NORCE Avalanche & Landslide hazard & risk

Introduction

Mass movement of snow, rock or soil on sloping terrain causes major hazards in mountainous areas worldwide. **Snow avalanches** constitute the deadliest geohazard events in Norway. They are affected by a complex interaction of terrain characteristics, snow properties and meteorological variables that makes them especially sensitive to climatic variations, but also challenging to forecast. **Landslides**, such as rockslides, rockfall, mud/debris flows and quick clays, are major threats to infrastructure and population if they occur in populated areas or in valleys/fjords where dam-burst flooding and tsunami can be generated. Ground temperature and precipitation regimes influence the dynamics of landslides. Changing climate has therefore an impact on landslide stability, but this relation is still poorly understood.

The consequence of avalanches and landslides in our society (**risk**) is the product of the extent and intensity of the events (**hazard**) and the characteristics of potentially impacted people or infrastructure (**vulnerability and exposition**). All these elements are dynamically evolving due to changing natural conditions (increasing precipitation, temperature and extreme weather intensity/frequency) and socio-economic structures (increasing demography and tourism, increasing poverty). There are therefore major **knowledge gaps** to understand the avalanche and landslides dynamics in a **changing climate** and solve critical **operational challenges** to mitigate the risk managed by public and private stakeholders in a **changing society**.

In this document, we summarize the unique set of **NORCE interdisciplinary expertise** that can contribute to **1)** develop advanced ground-based, airborne and satellite systems, visualization and data analysis tools for the monitoring of snow avalanches and landslides (**Energy & Technology**), **2)** understand the environmental controls and impact of climate change on the dynamics of such processes (**Climate & Environment**) and **3)** evaluate the risks for population and infrastructure, design mitigation solutions and adaptation strategies together with local communities and public stakeholders (**Hearth & Social Sciences**).

Authors and research groups

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Research groups: Earth Observation, Drones and Autonomous Systems, Data Assimilation and Optimization, Measurement Science, Digital Systems, Computational Geosciences and Modelling, Climate, Environment and Durability, Regional Climate, Forecasting Engine.

Radar remote sensing

NORCE has long experience in **Synthetic Aperture Radar (SAR) signal processing and time series analysis** for the detection and monitoring of avalanches and landslides at large scale. Our expertise covers methodologies exploiting all components of complex SAR images based on sensors mounted on **satellites, aircrafts or terrestrial platforms**.

Radar Interferometry and offset tracking

Contact persons: Line Rouyet, Tom Rune Lauknes

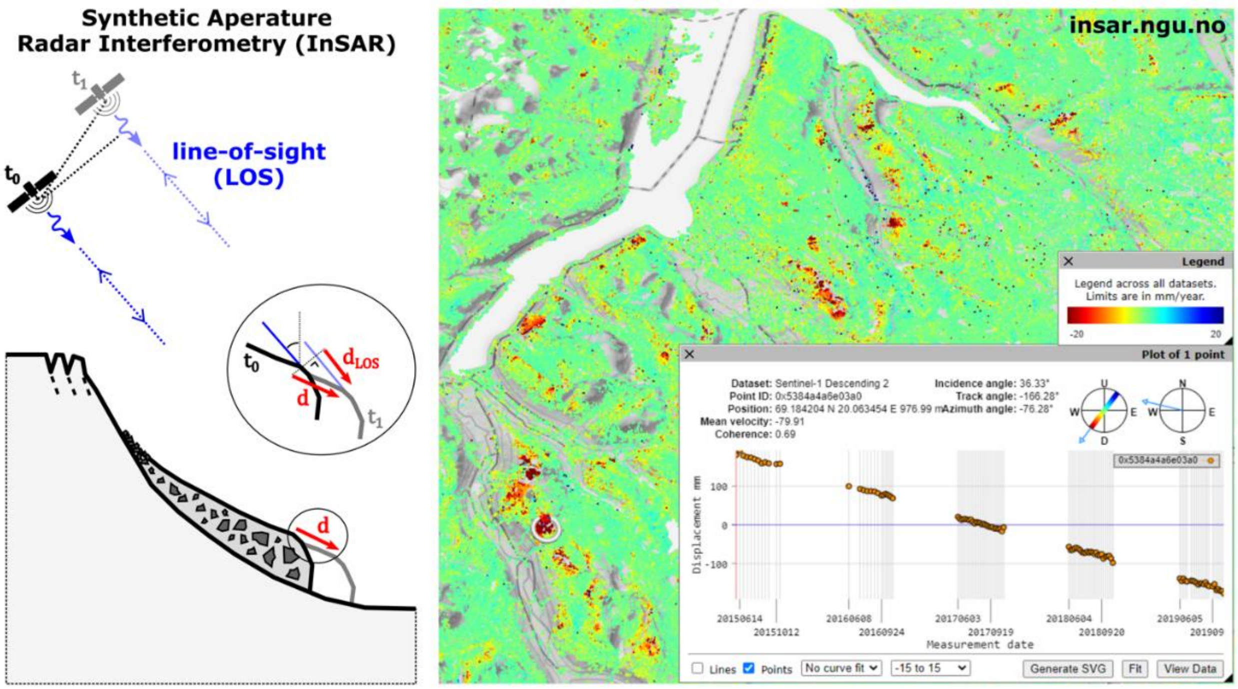

Figure 1. Synthetic Aperture Radar Interferometry (InSAR) for measuring ground surface displacements of gradually sliding/deforming rock slopes (landslides and creeping permafrost landforms).

