PRACTICAL EXPERIENCES WITH THE OPEN-SOURCE AVALANCHE SIMULATION TOOL AVAFRAME

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ABSTRACT: Since 2023, the open-source avalanche simulation framework AvaFrame has been in operational use. Developed through a cooperation between the Austrian Avalanche and Torrent Control Service (WLV) and the Austrian Research Centre for Forests (BFW), AvaFrame is licensed under the European Union Public Licence (EUPL). The tool is now routinely applied by Austrian governmental organizations for hazard mapping and protection measure planning as well as by engineering offices for safety and technical surveys. AvaFrame comprises 15 functional modules covering input, computation, analysis, visualization, and reporting. A QGIS interface integrates the framework directly into existing practitioner workflows, facilitating both operational use and training courses for quality management.

The current development extends the framework along operational and scientific tracks. Operational priorities include long-term user support, powder snow avalanche modelling via a depth-averaged approach, forest avalanche interaction (ForestFrame), snow slides (com5) and enhanced quality management through automated parameter optimization and standardized test catalogues. Scientific topics address entrainment and deposition processes, dam impact forces and systematic model intercomparison. Probabilistic scenario assessment is supported through parameter variation across multiple simulation runs. To support the model validation WLV and BFW recently installed a full-scale avalanche test site near Innsbruck featuring pressure and shear force measurements and radar-based flow measurements in a well-known avalanche path. Beyond snow avalanches AvaFrame expands towards other gravitational mass movements: the experimental module com6RockAvalanche enables the calculation of rock avalanches, while DebrisFrame, developed jointly with the BOKU University, extends the framework to debris flow simulation. Both projects are united under the OpenNHM (Open Natural Hazard Modelling) initiative to provide open-source tools for the assessment of alpine natural hazards.

KEYWORDS: avalanche modelling, AvaFrame, open-source tool, natural hazards, practical use.

1. INTRODUCTION

Numerical avalanche models support hazard-zone mapping, the design and assessment of protection measures, and technical safety studies. Their operational use requires more than a numerical solver: input preparation, parameter selection, analysis and reporting must be reproducible and integrated into established geospatial workflows.

AvaFrame is an open-source simulation framework developed jointly by the Austrian Avalanche and Torrent Control Service (WLV) and the Austrian Research Centre for Forests (BFW) and distributed under the European Union Public Licence (Oesterle et al., 2026). Since 2023, it has been used operationally by Austrian governmental organizations and engineering offices. Its 15 functional modules cover input processing, computation, analysis, visualization and reporting, while a QGIS interface integrates AvaFrame into established practitioner workflows. This contribution summarizes experience from operational application, the resulting development and quality-management priorities, current scientific validation activities, and the extension of the framework toward other gravitational mass movements.

2. OPERATIONAL USE AND PRACTICAL EXPERIENCE

Since 2023, AvaFrame has been applied in governmental and engineering practice for hazard-zone planning, the planning and assessment of protection measures, and technical expert studies. The operational workflow extends beyond numerical simulation and comprises data collection and analysis, preparation of terrain and scenario inputs, model execution, interpretation, reporting and archiving. AvaFrame supports these steps through modules

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for data processing, computation, analysis, visualization and reporting, while its QGIS interface embeds model application in established geospatial workflows.

Practical application shows that increasing automation does not replace expert judgement. Release areas, release depths, entrainment and resistance areas, relevant avalanche scenarios and the appropriate model configuration must be derived from historical evidence, field observations, terrain information and the intended application. Simulations are therefore generally evaluated iteratively, beginning with a baseline scenario and adding process components or alternative release scenarios step by step. Transparent documentation of input data, model versions, parameters, results and limitations are required to preserve traceability and support later reuse. Standardized guidance, training, user support, test cases and automated parameter reports provide the basis for consistent application across different users.

