Session 4
Dimensions of sustainability - Snow-making: energy consumption, energy management, water management

Title
Development and optimization of snow making systems for better resource management

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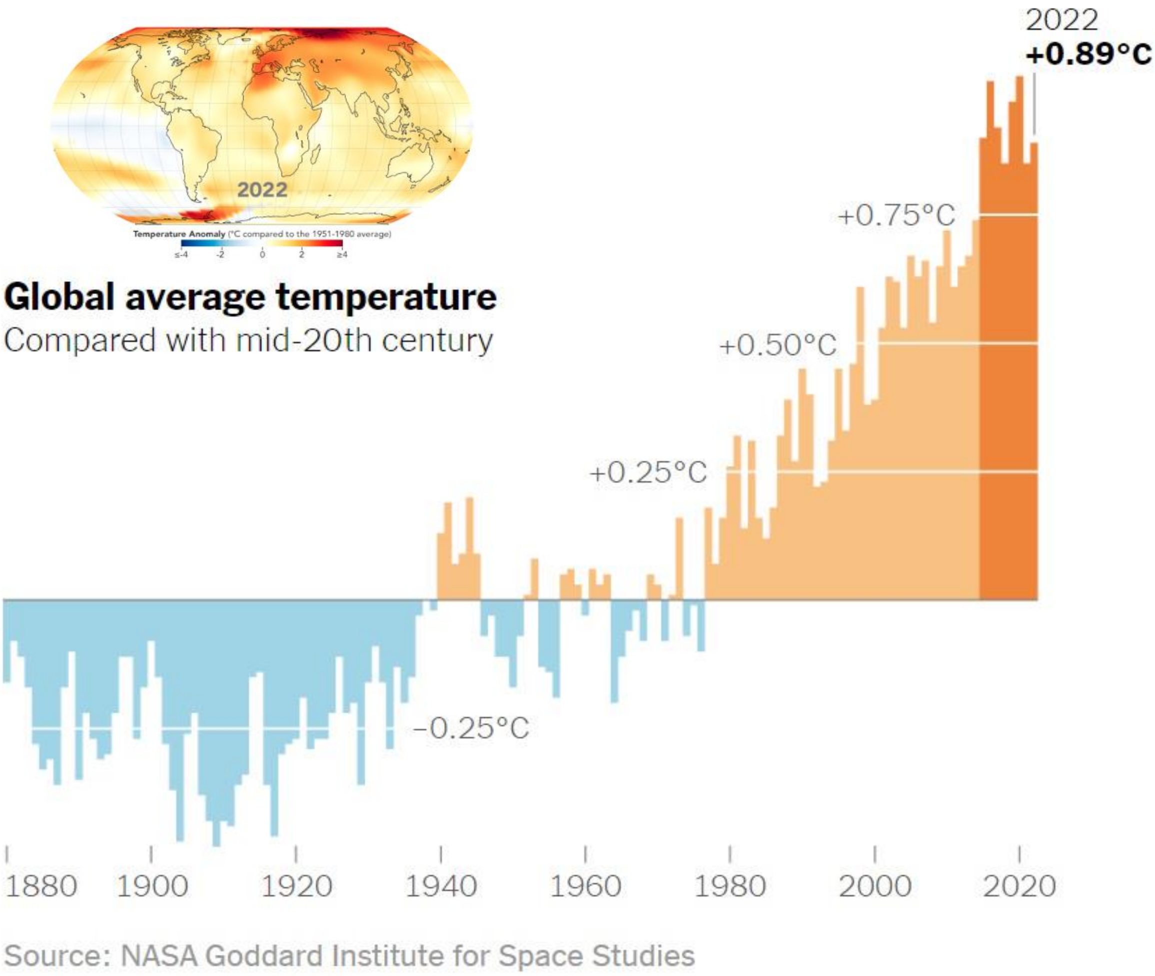
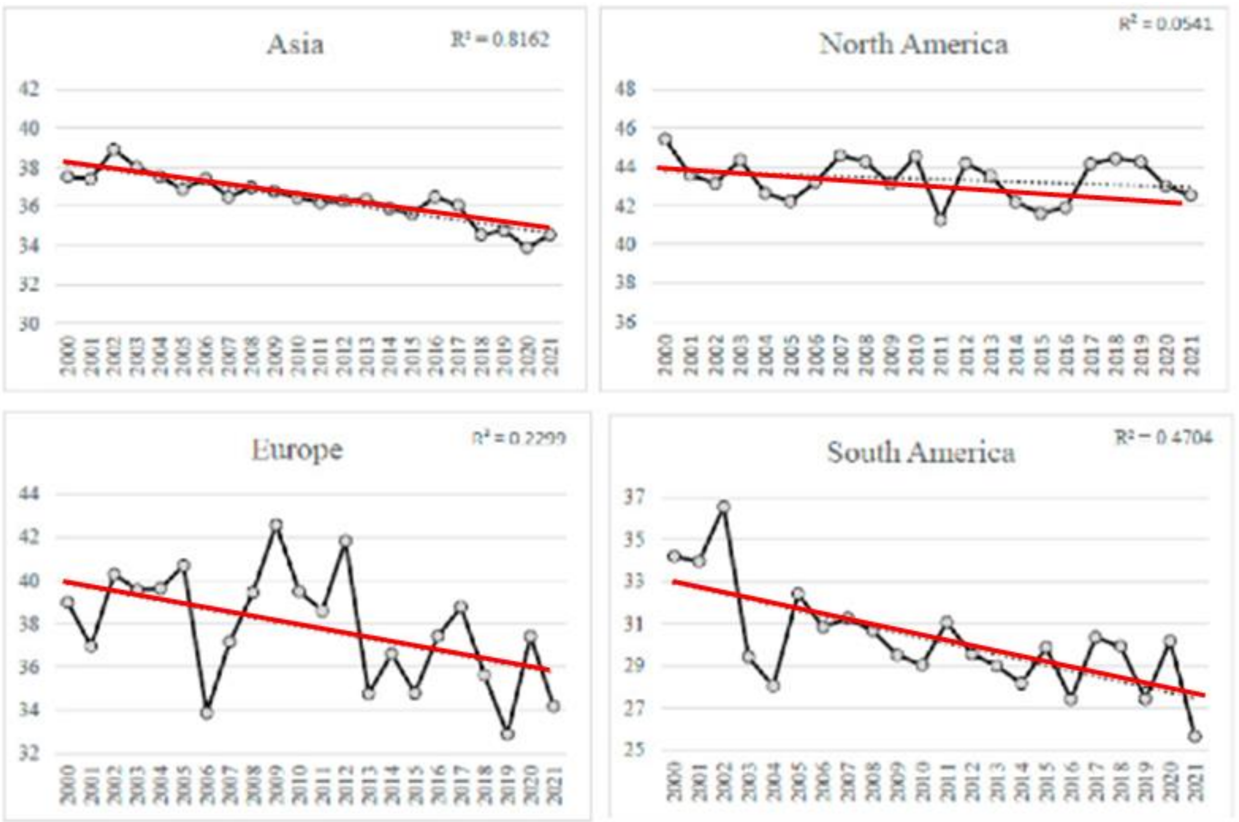
1- why & how

