

RAMMS::Extended Application Guide Dry-Snow Avalanches with Powder Cloud

Scenario-Based Parameter Recommendations

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Scenario-Based Avalanche Dynamics Calculations

Short Recommendation for Practice — Dry Snow Avalanches

Purpose

Scenario-based avalanche dynamics calculations are used to simulate hypothetical avalanche events for a defined return period (Stoffel et al., 2024). The method is intended for **engineering design** and **hazard assessment** when the objective is not to reproduce one specific historical event, but to construct a physically consistent avalanche scenario. The required input parameters are derived from terrain, snow-climate statistics, standardized return periods, and expert judgement.

The procedure applies to **dry snow avalanches**. For dense-flow calculations with RAMMS::Avalanche, four steps are required. These are the selection of a **return period** (1), **definition of a release area** (2) and **fracture depth** (3) and finally the selection of a **friction category** (4), see Figure 1. For mixed flowing/powder avalanches with RAMMS::Extended, an additional four steps are required because **erodible snow** (5), **snow temperature** (6), **density** (7) become **explicit model inputs**. Additionally, model parameters controlling the **powder cloud** (8) are required.

Avalanche dynamics calculations with RAMMS::Avalanche and RAMMS::Extended

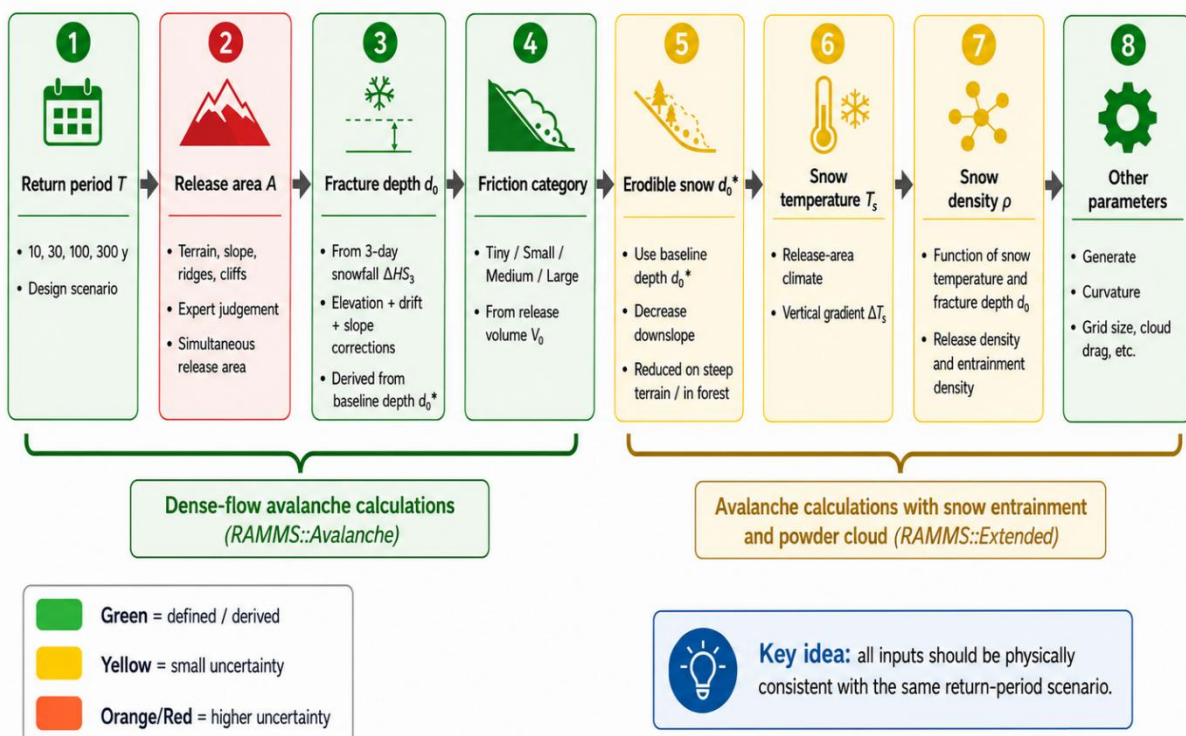


Figure 1: Overview of the scenario-based eight-step approach.

The central rule is **consistency**: fracture depth, release area, erodible snow, density, friction category, and additional model parameters should all describe the same return-period scenario.

Hazard assessment should therefore not rely on avalanche-dynamics calculations alone. It should be based on a consistent evaluation of **avalanche history, climatic and snow-loading conditions, terrain characteristics, and avalanche-dynamics modelling results**. The selected model scenario should be compatible with the return period being assessed and with the corresponding assumptions for fracture depth and release-area extent (see Figure 1, Step 3).

The Eight-Step Procedure

1. Select the avalanche return period

The **return period defines the design scenario**. In Swiss hazard assessment, the most common return periods are **10, 30, 100, and 300 years**. The selected return period influences the release area, fracture depth, erodible snow depth, friction category, and, indirectly, snow temperature and density.

A 300-year scenario should not simply be produced by increasing one parameter such as fracture depth. It should represent **a coherent extreme event**: larger potential release area, larger 3-day snowfall, larger erodible snow depth, and the appropriate friction category.

2. Define the release area

The release area is one of the most important inputs. It should be selected from the potential release area, not automatically taken as the entire slope that could theoretically fail. In RAMMS, the full release mass starts simultaneously; using the entire potential release zone can therefore produce unrealistic release volumes (Figure 2).

The selected release area should be based on:

- slope angles generally between about 28° and 55°;
- ridges, cliffs, convexities, roughness, and planarity;
- aspect and expected wind loading;
- known avalanche activity or historical observations;
- the selected return period;
- the expected subdivision into one or more avalanche tracks.

For larger return periods, the selected release area is generally larger, but it must remain physically plausible. If the release area contains distinctly different slope angles or drains into different tracks, it may be divided into subareas that release simultaneously.

A practical workflow is to first define and test release areas with RAMMS::Avalanche. If the dense-flow results are plausible, the same release areas can then be transferred to RAMMS::Extended.

Where the lower boundary of the release area is not clearly defined by terrain, the release length should be checked against a fracture-length criterion. A practical first estimate is that the maximum slope-parallel release length should be on the order of **150 times the fracture depth**. Longer release lengths may imply deeper fracture, denser snow, or partial involvement of old snow.

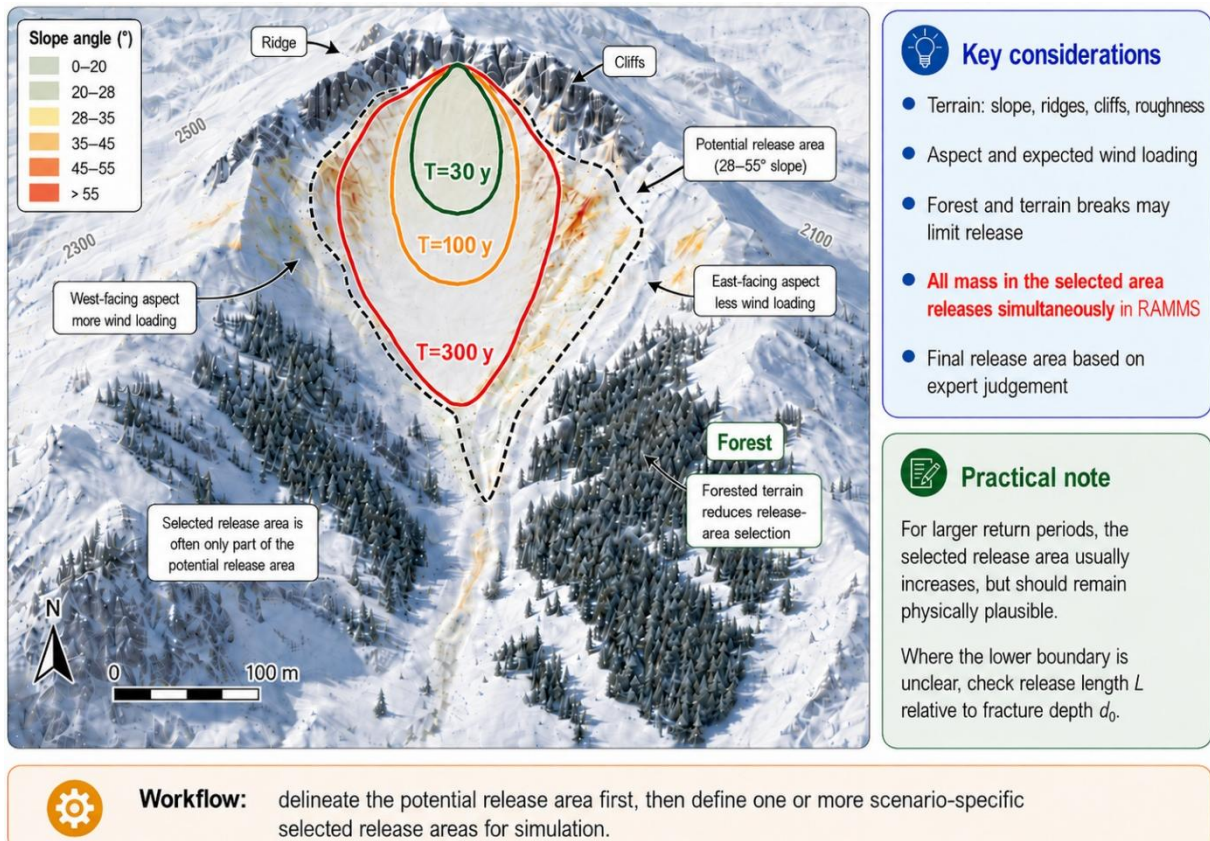


Figure 2: Selection of the release area. The selected release area should represent a physically plausible subdomain of the total potential release zone, constrained by terrain, slope angle, forest cover, drainage patterns, and the selected return-period scenario.

