mass entrainment for the dynamics of avalanches (Gauer, 2020). The simulations imply that, besides an effective friction coefficient, the ratio between snow entrainment and initial mass has a decisive role for fast moving avalanches and long runouts. Smaller ratios favour higher velocities and with increasing mass along the track the velocity squared dependency of the retarding acceleration should decrease. This is partially in contrast with todays proposed parameter values for the Voellmy friction law used in many avalanche models. Some discussion on this can also be found in 20200017-04-TN.

3.4 Mathematical equations of an improved avalanche model

A post-doctoral researcher will be hired 2021 to contribute to development of an advanced mathematical model of avalanche flow in AARN. In preparation for hiring in this position, options for different aspects of the model were investigated. These activities will be continued in 2021.

4 WP 3 – Avalanche interaction

Motivation for working with avalanche interaction in AARN is derived in part from NVE's, together with other experts, recent initiative to develop a digital handbook to guide the selection and implementation of structural mitigation measures for geohazards – including landslides, debris flows, rockfalls, floods, and avalanches. The digital handbook will give guidance in all phases from planning, management, operation and maintenance of physical mitigations. The handbook is meant for designing engineers, entrepreneurs, practitioners, and responsible persons in municipalities and governmental institutions, agencies and directorates.

4.1 Alternative mitigation measures

This year we investigated a large powder avalanche in Nærøydalen, Aurland, to study the effects of the powder part on a forest and observe the run-out zone (Figure 4). The aim is to back calculate the velocity and to estimate the pressure from the snow cloud. The results will be used to make criterion for physical mitigations for areas where the powder part of the avalanche is the dimensioning factor. For instance, several schools and playgrounds in Norway will benefit from these results.

Figure 4 The Kjerrskredene avalanche was filmed by Stine Larsen Ramsøy (2020)

In 2021 we hope to have a workshop with NVE and other relevant actors to discuss new pressure criteria to be used in hazard zone mapping and for securing constructions in avalanche areas. Other countries, including Austria, Switzerland, and Iceland, have included pressure criteria in hazard mapping. We will evaluate these criteria and consider their applicability to the Norwegian context. New criteria will make it possible to plan for strengthening buildings and secure outdoor activities in avalanche run-out zones.

New methods in physical mitigations are based in part on existing methodologies and materials commonly used for other engineering purposes. A significant challenge in the adoption of these novel mitigation measures will be ensuring that they conform to new pressure criteria. There is a high demand is for more buildable space in Norway and cost-efficient solutions for mitigating against natural hazards. Investigation of new physical mitigation methods will help to efficiently secure more housing areas, roads and other types of infrastructure, and may also help to address how existing mitigation measures may be considered in the context of multi-hazards.

Most of these new methods have been tested to a degree but not implemented in Norway so far. For instance, avalanche and rockfall catching wall made of sheet pile walls (in steel) have been erected for a main road in Iceland (Figure 2). These have proven efficient for stopping small snow avalanches as well as rockfalls coming down to the road. In addition, a flat area between the wall and mountain foot ensures increased storage capacity.

Figure 5 Sheet pile structure to stop rockfall and small avalanches. Photo A. Jonsson

Another physical mitigation we have observed is an avalanche deflecting steel wall along the steep part of the talus to direct avalanches and debris flows away from the village of Guttannen, Switzerland (Figure 3). Such structures are possible to erect in steeper terrain than what is possible with conventional solutions.

Figure 6 Guttannen, Berner Oberland, Switzerland. Photo NGI

A third new type of physical mitigation is in steep avalanche terrain just above the meteorological station under Zugspitze in Germany (Figure 4). The station is secured by supporting structures just above the station and in the avalanche release areas above, to keep the snow in place. In addition, a plough-shaped steel construction is in place to divert avalanches to around the station.

Supporting structures for deflecting snow avalanches have not been used in Norway. The solution is interesting since it can be used in steep, difficult terrain, and also permits some energy dissipation due to the open structure. Study of energy dissipation in semi-open structures can be used both for deflecting and dissipate energy from avalanches.