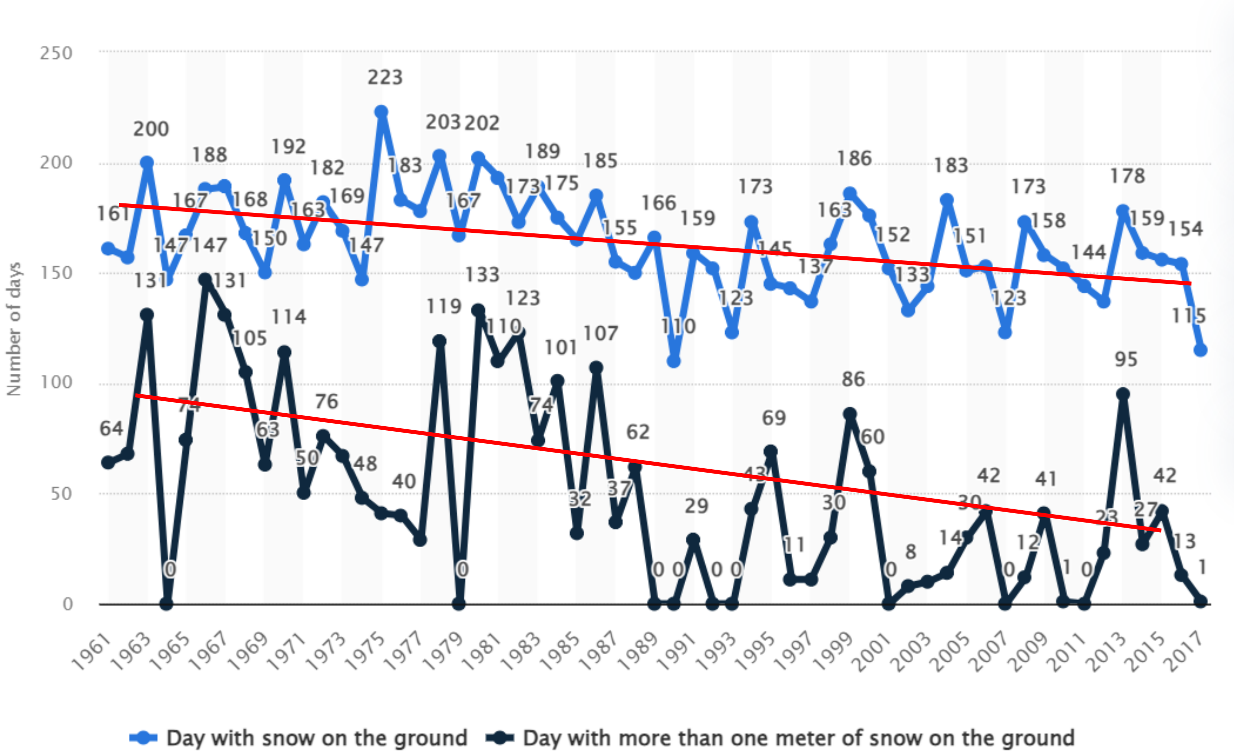
The economy of mountain areas is heavily dependent on tourism and to a large extent on winter tourism related to skiing. In recent decades, the increase in the planet's temperature together with the decrease in the permanence of snow on the ground represent a major challenge for ski resorts worldwide.
This paper analyses the development and optimisation of snowmaking products and systems to improve efficiency and resource management.
The following graph and related map show the changes in the average temperature of the planet compared to the average temperature of the 20th century.