3. Select fracture depth d_0 and check release-zone length L_0

The fracture depth d_0 is the mean slope-perpendicular fracture depth over the entire selected release area. It is **not** the maximum crown depth. Crown depths observed in the field are often larger than the mean fracture depth used in avalanche dynamics simulations.

For dry-snow avalanche scenarios in the Swiss Alps, d_0 is normally derived from 3-day snowfall statistics, corrected for elevation, wind drift, slope angle, and the selected return period. The result should represent the same scenario as the selected release area: a 10-year fracture depth should be combined with a plausible 10-year release area, while a 300-year fracture depth should be combined with a correspondingly larger, but still physically realistic, release area.

Typical mean fracture depths for avalanche simulations in the Swiss Alps are approximately:

$$d_0 = 0.8\text{--}1.6 \text{ m}$$

For very extreme scenarios, values approaching **2.0 m** may be possible, especially in snow-rich regions or where wind drift is important. However, d_0 values larger than 2 m should be used with caution and should be justified by local snow-climate data, terrain conditions, or observations.

Swiss procedure for estimating d_0

For Swiss applications, the following procedure is commonly used.

1. Determine the 3-day snow height increase ΔHS3

The starting point is the 3-day snow height increase for the selected return period, usually derived from extreme-value statistics at a representative study plot. If possible, long-term data from nearby measurement fields should be used.

2. Correct ΔHS3 for elevation

The measured snow-height increase is corrected for the elevation difference between the measurement station and the release area. For the Swiss Alps, a typical correction is:

$$+ / - 5 \text{ cm per } 100 \text{ m elevation difference}$$

Extrapolation to very high mountain regions should be avoided if wind redistribution or reduced snow accumulation is expected.

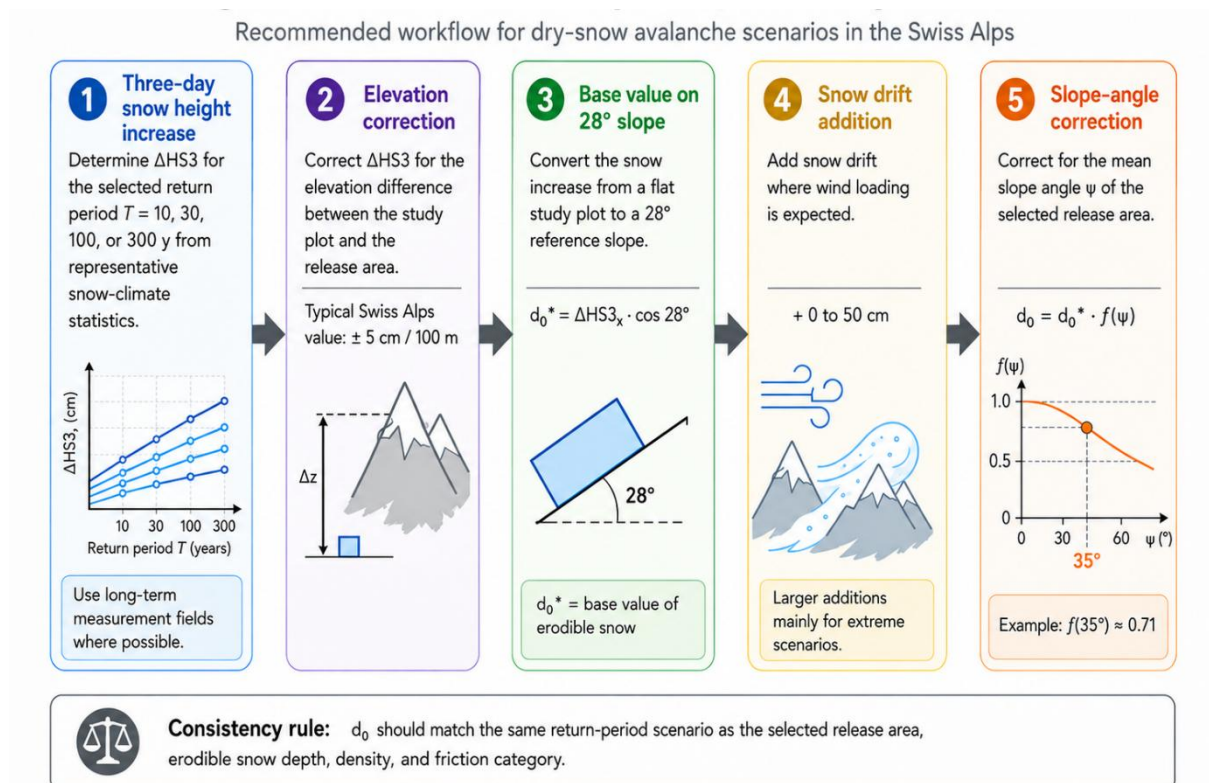


Figure 3a: Swiss procedure for estimating the mean fracture depth d_0 .

3. Convert to a 28° reference slope

Snow-height increase is usually measured on a flat study plot. For avalanche release calculations, it is converted to a 28° slope using:

$$d_0^* = \Delta HS3 \cdot \cos 28^\circ$$

The value d_0^* is the baseline value for erodible snow and for the subsequent calculation of the fracture depth.

4. Add snow drift where appropriate

Wind drift can significantly increase the amount of snow available in the release area. Depending on terrain and return period, an additional snow depth of approximately:

$$0\text{--}50 \text{ cm}$$

may be added to d_0^* . Larger additions are mainly appropriate for extreme scenarios, for example a 300-year event in a wind-loaded release area. In other climatic regions values greater than 50cm may be required.

5. Correct for the mean slope angle of the release area

Less snow can accumulate on steep slopes before avalanche release than on moderately steep slopes. Therefore, d_0^* is corrected using a slope-angle factor $f(\psi)$, where ψ is the mean slope angle of the selected release area:

$$d_0 = d_0^* \cdot f(\psi)$$

For example, the correction factor is 0.71 for a 35° slope. The resulting d_0 is the mean fracture depth used in the simulation,

$$f(\psi) = \frac{0.291}{\sin \psi - 0.202 \cos \psi}$$

Release-zone length consistency check

After selecting the release area and calculating d_0 , the maximum fall-line length of the release zone should be checked (Figure 3b).

This check is useful because RAMMS releases the full selected release area at once. If the release zone is too long, the model may produce an unrealistically large initial release volume, even if all terrain cells lie within the potential release area.

The release-zone length check is based on the ratio between release length and fracture depth:

$$R = \frac{L_0}{d_0}$$

where:

- L_0 is the maximum fall-line length of the selected release area;
- d_0 is the mean fracture depth.

Field observations show that natural slab avalanches (McClung, 2009) have a limited relationship between fracture depth and release length¹. For practical scenario calculations, this relationship can be simplified to:

$$L_{max} = 150 d_0.$$

Thus, the selected release area should normally satisfy (Table 1):

$$L_0 \leq 150 d_0.$$

This rule should not be interpreted as a prescribed release length. It is a **plausibility check**. Terrain boundaries remain the primary control on release-area selection. Ridges, rock bands, convexities, forest, slope breaks, and drainage divides may produce shorter release lengths. If the selected release area is longer than **150d₀**, the release area should be reconsidered. Possible interpretations are:

- the lower boundary of the release area is too far downslope;
- the release area should be divided into separate subareas;
- old snow or deeper slab involvement may need to be considered for a back-calculation of a known event;
- the scenario may be too extreme for a simultaneous release calculation.

