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Sustainable snow management

Toolkit Snow Grooming and Handling

How to groom and prepare tracks with lowest possible impact on the environment

Deliverable 4.6

31st May 2025

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Content

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(1) Grooming & Snow Handling

Challenging sustainable snow management

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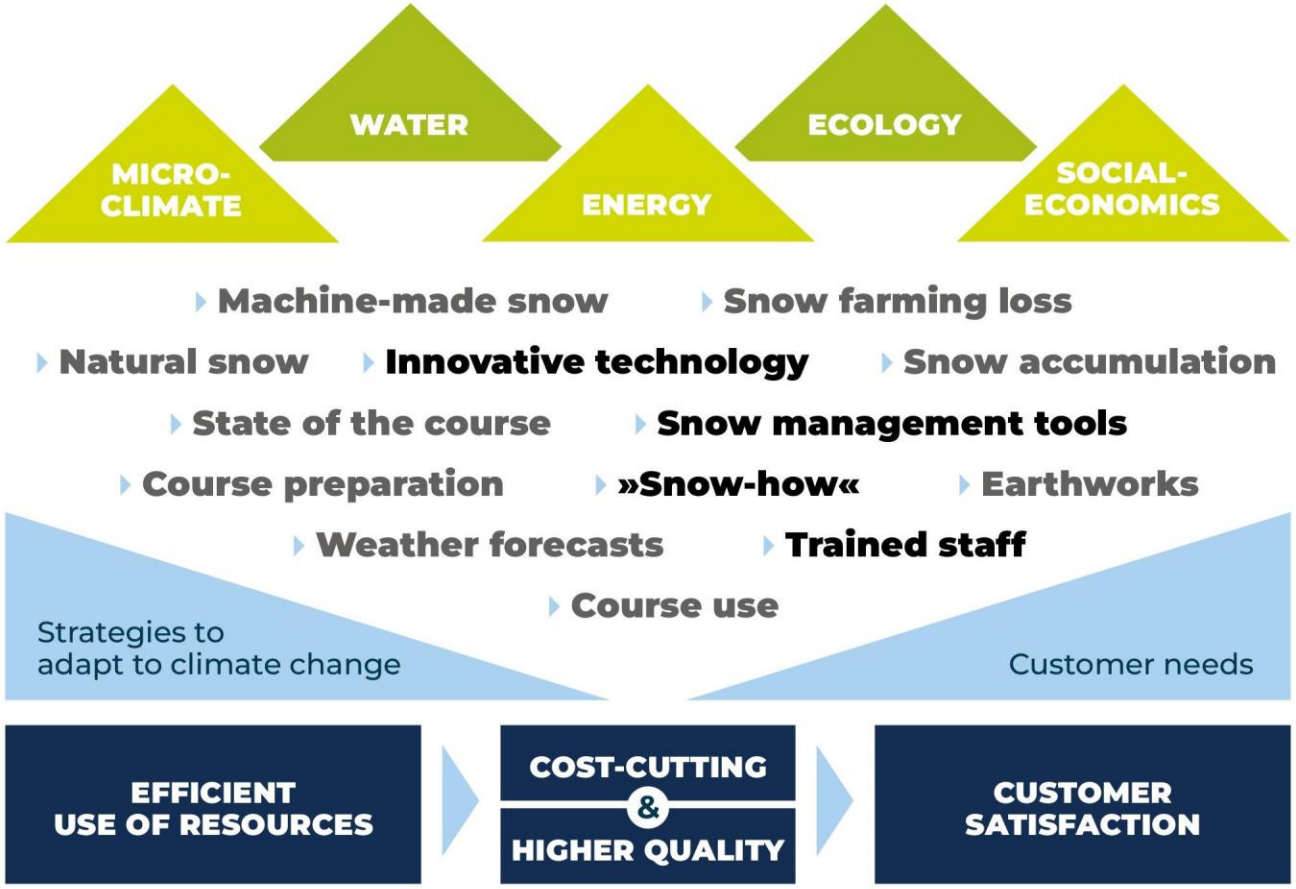
(1) Sustainable snow management



...to **reliably provide snow**...

...within a given set of climatological, hydrological, ecological, and social-economical constraints...

...to run snow sport infrastructures in an **ecologically and economically sustainable** manner.

...to reduce **costs** while improving the **quality of snow** sports facilities.

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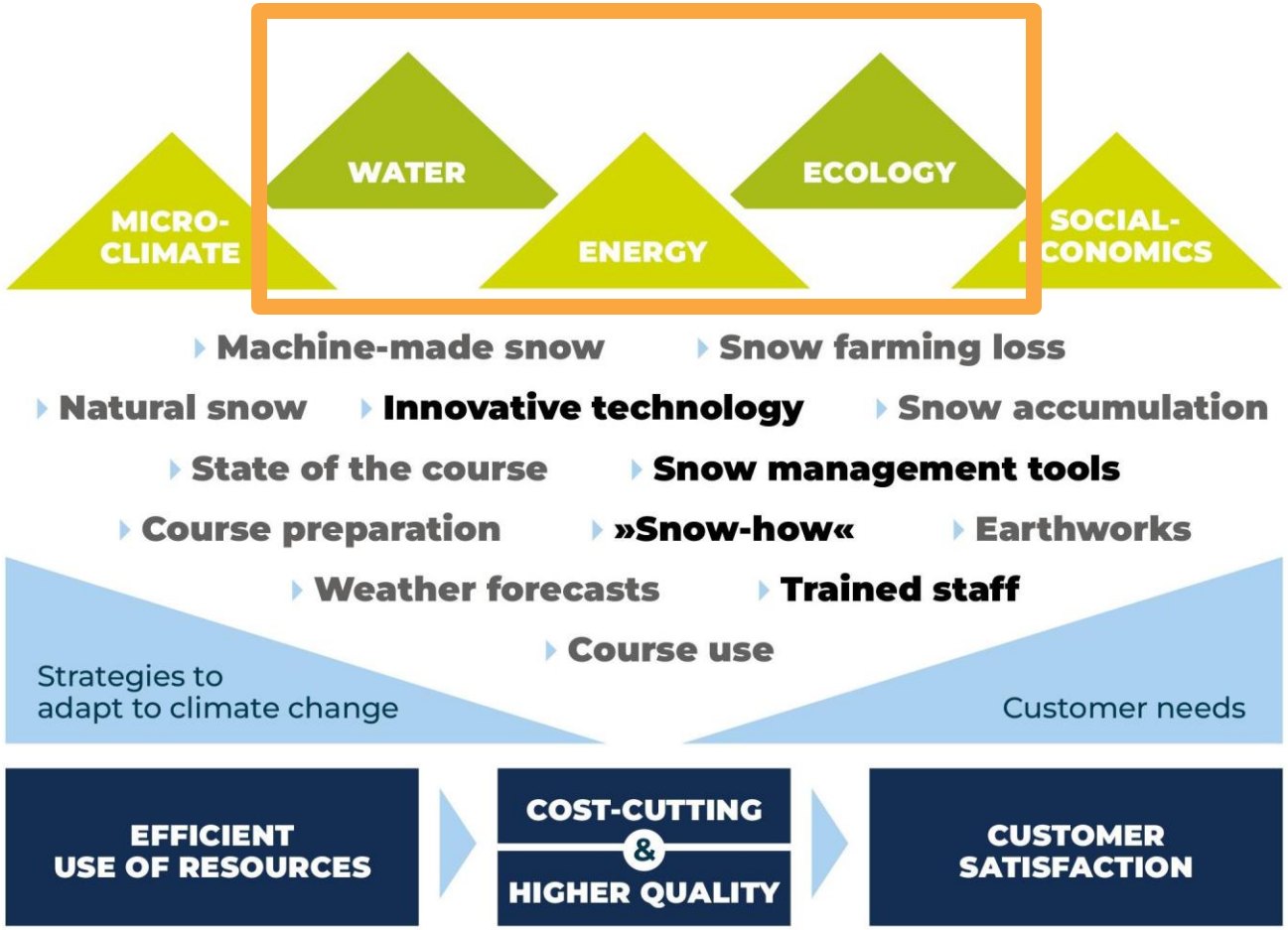
(1) Sustainable snow management - Grooming & Snow Handling



SNOW...

