

ADDRESSING THE NEEDS OF MOUNTAIN AREAS: MULTI-SOURCE DATA USE FOR RESOURCE-SAVING AND EFFICIENT SNOWMAKING IN A CHANGING CLIMATE A CASE STUDY FROM GASTEIN, SALZBURG, AUSTRIA

Andrea Mayer^{1*}, Maximilian Mündler¹, and Stefan Etzer²

¹ PowerGIS for you Geografische Informationssysteme GmbH, ARENA Slopemanagement, Salzburg, Austria

² Gasteiner Bergbahnen AG, Salzburg, Austria

ABSTRACT: Ski resorts in Austria and worldwide are facing significant challenges due to climate change, including rising temperatures, changing precipitation patterns, increased unpredictability, and rising energy and water costs. Winter tourism is an important part of Austria's economy, making artificial snow production indispensable for the sector's planning security. ARENA is conducting a project on slope management with the Gastein ski resort to address these challenges. The project focuses on efficient slope management and the reduction of energy and water consumption by analyzing multi-source data, for example, digital terrain data from drone flights, GPS-based snow depth measurements obtained by snow groomers, and natural snow depth data from the SNOWGRID model by GeoSphere Austria. Over the past three years, this project has enabled the resort to reduce its water and energy consumption by 18%, providing better planning security despite the impacts of climate change. The paper will give insights into the procedure of slope management projects, how different data sources are used and integrated, and presents learnings from the 3-year case study in Gastein Valley, Salzburg, Austria.

KEYWORDS: slope management, snowmaking, climate change, geo data, GIS, ski resorts.

1. INTRODUCTION

Ski resorts in the Alps and worldwide are under pressure from climate change. Rising temperatures, changing precipitation patterns, and increasing variability in predictions are challenges that they are facing (Olefs et al., 2020). With the Covid crisis and the war in the Ukraine, energy costs rose in Austria by more than 50% (Statistik Austria, 2024).

In Austria, winter tourism is an indispensable factor in the country's economy accounting for 6.1% of GDP. Skiing is a touristic product that should be as predictable as possible so that the associated winter sports industry also has planning security (Wirtschaftskammer Österreich, 2023).

To achieve this, ski resorts work with artificial snowmaking; without, skiing as it is currently practiced in Austria would not be possible. However, artificial snowmaking is also struggling with the changing framework conditions due to climate change. Energy consumption in snowmaking is high, the average costs amount to around 20 percent of a ski resort's turnover. At the same time, ski resorts need to function as an economic company while not only adapting to climate change but also protecting the climate so as not to exacerbate climate change effects.

ARENA carried out a slope management project in Gastein Valley, Salzburg, Austria to support the ski resort in exactly this challenge. The basis of this project is a time series of snow depth measurement data over 15 years. Results show that it is possible to save up to 25% percent of the resources needed for artificial snowmaking.

2. METHODS AND DATA

This project helps the ski resort reduce its resource consumption and generate planning security based on various GIS-based data sources:

- GPS-based models of the existing snow depth generated by the operating groomer machines (Figure 2 and Figure 3),
- High-resolution terrain model data from drone flights (Figure 1) and
- Natural snow depth data generated from the SNOWGRID model by Geosphere Austria (Figure 4).

* Corresponding author address:

Andrea Mayer, ARENA Slopemanagement,
Bayernstraße 45, A-5071 Wals-Siezenheim, Austria;
tel: +43 677 62324079;
email: andrea.mayer@powergis.at