Table 1: Practical release-length consistency values. The maximum fall-line release length L_0 is estimated from the mean fracture depth d_0 using the relation $L_0 \leq 150 d_0$. The values are intended as a plausibility check for the selected release area, not as prescribed release lengths.

Mean fracture depth d_0	Practical maximum release length $L_{max} = 150 d_0$
0.8 m	120 m
1.0 m	150 m
1.2 m	180 m
1.5 m	225 m
1.8 m	270 m
2.0 m	300 m

This means that for a typical 300-year Swiss avalanche scenario with $d_0 \approx \mathbf{1.5\ m}$, a maximum release length of approximately **225 m** is already a large, but plausible, slab geometry. A release area with a fall-line length > approximately 400 m should usually

¹ The practical value $L_{max} = 150 d_0$ is derived from McClung's fracture-efficiency relation (2009) for slab avalanches. McClung expressed the ratio between slope-parallel fracture length and fracture depth as $R = L_0/d_0$, with R following a lognormal distribution: $\ln R \sim \mathcal{N}(\mu_R, \sigma_R^2)$, where $\mu_R = 4.678$ and $\sigma_R = 0.593$. Using a cumulative probability of $p_L = 0.70$ gives $R \approx 150$. Thus, $L_{max} = 150 d_0$ is used here as a practical upper-bound consistency check for the selected release-zone length, not as a prescribed release length.

not be treated as one single simultaneous release unless there is strong supporting evidence.

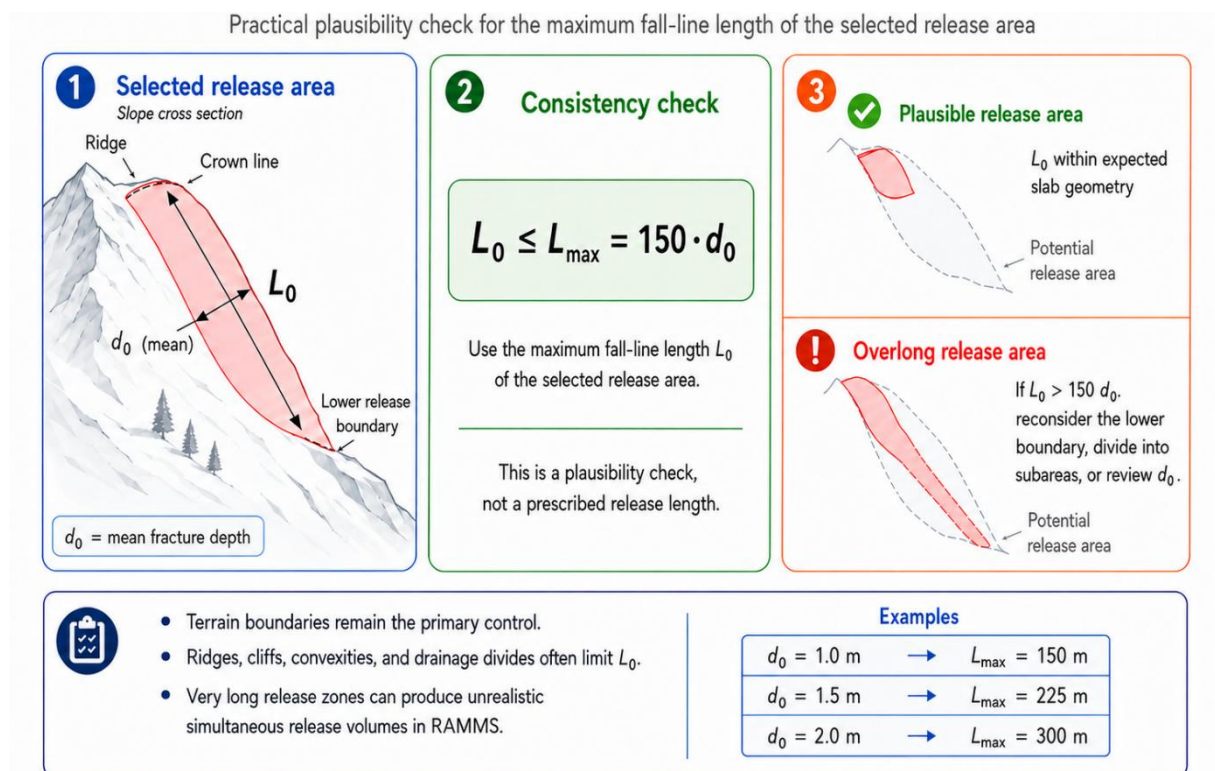


Figure 3b: Release-zone length consistency check. The maximum fall-line length L_0 of the selected release area should be checked against the practical relation $L_0 \leq 150 d_0$. This rule is a plausibility check for natural slab geometry and should not replace terrain-based release-area selection.

4. Select the friction category

The friction category defines the initial flow resistance used in the avalanche calculation. It is selected from the **release volume** and the **return period** of the scenario (Table 2).

For practical applications, the release volume is assigned to one of four volume classes:

Table 2: Release-volume classes used for friction-category selection. The initial release volume is assigned to one of four volume classes: **Tiny**, **Small**, **Medium**, or **Large**. This volume class, together with the selected return period, defines the friction category used in the scenario calculation.

Volume class	Release volume
Large (L)	> 60,000 m ³
Medium (M)	25,000–60,000 m ³
Small (S)	5,000–25,000 m ³
Tiny (T)	< 5,000 m ³

In **RAMMS::Avalanche**, the selected volume class and return period define the fixed Voellmy friction parameters μ and ξ . These parameters should normally not be

changed manually. The friction category is part of the scenario definition and should remain consistent with the selected return period, release area, fracture depth, and release volume.

In **RAMMS::Extended**, the same practical classification is used to define the initial friction state of the avalanche. The model then allows the effective friction to evolve during motion according to the internal state of the flow. The initial category therefore defines the starting resistance, while the subsequent friction evolution depends on shear deformation, fluidization, temperature, water content, entrainment, terrain, and flow path conditions.

For **RAMMS::Extended**, the volume class and return period are mapped to friction categories A–F (Table 3).

Table 3: RAMMS::Extended friction-category assignment. The release-volume class and return period are combined to define the initial friction category A–F. Larger release volumes and rarer return-period scenarios are assigned more mobile initial friction states.

Release Volume V_0 (m ³)	Category	10Y	30Y	100Y	300Y
< 5000	Tiny (T)	A	A	B	C
5'000-25'000	Small (S)	B	B	C	D
25'000-60'000	Medium (M)	C	C	D	E
>60'000	Large (L)	D	D	E	F

The corresponding initial **RAMMS::Extended** parameters are provided in Table 4. The largest change between categories is the initial Coulomb friction μ_0 . Larger and rarer avalanche scenarios are assigned lower initial friction, representing the greater mobility expected for large-volume, extreme-event avalanches. The friction category should not be used as a calibration parameter to obtain a desired runout. It should be selected from the scenario volume and return period. If the release volume lies close to a class boundary, both adjacent categories may be tested to evaluate sensitivity.

If the avalanche separates into two or more clearly distinct tracks over a significant part of the path, it may be appropriate to reduce the effective volume class for each branch (Figure 4). This assumes that each branch behaves more like a separate avalanche with a smaller effective volume. Such adjustments should be based on terrain and flow-path geometry, not on runout tuning.

Table 4: Initial **RAMMS::Extended** friction parameters for categories A–F. Each category defines a unique set of initial parameters μ_0 , ξ_0 , and N_0 . The largest variation between categories occurs in the Coulomb friction parameter μ_0 , while ξ_0 and N_0 vary more moderately.