Figure 7 Meteorological station Zugspitze (P. Gauer). Photo right is from Cortina, Italy (A. Jonsson).

A fourth physical mitigation is the use of wire rope net fences to stop small avalanches (Figure 5). We see examples from Fieberbrunn and Attersee, Switzerland, Honningsvåg, Nordvågen road, and in Alpine ski resort Lech (research test area).

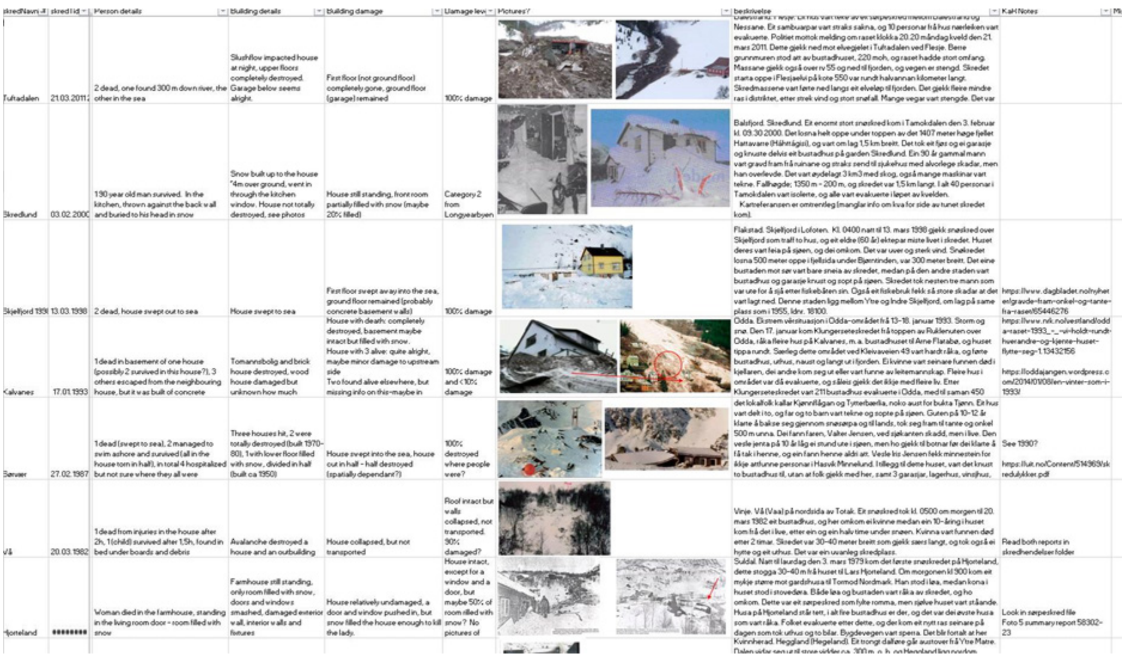
Figure 8 Barrier in Fieberbrunn, 15. April 2004 stopped a small avalanche (Photo Stefan Magreth).

4.2 Vulnerability of structures and persons in buildings

Activities in 2020 were focused on developing vulnerability curves for persons inside buildings. These curves were based on those created from the Longyearbyen avalanche in 2017. In 2021 work will continue on vulnerability of persons inside buildings with simulations run on buildings impacted with avalanches to create building vulnerability curves.

A compilation of avalanche/slush flow events from the Norwegian avalanche database which impacted buildings and have mention of people inside was compiled. Records were scanned from 1900 to present day (2020) and summarized in a table with number of persons inside, information on the persons where possible (age, gender, location in building), # survived, # injured, # escaped, and related articles such as blogs or news stories detailing the events. Approximately 90 cases were found with a reasonable amount of detail. A snapshot of the database is shown in Figure 9.