Grooming
creating a resistant, even & durable snow surface using motorized vehicles

Snow Handling
summarizes further snow preparation techniques

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(2) Grooming & Snow Handling

Overview

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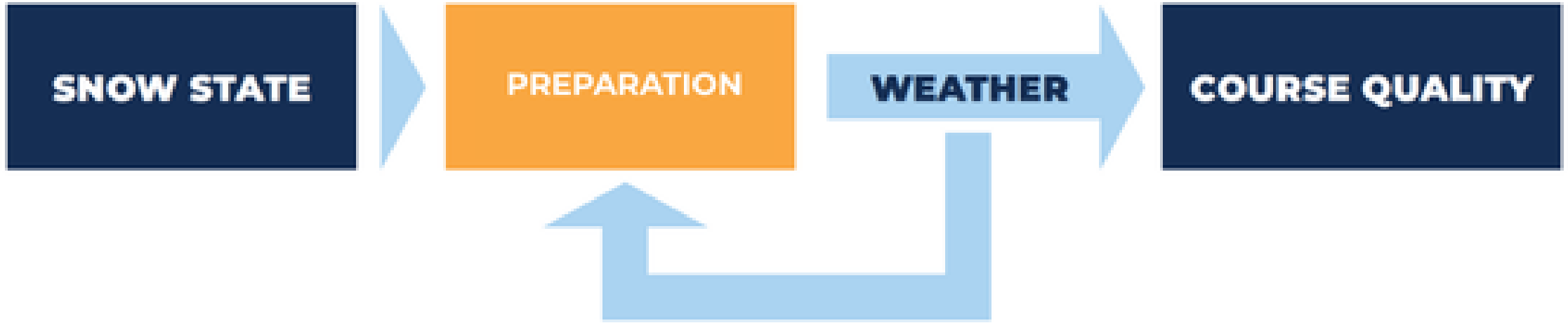
(2) Grooming & Snow Handling – Overview

Consider the natural processes in the snow
and how they depend on the weather
before choosing preparation tools & techniques



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(3) Grooming

Understanding the unique material snow

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(3) Grooming – understanding the unique material snow

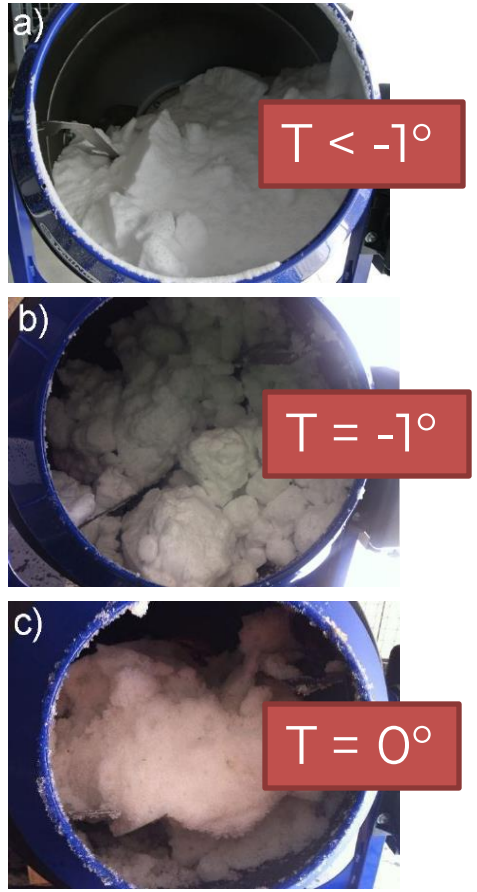
- **in the high-temperature range**
- **under constant transformation**
- **with variable structure**
- **with complex mechanical properties**

small changes in temperature

↓

strong changes of properties

snow temperature - a very important parameter



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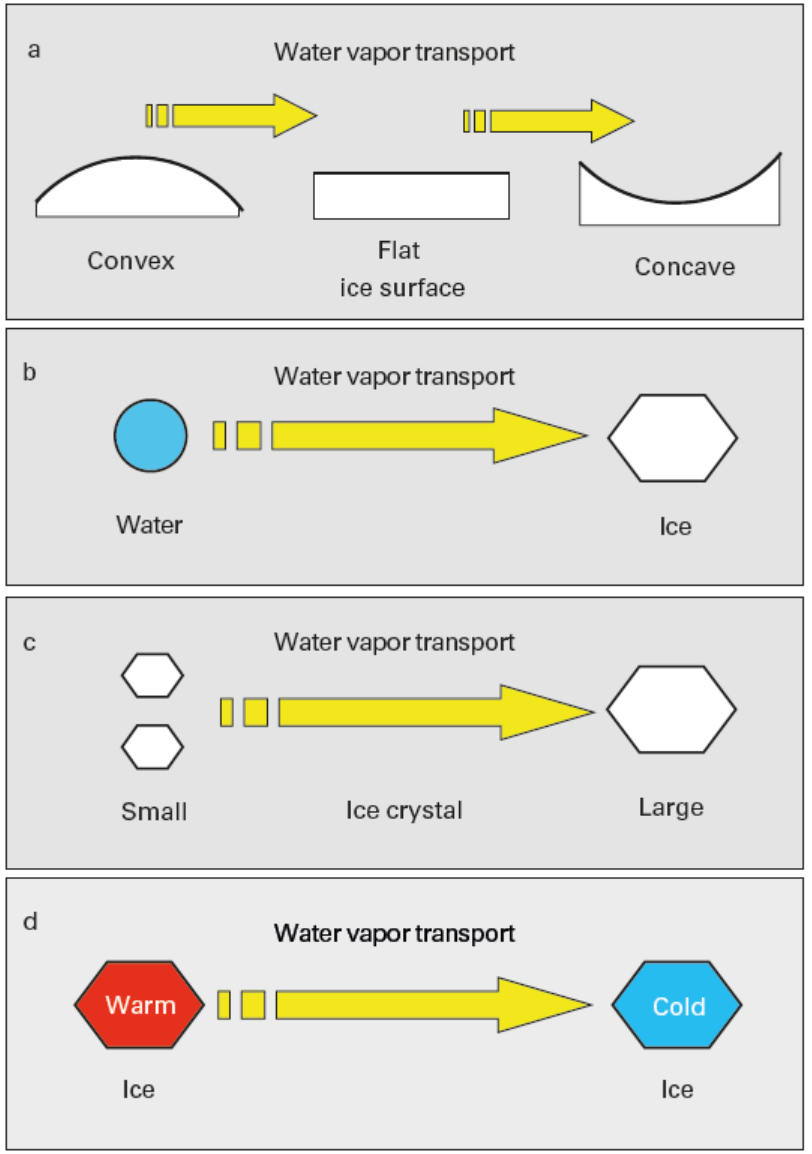
(3) Grooming – understanding the unique material snow