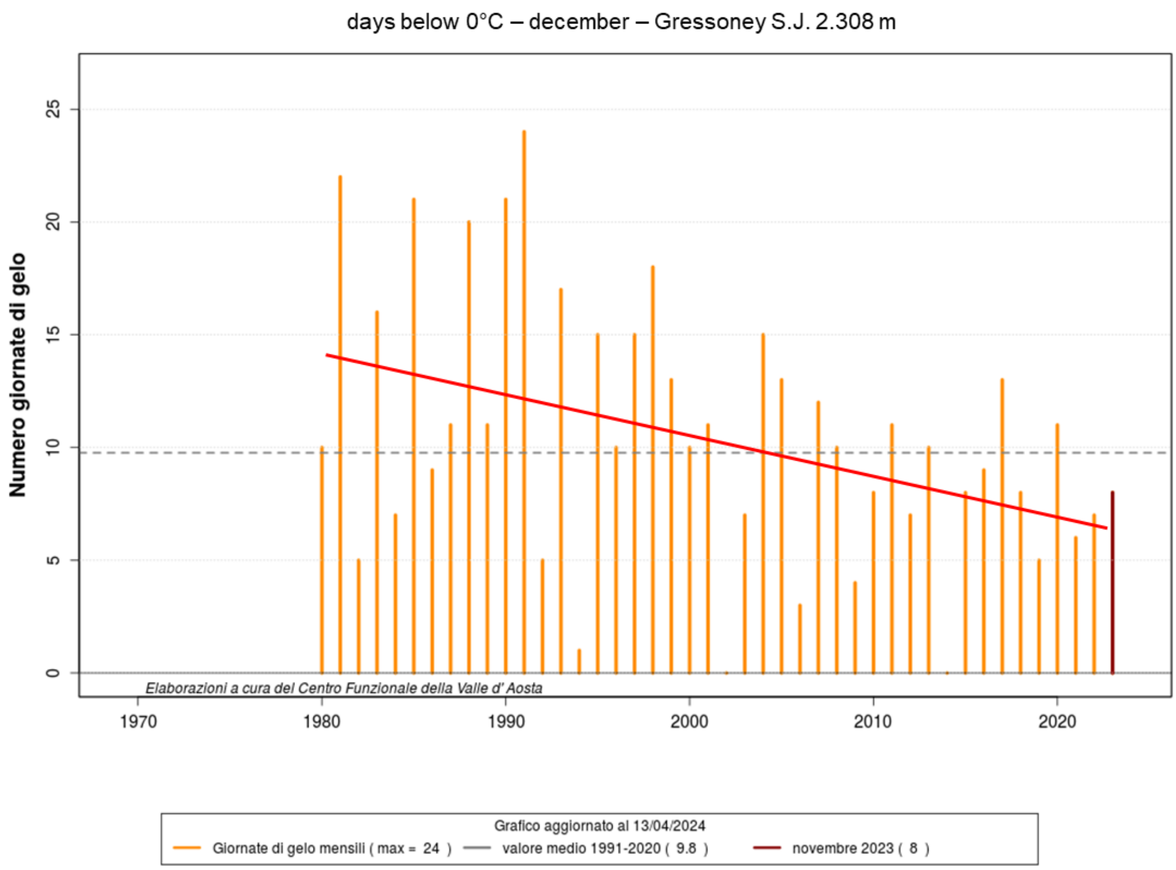
The permanence of snow on the ground is obviously correlated with this change in temperature. The graphs below show the trend in days and extent of snow cover “univariate differencing” which can represent the change in days.



Similarly, for the French Pyrenees, the following figure shows the trend in the number of days with snow on the ground:



It is therefore clear that artificial snowmaking is an indispensable technique for the proper management of ski resorts.
On a local scale, an example in the Western Alps at an altitude of around 2,000 m clearly shows that the amount of natural snow on the ground is also constantly decreasing, as are the days of frost (i.e. with temperatures below 0°C). Therefore, not only is it necessary to produce artificial snow, but it must be done with less time available.



Artificial snow is produced using water and air in the correct environmental conditions of temperature and wind.

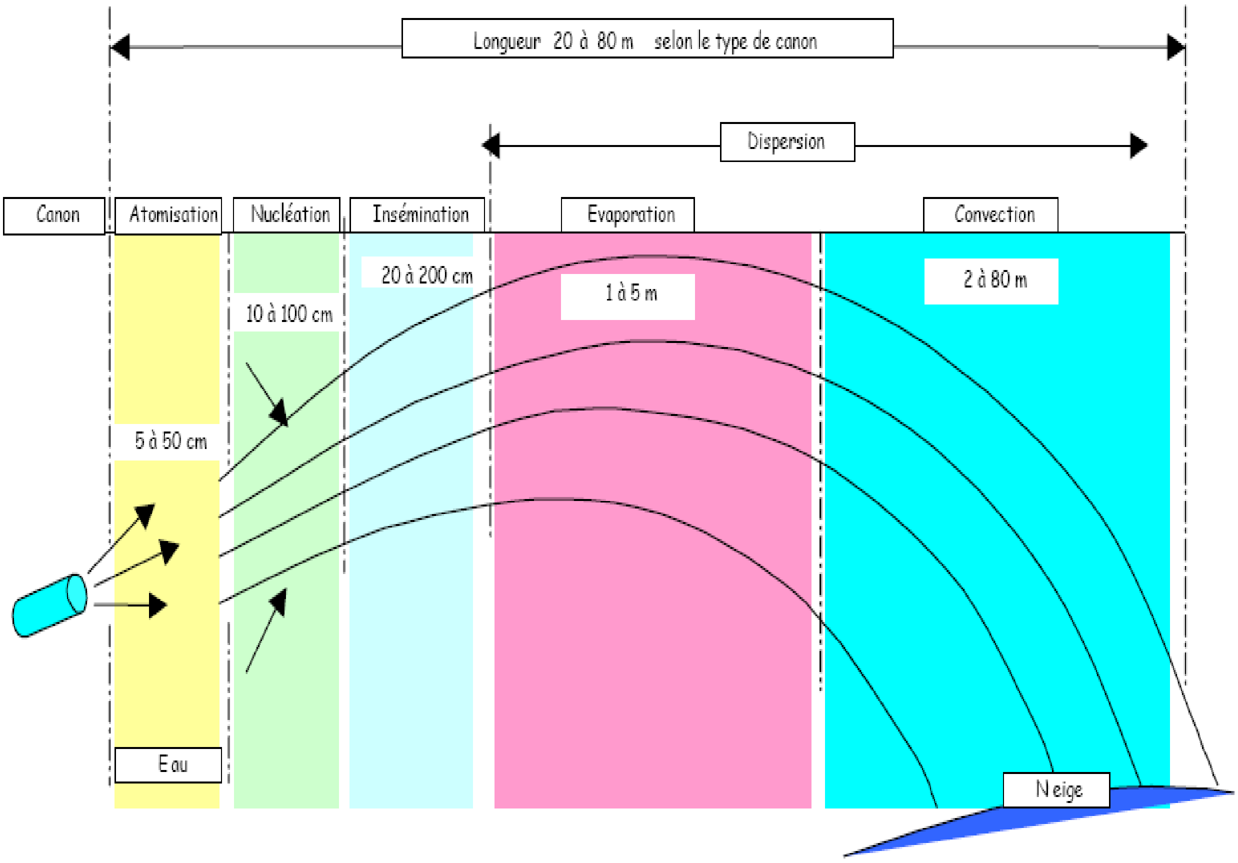
The first step in the transformation of water into snow is the atomisation of the water jet into fine droplets whose size facilitates crystallisation when they are projected into contact with air at a negative temperature. The larger the size of the droplets, the more difficult the freezing is; conversely, the finer the droplets, the quicker the phenomenon, but the control of their dispersion in the environment is more delicate.