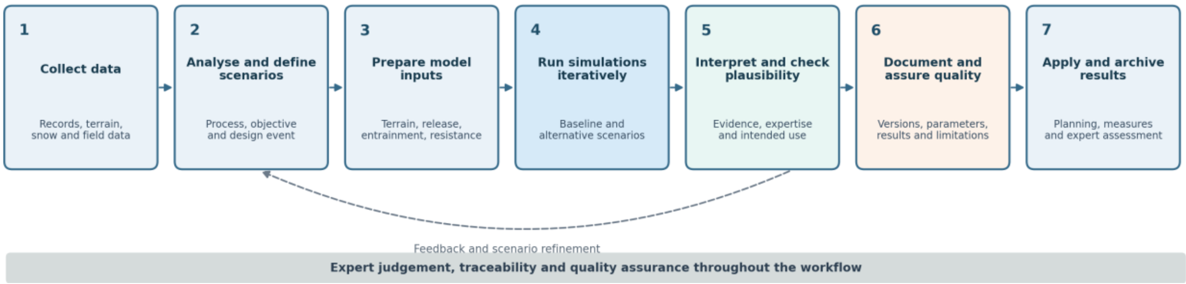

Figure 1: Simplified operational workflow for avalanche modelling in Austrian practice, adapted from the WLV practical guideline (Tollinger et al., 2026).

3. CURRENT MODEL DEVELOPMENTS

3.1 Operational developments

Current operational development focuses on extending the range of processes represented in AvaFrame while maintaining reliable long-term support. A prototype for powder snow avalanche modelling has been implemented using a depth-averaged formulation based on the MoT-PSA approach and is currently undergoing calibration (Vicari and Issler, 2025).

ForestFrame extends the dense-flow module com1DFA to represent avalanche-forest interaction. The project ForestFrame II evaluated alternative resistance formulations, parameter sensitivity and their influence on runout, velocity and pressure. The resulting approach reduces the required input to a practicable parameterization and introduces an adaptive formulation dependent on flow velocity, flow depth and, where applicable, mass removal. The implementation and corresponding recommendations are documented in the AvaFrame repository and included in the current release (Wirbel et al., 2025).

AvaFrame:com5SnowSlide addresses shallow snow-slide processes and remains experimental while practical experience is accumulated (Sampl, 2022). Automated parameter evaluation is currently being implemented to support calibration against observations, sensitivity analysis and comparison with reference results. Together with standardized test cases, documentation and user support, these developments aim to improve reproducibility without replacing the expert assessment required for operational application.

3.2 Scientific development and validation

Scientific development addresses entrainment and deposition processes, impact loads on protection structures, with reference to ÖNORM B 4801, and systematic model intercomparison. The ISeeSnow pilot study compares avalanche simulation tools using prescribed inputs and parameters for idealized and real topographies, thereby identifying differences arising from model formulations, numerical methods and geodata handling (Wirbel et al., 2026). Probabilistic scenario assessment is supported through automated parameter variation across multiple simulations. The resulting exceedance frequencies describe the selected scenario ensemble and must not be interpreted directly as the probability of avalanche occurrence. This distinction between parameter uncertainty, scenario uncertainty and event probability are essential when assessing residual hazards or the effects of protection measures.