- in the high-temperature range
- **under constant transformation**
- with variable structure
- with complex mechanical properties

snow lives, until…
…grains end up large & mostly round: → dead snow

snow sintering is THE most important process in grooming

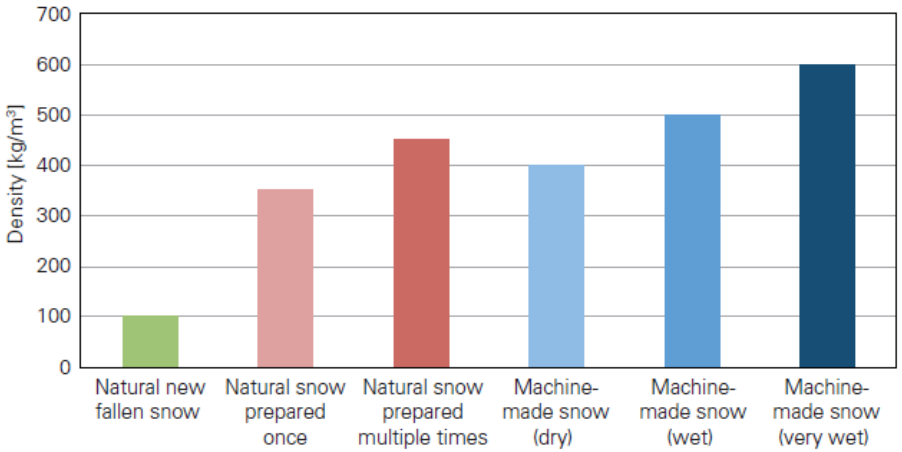
Processes are driven by difference in shape, size, temperature and phase within the snow cause vapor pressure difference

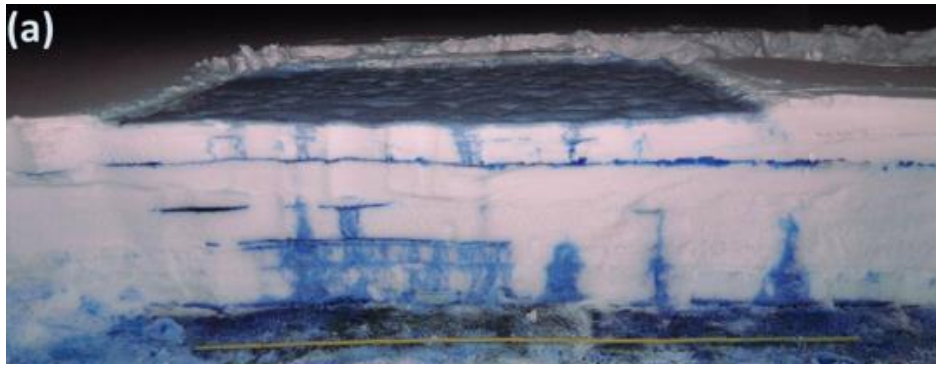


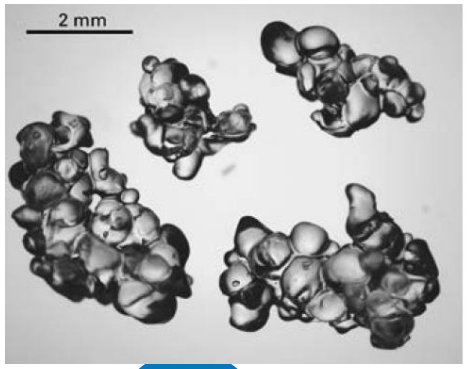
(3) Grooming – understanding the unique material snow

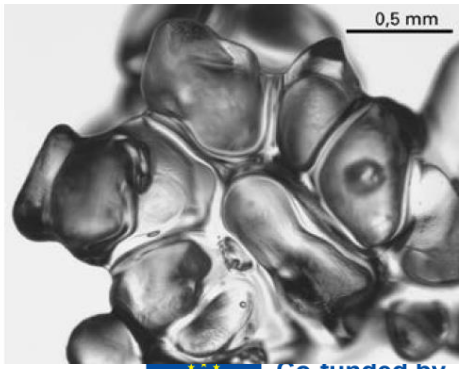
- in the high-temperature range
- under constant transformation
- **with variable structure**
- with complex mechanical properties

1) density = mass / volume
2) specific surface area = surface / volume
3) liquid water content = water / volume









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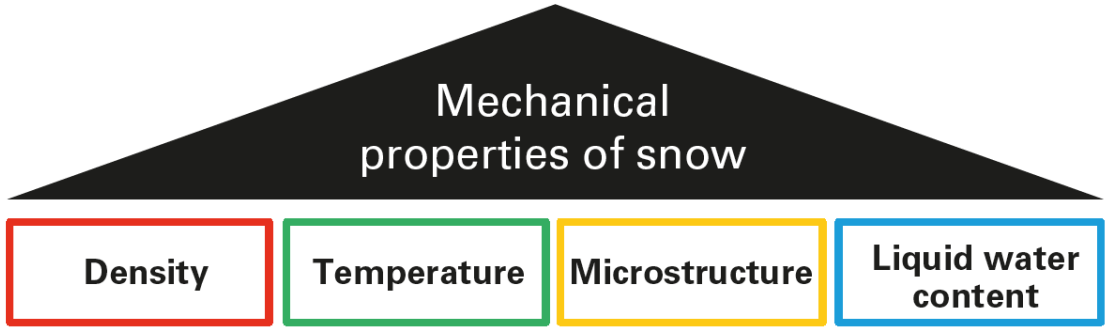
(3) Grooming – understanding the unique material snow

- **in the high-temperature range**
- **under constant transformation**
- **with variable structure**
- **with complex mechanical properties**

