

We thank Bruno Abegg for his helpful and constructive comments. The original comments of the reviewer are in blue. Our replies are in black.

## **Bruno Abegg (Referee) #1**

### **General comment**

This is an interesting and valuable manuscript. I fully agree with the authors that there is little research on past changes in natural and managed snow reliability in ski resorts (i.e. there is more research on future changes in snow reliability in the context of climate change). I am also fully aware of the data problem (lack of data!) and, therefore, I was happy to learn that more data is available in France (or at least in Savoie) than in many other ski tourism markets. Given the data, the methodology is appropriate. The manuscript clearly highlights an important feature, and that is the heterogeneity of ski areas or ski resorts – with regard to size, elevation ranges (to distinguish between ski slopes above and below 2000 m, for example, is very helpful), snowmaking development paths and, although noted in the margin only), business models. Recently, quite a few scholars suggested to pay more attention to this heterogeneity; the authors of the paper at hand did it – in a good way. Consequently, this manuscript is a valuable contribution/addition to the existing literature and worth to be published.

>>>> We thank B. Abegg for the positive general comments and helpful specific comments. We went through the comments and complemented and refined the manuscript accordingly, as described below.

### **Specific comments**

Line 30f.: "... explicit assessments of the impact of climate change on ski resorts operations, based on past observations, have remained limited (Beaudin & Huang, 2014, Hamilton et al.,2003). Here, you should add the analogue studies, e.g. Rutt, M., Scott, D., Johnson, P., Pons, M., Steiger, R., & Vilella, M. (2017). *Using ski industry response to climatic variability to assess climate change risk: An analogue study in Eastern Canada*. Tourism Management, 58, 196–204 or Steiger, R. (2011). *The impact of snow scarcity on ski tourism: An analysis of the record warm season 2006/2007 in Tyrol (Austria)*. Tourism Review, 66(3), 4–13.

>>>> We added both references mentioned, explicitly mentioning however that they correspond to analogue studies focusing on specific years rather than addressing past trends explicitly.

Line 38ff.: "The strongest evidence on climate change impacts to ski tourism has therefore been inferred primarily from future climate change projections, which is then used to interpret past and present situations, in the absence of solid studies assessing impacts based on past observations." This is a strong statement, and open to debate.

I refer to the sensibility analyses and the risk perception studies (see Steiger et al. 2019 for an overview) and recommend to reconsider the wording/phrasing.

>>> We have rephrased this statement to avoid over-interpreting it, see below:

*“In fact, a substantial body of evidence on climate change impacts to ski tourism has been inferred primarily from future climate change projections rather than on the analysis of past changes in snow conditions”*

Table 1: There is another figure often seen in the literature, although referring to investment costs per km (and not hectare): investment costs of approx. 1 million Swiss Francs per km ski slope (see [www.seilbahnen.org](http://www.seilbahnen.org) and look for “l’enneigement technique”).

>>> We have added a reference to this information in the text:

*“Furger (2002) and RTS [Remontées mécaniques suisses], the professional association of the Swiss ski resorts operators (2011) mentioned a cost investment in Switzerland but expressed it per km of slope equipped and not per hectare as figures in Table 1. Furger (2002) estimated the investment costs of snowmaking of 1 million Swiss Francs per km of slope equipped based on a sample of ten ski resorts located in the canton of Vaud”.*

Fig. 4 (and therefore also Fig. 7): These are interesting figures. The corresponding explanation in the text, however, is very brief. For a better and/or faster understanding of these figures, it is suggested to add some explanatory text.

>>> We have expanded the description of the results of Figure 4. The description of Figure 7 was already more detailed and was therefore not expanded.

Further, in line 267 (referring to Fig. 5 and 6), you write about “... the lower values at the beginning and end of the winter season ...”. The lower values at the beginning of the season are clear. The lower values at the end of the season are not, maybe in April but this is not shown in the figures (and in March, the values are high).