Parameter	A	B	C	D	E	F
μ_0	0.55	0.48	0.42	0.37	0.33	0.30
ξ_0 (m/s ²)	1800	1850	1900	1900	1950	2000
N_0 (Pa)	200	150	100	100	75	50

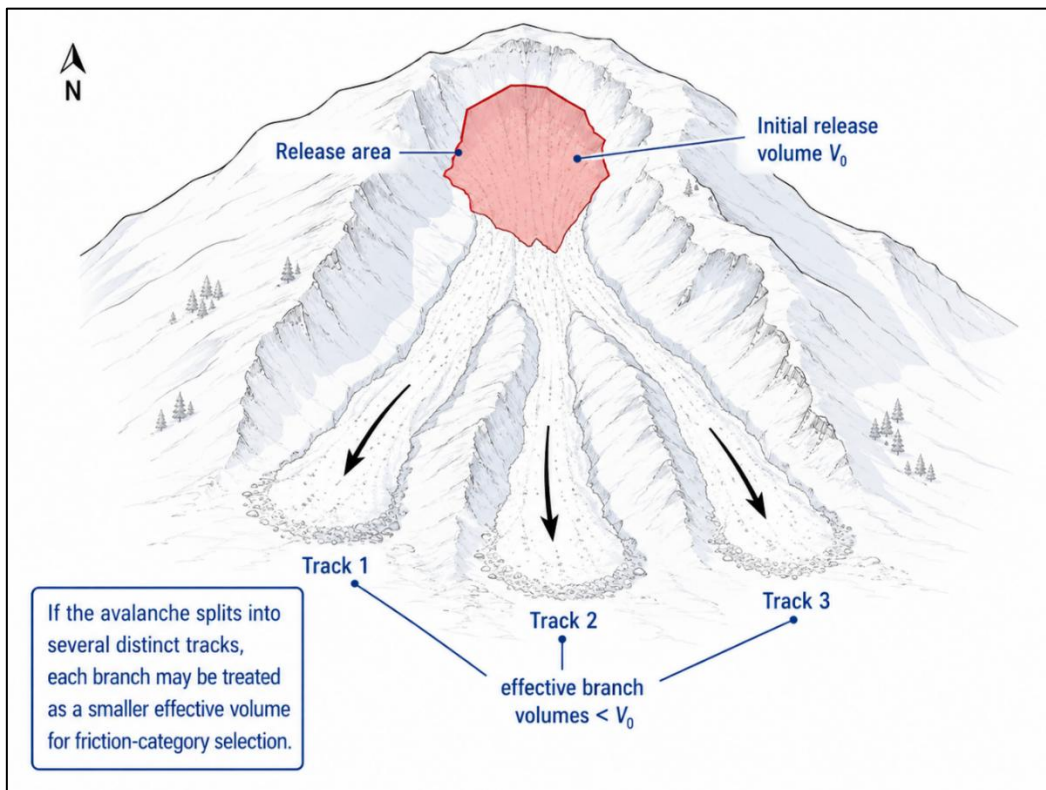


Figure 4: Track splitting and effective release volume for friction-category selection. If an avalanche separates into several distinct tracks over a significant part of its path, each branch may be treated as a smaller effective-volume avalanche for friction-category selection.

5. Define the erodible new snow along the track

For **RAMMS::Extended calculations**, an **erodible new snow layer** should be defined along the avalanche track. This layer represents the recently accumulated snow that can be entrained by the avalanche during motion.

The erodible snow depth is based on the baseline value d_0^* (see step 3 of 8-step procedure) which is derived from the 3-day snow height increase for the selected return period and converted to a 28° reference slope (Figure 5). In contrast to the fracture depth d_0 in the release area, the erodible snow depth along the track should normally **not include local drift-snow additions**. Drift snow is considered primarily in the release area, where it affects the fracture depth.

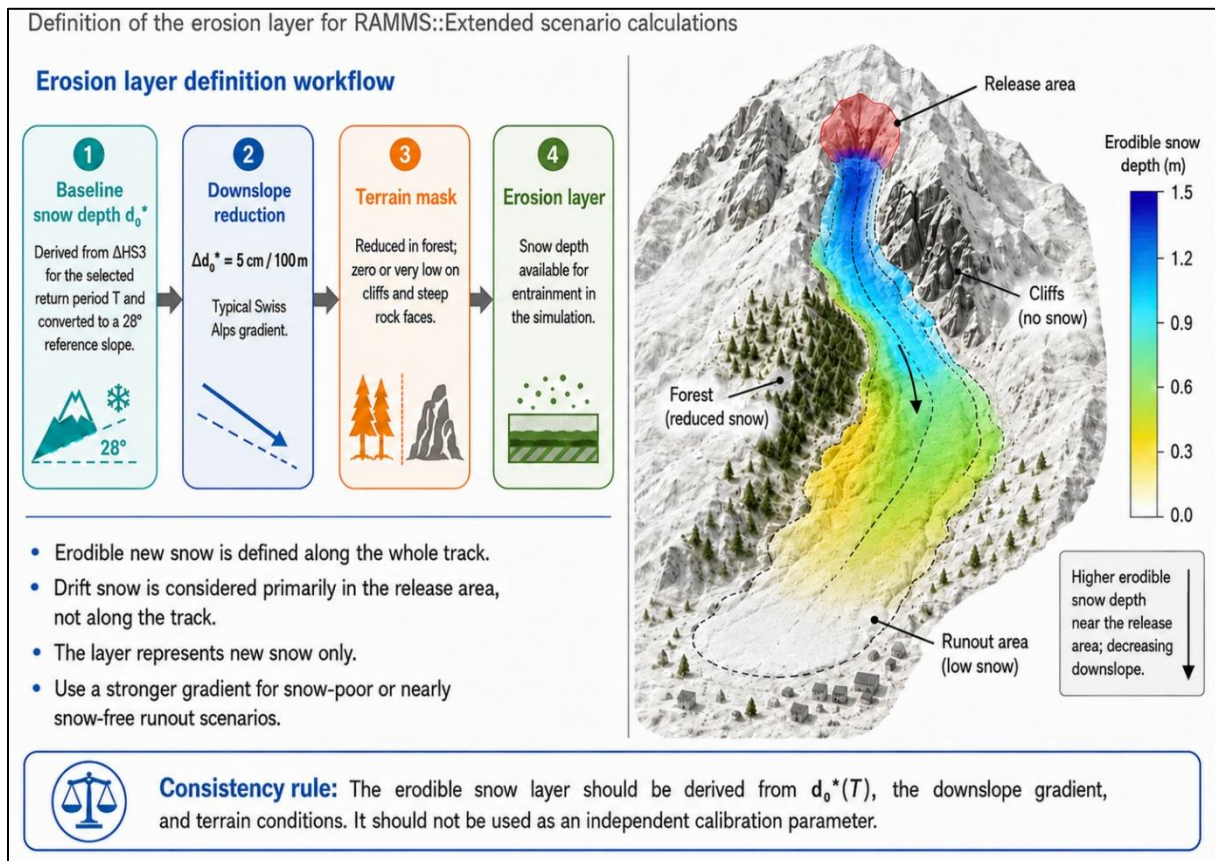


Figure 5: Definition of the erodible new snow layer along the avalanche track. The erosion layer is derived from the baseline snow depth d_0^* , reduced downslope using the elevation gradient Δd_0^* , and modified where terrain conditions limit snow availability, such as cliffs, steep rock faces, forest, or low-elevation runout areas.

The basic assumption is that the new snow along the track is available for entrainment. This is a simplification. In reality, the avalanche may erode only part of the new snow, or, in some cases, all new snow plus part of the old snowpack. For scenario-based calculations, however, the erodible layer provides a consistent and transparent way to represent the amount of entrainable new snow associated with the selected return period.

The erodible snow depth should decrease downslope to account for the elevation dependence of snowfall. For the Swiss Alps, a typical gradient is:

$$\Delta d_0^* = \text{vertical reduction rate (typically 5 cm per 100 m in the Swiss Alps)}$$

Thus, if Δd_0^* is defined at the elevation of the release area, the erodible snow depth is reduced at lower elevations along the track. For special scenarios, such as a nearly snow-free runout area, a stronger reduction gradient may be applied.

RAMMS::Extended calculates the erosion layer from d_0^* at a given reference elevation and the elevation gradient Δd_0^* . Erodible snow should generally be defined over the whole avalanche track, but it should be limited where snow cannot realistically be entrained. In particular:

- cliffs and very steep rock faces should contain little or no erodible snow (see “No snow steepness” parameter below);
- forested areas should have reduced erodible snow;
- lower-elevation runout areas may contain less snow, depending on the scenario;
- the erodible snow layer should remain consistent with the selected return period.

6. Define the mean snow temperature

For RAMMS::Extended calculations, the **snow temperature** describes the thermodynamic state of the snow involved in the avalanche. It applies to both (Figure 6):

- **the released slab**; and
- **the erodible new snow along the track**.

The snow temperature should represent the **mean temperature** of the storm-snow layer associated with the selected return period. It is not necessarily identical to the measured air temperature, although in the absence of better information the air temperature can be assigned the same value.

Snow-profile measurements during major snowfall periods in the Swiss Alps show that the mean temperature of the topmost meter of new snow typically lies between approximately:

$$-9.0^{\circ}\text{C to } -3.5^{\circ}\text{C}$$

for elevations between about 2100 m and 2700 m.a.s.l (Figure 6). These measurements exclude the uppermost surface layer, which can be strongly affected by short-term radiation and atmospheric exchange.

Snow temperature generally decreases with elevation. Based on snow-profile observations, a typical vertical snow-temperature gradient is approximately:

$$\Delta T_s \approx 0.28^{\circ}\text{C}/100\text{m}$$

For scenario-based calculations in the Swiss Alps, the following mean snow temperatures are recommended as practical input values (Table 5).

Table 5: Recommended snow temperature for release elevation.