snow strengthens
the more, the larger, and the faster
bonds build-up

→ grooming should
help the snow building bonds



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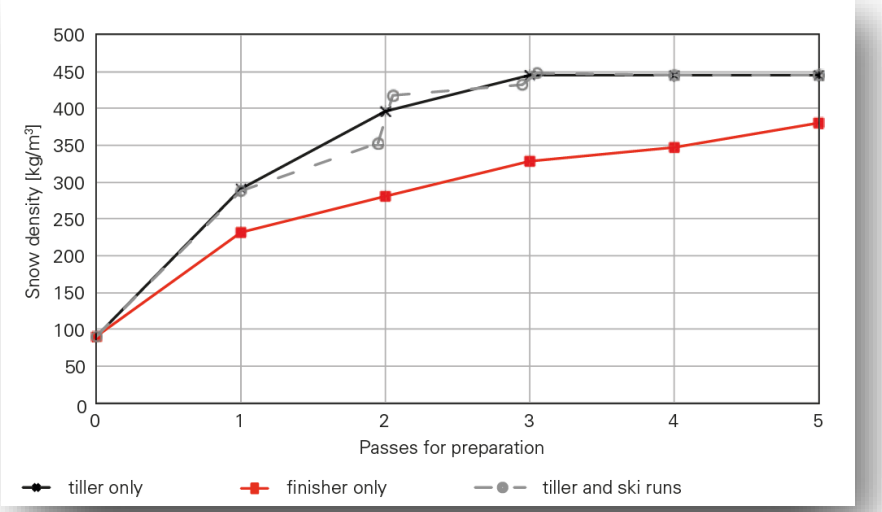
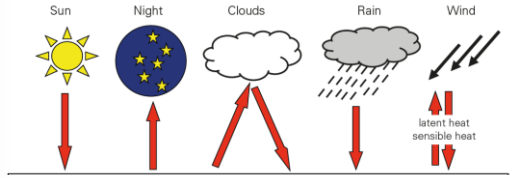
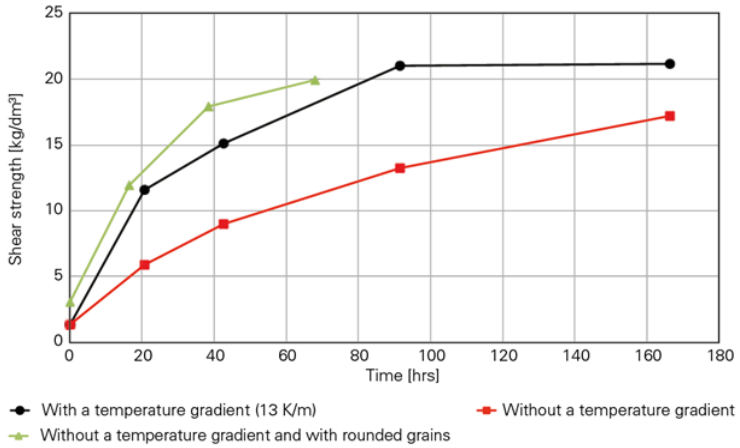
(3) Grooming – strengthening snow

- **Consolidation**
  - pressure / compaction
  - filling pores (fine material or water)

- **Strengthening bonds**
  - increase no. of grain contacts
  - round grains & reduce size
  - widen grain size distribution
  - increase snow temperature
  - provide temperature gradients
  - plan resting time







(3) Grooming – strengthening snow

Create optimal conditions for snow consolidation

Exploit existing natural conditions to consolidate snow

Compact snow
Pressure from snowcats and skis
Fill pore spaces with fine material
Make grains round

Change the snow structure
Make grains smaller and round
Create fine material (milling)

Mix snow densities
Raise temperature
Mix/bind grain shapes

Take account of the weather forecast
Precipitation?
Clouds approaching?
Is the air temperature rising/falling?

Snow state and development
Density
Temperature and wetness
Microstructure

Available time
For sintering
For freezing

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(4) Grooming

How weather impacts snow

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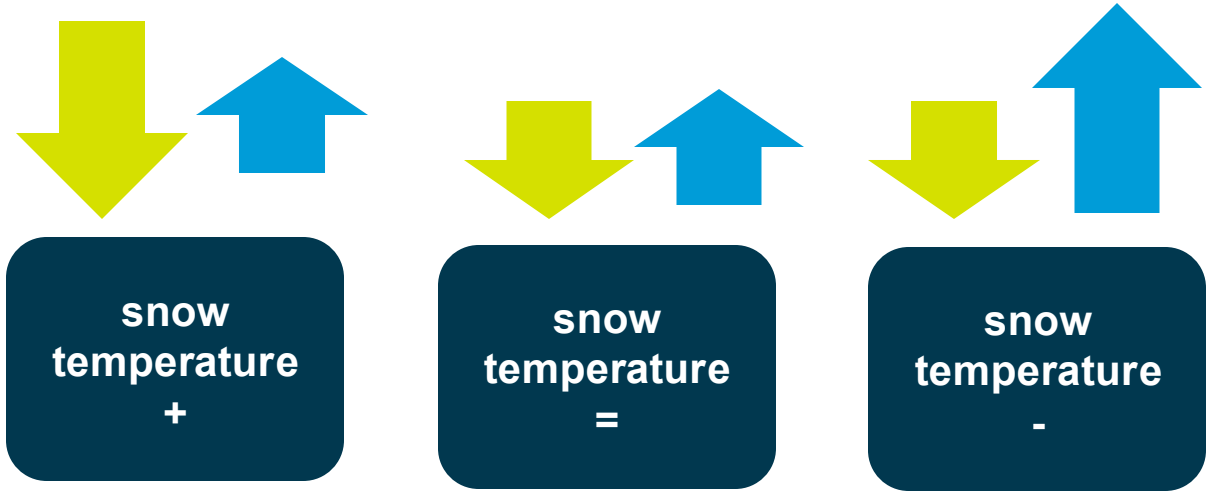
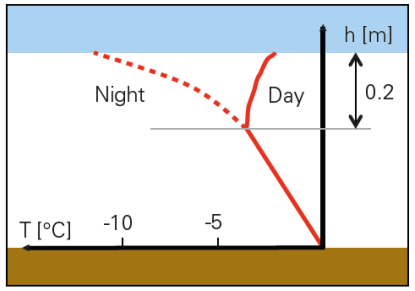
(4) Grooming – how weather impacts snow

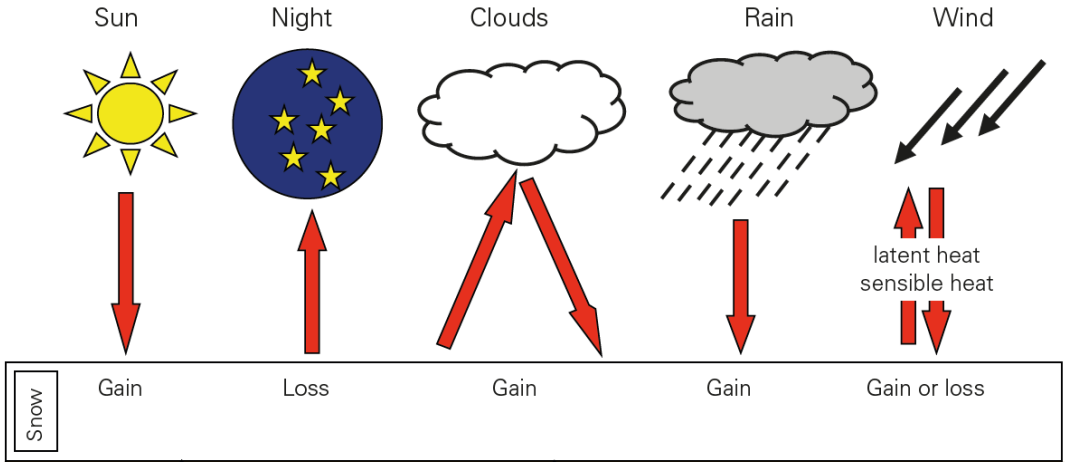
Energy exchange between snow surface and atmosphere:





Typical snowpack in winter

Thermal balance of the snow surface



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(4) Grooming – how weather impacts snow

