



# PROSNOW: a novel climate service enabling real-time optimisation of snow management in mountain ski resorts through weather and seasonal forecasting, in-situ observations and snow cover modelling

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The H2020 PROSNOW project has developed a prediction system for meteorological and snow conditions in ski resorts, spanning the range of weather (days/weeks) to seasonal forecast. The PROSNOW service enables real-time optimisation of grooming and snowmaking in ski resorts, thereby supporting their activities under increasingly challenging operating conditions due to climate change while reducing the related use of resources.



Ski tourism is deeply rooted within the economies, culture and livelihoods of European countries, within and outside mountainous areas. Among several challenges to this mature tourism market, such as the lack of attractiveness of skiing for younger populations, in part due to the high cost of this outdoor activity, climate change impacts and risks are increasingly recognised as a major threat to ski tourism. Indeed, ski tourism relies on snow on ski slopes as its main resource. The natural

snow cover is highly variable from year to year and is undergoing a substantial decline, especially at low elevation, due to rising temperature. In order to reduce the impact of the variability and reduction of the natural snow cover, and secure its operating conditions, the ski tourism industry has massively developed technical snowmaking, a.k.a. artificial snow. Artificial snow is usually produced early during the winter season (typically, in November and December), in order to provide a base

layer required to fully exploit early natural snowfall and ensure, as often as possible, satisfying snow conditions for the critical season start, especially the Christmas holiday period, and then secure the rest of the winter season.

Snowmaking bears a significant cost among ski resorts operating cost, hence optimising its use has a direct economic benefit (Figure 1). Furthermore, it requires the implementation of dedicated infrastructures, and its operations use

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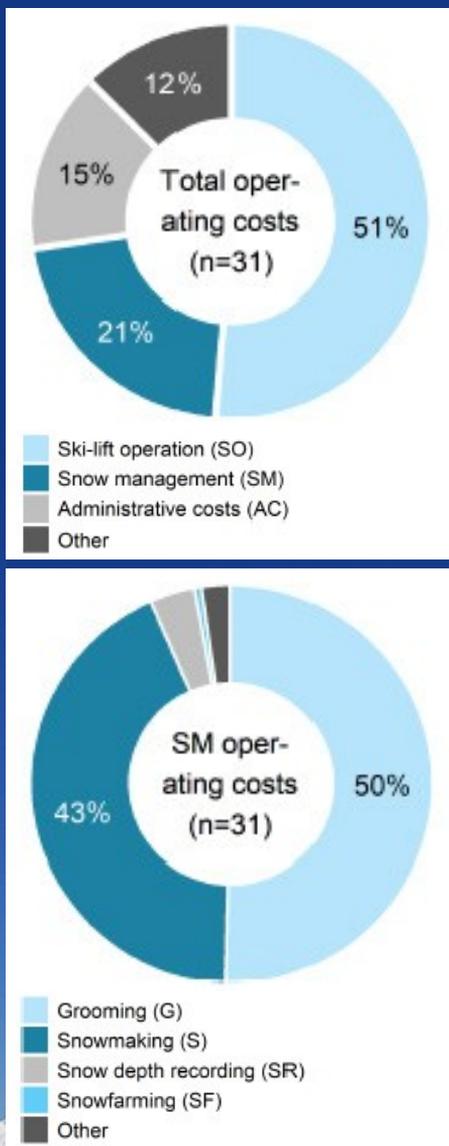


Figure 1: Positioning of snow management within ski resorts operating costs (left) and unpacking of snow management cost elements (right) (based on a survey of 44 respondents across the European Alps).

environmental resources such as water and energy. Resource management can be critical to preserving the snow production capacity in case there would not be enough snow later in the season (and thus avoid potential loss of income). Furthermore, the use of natural resources impacts the local landscape, ecosystems and water cycle, and contribute to the broader environmental footprint of human activities at all spatial scales. Ski tourism therefore, faces climate-related challenges at various interconnected time scales: how to efficiently adapt to ongoing climate change, now and in the future, using effective methods to cope with variable and declining snow cover, without committing to detrimental effects to the local and global environment in the long term? Several studies have documented the long

term impacts and risks of various climate change scenarios on snow reliability in ski resorts in various mountain areas, with and without accounting for snow management (grooming and snowmaking) (IPCC, 2019). Recently, the Copernicus Climate Change Service (C3S) has released a dataset of Mountain Tourism Meteorological and Snow Indicators (MTMSI), which provides a pan-European synthesis of the impact of climate change on snow reliability in mountainous regions of Europe (<https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-tourism-snow-indicators>).