Nucleation is the formation of micro-crystals of ice (freezing cores) that serve to initiate the snow-making process. The formation of the freezing cores is achieved through the following steps:

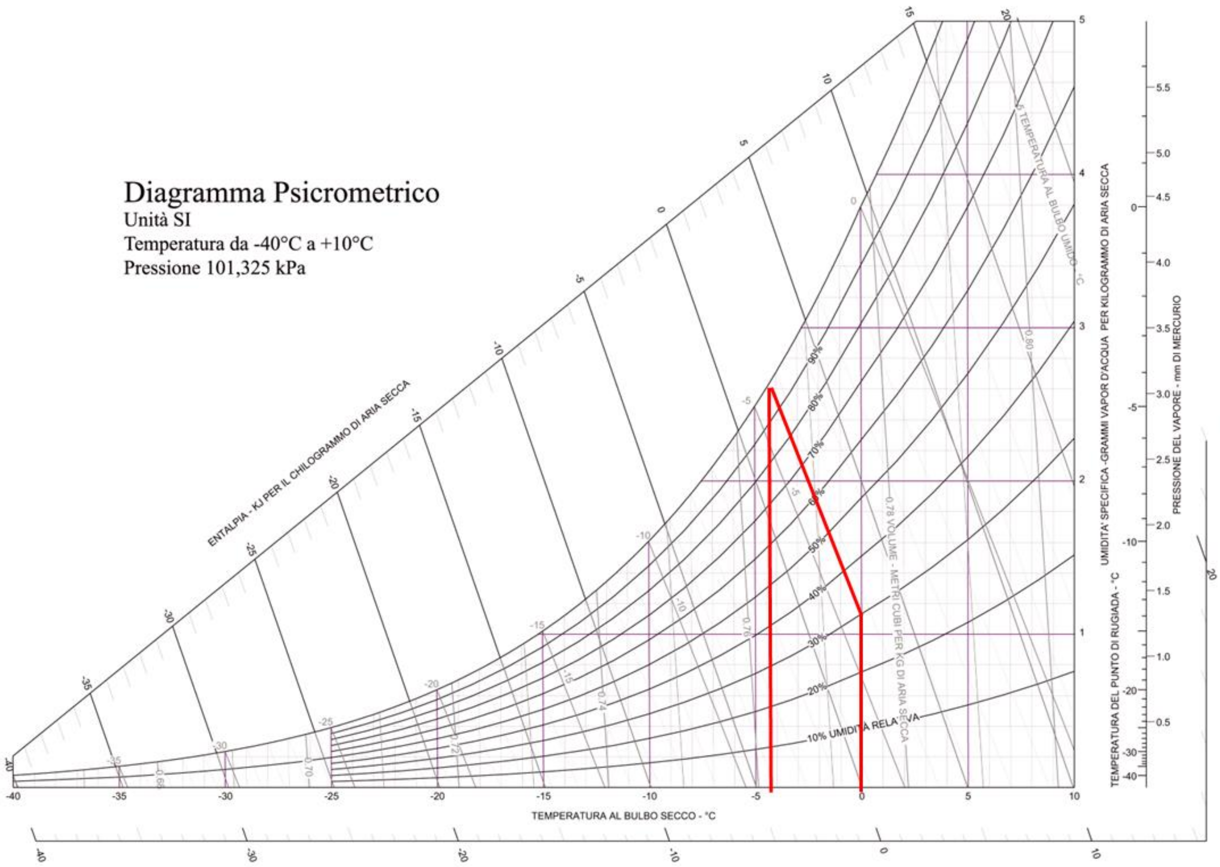
- mixing of air/water under pressure with a strong air component inside the nucleation chamber.
- expulsion and fragmentation of the mixture through a finely calibrated orifice called a nucleator.
- brutal release of air causing strong cooling of the environment as it exits the nucleator. The release of air at 8 bar at atmospheric pressure causes a cooling of about 40°C (measured on site).
- immediate crystallisation of some water particles due to the very low temperatures at the exit of the nucleator and formation of freezing nuclei.

The third step after atomisation and nucleation is the transformation of the water droplets into frozen grains. Insemination is the meeting of the nucleation stream and the atomised main water stream. Pure water does not naturally freeze at 0°C but, as we have seen, at much lower temperatures. Nucleation facilitates the freezing process by breaking the equilibrium state of supercooled water and allowing the freezing threshold to be raised to a humid -2°C at best, depending on the technology used.

The fourth step is the dispersion of water particles in the cold ambient air; the longer the water particles remain in suspension in contact with the cold air, the more likely they are to turn into ice before falling to the ground. Dispersion is necessary to promote evaporation and allow heat exchange between the atomised water and the ambient air.



All these processes require defined environmental conditions in terms of temperature, humidity and wind. The reference temperature for the process described is the wet bulb temperature, which is the temperature to which water is brought under convective exchange equilibrium conditions with a fully developed mass of air in turbulent motion. It is usually measured by a special thermometer covered by a cloth soaked in water. The wet bulb temperature is lower than the dry temperature the lower the humidity of the air (e.g. o°C at 30% humidity corresponds to -4°C wet bulb temperature). Therefore dry air favours the production of artificial snow.



Obviously, wind is also a determining factor for the possibility of snow production in terms of dispersing the snow produced outside the ski-slope or preventing the gun/lance from clogging.