In the same table, a start was made to assess the damage to buildings based on text descriptions, and compile supporting photographs, however a finalized damage scale has not been decided upon. Once the damage scale has been selected and each case is reviewed, a preliminary vulnerability curve for persons inside buildings will be created.



skredNavn	skredTid	Person details	Building details	Building damage	Damage level	Pictures?	beskrivelse	KaH Notes
Tuftadalen	21.03.2011	2 dead, one found 300 m down river, the other in the sea	Slushflow impacted house at night, upper floors completely destroyed. Garage below seems alright.	First floor (not ground floor) completely gone, ground floor (garage) remained	100% damage		Nessane. Eit sambuarpar vart straks sakna, og 10 personar frå hus nærleiken vart evakuerte. Politiet mottok melding om raset klokka 20.20 måndag kveld den 21. mars 2011. Dette gjekk ned mot elvegjelet i Tuftadalen ved Flesje. Berre grunnmuren stod att av bustadhuset, 220 moh, og raset hadde stort omfang. Massane gjekk også over rv 55 og ned til fjorden, og vegen er stengd. Skredet starta oppe i Flesjaelvi på kote 550 var rundt halvannan kilometer langt. Skredmassene vart førte ned langs eit elveløp til fjorden. Det gjekk fleire mindre ras i distriktet, etter sterk vind og stort snøfall. Mange vegar vart stengde. Det var	
Skredlund	03.02.2000	90 year old man survived. In the kitchen, thrown against the back wall and buried to his head in snow	Snow built up to the house ~4m over ground, went in through the kitchen window. House not totally destroyed, see photos	House still standing, front room partially filled with snow (maybe 20% filled)	Category 2 from Longyearbyen		Balsfjord. Skredlund. Eit enormt stort snøskred kom i Tamokdalen den 3. februar kl. 09.30 2000. Det losna heilt oppe under toppen av det 1407 meter høge fjellet Hattavarre (Háhttágisi), og vart om lag 1,5 km breitt. Det tok eit fjøs og ei garasje og knuste delvis eit bustadhus på garden Skredlund. Ein 90 år gammal mann vart gravd fram frå ruinane og straks send til sjukehus med alvorlege skadar, men han overlevde. Det vart øydelagt 3 km3 med skog, også mange maskinar vart tekne. Fallhøgde; 1350 m - 200 m, og skredet var 1,5 km langt. I alt 40 personar i Tamokdalen vart isolerte, og alle vart evakuerte i løpet av kvelden. Kartreferansen er omtrentleg (manglar info om kva for side av tunet skredet kom).	
Skjellfjord 1998	13.03.1998	2 dead, house swept out to sea	House swept to sea	First floor swept away into the sea, ground floor remained (probably concrete basement walls)	100% damage		Flakstad. Skjellfjord i Lofoten. Kl. 0400 natt til 13. mars 1998 gjekk snøskred over Skjellfjord som traff to hus, og eit eldre (60 år) ektepar miste livet i skredet. Huset deres vart feia på sjøen, og dei omkom. Det var uver og sterk vind. Snøskredet losna 500 meter oppe i fjellsida under Bjørntinden, var 300 meter breitt. Det eine bustaden mot sør vart bare sneia av skredet, medan på den andre staden vart bustadhus og garasje knust og sopt på sjøen. Skredet tok nesten tre mann som var ute for å sjå etter fiskebåten sin. Også eit fiskebruk fekk så store skadar at det vart lagt ned. Denne staden ligg mellom Ytre og Indre Skjellfjord, om lag på same plass som i 1955, ldnr. 18100.	https://www.dagbladet.no/nyheter/gravde-fram-onkel-og-tante-fra-raset/65446276