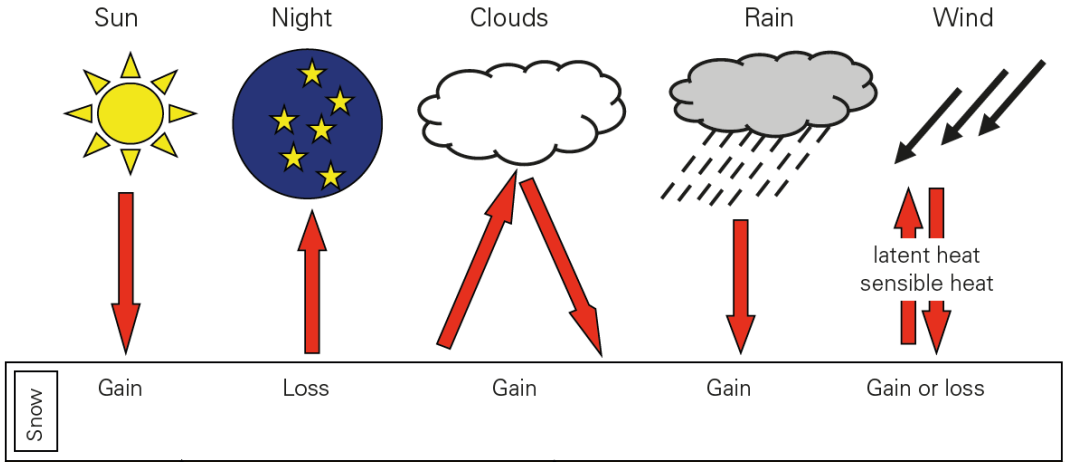
Energy exchange between snow surface and atmosphere:

Solar radiation (0.3-3.5 µm)
- latitude, time, exposition, sea level
- direct vs. diffuse (still ca. 25 %; hits all expositions)
- snow absorbs 5 to 50 % (depends on SSA)

Terrestrial radiation (3.5-100 µm)
- emitted by snow, soil etc.
- snow absorbs 99 %
- clear vs. cloudy nights

Heat exchange
- air (temp. difference snow, wind speed, air humidity
- rain (temp. differences, amount)
- soil

Thermal balance of the snow surface



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(5) Grooming

Learning from IBU venues

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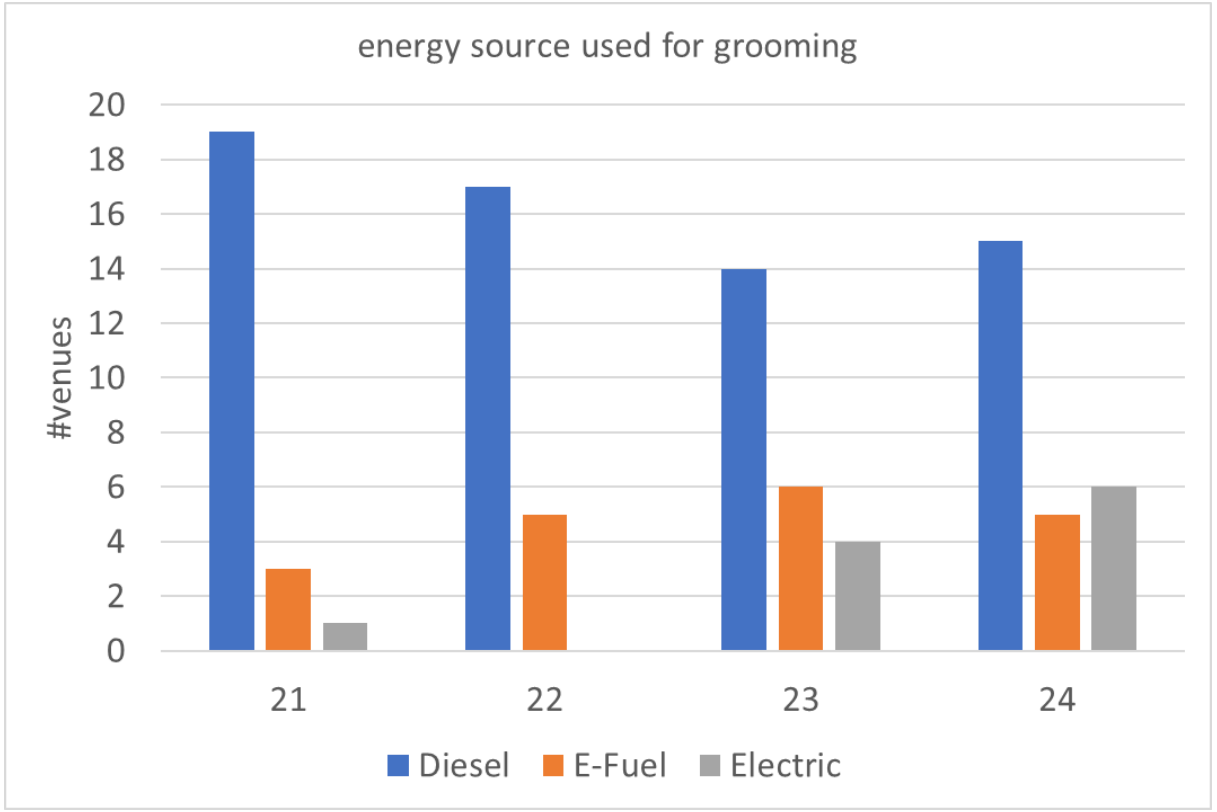
(5) Grooming – learnings from IBU venues



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(5) Grooming – learnings from IBU venues

Approximately same energy use as for snow making and storage

“However, the data of the IBU venues analysed so far show that snow making, snow storage and grooming are each associated with an energy use of several ten-thousands of kWh per season”

https://sustainablesnow.sport/wp-content/uploads/2024/04/D2.1_Current-state-of-snow-management_finish.pdf

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(5) Grooming – learnings from IBU venues

After transport or producing artificial snow to course

- Preparation of course to desired parameters (width, height of snow layer curves etc.)
- Push out air from snow
- Prepare top layer as same as possible over all courses

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(5) Grooming – learnings from IBU venues

Before event – preparation of course for the competition

- Width, banking of curves
- Grooming times depend on weather and specificity of venue
- Different weather/temperatures lead to use of different machines
- Having course nice packed and hard, but not icy, is the goal

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(6) Grooming

Sustainable grooming and news from the industry

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Alternative fuels

Challenge:
- To reduce carbon emissions of snow groomers

Solution:
- Hydrogenated vegetable oil (HVO) fuel (90% CO2 reduction)
- GTL (Gas to liquid) (8% CO2 reduction)
- E-fuels (under research)
- Hydrogen (under research)

- reduces the emissions of grooming

- All modern snow groomers from Prinoth and Pisten Bully can drive on HVO and GTL fuels

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Electric snow groomer

Challenge:
- To reduce the carbon dioxide emissions of grooming

Solution:
- Using an electricity-powered snow groomer
- Reduces the emissions
- Improves the work environment for the driver because it has less vibration and lower noise.