2- history

Planned snow production began in the middle of the last century, but became an industrial process from the 1970s and 1980s with a production process that aimed to supplement natural precipitation and thus required the use of low flow rates.
In the years that followed, the need to fully 'build' slopes with artificial snow from the early part of the winter season soon became apparent, and thus the question of the availability in flow rate and total quantity of the water resource arose.
In recent years, also in connection with the energy crisis and the growing sensitivity to resource management, the focus is on the factors of time, cost and better water management through the increasing use of automation and process data.

3- product & system evolution

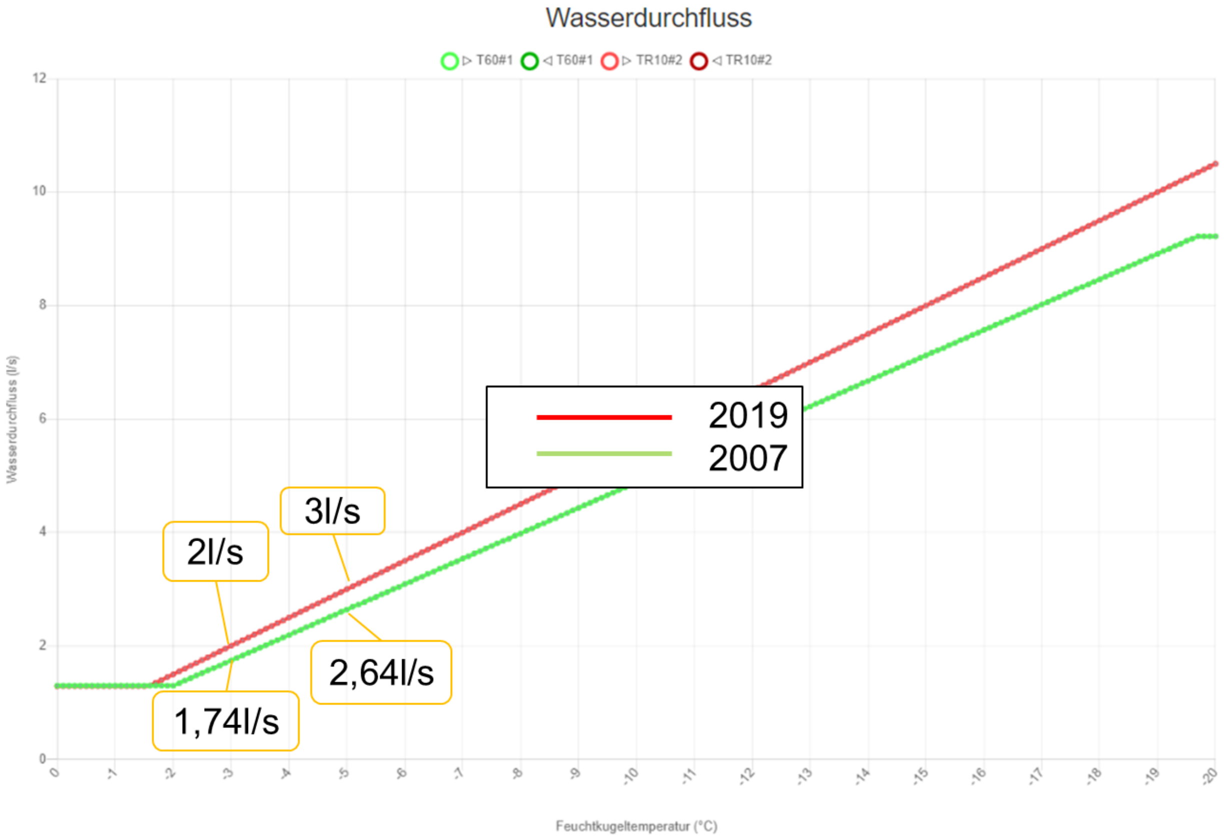
In order to achieve the goals of better time, cost and resource management, improvements have been made both in terms of product and process.
As far as lances are concerned, from the beginning of the 2000s to today, production capacity has been increased by 2.5 times while reducing the use of compressed air by a factor of 6. The reduction in compressed air is particularly interesting when you consider that a 450 kW compressor produces around

3,500 Nm3/h of compressed air, so we have gone from being able to power 11 first-generation lances to being able to power 80 lances with the same air and energy consumption.

	wet temp. [°C]	water flow [m3/h]	water press. [bar]	air flow [Nm3/h]	air / water ratio
B3	-4	5,1	7,4	315,1	61,8
	-9	7,9	8,5	229,3	29,0
B6	-4	6,9	8,7	255,0	37,0
	-9	10,1	9,8	178,0	17,6
R10	-4	5,0	40,0	42,0	8,4
	-9	19,9	40,0	42,0	2,1
TL8	-4	7,6	40,0	49,0	6,5
	-9	19,8	40,0	49,0	2,5

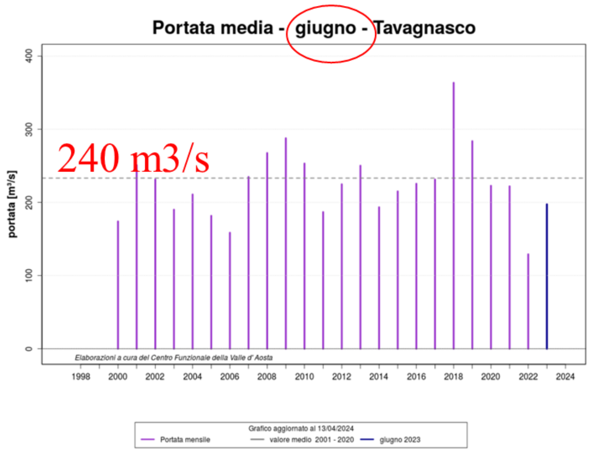
In addition, the improvement in nozzle shape and materials, and the use of a greater number of nozzles, makes it possible to utilise production conditions that were not possible with previous lances.
In the figure below, the areas in which this optimisation is most effective can be identified.