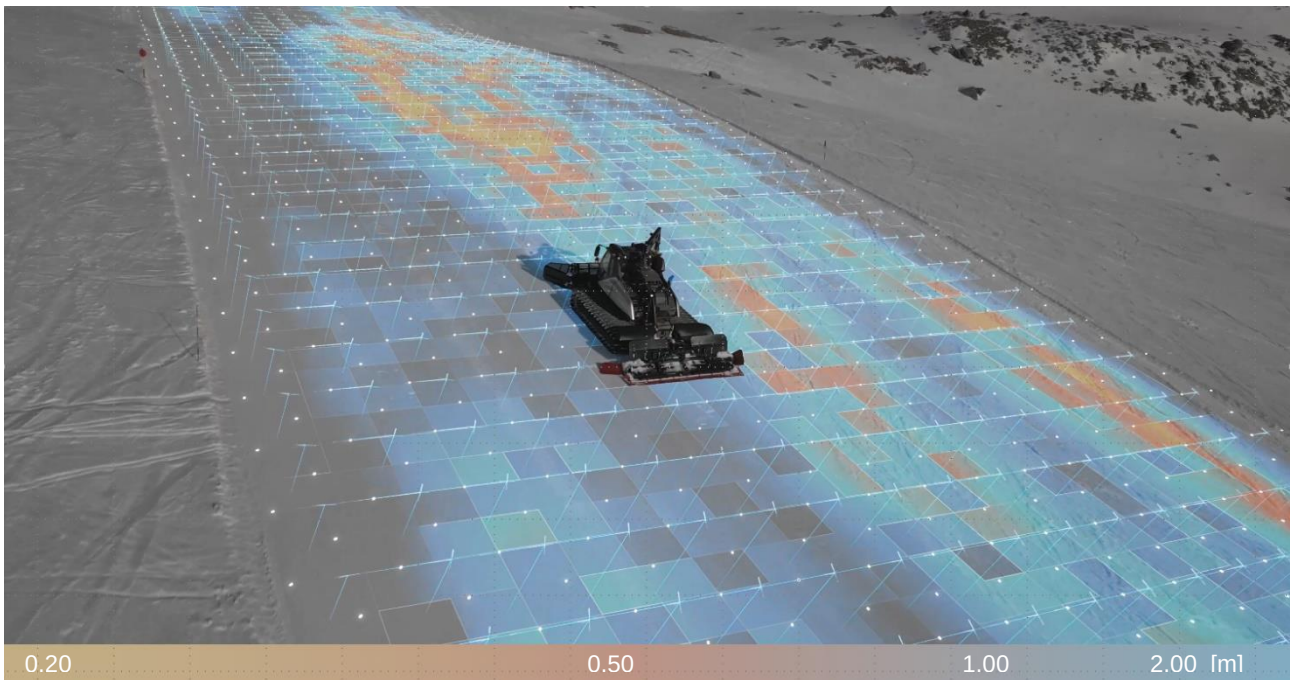


Figure 2: Visualization of measured snow depths by the groomer machines. Color ranges from yellow and orange, indicating low snow depth values to dark blue, indicating large snow depths (color range: 0,10 – 2,00 m). (Visualization: ARENA Slopemanagement).

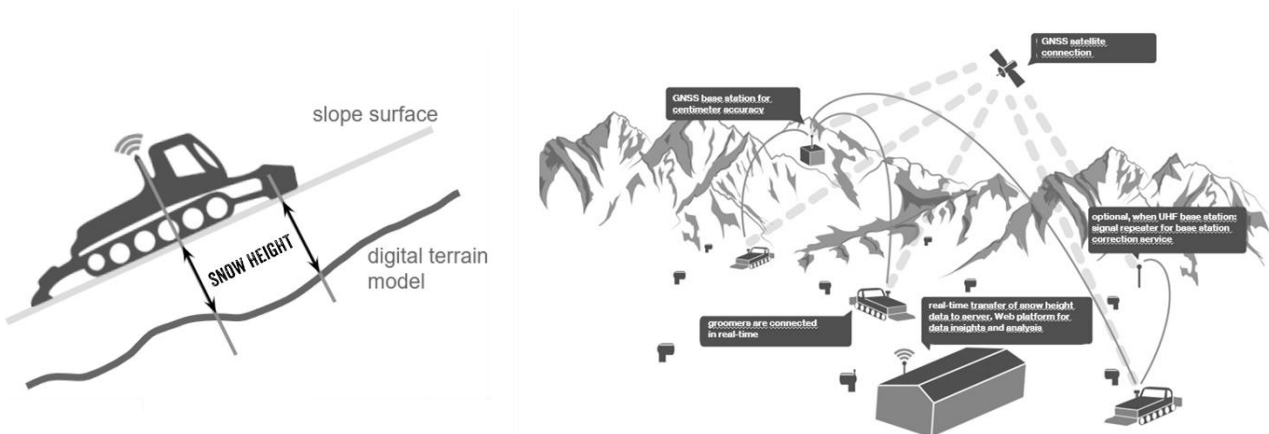


Figure 3: Snow depth measurement in the ski resort. The position of the machine is processed together with high-resolution terrain data resulting in snow depth data with an accuracy of 0,1m. Data is sent and processed real-time. (Graphic: ARENA Slopemanagement 2024).

