

Alaska Snow Avalanche Hazards Database

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Modeled avalanche extents that identify terrain susceptible to avalanche activity under the “Frequent” hazard scenario (estimated return period under 30 years) near Klukwan, Alaska. Yellow to red colors represent increasing impact pressure, while light to dark blue shades indicate increasing deposition depth.

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Alaska Snow Avalanche Hazards Database

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ABSTRACT

The Alaska Snow Avalanche Hazards Database is a statewide geospatial archive that systematically stores, organizes, and shares snow avalanche hazard information. It is designed to hold standardized raster and vector layers describing snow and terrain conditions, potential release areas, simulated avalanche extents, and derived hazard indication data. The structure emphasizes repeatable, map-based workflows that can be applied consistently across regions and scales, from broad hazard indication assessments to path-specific analyses. Modular and updateable, the database can incorporate new avalanche datasets as they become available. Its primary goal is to serve as a centralized repository of snow avalanche hazard information that supports evidence-based decision-making for land-use planning, transportation, resource management, and risk-reduction efforts. These data and accompanying discussion are released as a DGGS Digital Data Series publication, and all publication components are available from the DGGS website at <https://doi.org/10.14509/32076>.

INTRODUCTION

Snow avalanches are a recurring, consequential hazard across Alaska, where steep terrain, deep seasonal snowpacks, and critical transportation and lifeline corridors often intersect avalanche-prone slopes. Many communities face substantial exposure because roads, utilities, and residential and commercial areas occupy confined valleys and fjords where large, fast-moving avalanches can cause loss of life, damage to infrastructure, and prolonged loss of access. Avalanche hazard maps are produced with computer models that show where avalanches are likely to start and how far they might travel. These maps are especially helpful in places where it is hard to collect detailed information on the ground.

This report describes the creation of the Alaska Snow Avalanche Hazards Database. Using snow avalanche hazard indication mapping in Southeast Alaska as a case study, it demonstrates how remote sensing, geospatial analysis, and numerical simulations can be combined to produce standardized hazard data products. It documents the workflows used to derive snow height distribution, delineate potential release areas, and simulate probable runout patterns under different recurrence intervals and climate scenarios, and describes how these outputs are structured and stored in the database. The resulting map products and accompanying geospatial layers are intended to provide an objective, reproducible baseline for

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land-use planning, hazard mitigation, and future site-specific studies, while also serving as a template for expanding the database to other Alaska communities and transportation corridors.

ALASKA SNOW AVALANCHE HAZARDS DATABASE

The Alaska Snow Avalanche Hazards Database will initially store large-scale avalanche hazard indication maps, presented as standardized geospatial layers to support stakeholder decision-making. These core datasets include raster and vector products that describe snow and terrain conditions, potential release areas, and simulated avalanche extents and flow metrics (e.g., impact pressure, flow height, velocity, and deposition) under defined scenarios. Each dataset is structured with consistent spatial resolution, metadata, and attribution so users can readily interpret release zones, runout patterns, and derived hazard classes across different communities and corridors. The first iteration focuses on regional, model-based hazard indication products for Southcentral and Southeast Alaska (roughly from the central Chugach Mountains to Alaska's southeastern border). The database is also intentionally modular, so future updates can incorporate refined local studies, new remote sensing acquisitions, improved land cover information, and updated climate and snow scenarios without disrupting the existing framework. Its primary goal is to serve as a centralized, science-based repository of snow avalanche hazard information that supports evidence-based decision-making for land-use planning, transportation, resource management, and risk-reduction efforts, particularly where detailed, field-based mapping is limited.

AVALANCHE HAZARD INDICATION MAPPING

Avalanche hazard indication maps for Southeast Alaska in the Alaska Snow Avalanche Hazards Database follow methods from Bühler and others (2022). The mapping relies on three main datasets: terrain elevation (digital elevation model, DEM), forest cover, and daily snowfall records. These are used to identify where avalanches could start (potential release areas, PRAs) and to simulate how far they could travel, producing the regional hazard layers stored in the database.

Elevation Data

We used the Alaska interferometric synthetic aperture radar (IFSAR) digital elevation model (DEM), provided by the USGS at 5 m spatial resolution, as the base elevation dataset. The IFSAR data were resampled to 10 m to smooth the terrain representation and improve computational efficiency for avalanche simulations.