SAR satellites orbit around the Earth and take radar images at different times. When comparing images from different acquisitions, it becomes possible to detect distance change between the sensor and the ground surface, along the radar line-of-sight (LOS). The so-called **Synthetic Aperture Radar Interferometry (InSAR)** technique allows for measurement of ground surface displacements at millimetric-centimetric accuracy and is especially valuable **to detect, map and monitor deep-seated landslides and superficial creeping landforms** (Figure 1).

NORCE InSAR processing chain constitutes the backbone of the operational **InSAR Norway ground motion mapping service** (http://insar.ngu.no/), especially used by geologists to identify moving objects and evaluate the hazard they represent. In addition, we have several research projects exploiting InSAR for studying the kinematics of unstable mountain slopes and permafrost landforms in mainland Norway and Svalbard.

The loss of interferometric signal stability can limit the use of InSAR in areas characterized by very rapid movement. In these cases, another technique, called **SAR offset tracking** can be applied.

The method is especially valuable for documenting objects with a velocity of several meters per year (e.g. glacial flow, destabilized rock glaciers).

Radar sensors can also be mounted on airborne or ground-based platforms to reach better spatial/temporal resolutions and have complementary acquisition geometries. NORCE owns a **terrestrial radar, the Gamma Portable Radar Interferometer (GPRI)**. A GPRI allows for continuous monitoring at a second/minute resolution valuable for studying diurnal velocity variations in respect to external drivers, such as temperature and precipitation. The same system can be used on snow-covered surfaces and has the potential to detect millimeter snow deformation hours to days before snow avalanche release.

Radar backscatter analysis and change detection

Contact persons: Hannah Vickers, Jakob Grahn, Rolf Ole Jenssen, Eirik Malnes

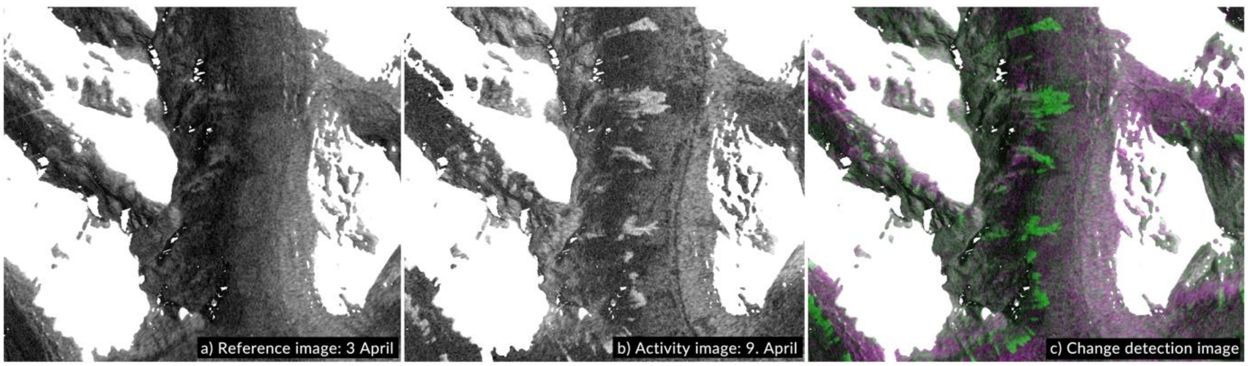

Figure 2. Snow avalanche detection from the change in SAR backscatter coefficient based on two satellite images taken before and after the release.

Utilizing the **change in SAR backscatter coefficient over time**, snow avalanches can be detected on daily basis in Norway (Figure 2). These daily detections are used by the Norwegian Avalanche Forecasting Service hosted by the Norwegian Water and Energy Resource Directorate (NVE) (www.satskred.nve.no) in their avalanche forecasting work.

The presence of **wet snow** can be important during several avalanche hazards (e.g. normal snow avalanches, slush avalanches, landslides). NORCE has a long history of using SAR to detect wet snow and has developed operational processing chains. A current focus is on long term mapping of wet snow on Svalbard related to rain-on-snow events and avalanche hazards. **Snow depth or Snow Water Equivalent (SWE)** are important parameters for snow avalanche release. NORCE has several projects where we focus on these parameters both with satellite and airborne radars.

NORCE has developed a **Ground Penetrating Radar (GPR)** that can be flown on drones (Figure 3). It is capable of measuring snow depth and layering valuable for avalanche hazard assessment. The GPR can be used to measure snow water equivalent (SWE), detect people buried in avalanches and study the soil properties by analyzing the differential wave penetration.