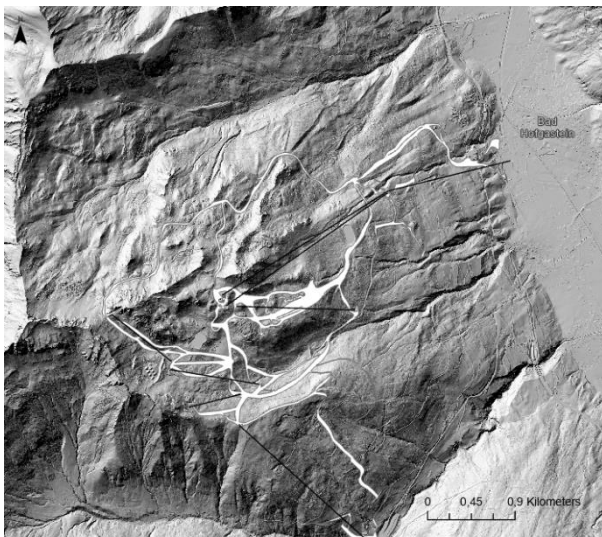


Figure 1: Hillshade, based on a digital terrain model in 0,25m resolution, overlaid with the lifts and slopes of the ski resort Gastein Schloßalm. (ARENA Slopemanagement 2024).

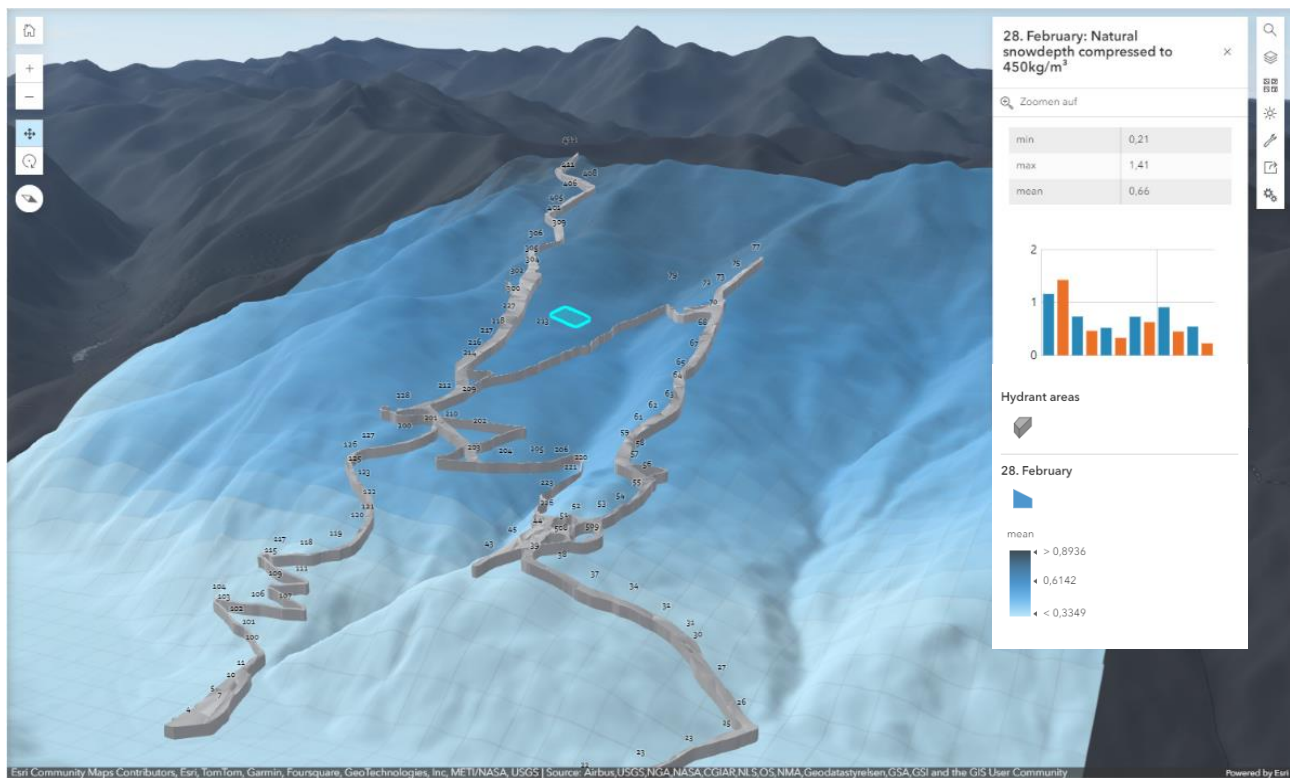


Figure 4: SNOWGRID model data, natural snow depth values compressed to slope density in blue shades as a base layer, slope network of the ski resort on top. The panel on the right shows the mean snow depth over the last 12 seasons for the selected grid cell on the 28th February. (Database SNOWGRID model Geosphere Austria, graphic representation ARENA Slopemanagement 2024).