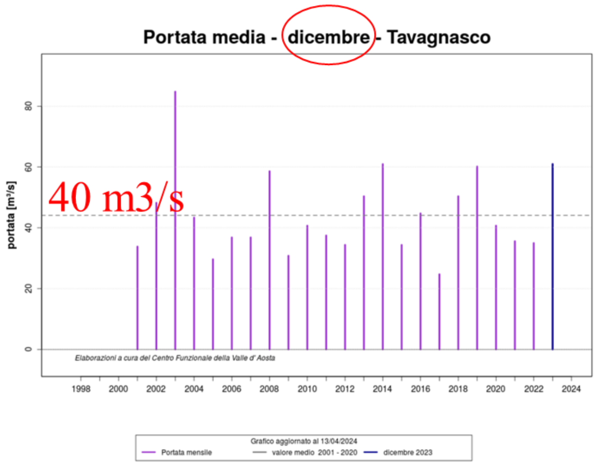
Similarly for fan guns, the improvement in output is evident in the figure below:



Even in the case of fan guns, this improvement relates to the shape and material of the nozzles. In addition, the nozzles can be individually controlled in order to achieve the best possible accuracy in terms of flow rate in relation to environmental conditions.
A further improvement in the production of a fan gun is the possibility of programming its position so that an actuator automatically positions the gun in production in relation to the shape of the ski slope and the prevailing wind.

In terms of process, however, the most significant improvements occur through the management of water, which is the main resource.
The creation of reservoirs at high altitude makes it possible to achieve various objectives in terms of process and environment. The large availability of water makes it possible to increase the instantaneous flow rate of the systems and thus makes it possible to make the most of the environmental conditions for snow production. The location of the reservoir can also give the water potential energy, which is transformed into less pumping energy. From an environmental point of view, the possibility of using stored water in periods when water itself is abundant means that the resource of streams or aquifers is not depleted in the autumn and winter period when the amount of water available is low. With regard to this point, it is interesting to verify the flow rate of the Dora Baltea river, which represents the hydraulic content of an entire region of the Western Alps: the river's flow rate in December is about 40 m3/s compared to 240 m3/s in June: it is evident that from an environmental point of view it is desirable to accumulate the resource when it is most available.





In addition, if the reservoirs are shared with other users (hydroelectricity, agriculture), an environmental benefit can also be achieved in terms of optimising the areas affected by the works.
In the 2019/2020 season, the MonterosaSki ski resort in the western Italian Alps carried out an experiment measuring the costs of snow production and the first grooming of the ski area's slopes (approx. 100 km) without energy costs due to other infrastructures and without grooming costs due to skiing activity as the resort was closed due to the Coronavirus epidemic after preparing the slopes. The results of this experiment are presented in the following table:

	slopes extension [m2]	snow production [m3]	cost [€]									
			energy		personnel		water cost		grooming		TOT	TOT/m3
			cost	incidence	cost	incidence	cost	incidence	cost	incidence		
Frachey	352.000	136.994	151.083,82	1,10	15.390,72	0,11	0,00	0,00	27.286,05	0,20	193.760,59	1,41
				78%		8%		0%		14%		
Crest	209.000	92.900	241.008,27	2,59	13.904,11	0,15	0,00	0,00	22.556,58	0,24	277.468,96	2,99
				87%		5%		0%		8%		
Gressoney	565.600	170.736	139.083,46	1,02	26.494,50	0,19	68.294,10	0,50	30.888,14	0,23	264.760,20	1,55
				53%		10%		26%		12%		

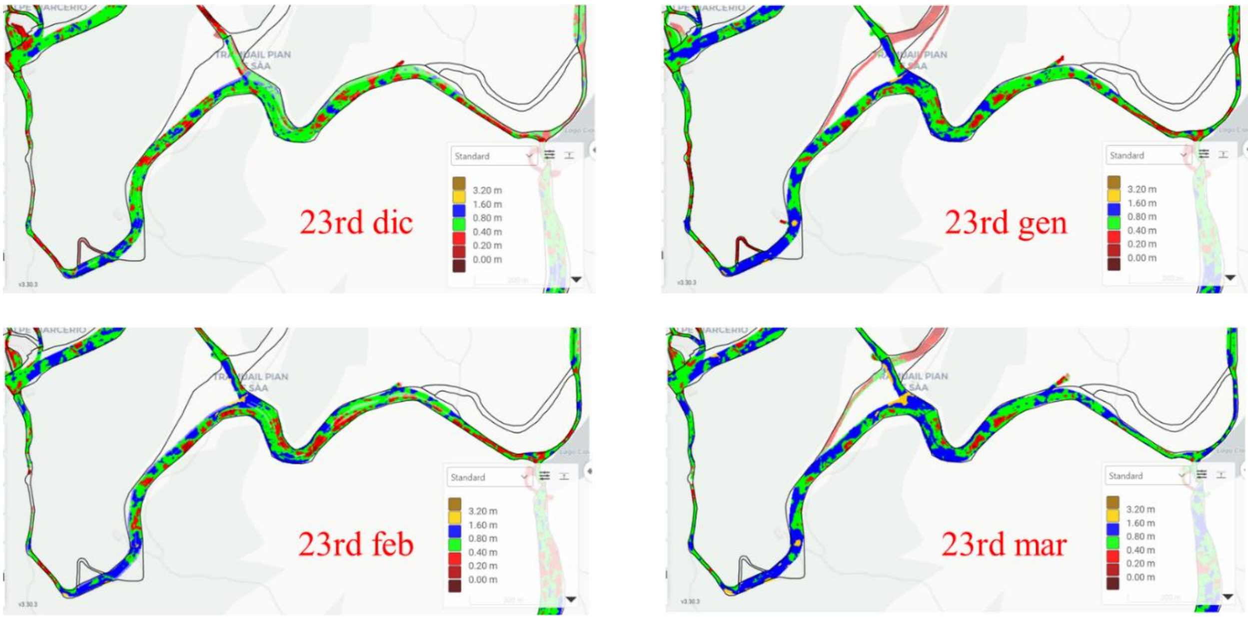
The Crest station draws its water at an altitude of 1,500 m and the upper part of the ski area is at 2,700 m. The Frachey and Gressoney stations draw their water at an altitude of 2,300 m and the upper parts of the ski area are at 2,700 m and 3,000 m. The Gressoney station captures water from a hydroelectric reservoir and therefore foresees an additional cost for non-production of electricity to be paid to the hydroelectric company operating the dam.
In any case, it is clear that the cost of energy is the most important item and that storing water at high altitudes allows significant savings.
Energy efficiency is also achieved through the greater availability of water in terms of instantaneous flow rate, as the higher flow rate makes it possible to make the most of periods of intense cold with higher production and, since the consumption of the cannons is constant, reduce the total energy consumption required.
Modern snowmaking systems operate an average of 300 hours per season. From an energy point of view, this low number of operating hours results in relatively low energy consumption, despite the high energy requirements (e.g. compared to industrial production systems, which generally operate for several thousand hours per year). This short period of time ultimately determines the success of the entire winter season. During snowmaking, the demand for energy is naturally high. This is because as many pumps, compressors and snow guns as possible are in operation at the same time to make the most of the temperature windows. Snowmaking usually takes place at times when energy demand is otherwise low: before the season (when hotels and lifts are not yet in operation) and at night. Beyond these approximately 300 operating hours, the