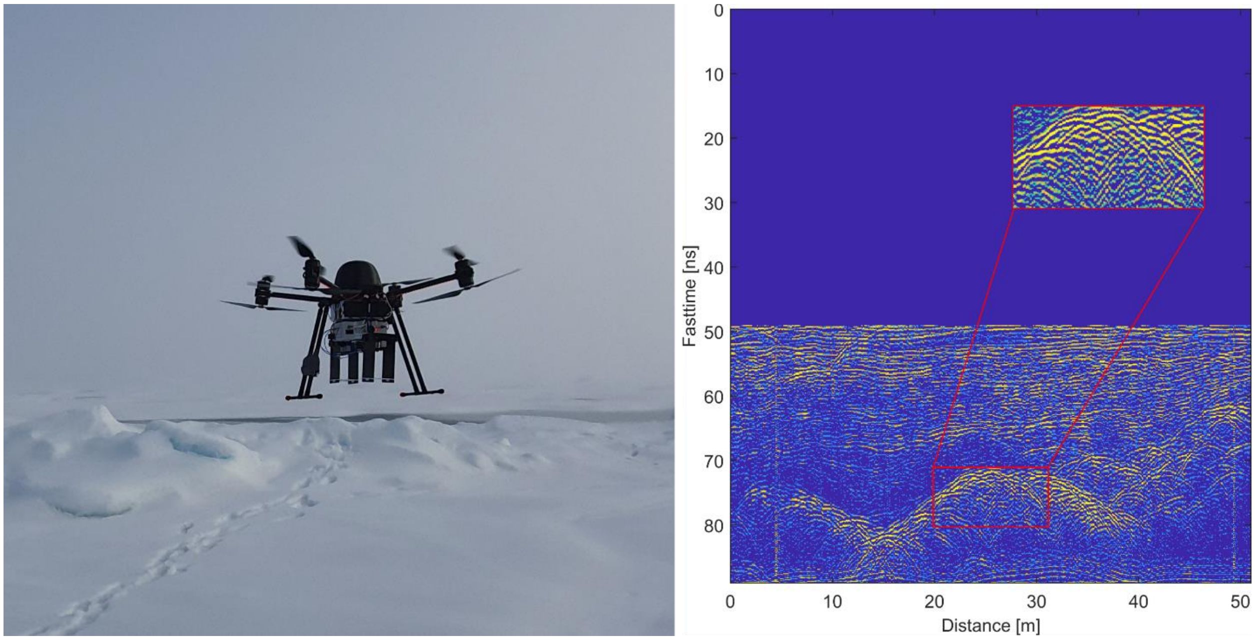

Figure 3. Ground Penetrating Radar mounted on drone for the measurement of snow properties and depth.

Radar backscatter is sensitive to **Soil Moisture Content (SMC)** and can be derived from SAR images. NORCE has an ongoing project where we try to establish several methods to derive SMC. Both relative methods (scaling backscatter) and absolute methods where we invert physical models for backscatter are considered.

Monitoring of hazards related to dams and water reservoirs can be done using SAR to measure **lake extent and level**. Monitoring of glacier limited lakes and outbursts (for example Jökullaup) can also be done. NORCE has long term expertise in **flood monitoring** using SAR. Floods can in some cases be a consequence of avalanche release (e.g. rock avalanches or avalanches that are released in rivers and cause river outburst).

SAR backscatter is to some extent sensitive to **freezing/thawing of the top layer of the soil**, which is especially important in the dynamics of permafrost areas and can play a role in avalanche release. NORCE has also tested out several methods to study the **quick clay** avalanche in Gjerdrum 2020. **Slush avalanches** have also been studied, but only large avalanches are detectable.

Optical and hyperspectral remote sensing

Unmanned Aircraft Systems or Drones

Contact persons: Agnar Sivertsen, Rolf Ole Jenssen

NORCE is the leading institution in Norway on the development of **Unmanned Aircraft Systems or drones.** We develop custom drone platforms, control systems and communication systems, that can be applied to acquire imagery for slope hazard applications. Droneborne cameras allow for acquiring **high resolution optical or hyperspectral imagery** valuable for the detection and mapping of hazardous areas.

Combined with **Surface from Motion (SfM)** processing, optical images can be used to provide detailed **Digital Elevation Models (DEMs)** of snow avalanches and landslides. For snow avalanches or abrupt landslide failure, comparison of two DEMs generated from images before and after the release can be used to estimate the **volume of the debris mass**. On gradual sliding processes, the comparison of DEMs acquired at different times can document the **movement rates** of the landforms.

Optical satellite and manned aircraft remote sensing

Contact persons: Agnar Sivertsen, Eirik Malnes

Techniques based on drone images can also be applied using **optical satellite and manned aircraft imagery**, typically with lower spatial resolution but larger coverage capability. NORCE have for example used Sentinel-2 optical imagery for snow avalanche detection on Greenland as a supplement to Sentinel-1 SAR data.

In Svalbard, NORCE has installed and tested a suite of optical imaging sensors on the Lufttransport **Dornier aircraft** stationed in Longyearbyen as part of the **Svalbard Integrated Arctic Earth Observing System (SIOS)** (https://sios-svalbard.org/research_aircraft). The aircraft is configured to acquire aerial imagery and hyperspectral remote sensing data in addition to its normal transport operation. The round-trip range of the aircraft is 2400 km, which enables a variety of geoscientific applications around Svalbard.

In-situ instrumentation and field investigation

Advanced in-situ sensors

Contact persons: Peter James Thomas, Kjetil Haukalid, Kjetil Folgerø

NORCE has long experience with **electromagnetic (EM) in-situ measurements**, modelling and sensor development. EM measurements techniques are in general well suited for measurement of **the ground moisture (water content in mixed materials)**, due to the large contrast between the dielectric properties of the water and other typical substances such as soil, rock, sediments, ice and snow. Both distributed measurement and point-based measurement techniques are available. Since slope hazards are often affected by ground wetness or the melting of ice/snow, in-situ EM measurements can be valuable both standalone and in combination with remote sensing techniques.

The last decade, NORCE has developed a significant project portfolio on **fiber optic measurements, both for distributed sensing and point measurements**. This includes applications where fiber optic measurements are used for detecting avalanches and landslides along roads and railways, measuring ground moisture and estimating snow water equivalent.