Forest Data

A forest cover mask was derived from the 2016 National Land Cover Database (NLCD) for Alaska, a Landsat-based product. Because the NLCD has a native resolution of 30 m, it was resampled to 10 m to match the DEM and modeling grid. Given the NLCD's native resolution of 30 m, it was resampled to 10 m to match the DEM and modeling grid. The forest cover mask classified grid cells as either “non-forest,” where PRAs could be defined, or “avalanche protection forest,” where PRAs were not allowed (see the Potential Release Areas section). Evergreen forests,

dominated by protective species, were included in the protection mask, while deciduous forests, characterized by less robust trees, were excluded. For PRAs with an area of 25,000 m² or less, a turbulent friction coefficient of 400 m s⁻² was applied within forested areas in the advanced hazard runout model, Rapid Mass Movement Simulation (RAMMS), to simulate reduced avalanche velocity. For larger PRAs, the forest mask's influence was ignored, assuming avalanches of that size have sufficient force to destroy vegetation. Mixed forests were also excluded from the protection mask under the assumption of limited protective capacity, which increased the occurrence of low-elevation PRAs; these were subsequently addressed through a filtering process.

Downscaled Historical and Projected Climate Data

A snowfall climatology for 1981–2010 was obtained from the Climate Forecast System Reanalysis (CFSR) product and dynamically downscaled to 4 km resolution using the Weather Research and Forecasting (WRF) model to estimate annual maximum 3-day snowfall. The maximum 3-day snowfall value for each 4 km pixel in the model domain was treated as an estimate of the 30-year extreme. Because long-term meteorological observations are sparse across much of Alaska, especially at high elevations where avalanches typically start, this approach may underestimate the true extent of extreme snowfall.

To obtain a higher-resolution (10 m) snowfall dataset that reflects maritime influences and complex topography, we applied a two-step downscaling procedure. First, a spatially variable lapse rate, influenced by distance to the open ocean, was derived from snowfall–elevation relationships within the 4 km climatology. This lapse rate was then used in a downscaling and smoothing algorithm to generate the 10 m maximum 3-day snowfall product. The precipitation lapse rate was mathematically defined from the gradients of precipitation and elevation. Although an empirical relationship between lapse rate and ocean distance was explored, a constant lapse rate of 0.0923 mm of snow per meter of elevation was ultimately applied across the study area due to the area's coastal setting. The 4 km WRF snowfall field was resampled to 10 m, smoothed using a Gaussian kernel via Fast Fourier Transform, and finally adjusted using the 10 m DEM and the derived lapse rate.

Potential Release Areas

Potential release areas were delineated using a methodology that combines DEM derivatives (slope, aspect, curvature, ruggedness) with the forest mask in an object-based image analysis framework (Bühler and others, 2013, 2018). This approach, calibrated on mapped avalanche release zones in Switzerland, was applied separately for the Frequent and Rare scenarios (approximating 30- and 300-year return intervals), typically producing larger PRAs for the Rare scenario. PRA identification was carried out within each tile's extended computational domain; PRAs located entirely within the margin were discarded, and those crossing tile boundaries were assigned to the tile containing their centroid.

The modeling workflow automatically assigned friction parameters based on avalanche release volume, which is calculated as the product of the PRA area and the release depth perpendicular to the slope. Following the standard Swiss modeling protocol, PRAs are categorized into four volume classes: Tiny ($<5,000 \text{ m}^3$), Small ($5,000\text{--}25,000 \text{ m}^3$), Medium ($25,000\text{--}60,000 \text{ m}^3$), and Large ($>60,000 \text{ m}^3$) (Bühler and others, 2022). These categories guide the selection of Voellmy friction parameters, friction (μ) and turbulent resistance (ξ), with larger avalanches generally receiving lower friction values to account for increased mobility (Christen and others, 2010). Here, we classified PRAs by measured area rather than estimated snow volume, a deviation from Bühler and others (2022). Some duplicate PRAs may occur due to overlapping tile margins, but their influence on final maps is minor because hazard layers are represented as maximum values.

For each PRA, a specific computational domain for the RAMMS avalanche model was generated to improve efficiency. Depressions in the DEM were filled to ensure hydrological connectivity, the contiguous set of grid cells with elevations equal to or lower than the PRA was identified, and the minimum bounding rectangle (MBR) of this potential extent was calculated and expanded by 1,000 m. RAMMS simulations were then run within this domain. This algorithm succeeded for about 95% of simulations; for the remaining cases, an additional 5 km margin was applied.

Numerical Avalanche Modeling

The study area was divided into four 30 km tiles. Numerical avalanche modeling was performed for each tile, including a 7,980 m buffer to allow for runout beyond tile boundaries. PRAs were uniquely assigned to a tile based on the centroid of their convex hull. Release depths (d_0) for each PRA were derived from the downscaled snowfall climatology and adjusted for slope angle. Two scenarios were simulated for each tile, representing Frequent and Rare avalanche events under recent historical (1981–2010) climate conditions.