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Snow height measurement system

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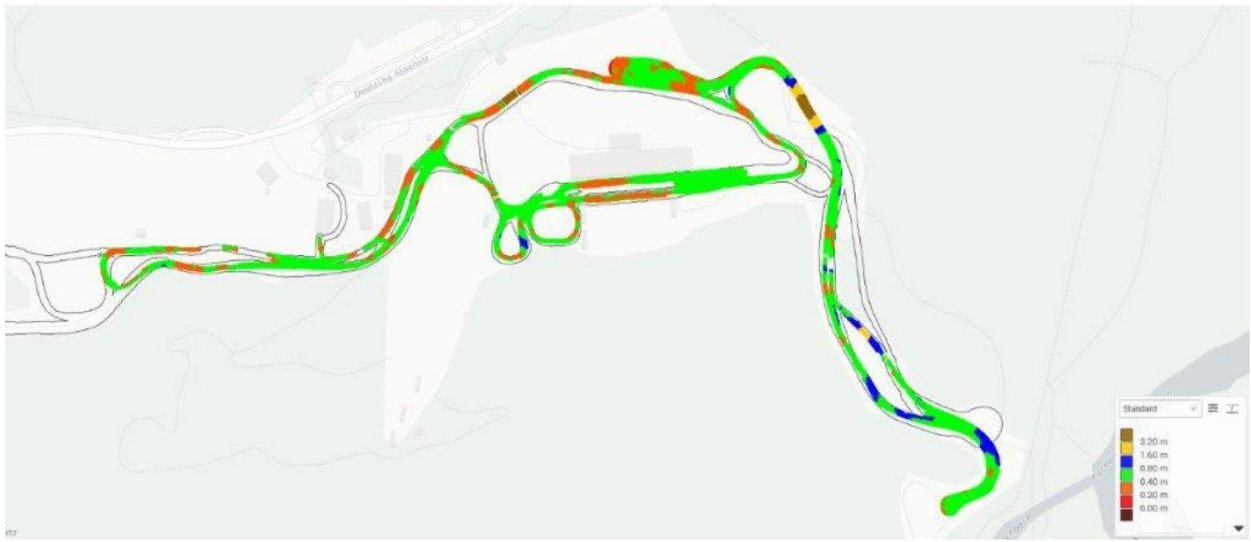
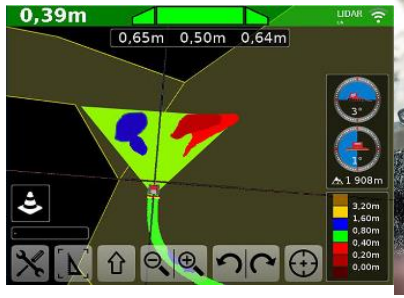
Challenge:
To prevent snow loss on the tracks

Solution:
- High precision GPS techniques and/or Lidar technology can measure snow depth

- This can be used to plan future snow production and snow distribution to ensure efficient use of resources and production of the right amount of snow.





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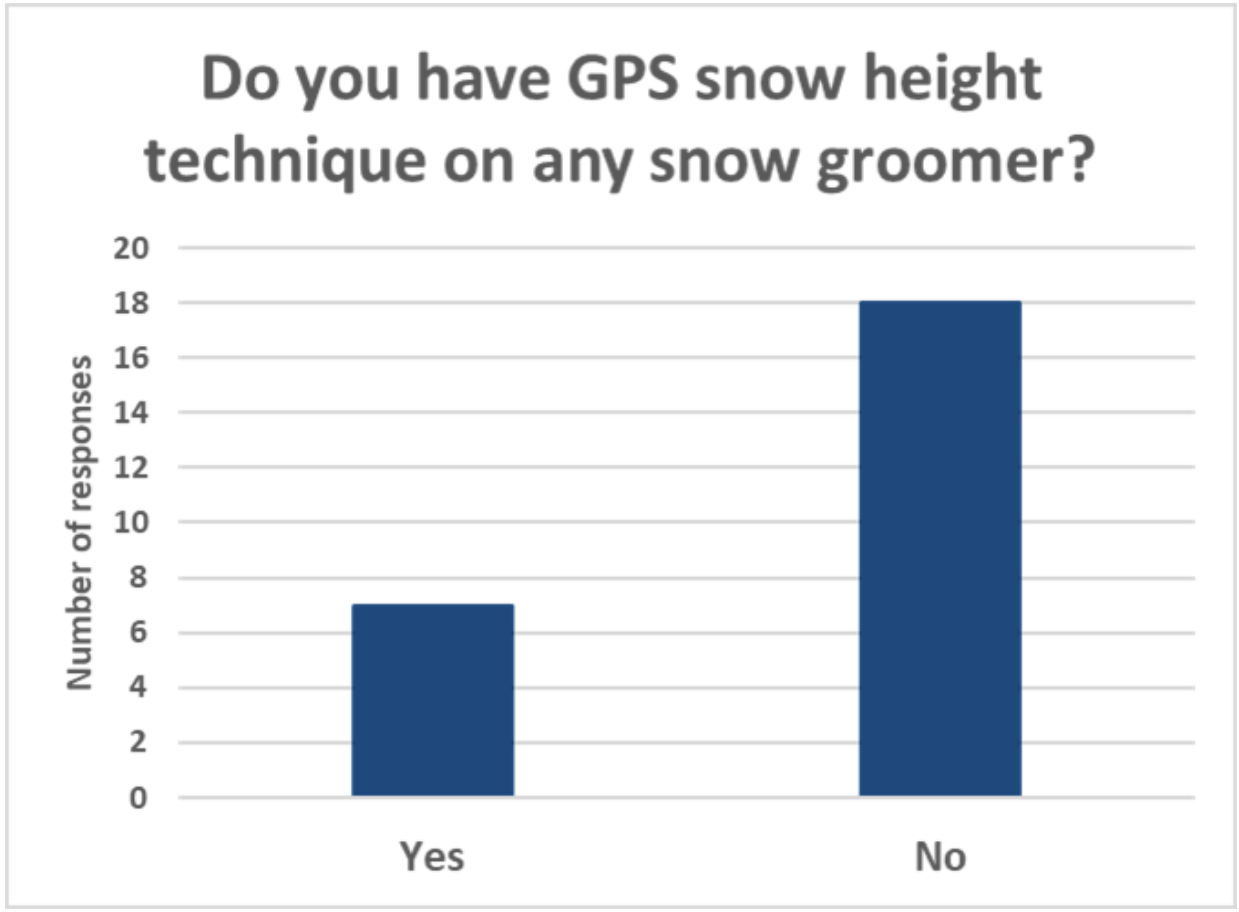
GPS snow height measurement systems at IBU venues



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(7) Snow Grooming

Good examples

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Parallel tracks

Challenge:
To prevent snow loss on the tracks

Solution:
- Making wide tracks and preparing tracks in both directions on a single snow lane.
- Prevent snow loss along the banks and
- More efficient snow distribution and grooming

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Snowplow to remove snow before a competition

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Challenge:

Snowfall that accumulates on top may reduce the snow quality if groomed in, making it softer.

Solution:

- Remove snow with a wooden plow/arrow, towed behind a snow mobile.
- Requires hard snow base and fluffy new snow
- Reduces need of grooming
- Reducing fuel consumption
- Increasing course quality.

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Use of skidoos/rollers/no tilling

Challenge:
Avoid breaking a hard snow base when only need to smooth out the surface and make the course visible.

Solution:
- Using a small skidoo grooming system rather than a large snow groomer.
- Alternatively, use rollers and avoid tilling.