Field surveys

Contact persons: Hannah Vickers, Eirik Malnes

Advanced technology based on new sensors and remote sensing techniques must be complemented and validated by traditional field investigations. NORCE has good knowledge and experience in **field surveying in mountainous and arctic environments**. Regular campaigns for **snow profiling and avalanche assessment** are performed to validate remote sensing products.

Data assimilation and Machine learning

Contact persons: Geir Nævdal, Xiaodong Luo, Andreas S. Stordal, Jakob Grahn

NORCE has a strong group within **data assimilation** and has applied it within a number of fields, including updating petroleum reservoir models, medical models, and snow and hydrological models. In one project, financed by Statkraft, our data assimilation expertise was utilized for improving hydropower inflow forecasts by assimilating snow data. The method has high potential for applications within the field of avalanche monitoring.

Machine learning, especially deep learning, has been widely used in computer vision tasks, e.g. for **image recognition and object detection** based on remote sensing images. Automatic identification targeted for avalanche detection can also be performed based on image recognition and/or object detection from appropriate information sources, e.g. SAR satellite images (Figure 4).

Avalanche prediction can potentially be achieved by **multimodal machine learning models**. Snow avalanches often occur as a result of different factors, e.g. weather and topographical conditions, human activities, etc. Therefore, a prediction model based on machine learning approach could be developed and trained on annotated multimodal data.

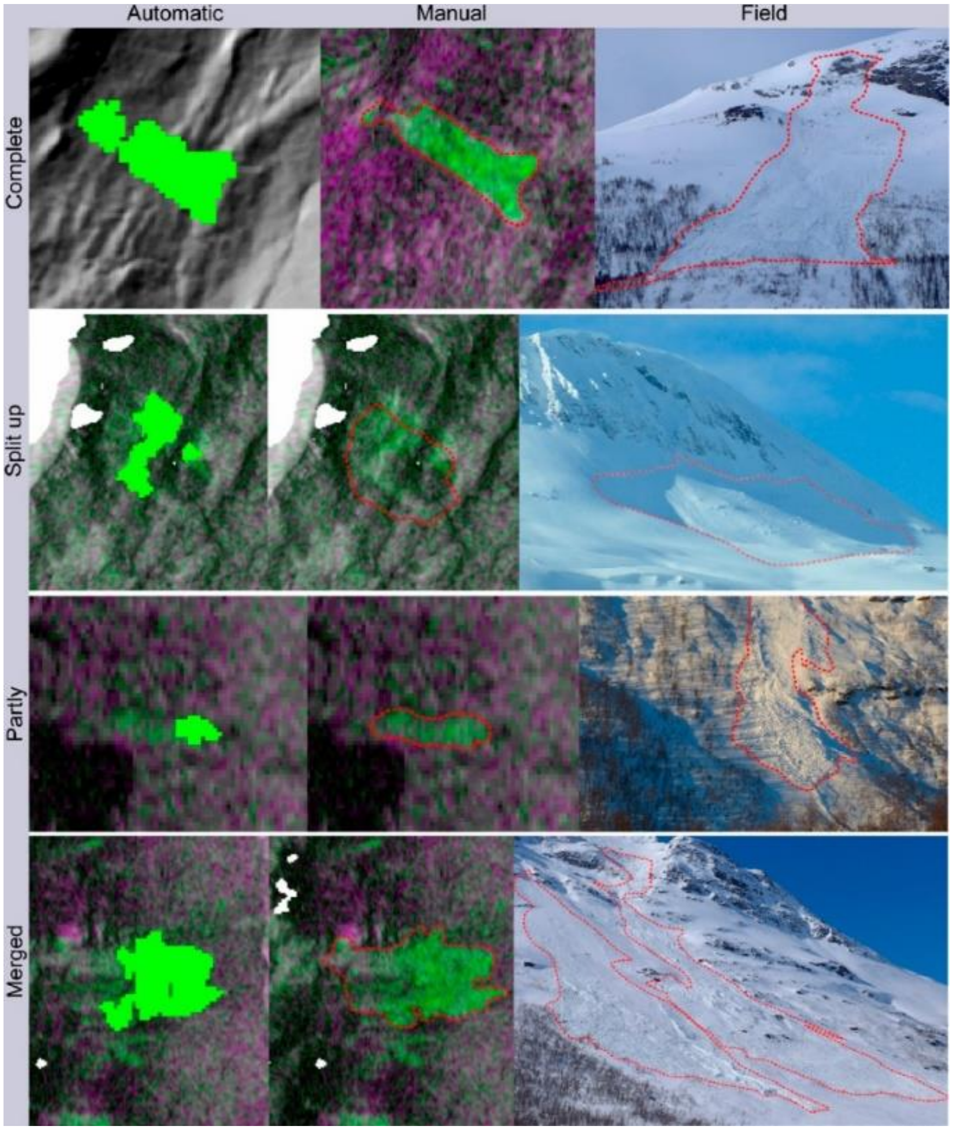

Figure 4. Results of the snow avalanche detection using machine learning based on SAR images (automatic detection), compared with manual detection and field pictures.

Geospatial analysis and visualization

Enlighten-web

Contact person: Tor Langeland

Enlighten-web is the engine used in several web portals. The **EPOS-Norway** (https://epos-no.uib.no:444/) is one of them. It is used to access and visually analyse earth science data in the Norwegian node of the European Plate Observing System (EPOS) (Figure 5).