Complementary to long term climate change impact studies, which can be used to inform deliberation and decision making regarding the long term planning of ski tourism development or transition to other forms of tourism activities, the development of early warning systems is recognised to enhance the adaptation capacity of socio-economic sectors under current and future climate conditions (IPCC, 2019). In this context, the initial motivation of the PROSNOW project was to contribute to developing early-warning systems to better cope with the impact of the variability of meteorological and snow conditions on ski resorts operating conditions and better adapt to increasingly challenging conditions in the future. One key requirement for early-warning systems is the provision of impact-based forecasts, at relevant time scales, designed to adapt operations, in real time, to expected upcoming conditions, in order to reduce their potential negative impacts or benefit from upcoming opportunities. Given the main characteristics of the ski tourism, business—in particular, snow production in early winter, potentially annihilated by warm spells—anticipating meteorological and snow conditions at time scales from days to weeks to months is the relevant time scale to optimise snow management in mountain ski resorts.

## The PROSNOW concept and tools

The core concept of PROSNOW has been to focus on the snow cover on ski slopes, in the most integrative possible way. Indeed, ski resort managers are used to rely on weather forecasts, and intellectually combine this information with observations of the snow cover within the ski resort, taking into account their knowledge about snow processes. Snow cover modelling,

i.e. the direct simulation of the state of the snow cover based on past and/or future meteorological conditions, has not been used for real-time ski resorts management hitherto, and this is the main gap that the PROSNOW project has contributed bridging. Indeed, one of the main benefits of numerical models is their capacity to integrate various sources of information and provide quantitative predictions beyond what the human mind can intuitively infer.

The PROSNOW project brought together 13 academic and industrial partners operating in the field of the mountain snow cover in more or less direct relationship with ski tourism, but with different perspectives on how to approach this medium. Numerical snow cover models simulate the evolution of the snow cover, based on the time evolution of meteorological conditions (temperature, precipitation, wind speed, incoming radiation, etc.). PROSNOW has enabled further development of such models to account for grooming and snowmaking in a physically sound and operationally meaningful manner (Hanzer *et al.*, 2020). This was developed thanks to the interactions between the diversity of partners involved in PROSNOW. Such models need to be fed by meteorological information, and the PROSNOW project has consolidated methods for feeding such snow cover models using not only past observations but also forecasts across weather (days to weeks) to seasonal (weeks to months) time scales. Because of the various sources of uncertainty involved, so-called ‘ensemble forecasting’ was implemented, which provides a range of meteorological scenarios at various lead times, based on the output of numerical weather models, based on which probability ranges for the upcoming conditions can be inferred. The PROSNOW system developed during the project (see Figure 2) combines an ensemble of meteorological and seasonal forecasts with an ensemble of model configurations, enabling to quantify the impact of various snow management tactics (e.g. various snow productions approaches, including no production), and therefore provide objective information to guide decision making in real time (see Figure 3).

Based on a detailed representation of the geographical organisation of the ski resort, the system makes it possible to identify the subsectors of the ski resorts with most challenging snow conditions and provide a forecast of water consumption for snowmaking associated with each option.