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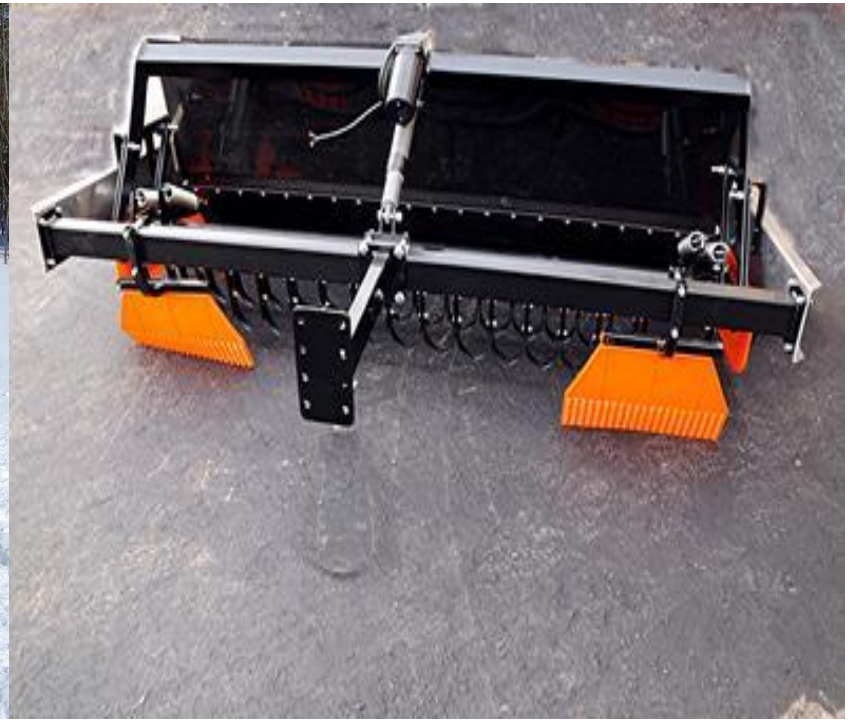
Use of skidoos/rollers/no tilling



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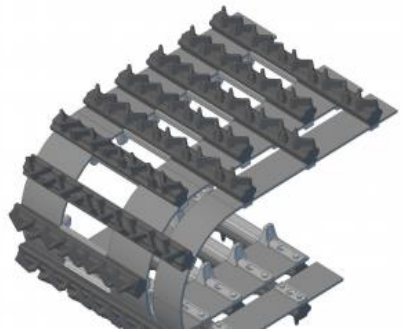
Different machines for different use

Use right size of machine for right grooming purpose. A larger machine uses more energy but groom wider and could limit grooming to one lap.



Rubber tracks (right) to minimize penetration and breaking of the snow surface.

Alu tracks (left) for moving snow, building tracks etc.

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Different tool for different use

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(8) Snow Handling

Snow Hardening

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(8) Handling – Hardening

General Guidelines

- Snow: Liquid water in the snow is required (T_{snow} = 0°C)
- Snow: Very coarse grained snow can not hold much water → hardens worse
- Quantities: If too much is used, snow hardens less (5 to 50 g/m^2)
- Grain size: Larger grains have a longer, deeper but weaker effect
- Weather: Snow hardeners are very ineffective in snowfall and fog

  (incoming longwave radiation; low heat conduction, no water accumulation at grain bonds)
- Weather: Rainwater can be conducive, but additional hardener is required
- Grooming: If tilling then right after the hardener was spread
- Grooming: Once the hardening process has begun, the snow should no longer be worked on

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(8) Handling – Hardening

Specific Guidelines

- Natural nitrogen input by atmospheric deposition: 0.5 to 4 g/m^2 per year
- Recommended nitrogen input to alpine meadows as fertilizer: 1 to 10 g/m^2 per year
- → about the order of magnitude as for one application of snow hardener
- Critical nitrogen input 0.5 to 3 g/m^2 → distribution of nitrophilous plants
- → be aware of nature reserves – preserve biodiversity!
- Increased eluviation of nitrate (NO_3+) can be assumed
- Road salt: up to 20.000 g/m^2 per year

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(8) Handling – Hardening

Environmental issues of hardening

Ammonium nitrate NH_4NO_3
Inorganic salt

NH_4+ NO_3-
80 g/mol
1920 g/l
-366 kJ/mol

tend to harms animals
overfertilisation – change vegation

Urea CH_4N_2O
Organic metabolite/ synthetic/ mineral

60 g/mol
790 g/l
-333 kJ/mol

harmless to environment
overfertilisation – change vegetation

Sodium chloride NaCl
Inorganic salt

Na+ Cl-
58 g/mol
317 g/l
-4 kJ/mol

high concentration harms waters/animals and soil organisms
change vegetation

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Learnings from IBU

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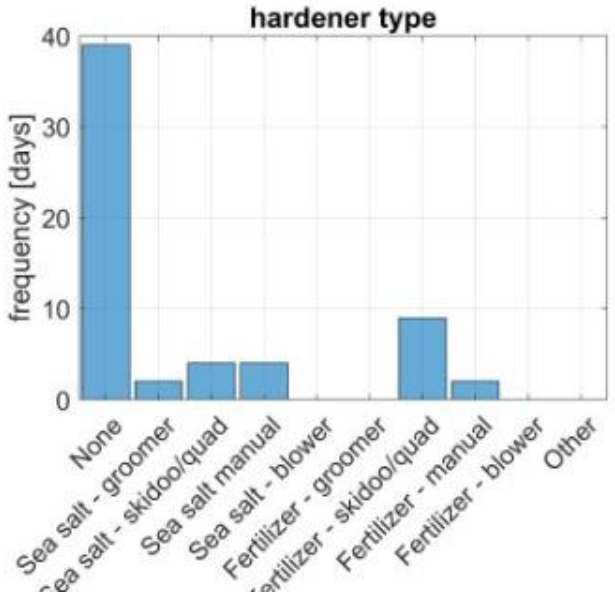
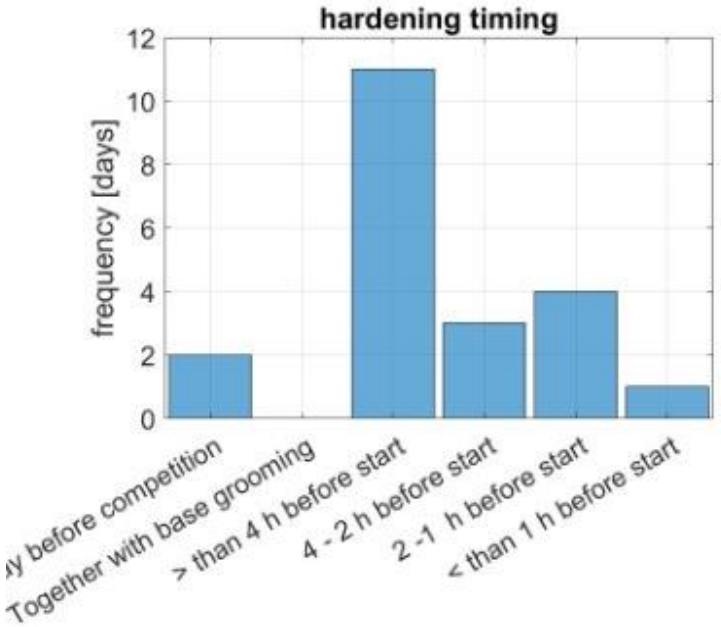
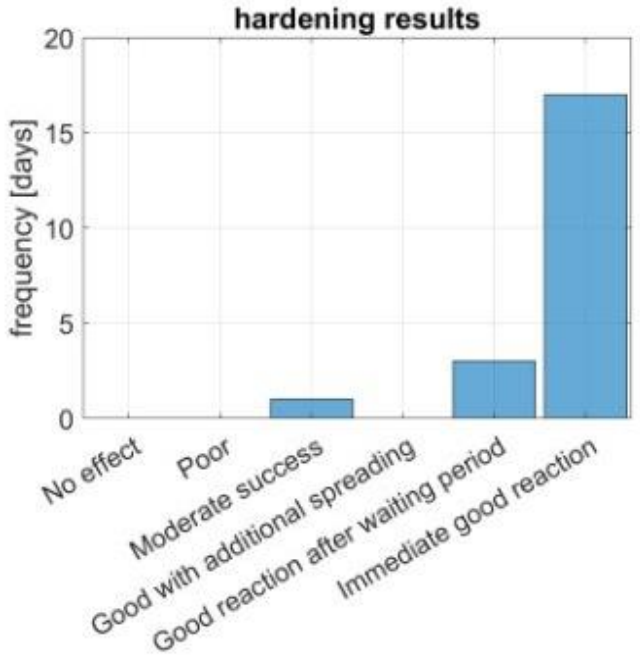
Did you use snow hardener at season 23/24