Enlighten-web facilitates **interactive visual analysis of large multidimensional data sets**. Figure 5 shows an example of how a user can explore seismic events information and compare them with slope information for an area near Longyearbyen on Svalbard. The rightmost plot shows event magnitudes over time, while the events in the selected area in the map are highlighted.

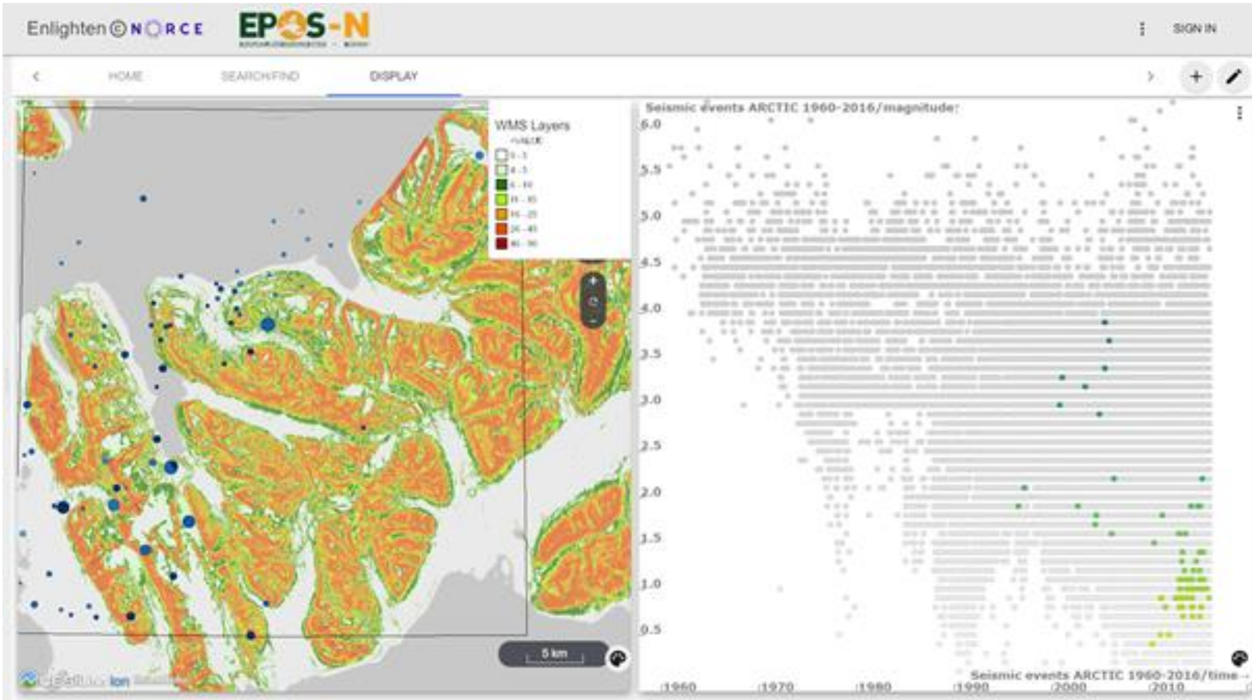

Figure 5. Enlighten-web technology used for analyzing the distribution and properties of seismic events in the European Plate Observing System (EPOS) Norway portal.

NLive

Contact person: Daniel Stødle

NLive is a system developed by NORCE that enables **high-performance visualization of georeferenced and time-stamped datasets in 3D on a virtual globe**, on the web or in virtual reality. The system can display both real-time and time-shifted datasets combined with different map and object layers, such as points or buildings. The time series can represent different kinds of data, such as drone flights, sensor logs, AIS or transponder data, air quality measurements, and more. The system is highly extensible and adaptable, enabling integration with new datasets and data sources in an efficient manner.

NLive is the foundation for several of NORCE's applications of 3D visualization on the web. It provides the frontend for the **InSAR Norway ground motion service** (https://insar.ngu.no), and comparable services outside Norway, such as InSAR Sweden and the European Ground Motion Service, enabling users to visualize ground deformation datasets that in total are approximately 100 TB. NLive is also being used as the 3D visualization component of the **European Space Agency's Cryosphere Virtual Laboratory** (https://cvl.eo.esa.int/), serving as a visualization playground for interactive research and development of new algorithms for processing remote sensing datasets. NLive has been used extensively for **NORCE's drone activities for monitoring and sharing of flight data** both internally and externally (Figure 6).