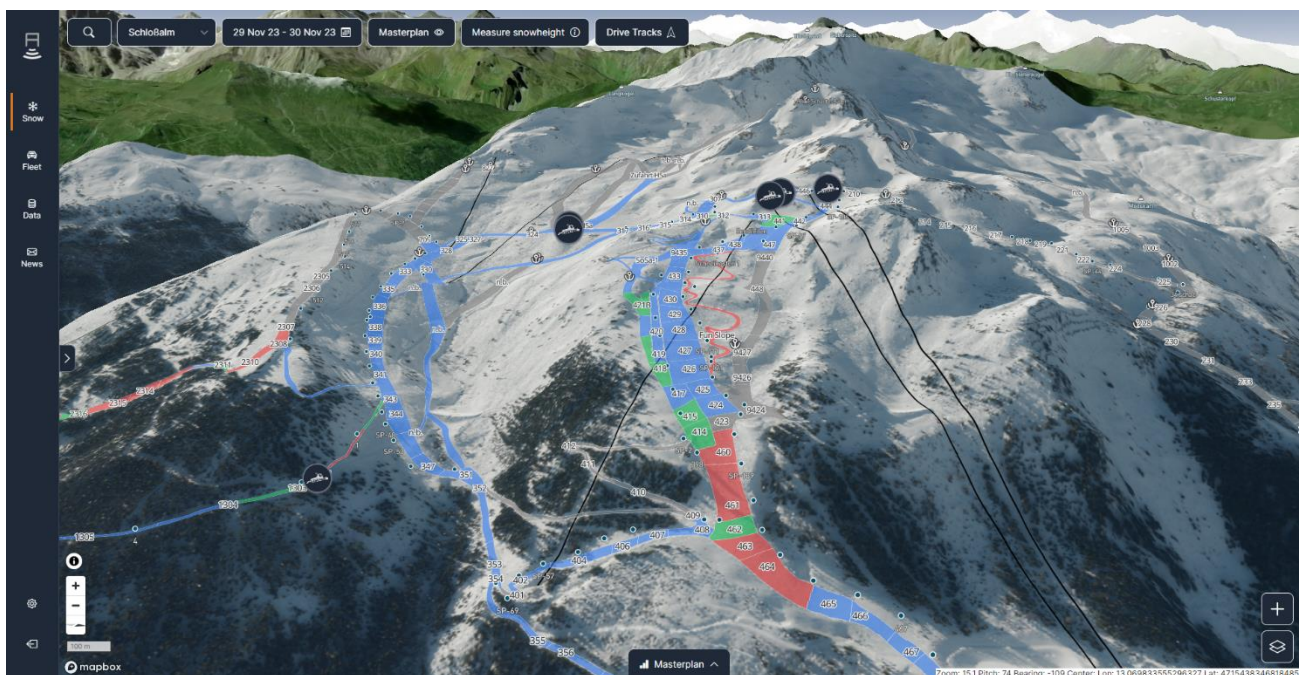


Figure 5: Masterplan of a part of the ski resort Gastein. Blue and green hydrant areas already reached the target snow depth values, and red sections are still below the limit. (ARENA Slopemanagement 2024).

