3.2.9 PROSNOW

Introduction

Scope of prototype

The level of activity, employment, turnover and profit of hundreds of ski resorts around the Alps depend on snow falls and associated snow levels, highly variable in space and time. By nature seasonal, winter tourism is also affected by a high inter-annual variability, which makes all the more important the improvement of seasonal forecasts. For mountain tourism operators, seasonal snow forecasts could be useful in decision-making, managing ski areas, promoting mountain destinations and communicating with clients. The objective of this prototype will be to deliver an operational system of seasonal forecasting of snowfall probabilities, and an evolving model of snow cover (depth…), constantly updating the forecasted snow cover from the recorded depth at a "t zero". The prototype itself will cover the Savoy (French northern Alps), with potential extension to other Alpine domains. Due to potential misuse of such forecasts by individual customers, this system will be reserved for tourism professionals.

Scope of vulnerability analysis

The focus of this vulnerability assessment is on the operation of ski-areas and the dependency on snowfall. Thus, ski-area operators and their decision-making processes will be considered. The critical situation of sub-optimal snow conditions for other decision-makers cannot be considered in this analysis.

System of concern

In France, mountain tourism takes place in six mountain ranges, which cover 25% of the country's surface area. Mountain regions generate 15% of tourism GDP, 120,000 jobs and 55.3 million skier days each year. France has 357 resorts, over 200 of which are located in the Alps. They range in size from village facilities to large international stations. Experts generally distinguish between the Northern and Southern Alps, which together account for around 80% of the country's ski areas. Key decision-makers are ski area operators, which manage ski trails and ski lifts. They are key players in resorts and central to economic activity. Some 44% of operators are publicly owned, 43% are private companies and 13% are semi-public companies (sociétés d'économie mixte or SEMs, where the government holds a majority interest). Almost all resorts are members of Domaines Skiables de France (DSF), an association of French ski areas.

Critical situations

The key climate change impacts of interest to the winter sports industry relate to 'natural snow reliability' and also 'technical snow reliability' (i.e., cold temperatures to make snow). The latter is important in areas where snowmaking is almost universal among ski areas and covers a high proportion of skiable terrain. Studies on climate change impact on winter tourism in the European Alps determine that the number of ski areas that were considered 'naturally snow reliable' will drop from 609 (91%) to 404 (61%) under a $+2^0$ warming scenario and further decline to 202 (30%) under a $+4^0$ warming scenario (Abegg, Jetté-Nantel et al. 2007). Thus snowmaking will become more important in the future. Snowmaking is already a widespread climate adaptation in the region, with the proportion of skiable terrain currently equipped with snowmaking estimated only at 15% in the French Alps (50% in Austria, 40%

in Italy). Major uncertainties on the impacts for businesses also relate to the acceptance of customers to ski on partially snow covered ski runs, or the potential for large reductions in opportunities for Nordic skiing at low mountain elevations. Inter-annual variability is very likely to be more pronounced under climate change, creating increasingly challenging business conditions. Two or three consecutive extremely warm winters, could cause substantive economic losses and if frequent enough perhaps adversely affecting skier perceptions and demand in the longer term (Abegg, Jetté-Nantel et al. 2007, WMO and UNEP 2008).

Hazard: Economic conditions, employment and earnings at hundreds of Alpine winter sports resorts depend almost entirely on one thing: snow. Winter tourism is, by nature, seasonal. Climate conditions of ski areas affect, in the first place, the possibility for the ski resort to exist (no snow, no ski). It also impacts the reputation of the resort and the willing of tourists to book a stay in this resort (guaranteed quality of skiing) and thus the turnover of the resort and of all socio-economic stakeholders. It is therefore affected by inter-annual variations in snowfall frequency and duration, as well as snow cover quality. The snow cover evolution and conditions is thus the attribute of concern and its variability in time space a potential hazard.