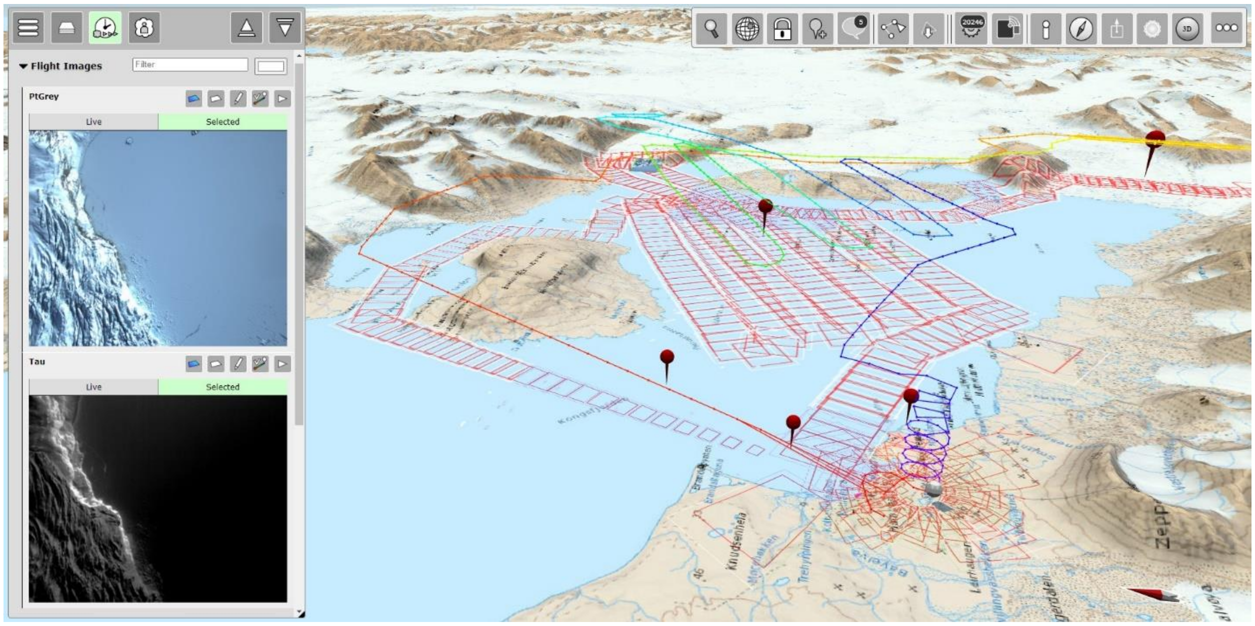

Figure 6. NLive visualizing optical and infrared images at the front of a calving glacier (left), flight track and image footprints from a drone flight in Ny-Ålesund, Svalbard (right).

LIME: visualisation, interpretation and presentation of 3D models in geoscience

Contact person: Simon Buckley

LIME is a desktop (currently Windows) software for working with 3D models generated primarily from laser scanning (lidar), photogrammetry or other terrain or laboratory-based optical measurement systems (Figure 7). The software supports standard 3D model formats and can handle **extremely large or detailed models** through generation of tiled models and out of core rendering. The software has been developed for geoscientists to obtain quantitative and qualitative results from their 3D model data, based on a simple user interface. Visualisation settings can be used to highlight surface orientation including dip (slope) and dip direction (aspect). LIME allows digitisation of lines, planes, points of interest and overlays. In addition, supplementary data can be easily **integrated and co-visualised**, such as field data (logs, photos, scales, subsurface sections), GIS data (elevation models, imagery, maps etc), geophysical sections, and multi/hyperspectral/thermal image overlays. LIME can be used to make attractive 3D presentations, training and course material, as well as virtual excursions using the built-in **presentation** tools.

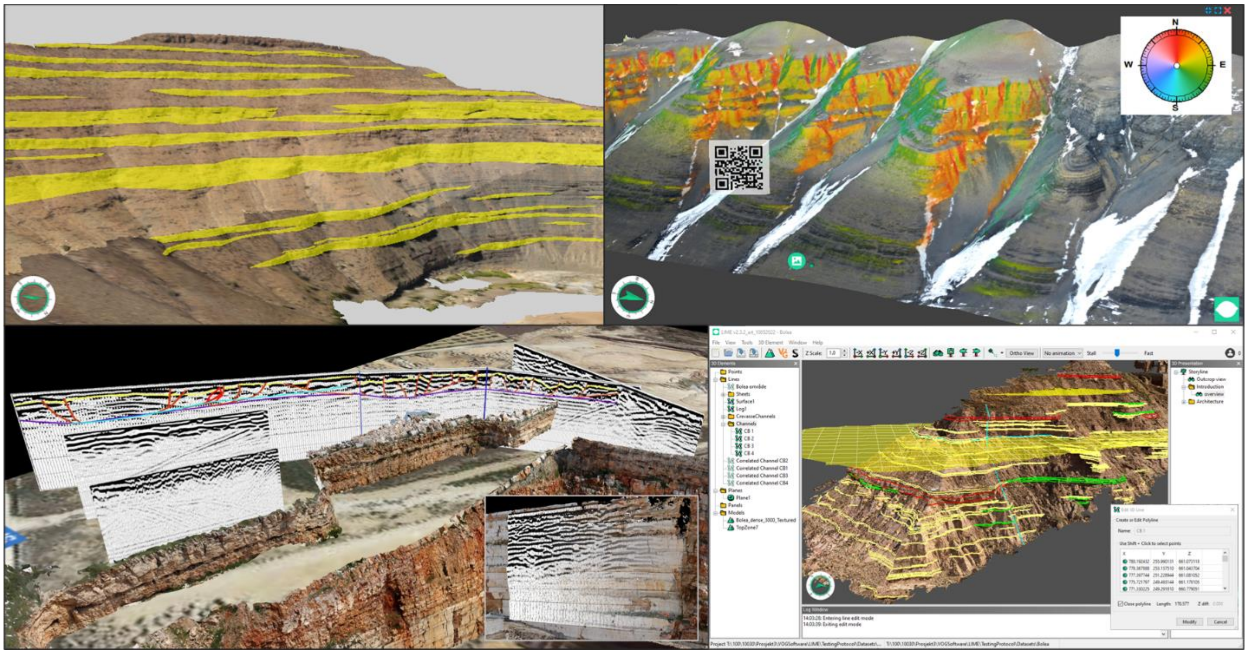

Figure 7. Co-visualisation and interpretation using LIME. Clockwise from top left: mapping zones (sandstone channel bodies) on a 3D outcrop model; visualization of surface aspect filtered by slope gradient (Eistradalen, Svalbard; https://v3geo.com/model/371); mapping tools and user interface; integration of ground-penetrating radar sections (inset: GPR section projected on a 3D surface model).