systems require very little energy. The expansion of the systems to an even shorter snow phase seems paradoxical at first sight. After all, the demand for energy increases in the short term. On closer inspection, however, high-performance systems with as few operating days as possible provide greater efficiency. The reason lies in the fact that snow generators have an almost constant energy consumption, and therefore the overall efficiency is higher at lower temperatures. The aim is therefore to make the best possible use of electrical energy.
Also in terms of process, the introduction of automatic plant management systems and their fine-tuning makes it possible to achieve higher levels of efficiency. Only through automation is it possible to realise ever larger snowmaking systems and the increasingly complex interaction between pumping stations, snow guns and pit valves. Automated systems are able to react perfectly to constant changes in the environment and are therefore much more efficient.

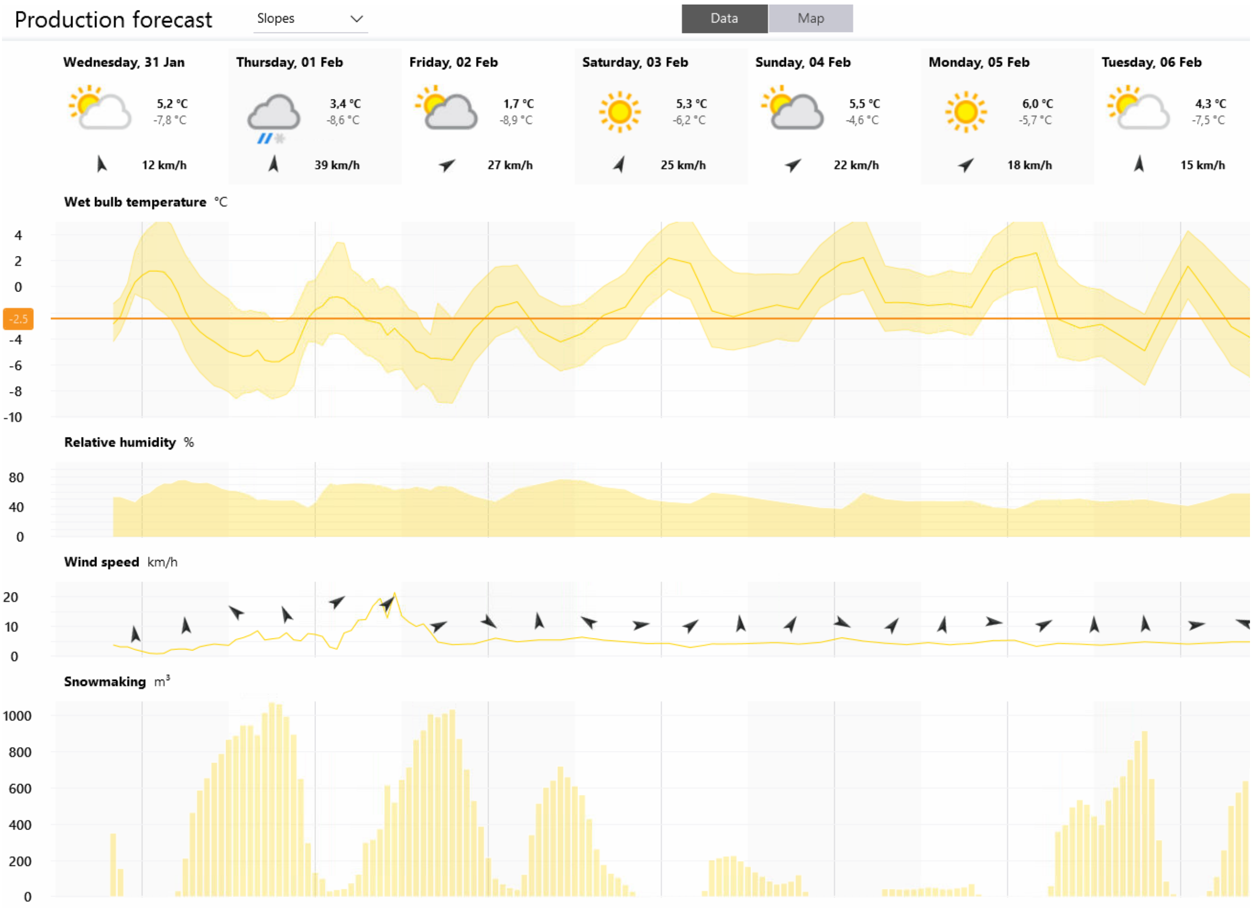
4- data analysis for further optimization

Control and management systems also provide designers and operators with a range of useful data for product and process development and for scheduling and verification of activity.
From the operators' point of view, control and management systems allow the planning and targeting of production per gun by providing targets and alarms when the target is reached. In this way, the system helps the operator to define the operating margins for each individual machine, stimulating a conscious use of the equipment. Targets can be defined both in terms of historical production and in territorial terms by assigning each gun a portion of territory and the equivalent expected snow height, thus determining a "target volume" for each machine.
Furthermore, it is possible to cross-reference the production data with the measurement data of the snow depth on the slope, making it possible on the one hand to validate production and on the other hand to assess the need to continue or not to continue production in certain slope areas or of certain guns.