Natural snow conditions suitable for skiing are generally defined by an ideal snow-depth of 30-50 cm (Elsasser and Messerli 2001, Fratianni 2001, Bürki, Elsasser et al. 2003) and quality which is generally assumed to decline at surface temperatures above -2°C. However, good skiing conditions are not predominantly determined by depth, since 30 cm dense snow provides better conditions than 1 m of powdery snow (pers com Lootvoet). The volumetric and spatial degradation of snow covers can occur by liquid precipitation >5mm but is dominantly controlled by air temperature > 6°C (Fazzini, Fratianni et al. 2004). Thus, lower lying ski-areas where beginner ski runs are typically found are especially affected by lack of snow. Especially because most people learn to ski on these lower-lying beginner slopes and the implications of fewer such slopes for discouraging beginning skiers or possibly diminishing the industry's client base over time remains uncertain (Abegg, Jetté-Nantel et al. 2007, WMO and UNEP 2008). Regarding the temporal scope of a good skiing season, 120-130 days are assumed for the Alps from December to March. At least 100 days per season are supposed to be covered by natural snow conditions to define an area as 'naturally snow reliable' (Bürki, Elsasser et al. 2003, Abegg, Jetté-Nantel et al. 2007; pers. com. Lootvoet). However, the total length of the season is not the critical factor but the periods of high demand. It may not matter to ski area operators if every ski season by mid-century is a couple of weeks shorter, as much of the season loss will occur at the beginning and end of the season when skier visits are relatively low. High demand periods are accompanied by school holidays which are in France two weeks at Christmas and four weeks in February/March. In one of these weeks, a resort earns 9% of its annual turnover. Visitor numbers during these weeks are therefore a major concern for most socio-economic operators (pers. com. Lootvoet).

Threshold for quality of skiing depends also on the capacity of the resort to produce snow from water. If the resort can guarantee a reasonable proportion of the ski area with artificial snow, then only temperature will be really important factor. Water droplets generally freeze between -6 and -10 °C which is the ideal temperature for snowmaking. However, the minimum temperature is at -2° C. Snowmaking is more difficult at these high temperatures, hence additives are sometimes used to induce freezing (Forget 1997, Schneider and

Schönbein 2006, Hofstätter and Formayer 2007). For the system of concern ski-area operators use this artificial snow in order to guarantee 30% of the ski area to have enough snow to allow skiing (pers com. Lootvoet).

Decision-making processes: the main challenge for decision-makers is basically to meet the demand for skiing and provide favourable snow conditions when this is desired. From a climatological point of view snow conditions are most critical at the beginning and end of season. However, the demand for skiing is closely linked to school holidays which are at Christmas and French winter holidays in February/March, this period is central to resorts' economic performance. Some ski trails may open around 10th of November but the period before Christmas is critical as this is the time when many tourists make decision to book ski holidays. Major difficulties may therefore arise during warm winters without snow or when no snow has fallen by Christmas. Thus, decision-makers have to be prepared for (i) late onset of snowfall and early finishing of snow-season and (ii) variability of snow conditions.

The ***start of the skiing-season*** has to be carefully prepared. Especially the promotion of the coming skiing-season is very sensitive. From September onwards, tourism promotion agencies and resorts face questions from the media about the upcoming winter season. Snow quality and conditions for snow-related activities are the most frequently raised issues that can affect customer decision-making and therefore turnover. *Promotion and communication strategies* like the pricing and promotion policy have to be adapted to an unfavourable start of the skiing-season. But also the *Human Resource (HR) policy* e.g. the offer of goods and services (e.g. activities that are not snow-related) have to be adapted and HR management (less seasonal jobs, different skills…) and orders. The latter requires a lead-time of a few days and can be optimized during the season. But the more anticipated it is, the lower the operational costs will be.

Decision-making on ***variable snow conditions*** implies the preparation of snowmaking and trail maintenance activities. Preparations begin mid to late October, when *snowmaking* resources are first mobilised. When preparing the season, decisions must be made regarding snow production: whether to put machines on standby, start snowmaking, etc. At the beginning of the season (around 10th of November) decisions must be made regarding *grooming machines and schedules* to ensure good trail quality and optimised operating costs as well as hiring and training seasonal employees for trail maintenance and security. Towards the middle of the season (late January), resort managers analyse the quality of snow cover, predictions for the next two or three months and temperature forecasts for April to anticipate end-of-season conditions for trail maintenance and snowmaking. Most of these decisions can be made and adjusted on a day-to-day basis but the more anticipated it can be (about one month before the start of the season), the lower the operational costs will be.

Critical situation: the demand on snow conditions are clearly defined by tourists and thus ski-area operators:

A critical situation arises when the coming winter season is unexpectedly bad which is especially characterized by low snow cover (<30cm), late start of the season (after mid-December) and warm temperatures (> -2°C) which prevents snowmaking.