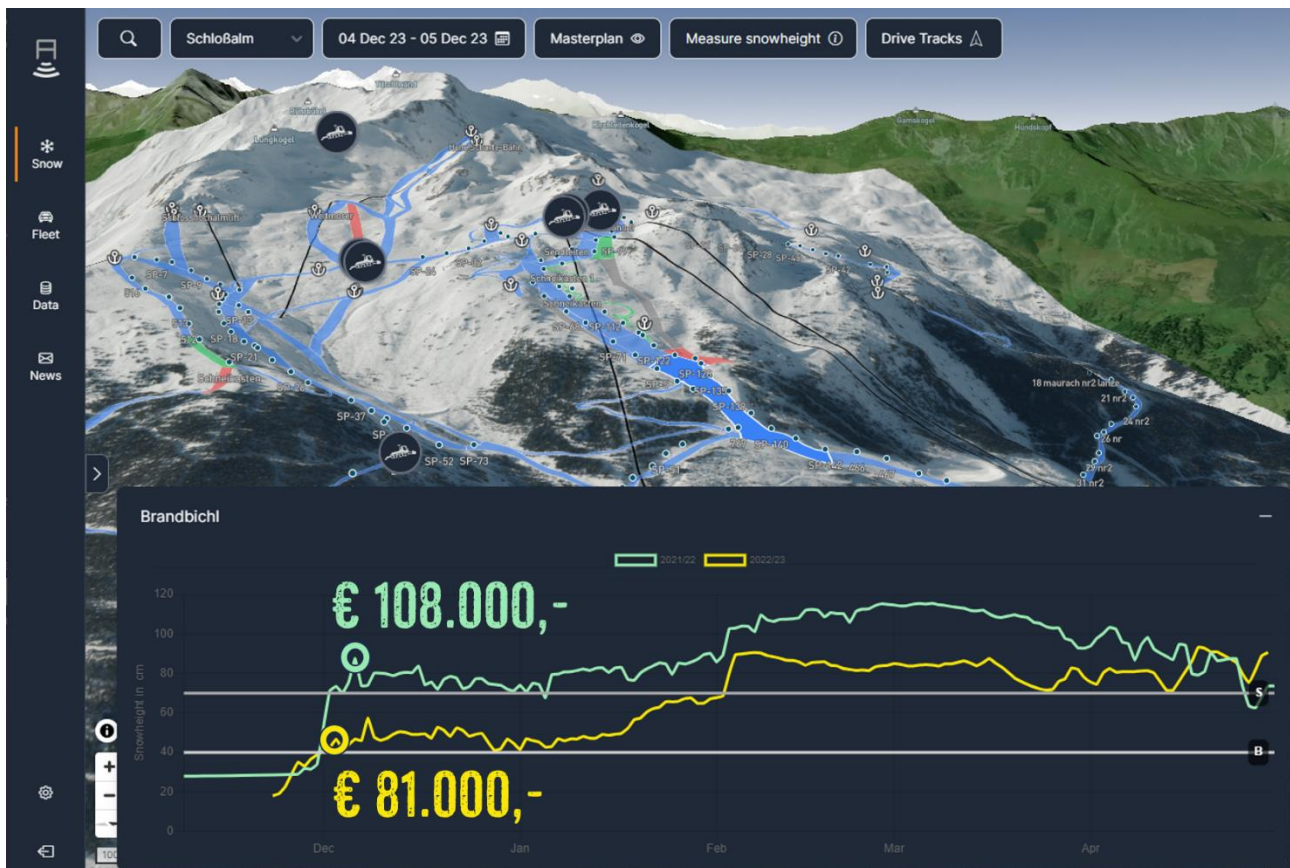


Figure 6: ARENA management platform, showing the analysis of one slope section in the ski resort Gastein.

Based on these data sources a master plan is created. The plan includes a geometrically correct map of the slope network, based on the digital terrain model and data of the groomer machines, divided into slope sections and hydrant areas (see Figure 5). Each hydrant area corresponds to a snow gun and includes the area that is covered with snow by this hydrant. For each hydrant area, target snow depths are defined, indicating the amount of snow that is required to open the slope section for skiing, and the amount of snow that needs to be reached during the season as maximum value. At the same time, this maximum value should not be exceeded (Figure 6). Hydrant areas are categorized among their type of snow machine (fan guns on tower or ground, snow lances) and treated differently depending on their position in the resort (altitude, slope, exposure, importance of the slope section).

Considering the expected amount of natural snow, target water volumes are determined for each hydrant area. These target values are sent by an interface to the snow-making control system to mark the upper limit of the amount of water available. The responsible person for snowmaking has of course the possibility to adjust these water values if the conditions require it. As soon as the groomer machines start running, they measure the snow depth present on the slopes with a centimeter accuracy based on GNSS (Figure 3). The snow depth data is then displayed in the ARENA management platform together with the defined target values allowing a continuous monitoring of the condition of the slopes throughout the ski resort (Figure 6). Responsible operators receive personal support for decision-making by the ARENA team during the winter season.