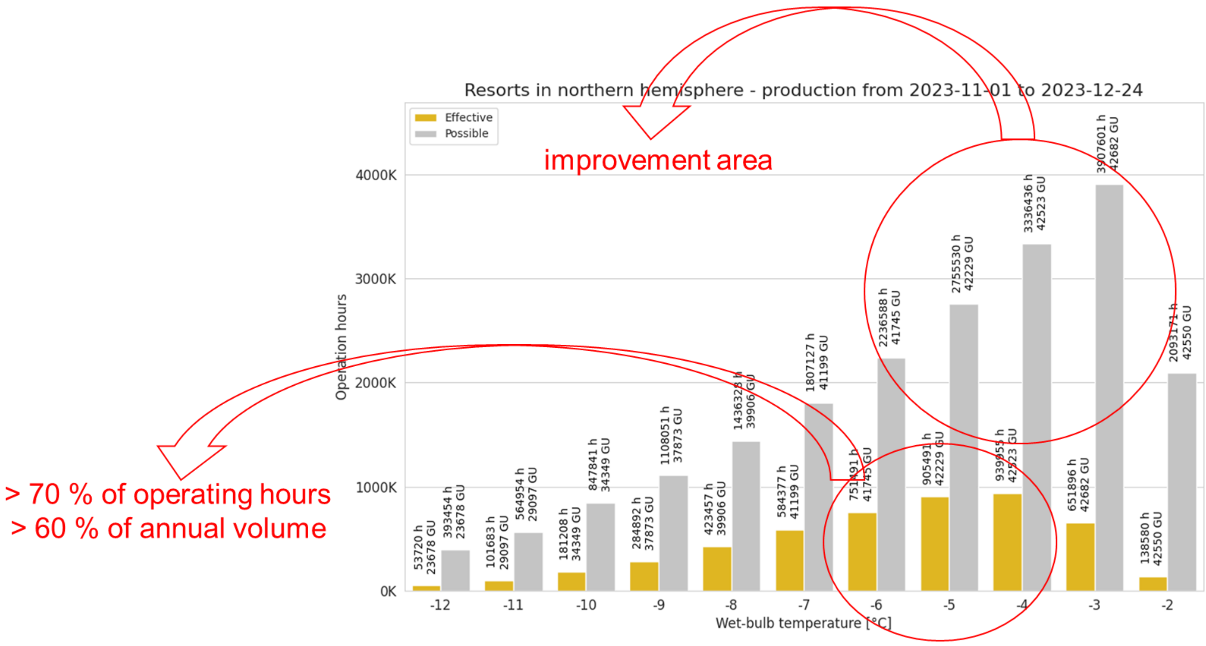
Snow height measurement systems are based on the processing of satellite signals of the position of snow groomers in relation to the digital terrain model and provide snow height maps as output. Being able to track snow depth on the slope also allows the 'consumption' of snow by melting, sublimation, skier transport and wind to be taken into account.



In the example above, the same slope is shown at 1-month intervals. The operator has immediate knowledge of whether the snow situation on the slope is deteriorating (February) and therefore a further snowmaking campaign is required.
Also in terms of data that allow operators to better define operating conditions, it is possible to refer to detailed weather forecasts whose models are based on historical data recorded by the guns. In this way, reference does not have to be made to large-scale forecasts that, especially in mountainous areas, may not represent local conditions.



Operators can thus know local forecasts and decide whether to wait for better environmental conditions to optimise production or to exploit current conditions. In addition, if water is a limited resource, it is possible to limit its use to only the best expected conditions without incurring the fact that reserves are exhausted having been used during periods of poor system efficiency.
From the designers point of view, on the other hand, the large amount of data available with automatic control and management systems allows the identification of areas for product and process improvement. Analysing the actual production possibility and actual production of a large number of stations/guns makes it possible to ascertain which environmental conditions are most present and most used, and thus allows production and design choices to be oriented to make the most of these conditions.



From the figure above, which summarises data from some 40,000 guns operating throughout the northern hemisphere, it is clear that the most commonly used temperatures are 'average' temperatures and not extremely hot or extremely cold, and that great scope for improvement in terms of available hours lies in exploiting 'marginal' temperatures.

5- efficiency in detail

In addition to the efficiency improvements discussed above, it is possible to improve production methods in order to achieve even greater efficiency by analysing the processes themselves in detail.
Most of the energy consumed is in the pumping stations (about 65% of the electrical energy is used for pumping water). Using pumps with variable frequency drives and thus with the possibility of varying the outlet pressure depending on the operating conditions of the system can lead to significant energy savings, as 5 bar of decrease in the outlet pressure of the pumps corresponds to approximately 16% energy savings. The outlet pressure should be set according to the guns furthest away from the pump room and, when the furthest guns have finished production, the outlet pressure can be reduced. Obviously, concentrating the production of the guns furthest away from the pump room during colder periods increases their efficiency and thus decreases the hours of operation with high pressure.
Similarly, reducing the set point and regulation of air compressors allows energy savings of about 7 per cent per bar of reduction in line pressure. With the latest generation of snowmakers, the in-line delivery pressure normally set at 8 bar with Δ 1 bar regulation can be increased to 7 bar with Δ 2 bar regulation.
Also from an energy point of view, the control and management systems allow operators to visualise production energy parameters in relation to the amount of snow produced. In this way it is possible to recognise whether the system is working under optimal conditions or if there is a lack of balance between the pump room set-up and the line set-up (e.g. too many pumps switched on in relation to the number of guns in operation).

Ultimately, technology and enormous availability have enabled huge steps on the road to optimising artificial snow production. For the future, the availability of this enormous amount of data must be matched by a growth in culture and awareness of managers and operators.