Release Area Elevation (m.a.s.l.)	Mean Snow Temperature [°C]
1700-2100	$T_0 = -5$
2100-2600	$T_0 = -6$
2600-3000	$T_0 = -7$

These values are intended as robust scenario inputs for dry-snow avalanche calculations. They represent typical mean temperatures of storm snow during large avalanche-producing snowfall events in the Swiss Alps.

The released slab and the erodible snow layer should normally be assigned to the same mean snow temperature, because both originate from the same 3-day storm accumulation used to define the return-period scenario. This ensures consistency between fracture depth, erodible snow depth and density. A temperature gradient should also be specified to account for changes in snow temperature with elevation along the track. For the Swiss Alps, recommended values are:

$$\Delta T_s^* = 0.2 - 0.4 \text{ } ^\circ\text{C}/100\text{m}$$

with **0.3°C/100 m** as the **standard value**.

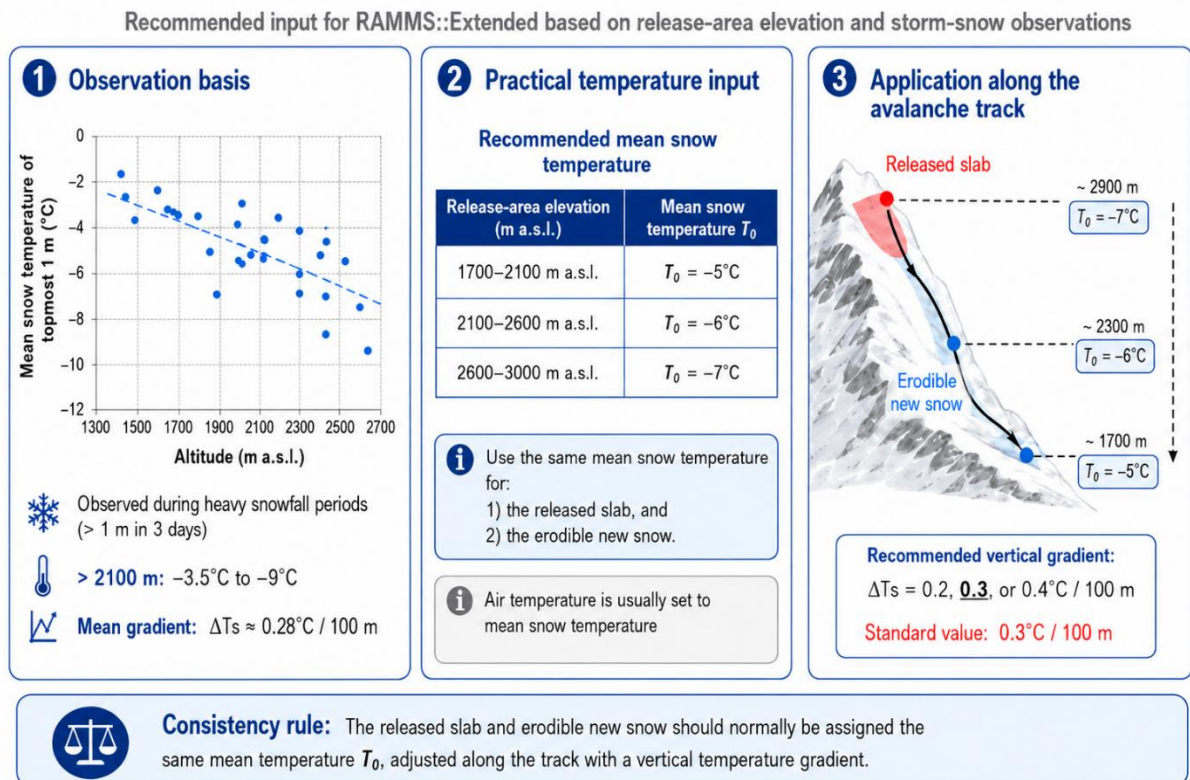


Figure 6: Definition of mean snow temperature for scenario-based RAMMS::Extended calculations. The input temperature represents the mean temperature of the released slab and the erodible new snow associated with the selected storm scenario. Recommended Swiss Alps values are based on release-area elevation and may be adjusted along the track using a vertical snow-temperature gradient, typically $\Delta T_s^* = 0.3 \text{ } ^\circ\text{C}/100\text{m}$.

Lower gradients, for example $\Delta T_s^* = 0.2 \text{ }^\circ\text{C}/100\text{m}$, are appropriate for deep, well-buffered snowpacks and large return-period scenarios. **Higher gradients**, for example $\Delta T_s^* = 0.4 \text{ }^\circ\text{C}/100\text{m}$, may be appropriate for shallower snowpacks, early-winter conditions, wind-exposed terrain, or situations with stronger atmospheric influence.

The snow temperature should not be used as an arbitrary calibration parameter. It should be selected from the release-area elevation, local snow-climate conditions, and the temperature gradient associated with the scenario. Depending on the situation, it is recommended to check the results by performing an additional calculation with a snow temperature that is 1°C warmer.

7. Define the mean snow density

The **mean snow density** controls the mass of both the **released slab** and the **erodible storm-snow layer**. In RAMMS::Extended, it therefore affects release mass, entrainment mass, flow momentum, and the thermodynamic evolution of the avalanche. For scenario-based calculations, the density should represent the mean density of the 3-day storm-snow accumulation associated with the selected return period and should not be treated as an independent calibration parameter.

The recommended values in Table 6 are obtained using two complementary approaches. The first is a **Kojima-type settlement model** (Kojima, 1967), which describes the increase in storm-snow density with temperature, overburden, and settlement². The second is an empirical **Jamieson–McClung relationship** (Jamieson and Johnston, 1980) linking slab density, fracture depth, and characteristic release length³. When applied with $L = 150 d_0$, both approaches produce closely comparable density estimates over the relevant range of fracture depths (Figure 7a). The tabulated values (Table 6) therefore provide a physically based and literature-supported representation of typical 3-day storm-snow densities for scenario calculations in the Swiss Alps. Lower values correspond to colder, less-settled snow, while higher values represent warmer or more strongly settled storm snow (Figure 7b).

For new snow accumulated over two or more days, values between about 150 and 225 kg/m³ are realistic in the Swiss Alps. Higher values may occur for warmer snow, deeper 3-day accumulations, or wind-influenced snow.

²The density values are consistent with a simplified **Kojima-type settlement concept**, in which 3-day storm-snow density increases with temperature, overburden, and reduced slope angle. The full settlement relation can be expressed schematically as $[1/\rho][d\rho/dt] = \sigma/\eta_c(\rho, T)$, where σ is the overburden stress and $\eta_c(\rho, T)$ is the compactive viscosity. In RAMMS::Extended this behaviour is represented by a precomputed regression form, so that warmer snow and deeper snowpacks produce higher settled densities without requiring numerical integration of the settlement equation at every grid cell.

³The tabulated densities are derived from the empirical **Jamieson–McClung relationship** $L \rho d_0 = 1534 c_0^{2.4} d_0^{0.542} (\rho/917)^{1.942}$, where L is the characteristic release length, d_0 is the mean fracture depth, ρ is the mean slab density in kg m^{-3} , and 917 kg m^{-3} is the density of ice. Assuming $L = 150 d_0$, the relation is solved for ρ using $c_0 = 1.45, 1.40$, and 1.35 for -7°C , -6°C , and -5°C , respectively; the resulting values are rounded to the nearest 5 kg m^{-3} .

As a practical rule, density should increase for warmer snow temperatures, deeper storm accumulations, and wind-influenced conditions. Density should not be adjusted independently to obtain a desired runout.

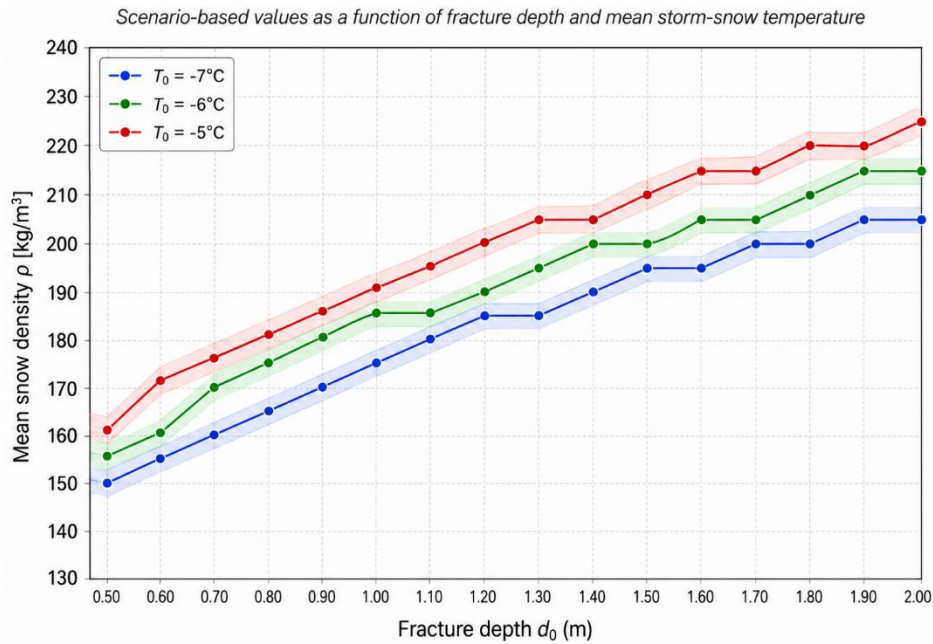


Figure 7a: Recommended mean snow density, rounded to the nearest 5 kg/m³, as a function of fracture depth d_0 and mean storm-snow temperature T_0 .