Kalvanes	17.01.1993	1 dead in basement of one house (possibly 2 survived in this house?), 3 others escaped from the neighbouring house, but it was built of concrete	Tomannsbolig and brick house destroyed, wood house damaged but unknown how much	House with death: completely destroyed, basement maybe intact but filled with snow. House with 3 alive: quite alright, maybe minor damage to upstream side. Two found alive elsewhere, but missing info on this-maybe in	100% damage and <10% damage		Odda. Ekstrem vêrsituasjon i Odda-området frå 13-18. januar 1993. Storm og snø. Den 17. januar kom Klungerseteskredet frå toppen av Ruklenuten over Odda, råka fleire hus på Kalvanes, m. a. bustadhuset til Arne Flatabø, og huset tippa rundt. Særleg dette området ved Kleivaveien 43 vart hardt råka, og førte bustadhus, uthus, naust og langt ut i fjorden. Ei kvinne vart seinare funnen død i kjellaren, dei andre kom seg ut eller vart funne av leitemannskap. Fleire hus i området var då evakuerte, og såleis gjekk det ikkje med fleire liv. Etter Klungerseteskredet vart 211 bustadhus evakuerte i Odda, med til saman 450	https://www.nrk.no/vestland/odda-raset-1993_-_-vi-holdt-rundt-hverandre-og-kjente-huset-flytte-seg-1.13432156 https://oddajangen.wordpress.com/2014/01/08/en-vinter-som-i-1993/
Sørvær	27.02.1987	1 dead (swept to sea), 2 managed to swim ashore and survived (all in the house torn in half), in total 4 hospitalized but not sure where they all were	Three houses hit, 2 were totally destroyed (built 1970-80), 1 with lower floor filled with snow, divided in half (built ca 1950)	House swept into the sea, house cut in half - half destroyed (spatially dependant?)	100% destroyed where people were?		det lokalfolk kallar Kjønnflågan og Tynerbaerka, noko aust for bukta Tjønn. Eit hus vart delt i to, og far og to barn vart tekne og sopte på sjøen. Guten på 10-12 år klarte å bakse seg gjennom snøsørpa og til lands, tok seg fram til tante og onkel 500 m unna. Dei fann faren, Valter Jensen, ved sjøkanten skadd, men i live. Den vesle jenta på 10 år låg ei stund ute i sjøen, men ho gjekk til botnar før dei klarte å få tak i henne, og ein fann henne aldri att. Vesle Iris Jensen fekk minnestein for ikkje attfunne personar i Hasvik Minnelund. I tillegg til dette huset, vart det knust to bustadhus til, utan at folk gjekk med her, samt 3 garasjar, lagerhus, vinsjhus,	See 1990? https://uit.no/Content/514963/skredulykker.pdf
Vå	20.03.1982	1 dead from injuries in the house after 2h, 1 (child) survived after 1.5h, found in bed under boards and debris	Avalanche destroyed a house and an outbuilding	House collapsed, but not transported	Roof intact but walls collapsed, not transported. 90% damaged?		Vinje. Vå (Vaa) på nordsida av Totak. Eit snøskred tok kl. 0500 om morgen til 20. mars 1982 eit bustadhus, og her omkom ei kvinne medan ein 10-åring i huset kom frå det i live, etter ein og ein halv time under snøen. Kvinna vart funnen død etter 2 timar. Skredet var 30-40 meter breitt som gjekk særs langt, og tok også ei hytte og eit uthus. Det var ein uvanleg skredplass.	Read both reports in skredhendelser folder
Hjorteland	########	Woman died in the farmhouse, standing in the living room door - room filled with snow	Farmhouse still standing, only room filled with snow, doors and windows smashed, damaged exterior wall, interior walls and fixtures	House relatively undamaged, a door and window pushed in, but snow filled the house enough to kill the lady.	House intact, except for a window and a door, but maybe 50% of room filled with snow? No pictures of		Suldal. Natt til laurdag den 3. mars 1979 kom det første snøskredet på Hjorteland, dette stogga 30-40 m frå huset til Lars Hjorteland. Om morgonen kl 900 kom eit mykje større mot gardshusa til Tormod Nordmark. Han stod i løa, medan kona i huset stod i stovedøra. Både løa og bustaden vart råka av skredet, og ho omkom. Dette var eit sørpeskred som fylte romma, men sjølve huset vart ståande. Husa på Hjorteland står tett, i alt fire bustadhus er der, og det var dei øvste husa som vart råka. Folket evakuerte etter dette, og der kom eit nytt ras seinare på dagen som tok uthus og to bilar. Bygdevegen vart sperra. Det blir fortalt at her	Look in sørpeskred file Foto 5 summary report 58302-23
							Kvinnherad. Heggland (Hegeland). Eit trongt dalføre går austover frå Ytre Matre.	