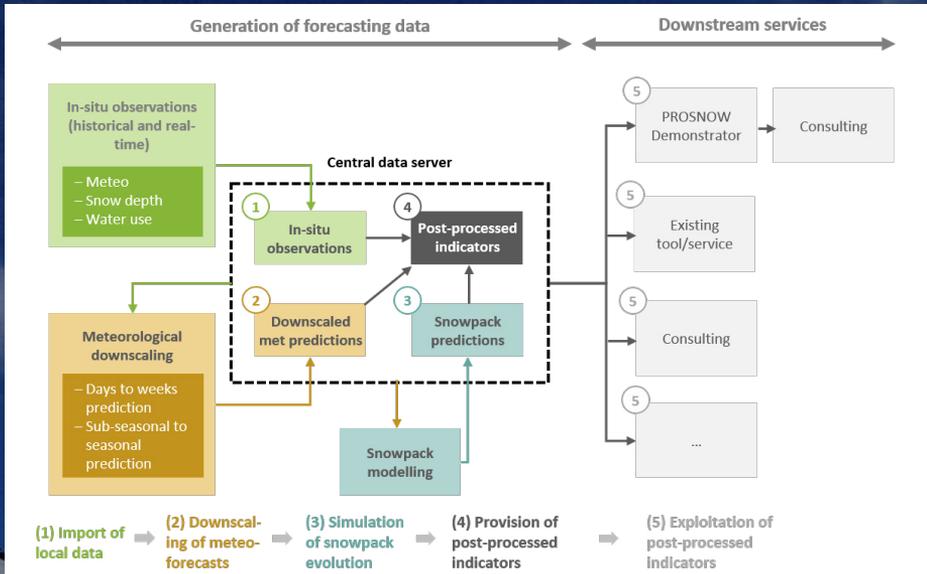


Figure 2: PROSNOW service supply chain.

Thanks to snow cover modelling, the system makes it possible to provide outputs directly in the form of snow cover height or snow mass, which can be displayed on a ski resort map and compared to in situ measurements (Figure 3). In fact, in situ measurements of snow depth (using sensors embarked on grooming machines) or snow production can be used, in the PROSNOW system, to adjust the simulations and enhance the realism of the results, thereby fostering adoption and uptake by the users. Functional choices relevant to the development of the main configurations handled by the system and the design of the user-facing tool were developed thanks to a co-design approach involving pilot ski resorts. These specifications were confirmed by a wider-ranging survey across ski resorts in the European Alps, which further indicated the strong desire by the ski tourism industry to better manage its resources and a widely-shared opinion that better and more customised forecasts could indeed save resources and optimise their use.

### Main results and perspectives

Thanks to the strong involvement of all PROSNOW partners, the project delivered its expected results, i.e. a fully operational modelling and data visualisation system tailored to the needs of ski resorts managers. The PROSNOW project has developed a dedicated advanced programming interface (API) for exchanging snow-related information between ski industry service providers and stakeholders, thereby enabling an acceleration of data sharing in this sector. All software dedicated to operating the PROSNOW data server and user-facing tool has been deposited on a code repository, with access restricted to project partners until August 2023, after which the software will be openly available. This will enable additional stakeholders in this field to benefit from PROSNOW results, without endangering the commercial exploitation of the service by the organisations which have invested time and energy in its development. PROSNOW has also delivered improvements of existing open-source software elements, with immediate benefits to their community of users (e.g. snow cover models, or tools for the post-processing of seasonal forecasts). Scientific results from the PROSNOW project have been published in open access journals, with several publications still under preparation.

During winter 2019–2020 (the last winter of the project), pilot ski resorts were even able to test in real time the user-facing