Table 6: Recommended mean snow density as a function of mean fracture depth d_0 and mean storm-snow temperature. The values represent typical 3-day storm-snow conditions for scenario calculations in the Swiss Alps and are rounded to the nearest 5 kg/m³.

d_0 [m]	Density ρ [kg/m ³]		
	$T_0 = -7[^\circ\text{C}]$	$T_0 = -6[^\circ\text{C}]$	$T_0 = -5[^\circ\text{C}]$
0.50	150	155	160
0.60	155	160	170
0.70	160	170	175
0.80	165	175	180
0.90	170	180	185
1.00	175	185	190
1.10	180	185	195
1.20	185	190	200
1.30	185	195	205
1.40	190	200	205
1.50	195	200	210
1.60	195	205	215
1.70	200	205	215
1.80	200	210	220
1.90	205	215	220
2.00	205	215	225

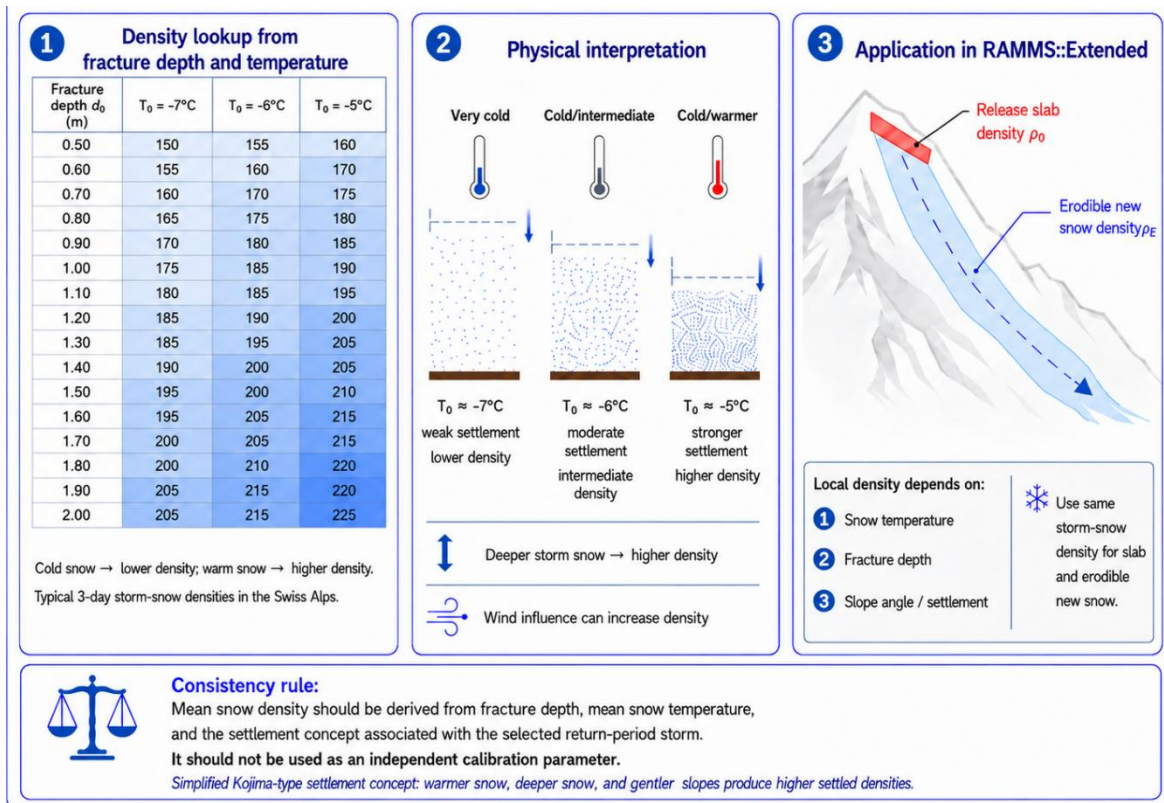


Figure 7b: Definition of mean snow density for scenario-based RAMMS::Extended calculations.

8. Other input parameters

In addition to fracture depth, density and friction, several secondary parameters influence how a dry-snow avalanche disperses, interacts with the terrain and couples to the powder cloud. Among the most important for RAMMS::Extended are **generate**, **curvature** and **cliff factor**.

Generate

The **generate** parameter controls the production of **internal random kinetic energy** within the avalanche core. This random energy governs how strongly the flow disperses, how easily it fluidizes and how effectively a powder-snow cloud can develop. Physically, cold snow is more brittle and fractures more violently, so collisions and shearing between snow granules produce more random motion. Warm snow, by contrast, deforms more plastically and dissipates energy rather than converting it into turbulence. For this reason, cold low-density snow should typically **generate = 7 %**, while cold dense snow should use **generate = 8 %**. As temperature increases toward wet-snow conditions, the generate value should be reduced, with **about 5 %** being appropriate for warm, dense or wet avalanches (Figure 8).

Curvature

The **curvature** option accounts for **centripetal accelerations** caused by bends and undulations in the DEM. It should only be used when the summer DEM is a good representation of the actual winter sliding surface. In practice, this is often not the

case. Deep winter snow can fill gullies and smooth rocky terrain, and previous avalanche deposits can create an elevated snow surface that differs strongly from the underlying ground. In such situations, DEM-based curvature forces become unrealistically large and may over constrain the avalanche core. Therefore, **curvature = OFF** is generally recommended for deep snow conditions, or whenever the winter terrain is much smoother than the bare-ground DEM (Figure 8).

Curvature ON: standard.

Curvature OFF: in many cases recommended for situations with avalanche paths along gullies.