Table 1: water consumption in m³ for the Gastein ski resort from winter season 2018/19 to 2023/24.

m ³	Stubnerkogel	Schloßalm	Angertal	total
2018/19	104 302	312 727	210 341	627 370
2019/20	77 046	258 815	162 331	498 192
2020/21	90 622	290 772	191 505	572 899
2021/22	88 377	261 785	188 321	538 483
2022/23	101 292	261 918	212 675	575 885
2023/24	70 840	214 140	113 303	398 283

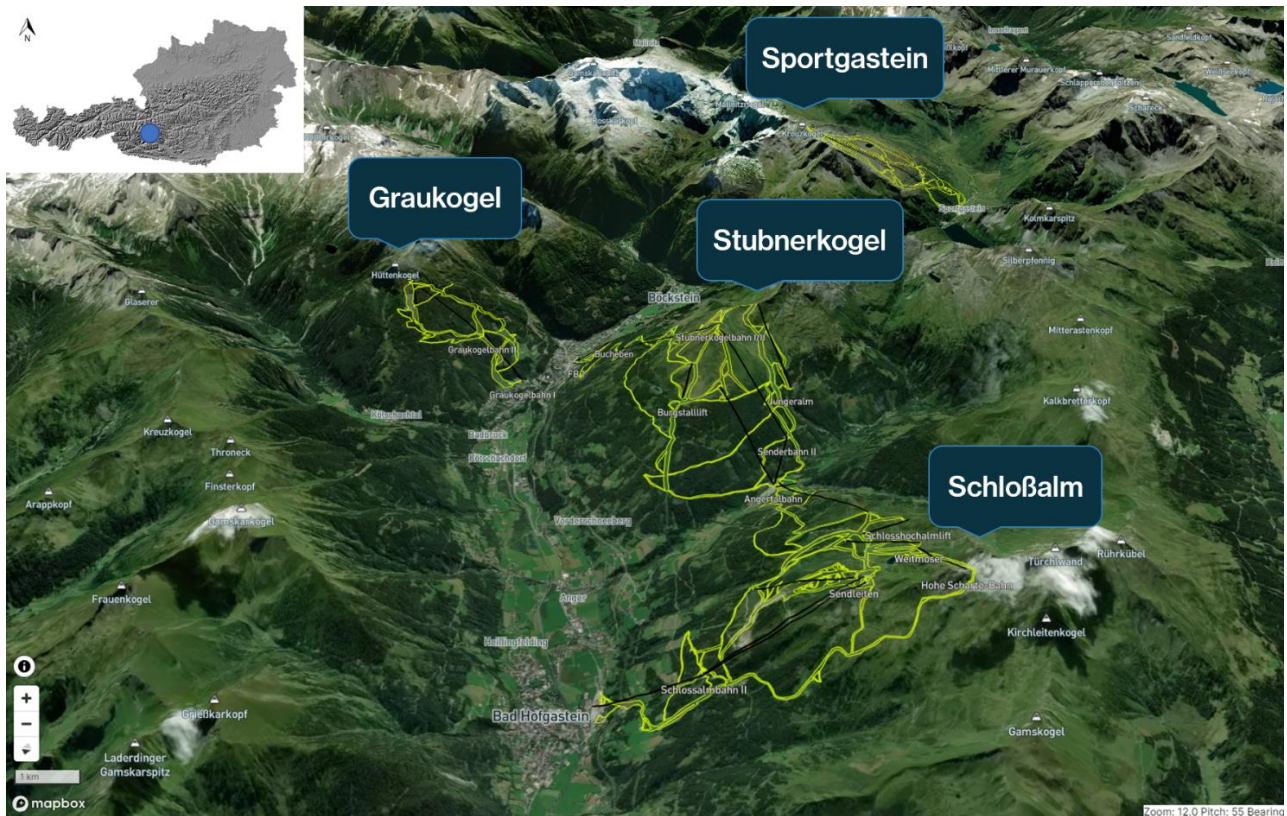


Figure 7: Gastein ski resort with the departments Schloßalm, Graukogel, Stubnerkogel, and Sportgastein, located in the Gastein Valley, Salzburg, Austria. (ARENA Slopemanagement 2024).

3. GASTEIN SKI RESORT, GASTEIN VALLEY, SALZBURG, AUSTRIA

Gastein ski resort is located in the Gastein Valley in the Hohe Tauern range in Salzburg, Austria. The ski resort includes 2,5 km² of slopes and reaches up to an altitude of 2 700m a.s.l. The water consumption for artificial snowmaking varies between 500.000 m³ and 700.000 m³ depending on the meteorological conditions during the winter. The goal set by the snow making team of the ski resort together with ARENA was to reduce the water consumption for snow making for the whole resort to under 500.000 m³. The snow depth measurement and the visualization in the ARENA management platform allowed us to analyze the situation for each hydrant area. In the following, the situation for three slope sections is shown in detail (see Figure 8). The three graphs belong to three different slope sections. For each slope section, the evolution of the snow depth on the section is shown throughout the winter season, while the green graph indicates season 2021/22, the yellow one 2022/23, and the blue one 2023/24. The horizontal grey lines indicate the defined target snow depth values, the lower one for the opening of the slope and the upper one to be reached during the season.