>>> We have added April to Fig. 5, 6 and 7

Discussion (and limitations) is well done. In chapter 4.4 you could add Abegg, B., Steiger, R. & Trawöger, L. (2017). Resilience and perceptions of problems in Alpine regions. In R. W. Butler (Ed.), *Tourism and resilience* (pp. 105–117). Wallingford: CABI Publications.

>>>> We added the reference recommended since it mentions the optimistic confidence towards snowmaking to face climate change impacts in the ski tourism industry, see below:

*“According to Abegg et al. (2017) the faith placed in snowmaking by the ski tourism industry is one of the reasons why there remains a perception gap between scientific literature and some ski tourism industry stakeholders regarding climate change upcoming challenges.”*

Conclusions and perspectives, though, are very brief. I would have expected to read more about the wider consequences of your research (e.g. the feasibility of future snowmaking investments in low and middle altitudes). And, apart from more company-/site-specific data is needed to refine this kind of research, what are exactly the perspectives, or more precisely, what is the research outlook?

>>>> We have added further information about the wider implications of this work and perspectives, see below:

*“Nevertheless, our results pave the way for further studies addressing not only the detection and attribution of past changes and impacts of climate change on social-ecological systems, which requires analyzing not only changes in climatic-impact drivers but actual impacts, taking into account all the components of climate change risk (climatic-impact drivers, exposure and vulnerability).*

*Beyond these methodological perspectives, our work opens the way to broader investigations into the consequences of the development of snowmaking facilities in mountain regions. Steiger et al (2019) mentioned the challenge of a better understanding of ski tourism path dependency. We speculate that initial gains provided by snowmaking can foster the pursuit of these investments and embark ski tourism stakeholders on a path dependency. Beyond a general trend of snowmaking investments in Savoie, we pointed out that individual situations greatly differ in terms of snowmaking equipment dynamics and snow reliability outcomes, depending on ski resorts particularities. While this study explicitly considers geographical characteristics, it still under-estimates the potential influence of business models, which plays a key role for climate change vulnerability, with implications for the climate change adaptation strategy at the individual ski resort level, and warrants further investigations.”*

### **Some technical corrections**

General point: I am not a native English speaker but I think there is room for improvement in the use of the language.

- Line 34: led (instead of lead)

>>>> Corrected

- Line 73: ... snow cover simulation produced using ...

>>>> Corrected

- Line 83: what do exactly mean by ski lift maintenance? Replacement of old ski lift by new ones?

>>>> Ski lift maintenance is not the replacement of old ski lifts by new ones. The ski lift maintenance refers to the servicing or partial replacement of existing ski lifts. Since public authorities frequently conduct periodic inspections of ski lifts, ski lift operators have to do some maintenance investments: cable replacement, electric system upgrades, compliance investments, etc.

We clarified to: *Ski lift maintenance (i.e. servicing and replacement of parts on existing ski lifts and compliance investments)*

- Line 110: "... it is not fully certain ..." – this is a bit cryptic, please clarify.

>>>> We rephrased to:

*"The comparison between the DSF snowmaking facilities rate in 2020 and the estimation of Spandre et al. is difficult since the latter only considers the French Alps and DSF does not provide any information regarding the representativeness of its sample and how the aggregated value was derived for all ski resorts in France".*

- Fig. 3: divide into top, middle and bottom graph (and not into top, bottom and last row)

>>>> Corrected

- Line 233: in 2018 (not: en)

>>>> Corrected

- Line 247: it is with grooming only (and not without grooming), right?

>>>> That is correct, we rephrased the sentence to: "the snow cover reliability with grooming (no snowmaking, x-axis),"

- Line 456: These figures (not: this)

>>>> Corrected

Beyond the changes described below in response to the comments, and changes in response to the feedback from Reviewer #2, note that we have performed some further updates to the manuscript in order to improve. In particular, we have extended the time period covered by the study from the winter 1960-1961 to the winter 2018-2019. Figures 8, 9 and 10 have been improved by sorting the ski resorts the other way around (higher elevation resorts are at the top, not at the bottom).