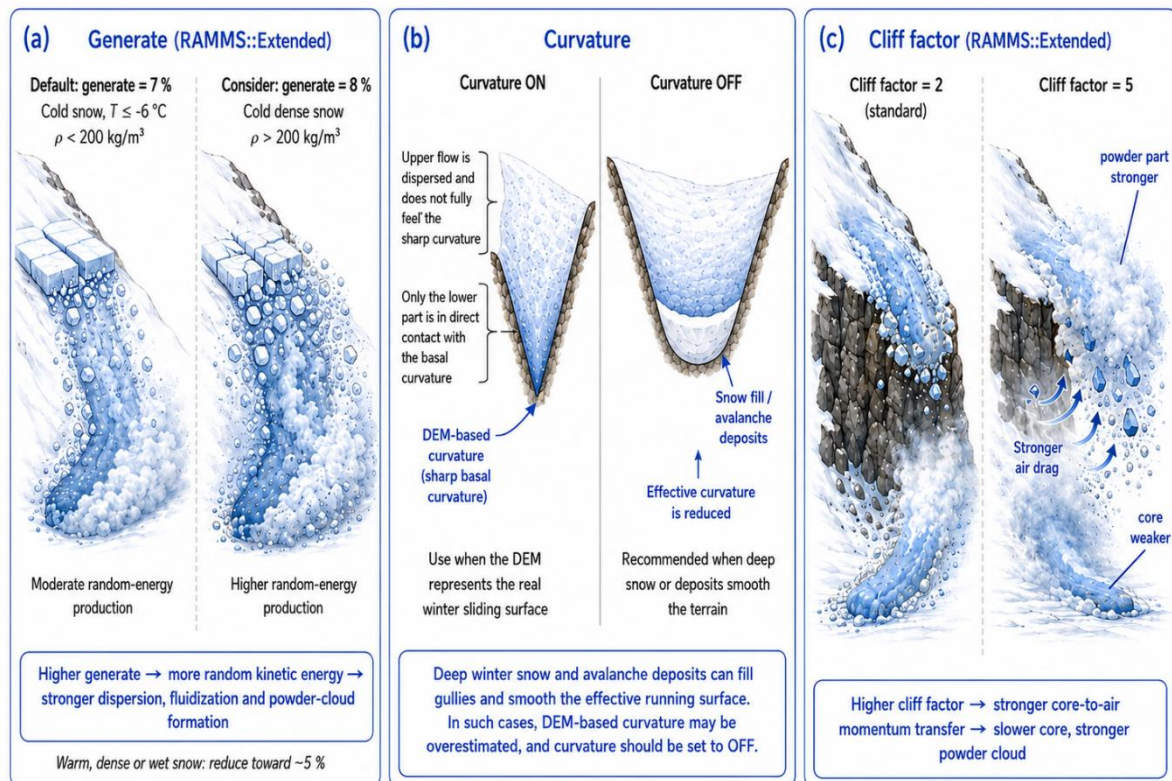


Figure 8: Conceptual illustration of three important secondary input parameters in RAMMS::Extended. (a) The **generate parameter** controls the production of internal random kinetic energy within the avalanche core. Higher values increase dispersion, fluidization and powder-cloud formation, with recommended values of 7% for cold low-density snow and 8% for cold dense snow. (b) The **curvature option** introduces DEM-based centripetal accelerations and should be switched off when deep snow or previous avalanche deposits smooth the effective winter terrain. (c) The **cliff factor** controls momentum exchange between the dense core and the powder cloud in steep rocky terrain. Higher values enhance dispersion and air drag, thereby weakening the core and strengthening the powder-snow cloud.

Cliff Factor

The **cliff factor** controls the **momentum exchange between the dense avalanche core and the powder cloud**, especially in very steep rocky tracks or sections where cliff effects are pronounced. When the avalanche partially loses contact with the ground, the snow granules disperse more strongly, and experience increased air drag. By Newton's third law, this stronger drag on the particles produces an equal and opposite force on the air, transferring more momentum from the core to the powder cloud. A higher cliff factor therefore tends to produce a **slower and weaker dense**

core, but a **faster and more energetic powder cloud**. The standard value is **2**, while values up to **5** may be used for very steep rocky sections where cliff effects are pronounced (Figure 8).

Table 7: Secondary core parameters.

Input parameter	Value	Information	Remarks
Curvature	On	Standard	
	Off	Use when there is a deep snowpack or avalanche deposits modify the summer surface significantly.	Especially for RAMMS::Extended to create stronger powder cloud
Generate (RAMMS::Extended)	7 %	Cold $T \leq -6\text{ °C}$, low-density snow $\rho < 200\text{kg/m}^3$	
	8 %	Cold $T \leq -6\text{ °C}$, high-density snow $\rho \geq 200\text{kg/m}^3$	
Cliff factor (RAMMS::Extended)	2	Standard	
	5	Very steep rocky sections in the track	Core gets weaker , powder part stronger

Parameters controlling snow-cover interaction

Several secondary parameters in RAMMS::EXTENDED control the interaction between the moving avalanche and the snow cover. These parameters do not define the release mass directly, but they influence how much snow is available for entrainment, how easily this snow can be mobilized, and how much energy is consumed at the avalanche front. They are therefore especially important in scenario calculations where the avalanche grows substantially by entraining snow along the track.

Erosion Mode

The **erosion mode** defines how the snow cover is distributed over the terrain before the avalanche arrives. For scenario-based calculations, the recommended setting is the **3-day settlement** option. In this mode, the snow cover is densified according to snow temperature, snow amount and the local temperature gradient. The entrainable snow mass is therefore not only a function of snow depth, but also of elevation and thermal conditions. This is important for cold, dry snow avalanches, where the snow cover can remain light and easily erodible at high elevations, while becoming denser and more settled lower in the track. Other distribution options, such as **variable** or **constant**, can be used when older snow, wet snow or user-defined snow-cover conditions are more appropriate (Table 8).

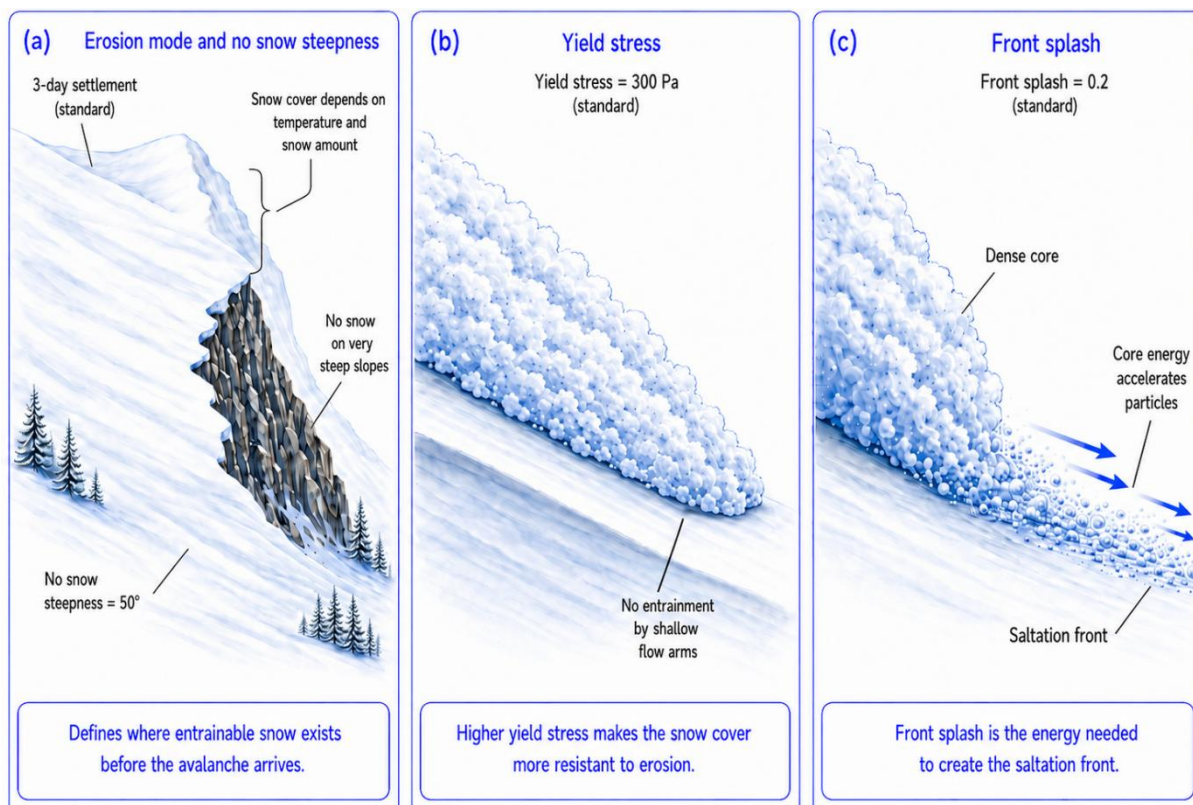


Figure 9: Input parameters controlling the interaction between the avalanche and the snow cover. **(a)** The erosion mode defines the spatial distribution and density of entrainable snow, while the no-snow-steepness angle removes snow from terrain that is too steep to retain a stable snow cover. **(b)** The yield stress controls the resistance of the snow cover to erosion. Higher values prevent shallow flow arms from entraining snow and allow the avalanche to ride on top of the basal running surface. **(c)** The front-splash parameter represents the energy required to accelerate snow particles forward at the avalanche front, producing a slope-parallel saltation zone ahead of the dense core.

Reference altitude

We recommend that the reference altitude has the elevation of the release area. The altitude of the release area plays an important role in scenario-based calculations because it helps define the **temperature of the released snow**. This is especially important for cold dry-snow avalanches, where temperature controls snow density, brittleness, random-energy production and the potential for powder-cloud formation. For this reason, altitude should be documented together with the snow-temperature and snow-cover parameters rather than treated as a purely numerical input.

No snow steepness

The **no snow steepness** parameter defines the slope angle above which no snow is allowed to accumulate. The standard value is 50° . This parameter prevents unrealistic snow storage on very steep rock faces, cliffs or terrain sections where snow would normally slough off or be removed by wind and gravity. It therefore works together with the erosion mode: the erosion mode distributes and densifies the snow cover, while the no-snow-steepness angle removes snow from slopes that are too steep to retain it (Figure 9).

Table 8: Snowcover interaction parameters.

Input parameter	Value	Information	Remarks
Erosion mode (RAMMS::Extended)	3-day settlement	New snow conditions	Used for Scenario-Based calculations
	Variable	e.g. conditions with older snow	
	Constant	e.g. wet snow conditions	
Reference altitude		Altitude of release area	Place an important role, especially for cold avalanches, because it defines temperature of release zone.
Air temperature		Temperature of air at the time of the avalanche	Low air temperatures can strengthen the powder cloud; warm air temperatures can help to damp the core and cloud.
Front splash	0.2	Standard	Small energy correction to avalanche front. Fraction of energy required to accelerate particles to speeds faster than core.
No snow steepness	50°	Standard	Value of ψ^*
Yield stress	300 Pa	Standard	Not important for low strength new snow.