Avalanche simulations used the Large-scale Hazard Indication Mapping version of RAMMS (RAMMS::LSHIM) with standard parameter settings for avalanche hazard mapping. Simulations were run for all PRAs in both scenarios on a high-performance computing cluster. Avalanche extent polygons were generated by enclosing grid cells with flow depth greater than 0.25 m and velocity greater than 1 m s^{-1} .

To reduce unrealistic low-elevation avalanches arising from land cover misclassification in the NLCD, we applied a post-processing filter based on forest cover within both the PRA and the simulated avalanche extent. Avalanches were removed if the PRA contained at least 30% deciduous or mixed forest, or if the avalanche extent contained at least 30% evergreen or mixed forest. This assumes that substantial forest cover suppresses both the initiation and the runout of significant avalanches at low elevations. After filtering, data from all tiles were merged to produce continuous avalanche hazard indication maps for the study area.

ASSUMPTIONS AND LIMITATIONS

The methodology underlying the data in this database enables automated delineation of potential release areas (PRAs), estimation of snow volumes, and simulation of avalanche flow dynamics at both regional and local scales. While this provides a scalable framework for snow avalanche hazard susceptibility analysis, it relies on several assumptions and data proxies that introduce uncertainty at each stage. Appropriate use of the database depends on transparent communication of these limitations, especially in Alaska, where rugged terrain, sparse observations, and complex snow climates constrain both input quality and validation.

- **DEM resolution and terrain representation:** Simulations depend on a current, high-resolution DEM to accurately delineate PRAs. Resampling to a coarser resolution (for example, 10 m) for computational efficiency can omit fine-scale terrain features important for avalanche initiation. Differences in lidar point density between snow-on and snow-off datasets can also introduce interpolation artifacts and bias snow height estimates.
- **Land cover data accuracy and forest interaction:** Land cover from the 2016 Alaska NLCD contains classification errors, particularly in forests, which affect PRA identification and may exclude known paths. RAMMS includes simplified forest interaction and does not represent snow entrainment of trees or debris, or built infrastructure, all of which can modify avalanche behavior.
- **Climate and snow input uncertainty:** Limited meteorological data in Alaska require simulations to rely on climate reanalysis products and downscaled fields to describe snow conditions. These modeled inputs introduce uncertainty in precipitation and snow depth and restrict the ability to validate release conditions and return-period estimates. Lidar-derived snow height maps capture only a single point in time and do not represent interannual variability.
- **Deterministic PRA release assumptions:** The approach assumes deterministic release of all mapped PRAs under a prescribed maximum 3-day snowfall scenario. Return periods are inferred from PRA size and modeled snow volume rather than from probabilistic release or impact models based on avalanche incidence records, reflecting the lack of long-term avalanche datasets in Alaska.
- **Model scope and process representation:** RAMMS::LSHIM simulates only the dense-flow phase of dry snow avalanches. Powder avalanches, wet-snow dynamics, multiphase events, and detailed snow-entrainment processes are not represented, limiting applicability in areas with diverse avalanche types.
- **Unmodeled initiation mechanisms and extremes:** Certain initiation mechanisms, such as cornice failures, releases within forested terrain, or events from extreme terrain, are not captured. The framework may also underrepresent rare, very large avalanches in broad alpine terrain, potentially underestimating hazard extent and runout distances.

- **Calibration and validation constraints:** The absence of a spatially and temporally extensive avalanche incident database in Alaska limits calibration and validation of model outputs. Tuning the model against well-documented historical events, a key step for improving realism, was not feasible for this project.
- **Parameter sensitivity and modeling uncertainty:** The cumulative use of modeled inputs and fixed parameters contributes to uncertainty in the final avalanche hazard products.

These limitations are critical to interpreting and applying the avalanche hazard indication maps in planning, mitigation, and risk assessment. Despite these limitations, the analyses provide essential first-order insight into avalanche susceptibility in parts of Alaska where traditional hazard assessments are not feasible and large-scale evaluations are absent.

INTENDED USE

The Alaska Snow Avalanche Hazards Database is not suitable for answering site-specific or legal questions and should only be used for regional- or community-scale purposes. Maps generated from the database should not be viewed at scales finer than those specified in the original data sources, and all limitations of the original publications apply to this database.

FUTURE GOALS AND DATABASE UPDATES

The Climate and Cryosphere Hazards Program plans to update this database as new, relevant data become available. Future releases may incorporate additional regional hazard indication products, refined local studies, improved land-cover and elevation datasets, and updated climate and snow scenarios. New data will be added to this DGGs Digital Data Series publication, allowing users to track changes in methods, coverage, and data quality over time.

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