Figure 9 Preliminary database on avalanche events impacting buildings with persons inside

A document from Switzerland with numerous detailed records of avalanches was also received, and translation is nearly complete. These records will be added to the Norwegian records. It may be possible during the coming year to contact researchers from other countries (i.e. Iceland, Austria, etc) for access to their avalanche records.

Activities in 2021 will also focus on including uncertainties into empirical vulnerability curves based on historical avalanche events and assess vulnerability of typical Norwegian buildings subjected to avalanche loads in a probabilistic framework, using finite element method (FEM), e.g. Opensees or Plaxis. A comparison of empirical vulnerability curves and vulnerability curves derived from FEM will be conducted.

4.3 Residual risk

The risk from avalanches can never be totally mitigated by avalanche protection measures. Support structures can be overtopped, avalanche dams can prove to be too low and avalanche forecasting can assess the avalanche danger wrong. We want to develop a framework to estimate the residual risk after mitigation such that we are able to estimate and quantify the effects of mitigation measures and the consequences of using protected areas after mitigation. This work is strongly based on the outcome from other work packages and is therefore not started in 2021.

5 Research infrastructure resources (RIR)

AARN is utilising two main sites with actively deployed research infrastructure; (1) the full-scale test-site Ryggfonn and (2) the mountain research station Fonnbu. Both are organised as a "leiested" and receive basic funding from AARN to maintain the resourced and provide services for the research activities. In autumn 2020 a proposal was submitted to NFR to apply for a significant upgrade of the Ryggfonn-Fonnbu facility to the Strynefjellet Mountain experiment. We anticipate the outcome of this application during late 2021.

5.1 Full-scale avalanche test-site Ryggfonn

Under this task, necessary repairs and updating of the data acquisition system at the Ryggfonn avalanche test site (Stryn municipality, Vestland county, western Norway) were carried out so that the site is ready for the winter season 2020/2021.

Several upgrades were made at the Ryggfonn test site, financed by other research funding available at NGI. The updates include two compact weather stations, positioned at the top and at the valley bottom, to have better information on the environmental conditions during avalanche release. Secondly, the infrastructure for the installation of an autonomous pulsed Doppler radar was put in place. The radar was installed early 2021 in cooperation with BFW in Innsbruck, Austria, which offered a Doppler RADAR systems for Ryggfonn. Figure 6 show the new instruments.

Figure 10 Doppler Radar from BFW (left) and weather station at the instrumentation hut (right).

5.2 Research station Fonnbu

The research station Fonnbu had a general clean up and update of facilities to meet the needs of the winter activities. Due to the travel restrictions in 2020, the research station was not used as often as planned. During the autumn, the weather observation system was improved by including temperature and wind measurements at the meteo mast. This is important to maintain continuous observations from the same location. At the same time, a new camera was installed on the meteo mast. The fully remote controllable camera can turn 360 degrees and has a high optical zoom function. The camera provides live video and can be programmed to take still pictures from specific locations at a given time interval. This allows us to follow the development of snow distribution and avalanche activity. Currently other research projects at NGI are looking into the possibilities of automatic image analysis for snow distribution and avalanche activity.

Figure 11 Pictures from the new camera on the meteo mast at Fonnbu. Left shows the research station, right shows the release area of Ryggfonn.