Yield stress

The **yield stress** controls how easily the avalanche front can pick up and mobilize the available snow cover. The standard value is **300 Pa**, which is appropriate for low-strength new snow. In this case, entrainment is easy and the avalanche can rapidly grow along the track. Higher yield-stress values can be useful when shallow avalanche arms or low-height flow branches entrain too much snow. Increasing the yield stress makes the snow cover more resistant to erosion and can help suppress unrealistic secondary flow arms or excessive lateral spreading caused by weak numerical entrainment (Figure 9).

Front splash

The **front splash** parameter represents a small energy correction at the avalanche front. It describes the fraction of energy needed to accelerate snow particles to

velocities higher than the mean core velocity, producing a saltation-like front. The standard value is **0.2**. Physically, a stronger saltation front requires more kinetic energy from the dense core. This means that part of the core energy is consumed by accelerating particles forward and upward at the front, rather than being used only to maintain the bulk motion of the avalanche.

Together, these parameters define the first-order interaction between the avalanche and the winter snow cover: where snow is present, how dense and resistant it is, whether it can be entrained, and how much energy is lost when the front mobilizes it (Figure 9).

Powder Cloud Parameters

The powder-cloud parameters control how the suspended part of the avalanche interacts with the surrounding air (Table 9).

Cloud drag

Cloud drag regulates the resistance acting on the powder cloud and is selected according to track steepness: lower values are appropriate for very steep paths, while higher values are used for flatter tracks or small avalanches (Figure 10).

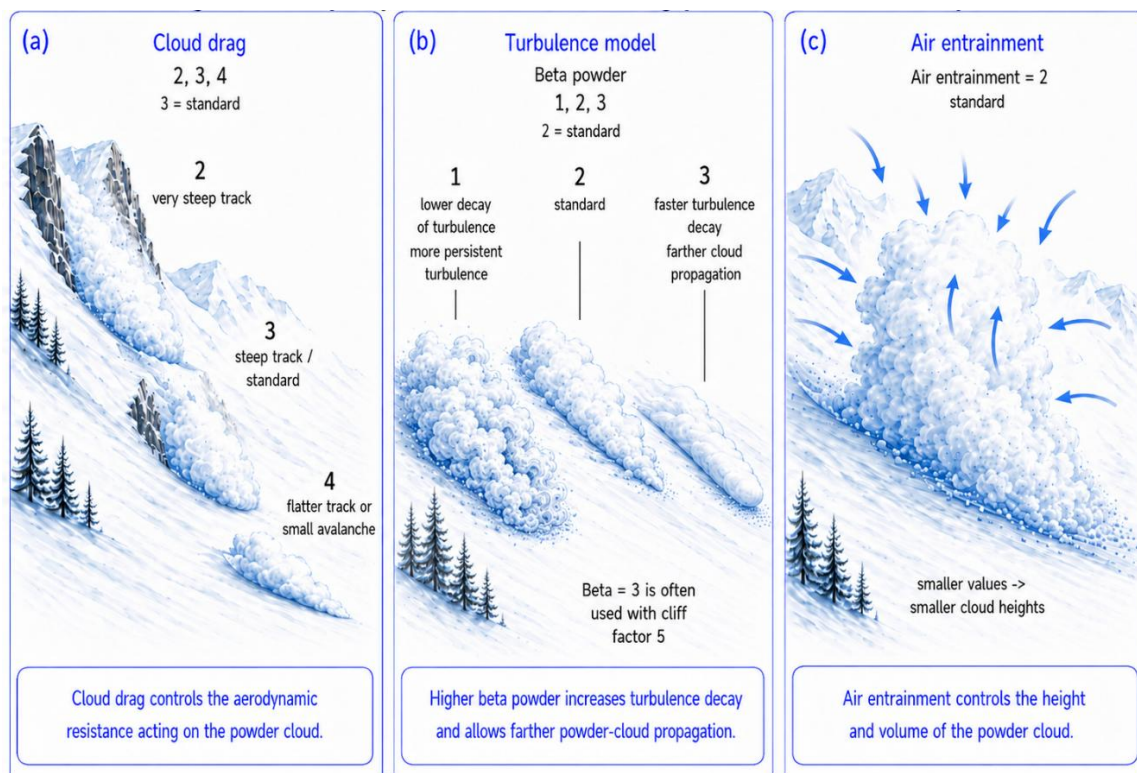


Figure 10: Input parameters controlling powder-cloud development. (a) The **cloud-drag parameter** controls the aerodynamic resistance acting on the powder cloud and is selected according to track geometry. (b) The **turbulence parameter, beta powder**, controls the decay of turbulence within the cloud. Lower values allow turbulence to persist longer, while higher values increase turbulence decay and permit more organized, farther powder-cloud propagation. Beta = 3 is often used together with cliff factor = 5. (c) **Air entrainment** controls the incorporation of ambient air into the powder cloud and therefore influences cloud height and volume. Smaller air-entrainment values produce lower, less-developed powder clouds.

Turbulence decay

The **turbulence model parameter β** powder controls the strength and persistence of the powder part; higher values produce a stronger powder cloud and are often combined with a high cliff factor (Figure 10).

Air entrainment

Air entrainment controls how much ambient air is incorporated into the powder cloud and therefore strongly influences cloud height and volume. Smaller air-entrainment values produce lower, less-developed powder clouds (Figure 10).

Table 9: Powder cloud parameters.

Input parameter	Value	Information	Remarks
Cloud drag (RAMMS::Extended)	2	Very steep track	
	3	Steep track / standard	
	4	e.g. track with less than approx. 30° (mean slope angle)	OR small avalanches
Turbulence model: Beta powder (RAMMS::Extended)	1	Smaller powder part	
	2	Standard	
	3	Stronger powder part	Use in combination with cliff factor 5
Air entrainment	2	Standard	Helps control the height of the powder cloud, smaller values smaller cloud heights.

Additional numerical and scenario-control parameters

Several remaining input parameters control the numerical resolution, output frequency and practical execution of the simulation. These parameters do not directly define the avalanche material properties, but they influence the numerical representation of the flow, the interpretation of the results and the efficiency of the calculation (Table 10).

Percentage of total momentum

The **percentage of total momentum** is normally set to **5 %**. This parameter is mainly used to define when the remaining moving mass has lost sufficient momentum for the simulation to stop. For small avalanches, a higher value, for example **8 %**, can be used to obtain more realistic stopping behavior. This is especially useful in RAMMS::Avalanche, where very small residual flow depths may otherwise continue to move slowly and produce artificial flow “creep”.

Table 10: Numerical and scenario control parameters.

Input parameter	Value	Information	Remarks
Percentage of total momentum (%)	5	Standard	
	Higher, e.g. 8	Small avalanches: higher % to stop the flow more realistic	Especially for RAMMS::Avalanche to avoid flow “creep”
Grid resolution	5 m	Standard	
	3 m	e.g. if already small terrain features influence the flow path	Often valid for avalanches in the category T or S .
	> 5 m: e.g. 8 m - 10 m		Often useful to save calculation time on initial runs.
Dump step	2	Standard	Needed to plot time-history of heights, velocities and pressures. Animations are better with higher dump-step resolution.
CPU threads	12	Standard	Depends on computer. If the user was to perform other tasks (using word, internet), then they never use all processors.

Grid resolution

The standard **grid resolution** is **5 m**, which provides a good compromise between terrain representation and calculation time. Finer resolutions, for example **3 m**, can be useful where small terrain features strongly influence the flow path. Coarser resolutions, for example **8–10 m**, may be appropriate when small dams, ridges or terrain irregularities in the DEM would otherwise produce unrealistic blocking or deflection. The selected grid resolution should therefore reflect both the scale of the avalanche and the quality and relevance of the terrain model.

Dump step

The **dump step** controls how often simulation results are written to output files. The standard value is **2**. This is usually sufficient for analyzing maximum heights, velocities and pressures, but a smaller dump interval may be useful when detailed time histories or smooth animations are required. Increasing the temporal output resolution improves the interpretation of transient flow behavior but also increases file size.

Number of CPU threads

The **number of CPU threads** controls how many processors are used during a CPU calculation. A standard value of **12** is suitable for many workstations, but the optimal value depends on the computer. If other tasks are being performed at the same time, such as writing, plotting or working with GIS data, not all available processors should be used. Leaving some processors free improves the usability and stability of the computer during long calculations.

9. References

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