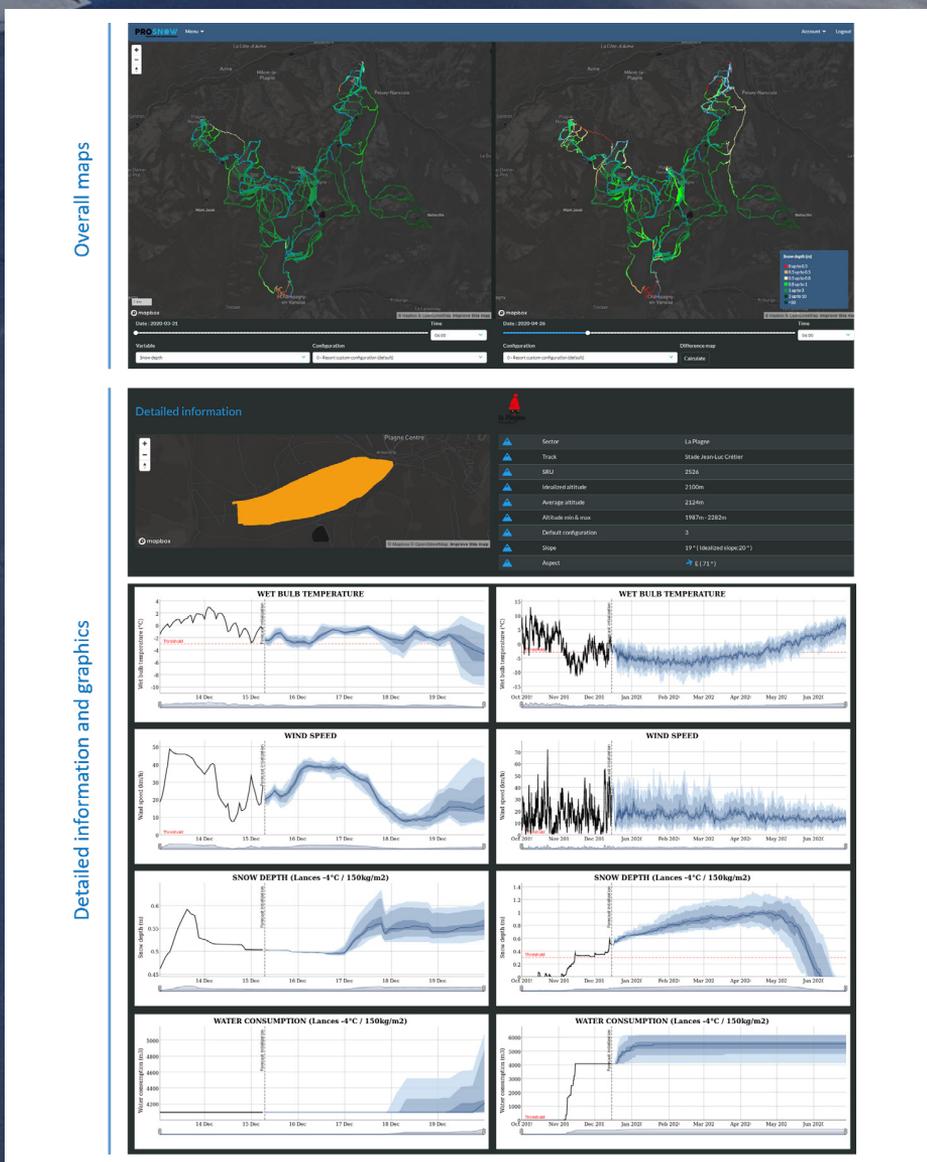


Figure 3: Snapshots of the PROSNOW user-facing tool showing, from top to bottom, the geographical representation of a ski resort in the PROSNOW user-facing tool, the information about dedicated subsectors, and graphs showing the past (observed) and future (predicted) evolution of meteorological and snow cover information, including water consumption.

Respondents' experienced or imagined usefulness of PROSNOW for different application areas (n=8)