Weitmöser Trasse (Schloßalm, upper graph on Figure 8) is a broad slope section, located in the upper part of the ski resort, above the tree line. The inclination is gentle, the section is orientated to the east. In the winter season 2021/22 the graph shows that the “during the season target” was already reached in December, which is the case for all three slope sections. In contrast, the following year, less snow was produced so that the snow depth line stayed around the upper limit until January. Then, in February, natural precipitation rose the snow depth. At this altitude, snow depth normally stays high until the end of the season as melt is limited. Nevertheless, the artificial snow production on this slope section was well planned for the season 2022/23.

For the slope section B11/11 (Stubnerkogel), the situation is different. This section is a narrow slope section, located in the forest close to the valley. Although the trees provide shade, the temperatures at this altitude rise in spring. With February snow starts to melt in this section, which can be seen in all three graphs. The situation is made even more difficult by the fact that the snow guns on this section need to be removed when the snowmaking is

completed, meaning that no additional snowmaking is possible later in the season. This explains the fact, that snow depth rises to the upper limit for all three winter seasons already in December. Beginning with February, snow depth starts to decrease and reaches the base level by the end of April/ end of the season. In this slope section, the target values are adequately defined and well-considered in snow production. The last slope section shown in Figure 8 is

Brandbichl, which again shows saving potential in the season 2021/22. This slope section is located in the Schloßalm department at tree line. It is north east orientated and shows steeper inclination. While in the season 2021/22 the target values were strongly exceeded, the target values were adhered to very well during the winter season 2022/23. This slope section showed that the water and energy consumption could be reduced by 25%.