V3Geo: cloud-based database of virtual 3D models

Contact person: Simon Buckley

V3Geo is a purpose-built repository for sharing virtual 3D models within the geoscience community (Figure 8). The repository includes hundreds of high-quality virtual outcrop and other 3D geoscience models that have been uploaded and shared by the community. All public models are available under Creative Commons licenses and can be used in classrooms, publications, research, or as the basis of virtual field courses and excursions. A key advantage of V3Geo is the ability to handle **large, multi-section 3D models**, allowing high detail or extremely large areas to be stored without compromising on detail. A **3D web viewer** can be used to browse the models online, while a connection to LIME is available for further annotation and presentation.

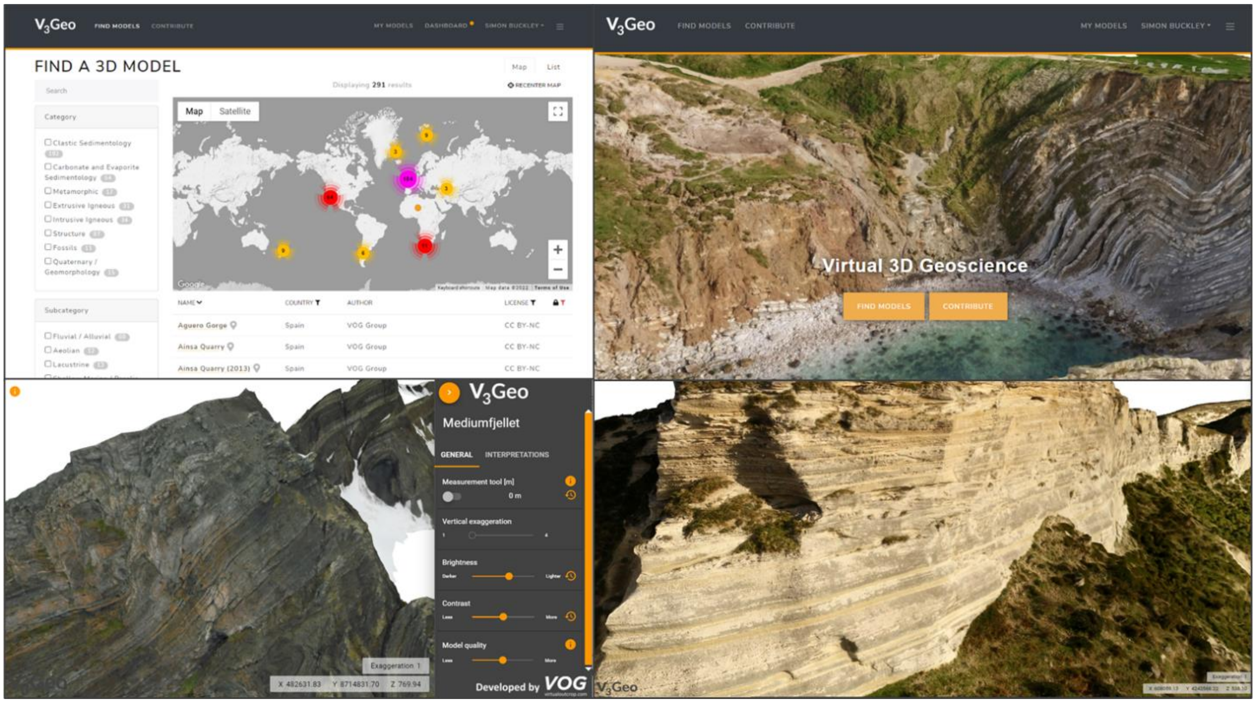

Figure 8. V3Geo online 3D model database showing search and filter tools and examples of 3D web viewer allowing interactive exploration of the model content (Mediumfjellet, VOG Group, https://v3geo.com/model/142; Aspalmo, VOG Group, https://v3geo.com/model/71).

Climate modelling

Contact persons: Marie Pontoppidan, Stephanie Mayer

Our research groups use **regional models** to increase current understanding of physical processes in the climate system relevant at scales ranging from continental to regional to local scales. We provide research and data suitable for impact studies to ensure a solid knowledge base for society and for decision-making support. We focus on **hydrological and atmospheric** processes and long-term changes by employing a wide range of tools including **seasonal to decadal climate projections and scenario-based projections**. In addition, we explore **extreme events and land-atmosphere interactions**.

We are leading the Centre for research-based innovation Climate Futures which co-produces new and innovative solutions for predicting and managing climate risks from 10 days to 10 years. We are also key partners in national centres such as the Bjerknes Centre for Climate Research, the Norwegian Centre for Climate Service (Figure 9) and the Norwegian Research Centre on Sustainable Climate Change Adaptation. We are involved in international initiatives such as the World Climate Research Program sponsored Coordinated Regional Downscaling Experiments (CORDEX), which coordinates an extensive effort in multi-model ensemble downscaling at high spatial resolution, in addition to the CORDEX-sponsored Flagship Pilot Studies.