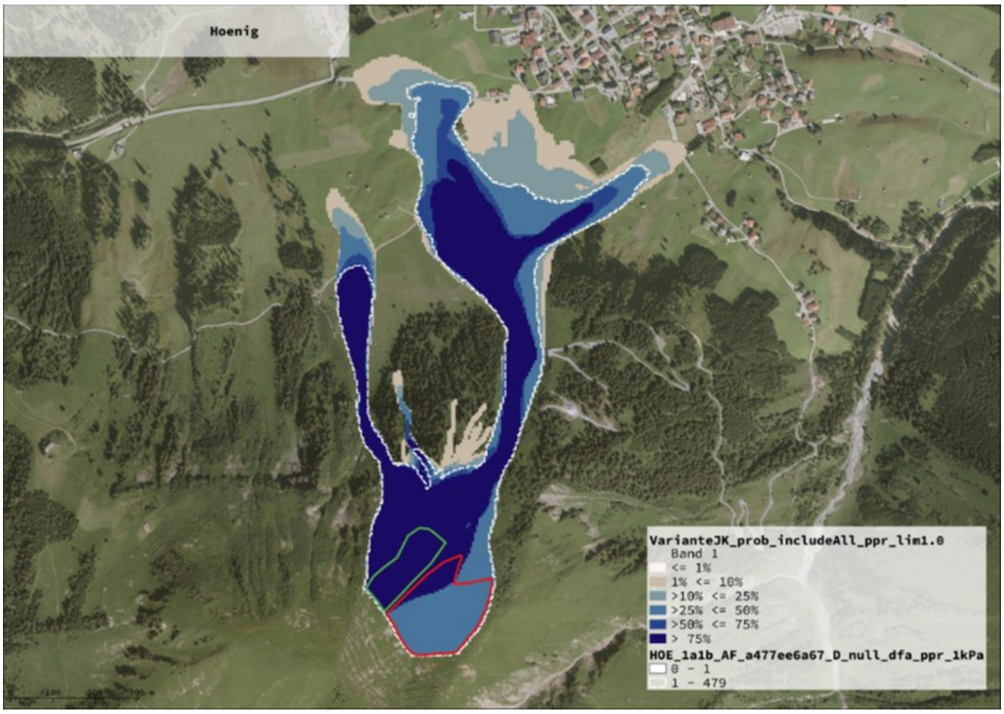

Figure 2: Probability plot with AvaFrame

Model development and evaluation remain limited by the scarcity of full-scale observations. To improve this empirical basis, WLV and BFW installed a full-scale avalanche test site at the Arzler Alm above Innsbruck, operational since early 2026. The site covers a south-facing avalanche path with a vertical drop of approximately 1300 m and expected avalanche volumes of up to 100,000 m³. Six instrumented plates on a 5 m high breaking wedge measure normal and shear forces at 5 kHz, while Doppler radar records avalanche activity and flow velocities along the path. Video cameras provide complementary observations of flow velocity, depth, deflection and deposition. The combined measurements will support investigation of avalanche-obstacle interaction and evaluation of simulated flow dynamics and impact loads; future work will extend this validation toward entrainment and deposition processes (Gleirscher et al., 2026).

Figure 3: The avalanche track with the new testsite Arzleralm above Innsbruck

4. EXTENSION TOWARD MULTI-HAZARD MODELLING

The modular structure developed for AvaFrame also provides a basis for modelling other gravitational mass movements. AvaFrame:com6RockAvalanche adapts the com1DFA workflow and configuration to rock-avalanche simulations. The module can use spatially variable friction parameters and includes tools for defining potential failure geometries, but remains highly experimental and has not yet been systematically tested.

DebrisFrame, developed by BOKU University in cooperation with WLV and BFW, extends the open-source approach to debris-flow simulation. AvaFrame and DebrisFrame are brought together under the Open Natural Hazard Modelling initiative, OpenNHM, which provides shared software repositories, documentation, event and test data, and a common QGIS connector. This allows process-specific models to reuse components for project preparation, geospatial integration, analysis and reproducible reporting, while retaining separate physical formulations and clearly defined maturity levels (OpenNHM, 2026).

5. DISCUSSION AND CONCLUSIONS

Open-source numerical modelling has become part of routine avalanche-hazard assessment in Austria. Operational experience since 2023 shows that this requires numerical models to be embedded in a broader workflow of expert scenario definition, transparent documentation, training and quality assurance. AvaFrame improves accessibility and reproducibility, but does not remove the need for process knowledge or critical interpretation of model results.

Continued development must therefore balance new functionality with calibration, validation and clearly communicated limits of application. Standardized test cases, automated parameter evaluation and full-scale measurements at the Arzler Alm strengthen this quality-management framework. At the same time, OpenNHM demonstrates how shared software, data and geospatial tools can support development across different natural-hazard processes without treating models of different maturity as operationally equivalent.

AvaFrame’s main contribution is not to make avalanche simulation inherently simple, but to make its assumptions, workflows and limitations visible, testable and reproducible across research and practice.

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