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Challenges of 2023/2024 Season
Warm, windy and rainy weather

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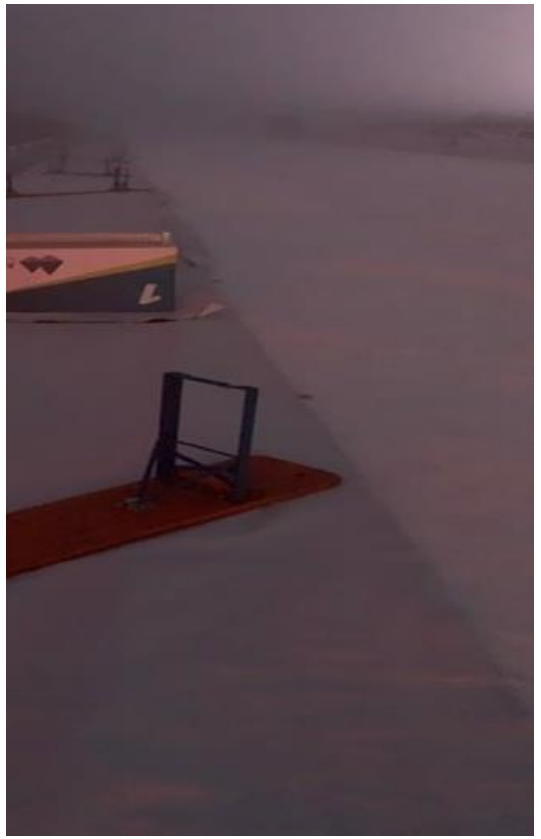
Challenges:
Warm and rainy weather and standing water on snow.

Solution:
- Dig trenches
- Pump water.
- Need equipment such as excavators, shovels, pumps, pipes
- Need volunteers/man power

Challenges:
warm, windy and rainy weather, creating water and ice on the course

Solution:
- Making snow areas soft
- Carpet protecting shooting range.
- Carpets to prevent athletes and fans from falling on ice



Challenges:
Reduce the amount of snow needed for racecourse

Solution:
- Make short cutoffs between the different course sections
- All slopes on a total length of “only” 4284m
- Longest slope 4km (4074m)
  +2 x 20m
  +2 x 40m
  +1 x 90m

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(10) Snow Handling

Good examples

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Snow hardener use plan

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Challenge:
To determine when and how to use snow hardeners

Solution:
- Detailed plan as to how and under which circumstances (weather snow conditions) hardener will be applied
- Amount and method of spreading.

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Snow hardener distribution tools

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Challenge: To distribute snow hardener homogenously and efficiently.

Solution: Tools to distribute hardener homogenously and fast independently of the operator. Generally reduces the amount of hardener used.

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Snow hardener protocol

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Challenge: To understand the amount of snow hardener chemicals used

Solution: Documenting the amount of snow hardener used per surface area to understand the total annual input of chemicals into the ground. Recording experiences on the snow, weather conditions and the success of hardener use can help determine future reduction and implementation protocols.

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Sun cover shields

Challenge: Snow melting on course sections that are heavily exposed to the sun.

Solution: Temporarily covering sections that are heavily exposed to the sun, reducing melting. It is important that the cover is removed as soon sun exposure is weak enough, to facilitate refreezing of the snow.

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Covering of snow-free banks or walls next to the course

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Challenge: Snow free structures, such as banks or walls next to the course, heat up strongly in the sun. Their warm surfaces radiates heat which increases snow melting on the course

Solution: Covering snow-free structures next to the course

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Covering snowbanks with textile sheets

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Challenge: Snow melting on course sections that are heavily exposed to the wind. The banks of snow are most exposed to melting. Works best with 45 degree flattened snowbanks

Solution: Cover the banks of snow with strips of textile significantly reduce melting especially at wind exposed sections.

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Excavator use for compressing snow

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Challenge: Stored snow usually consists of chunks of snow and requires removal of air pockets in the snow to ensure course becomes even and strong.

Solution: Using an excavator to drive over the snow once distributed from snow storage rather than a snow groomer. An excavator has more weight distributed on less area compared to a groomer and will therefore compact the snow better.

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Flattening banks

Challenge: To prevent snow melt along course banks

Solution: Preventing strong snow melt by reducing convective heat transfer (surface roughness) from warm air to snow by making the edges of the snow smoother at an approximately 45 degree angle.

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Ground work and terrain adjustments

Challenge: Uneven course requires more snow.

Solution: Make the course smoother needs less snow

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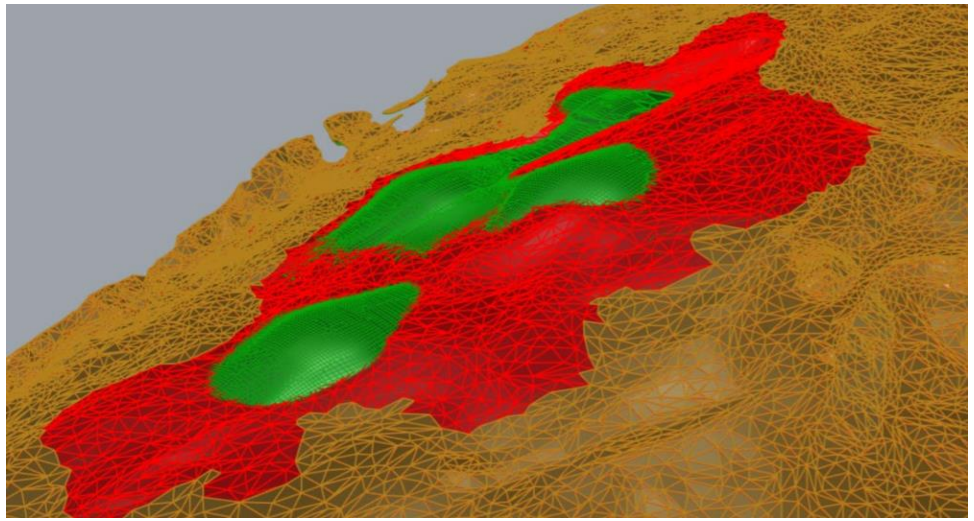
Terrain work to reduce snow

Optimization of the ground can be visualized in 3D

For ground work and

snow requirement calculations



- Example Ridnaun about 1500m^3 Snow requierment saved

Photos: Prinoth

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Ground Insulation

Challenge: Heat transfer from geothermal fluxes causing snow loss

Solution: Adding isolating plates underneath the ground under the ski course to prevent heat transfer from geothermal fluxes

Location: Multiple ski areas in southern Finland

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