6 Cross-package topics (CPTs)

6.1 Avalanche observations and monitoring

Observations of avalanche events in Norway are often biased by the initiator and the personal interests of the observer. While an engineer would be interested in the damage on structures in the avalanche path and run out zone, an avalanche forecaster would most likely be more interested in the properties of the weak layer in the starting zone. The element of avalanche dynamics which experts are most interested in the run-out length. Experience with analysing the historical avalanche events in the national database, NGI archives and other sources show that we lack a uniform documentation of the events. We have therefore designed observational guidelines for avalanche events to ensure that all important parameters are recorded when we conduct field surveys of interesting events. The parameters are chosen according to the dataset in the national database such that registrations from AARN easily can be transferred to the national database.

6.2 Quantitative risk assessment

A quantitative risk assessment needs to implement the results from other work packages (4.3 probabilistic release modelling, 5.4 probabilistic runout modelling, and 4.2 vulnerability assessment). We therefore await results from the other work packages before we put efforts into this work. In the GBV-HARM, a probabilistic version of Voellmy model was developed to conduct runout analysis in a probabilistic way using Monte Carlo simulations. However, uncertainty quantification of friction parameters needs further refinement and will be addressed later in the project.

6.3 Forest effects

Work on a simple probabilistic release model for avalanche Hazard Mapping (Gauer 2018), was taken up again. The model involves meteorological data from SeNorge, such as HS, HNW, RR, SWE, TA. The model now includes an extended forest parametrization that also accounts for interception. Forest influence the snowpack and its stability in various way. Forest covers to a certain degree the amount of snow on the ground. Loading intensity is reduced due to interception, which depends on the leaf area index (LAI), the crown cover, and the amount of precipitation; with increasing precipitation the effect of interception decreases. The forest-cover also influences the weak layer properties directly and it is generally agreed that wide spread of weak layers decreases increasing crown cover. In certain case, "tree bombs" can however cause intense loading of the snowpack and so avalanche release.

7 Project plan and budget – 2021

7.1 Revised work plan 2021

Table 4 Summary of the AARN project activities planned in 2021, based on the project proposal. Note the research activities in most topics are ongoing.

WP 1 – Avalanche formation and release	• Test methodology to derive PRA from WindSim or Winstral in combination with Arome wind data • Calculate distribution of strong wind on 8 wind directions during winter based on Arome • Use the distribution (fraction of wind per direction) to weight the wind effect maps from Winstral and WindSim • Set thresholds in weighted wind maps to automatically derive PRA map (together with steepness and the rest of the PRA methodology used in NAKSIN) • Validate against mapped snow avalanches in Stryn/Grasdalen • Validate against PRA map from hazard mapping projects (e.g. Lom, Stryn etc)
WP 2 – Avalanche dynamics	• Implement the results from the new radar at Ryggfonn in the workflow of experiment documentation • Start work with the new PostDoc at model approach for a new integrated dynamical avalanche model
WP 3 – Avalanche interaction	• Development of a physical model for the powder part of the avalanche. • Investigate the applications for cross-laminated timber (CLT) to strengthen buildings against the powder snow cloud. • Workshop to discuss alternative mitigation measures and new materials (e.g. CLT). • Continue to gather information of the performance of existing physical mitigations to improve avalanche modelling.

Research infrastructure resources (RIR)	• Installation of similar camera at as installed at Fonnbu on top of the new radar mast at Ryggfonn • Continue the work to integrate all data that is collected in Grasdalen into one data acquisition system
Cross-Package Topics (CPT)	• Follow up on interesting avalanches, collect information and make data easily available for research • Study the impact of forest on snow pack stratigraphy and instability

7.2 Budget 2021

The Budget for 2021 is adjusted based on the experience of the last year and the fact that we will employ a PostDoc for the second half of 2021.

Table 5 Budgeted allocation for 2021 (amounts in kNOK)

	WP 0 (Admin & reporting)	**PostDoc**	**WP 1**	**WP 2**	**WP 3**	**RIR**	**CPT**	**Total**
Allocated	350	600	400	700	400	650	900	4 000

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