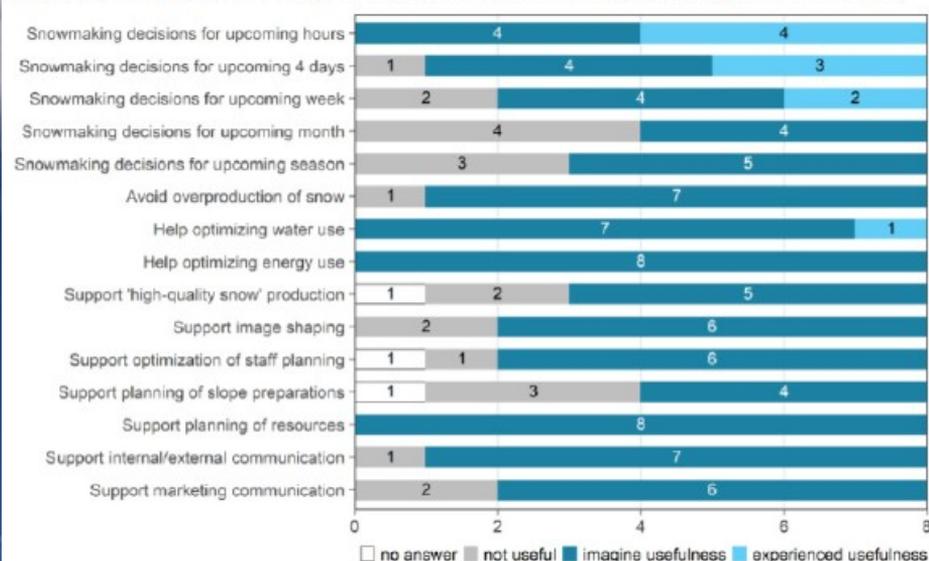


Figure 4: Feedback from pilot ski resorts after one winter of testing of the PROSNOW service. The responses confirm the potential of the PROSNOW service to address a wide range of issues related to snow management in ski resorts.

tool from PROSNOW and assess its added value for their daily operations. Based on their feedback, and a complementary analysis, potential water savings, which would arise from better optimisation of the use of this resource, amount between 10 to 40 per cent of the total annual water consumption within a given ski resort, corresponding to hundreds to millions of euros per year, depending on the size of the ski resorts. Such figures are yet to be confirmed by several years of operations of the PROSNOW service, in a way that leads to in-depth modifications of the workflow of ski resorts managers and their internal organisation. Nevertheless, such figures and generally positive feedback from the pilot ski resorts and industry experts exposed to the PROSNOW user-facing tool (online showcase available here: <https://prosnow.org/get-to-know-prosnow/>), confirm the relevance of the initial vision of an early-warning system fostering the adaptation potential of ski resorts (Figure 4).

Along with the completion of the H2020 PROSNOW project in August 2020, work is in order to bring this service to the market. This is currently taking place in the form of various exploitation entities, consisting of one or several partners of the PROSNOW project, pooling resources and ambition in order to commercialise the PROSNOW service in various markets. For example, one exploitation entity targets the French Alps and Pyrenees market (including Andorra and Spain), while other exploitation entities target the Northern Italy and Swiss markets, and Austria. Time will tell whether, despite the high potential demonstrated by this tool, and the encouraging business model analysis performed by the project, its

commercial exploitation will be successful, especially in the context of the COVID-19 pandemic. Regardless of the materialisation of this commercial success, this project will serve as an example of a genuine innovation action, targeting a critical sectoral need based on state-of-the-art scientific tools, in order to develop cutting edge tools beyond the state-of-the-art. PROSNOW has also served a potent vehicle to raise awareness about climate change impacts to the ski tourism sector, in a very concrete way, therefore generating generally stronger interest from relevant parties than when only long-term climate change impact scenarios are used. Such results could inform the development of other initiatives in neighbouring domains, not only because of the re-use of scientific knowledge and tools developed through PROSNOW, but also because of the lessons learnt about co-design of climate services through this project.

## References

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## PROJECT SUMMARY

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## PROJECT LEAD PROFILE

**Samuel Morin** is a research scientist in the field of pure and applied snow science, working since 2009 at the Snow Research Center (Météo-France – CNRS, Grenoble, France) on observations and modelling of the mountain snow cover across weather to climate time scales. Lead Author for the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC, 2019).

## PROJECT PARTNERS

Coordinated by Météo-France, the PROSNOW project brought together academic (WSL-SLF Davos, INRAE, University of Innsbruck, BOKU Vienna, Joanneum Research, EURAC) and industrial (Ramboll, Alpsolut, TechnoAlpin, CGX, Dianeige and SnowSat) partners in Austria, Italy, Switzerland and France. It involved nine pilot ski resorts from the European Alps in the co-design and evaluation of the PROSNOW service at all development steps.

## CONTACT DETAILS

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