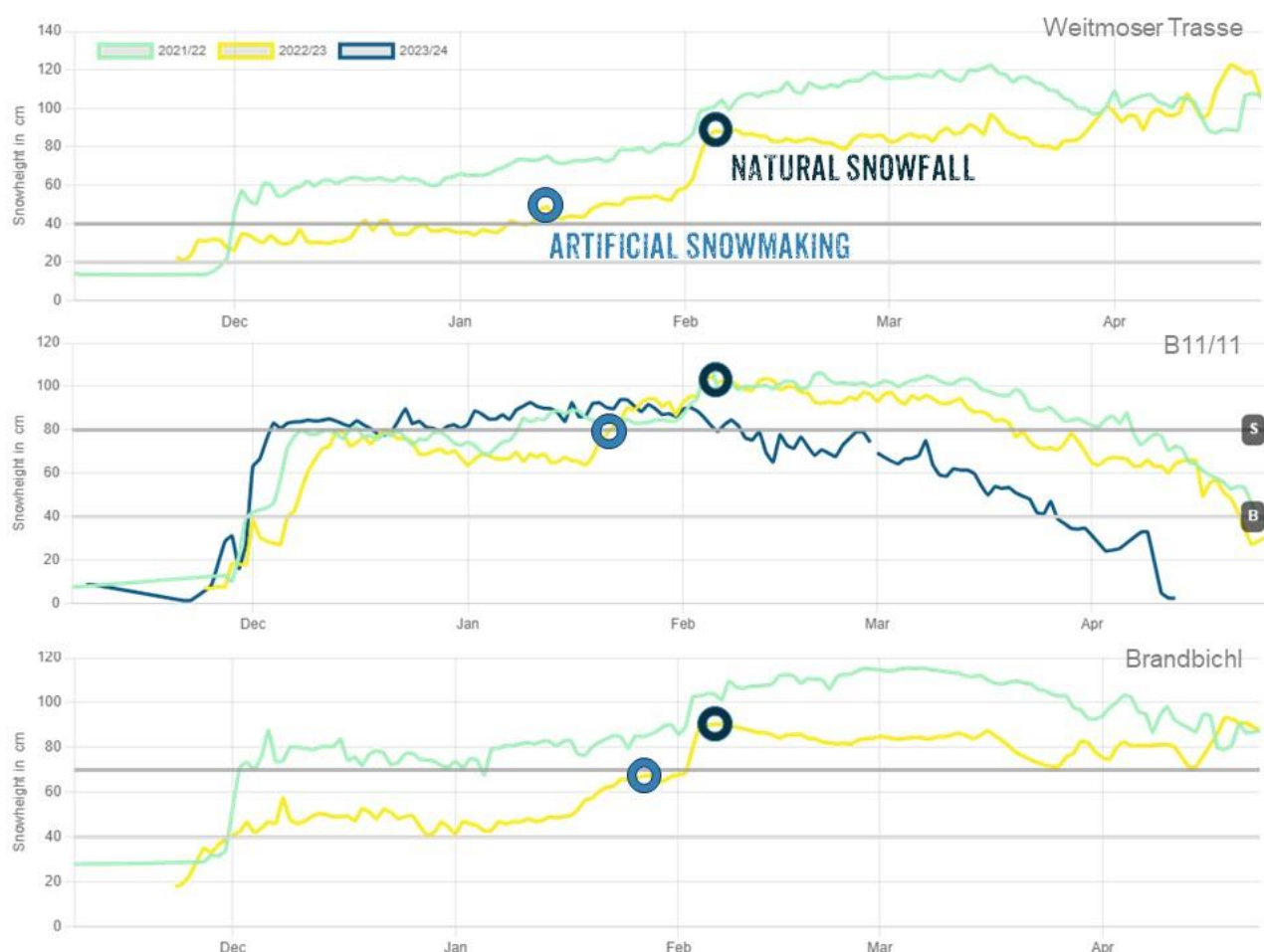


Figure 8 Snowdepth evolution for 3 winter seasons on three slope sections in the ski resort Gastein.

4. RESULTS

While the winter season 2022/23 was exceptional in terms of high temperatures and limited precipitation, the season 23/24 was at least at higher altitudes comparable to the winter season 2019/20. The slope management project started in Gastein in the season 2021/22, while during this season, nothing in the strategy was changed, and only analyses were conducted. The findings from this analysis were then applied in the following season, meaning in winter 2022/23. This is already well pictured in the graphs shown in Chapter 3. Table 1 shows the total amounts of water in m³ used per winter season for each section and for the whole ski resort of Gastein.

The overall water consumption decreased in the winter season 2023/24 down below 400.000 m³ which even surpassed the goal that was set to reach during the 3 years project.

The project has enabled the ski resort to save resources continuously over the last 3 years, from 22/23 to 23/24 they reduced their water and energy consumption again by 18%. This generates not only savings but at the same time planning security, also in view of the changing framework conditions in on-going climate change.

5. DISCUSSION

Every ski resort is different concerning the framework conditions, for example, the altitude and exposition of the slopes, the snow making system, the available amount of water and energy, time, and personnel resources. But the challenges ski resorts are facing are similar. It is not always necessary to invest exclusively in technical innovations like more efficient snow guns or larger storage ponds. For all ski resorts ARENA has conducted a slope management project yet, a significant potential in process optimization was found, as the presented study of Gastein showed. The aim is not only to create a good database and conduct analysis but also to adapt the target values to local conditions to be able to make well-founded decisions, especially in the important first phase of snow making during the winter. Already in this period, the foundation for a successful winter season is created and decisions about one night more or less of working snow guns are decisive for the overall balance of the season.

The most important part of slope management projects is a good connection with the operating team. The acceptance of this type of project can be difficult at the beginning meaning that good stakeholder engagement is key for a successful project. Guidance and good communication from the beginning ensure that the aims of the project are taken over by the team and resource saving is not a goal but “their” goal.

6. CONCLUSION

Ski resorts in Austria have a total area of 17.000 ha of slopes equipped with artificial snow making. Assuming that 1000 m³ of water can be saved per hectare slope area, this results in 17.000.000 m³ for the whole of Austria. 1 m³ of water results on average in 1,5 m³ of artificial snow. In the year 2023, the m³ artificial snow costs 3 € (Wirtschaftskammer Österreich, 2023). For the whole of Austria there would be a potential of saving 76 Mio. € if all ski resorts would take care of their slope management. Not only saving energy and water but also money goes in hand with the development goals and the sustainability and climate strategy of Austria (Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie, 2024).

Climate Scenarios (ÖKS15 and ÖKS26+ in preparation) show that skiing in Austria above 1800 m a.s.l. is still possible by the end of the century. Due to higher costs in snowmaking and grooming and due to inflation, it is assumed that prices will rise and skiing will develop into an elite sport (ÖKS Projekt-Konsortium, 2015 and Gobiet et al., 2022).

In the interest of resource efficiency and sustainability, every measure that leads to a reduction in resource consumption should be taken. Thus conducting slope management projects is a very interesting option for ski resorts in Austria (and worldwide). Consideration could even be given to mandatory political implementation as Austria needs to take action to reach their climate and emission goals. In addition, there is a lot at stake for Austria in terms of direct and indirect value creation.

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