Buffer system characteristics

The impact of climate conditions on the attribute of concern (snowpack) is very direct. For the accumulation of a snowpack, very few heavy snowfall events may already be sufficient to accumulate a snow pack suitable for skiing (Spreitzhofer 1999). Also the degradation of the snowpack may occur over very short time scales (days) (Hock 2003). The persistence of a snowpack is dependent on snowfall but mainly on temperature which significantly influenced by local topographic and geomorphic conditions. Thus, as soon as a snowpack has accumulated, it continuously persists as long as temperatures do not cross a critical threshold (>0°C) and precipitation becomes liquid and thus significantly degrades snow pack quality and decreases its volume. Such temperature conditions are generally a function of elevation which in turn makes snow pack conditions sensitive to climate conditions (Beniston, Keller et al. 2003, Fazzini, Fratianni et al. 2004, Scherrer and Appenzeller 2004, Gajić-Čapka 2011). Consequently, snow packs are sensitive to the start of the snowing season and the initial accumulation of a snow pack and to the end of the snow season when temperatures frequently become positive, enhance melting processes and degrade the snow pack. The sensitivity of snow packs to climate variability and change is thus measured by its duration in snow days in relation to elevation (Egli 2011, Gajić-Čapka 2011, Serquet, Marty et al. 2013).

Critical climate conditions and climate information

Critical climate conditions

Snow pack accumulation is primarily dependent on the availability of snow and thus snowfall events. However, the persistence of the snow pack is dominated by temperature which controls melting processes but also the aggregate state of precipitation (snow or rain). Also the option of snowmaking is primarily temperature dependent. Thus, consistent low temperatures can compensate the lack of snowfall at least to a certain extend by the provision of an already existing snow cover (with probably lower quality) or the opportunity to make artificial snow. Furthermore, decision-making processes put a focus on the timing of snowfall and low temperatures. Thus, critical climate conditions are lack of snowfall or rather low-magnitude events especially at the beginning of the season (November/December) and at the end of the season when mean temperatures start to increase again. But high variability of snowfall during the season may also be critical since it creates need for more snowmaking (low snowfalls) and need for more trail grooming and maintenance (very intense and frequent snowfalls). Additionally, warm mean temperatures for all the winter season are critical with a special temporal focus again on the beginning of the season.

Critical climate conditions are (in order of priority)

- ***a late onset of seasonal snowfall (after mid-December),***
- ***warm temperatures (>2°C) and***
- ***highly variable in-seasonal snowfall.***

Climate information

Of major importance is the information on the start of the winter season, i.e. the onset of the first snowfall events which provide skiing conditions. Or rather the snow conditions for the beginning of December with a lead time of one month. Climate information on snowfall and temperature with a respective high temporal resolution for November/December is desired.

A general knowledge on the snow conditions of the coming winter season is desired in October to adjust the availability of staff and machines. To assess the need for grooming and snowmaking activities, information on the snowfall and temperature variability during the season and especially at the end is desired.

Vulnerability attributes

Criticality of decision-making processes: Economic conditions in mountain resorts are almost entirely dependent on tourism. In Northern Alpine resorts especially, winter is often the main season. A resort earns 9% of its annual turnover within one week of the high-season. Thus, snow is the basic resource on which business is built on which implies a very high dependency on climate. The opportunity of snowmaking moderates this climate dependency or rather shifts or spreads the dependency from snowfall to temperature. Consequently, decisions on promotion for the coming winter season are crucial for business development and climate takes a major role in this decision.

Usability of S2D climate information: the basic climate information required by ski area operators is whether the winter season becomes good or bad with respect to the amount of snow available and the need for snow making. Since decision on concrete measures can be made short-term the timing of high- or low snowfall events is not critical for strategic decisions on the coming winter season. Thus, information about snow conditions referring to mean values is potentially of good use. However, the temporal focus on the start of the season as well as the school holidays complicates the usability of climate information: the timing of snow conditions gains importance which adds a lot of uncertainty to information from S2D climate forecasts or requires sub-seasonal forecasts covering short time periods.

This misfit of S2D climate information and critical climate conditions is increased by the related decision-making processes which requires lead-times of up to 3 months for climate information comprising a couple of weeks. Furthermore, the very demand for spatial high resolution of climate information (micro climate of valleys and slopes) additionally increases the challenge of the use of climate information for this problem.