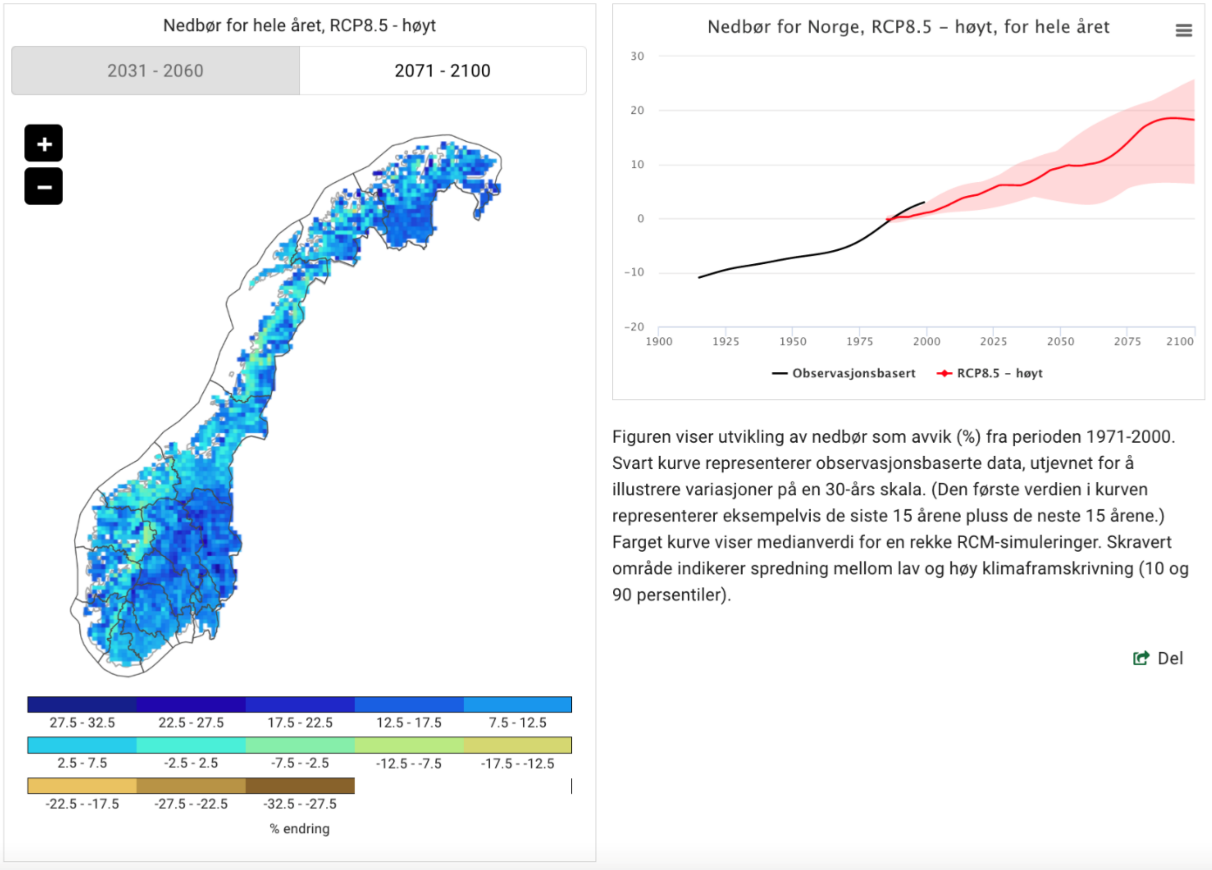

Figure 9. Relative change in precipitation over Norway by the middle of this century (2031-2060 compared to 1971-2000 for the emission scenario RCP8.5), data and figures are available at https://klimaservicesenter.no.

Climate and risk adaptation

Contact person: Elisabeth Angell

How do local communities manage to prevent natural events, such as landslides and avalanche, which can cause damage to people, buildings and other infrastructure? How do the authorities work with climate risk and adaptation? Social scientists can **evaluate how national, regional and local authorities work to reduce risk and prevent undesirable natural events**. We can also investigate how this work is organised and funded.

Norway has a Climate Act, a Planning and Building Act, national regulations for regional and municipal planning (SF), as well as national guidelines for climate & energy planning and climate adaptation (SPR), which provide a formal framework for community planning. Maps are also important tools, both to describe the current territory organisation and to define management priorities. Natural and human environments must be mapped to identify risks of undesirable events, while taking into account future evolution in relation with climate change.

The national report on climate adaption for infrastructure management[1] contains serious criticism related to the lack of mapping and overview to secure Norwegian buildings and other infrastructure. We can contribute to this objective to **include avalanche and landslide risk analysis in municipal and regional management and transport plan** (roads, railways and ports), and assist the expert knowledge transfer to the authorities. Risk mitigation measures, such as snow protection fens (Figure 10), must be integrated in the work for adaption to the future climate, at local, regional and national scales.

Figure 10. Example of avalanche fens to protect buildings in Hammerfest (Picture: Tom Erik Ness)

We can also contribute to mobilize and disseminate the knowledge to stakeholders through co-creation arenas. In recent years, NORCE, together with several partners have organised the **Klimathon**, with a focus on climate adaption in Norwegian municipalities. Klimathon is a hackathon-inspired event and brings together participants from municipalities, counties, State, voluntary organization, private companies and research institutes. All partners bring with their own knowledge sets and contribute to solve specific tasks about climate adaption, through group discussion and exchange of ideas.

[1] Document 3:6 (2021-2022) [Alvorlig kritikk til myndighetenes arbeid med klimatilpasning (riksrevisjonen.no)]