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## **Vulnerability of cross-country skiing to climate change in Finland – an interactive mapping tool**

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## **Vulnerability of cross-country skiing to climate change in Finland – an interactive mapping tool**

### **Abstract**

Cross-country skiing is one of the most popular recreational activities in Finland, but it is now becoming clear that it will be severely affected by climate change. In this paper we introduce an interactive vulnerability mapping tool that has been developed to raise awareness of the possible implications of climate change for cross-country skiing. Users of the tool are able to map indicators of exposure to climate change, characterising municipal-scale snow conditions under a warming climate, together with indicators of sensitivity and adaptive capacity, which are based on a national survey of 769 cross-country skiers aged 15-74 years from 2010. The indicators can be combined to produce composite vulnerability indices that can also be mapped. The mapping tool is designed to assist stakeholders in planning and developing skiing services and in studying the challenges of future regional cross-country skiing demand. It is available at: <http://www.iav-mapping.net/U-C-IAV>.

### **Keywords**

Recreation demand, climate change vulnerability, exposure, sensitivity, adaptive capacity, indicator mapping, visualisation, cross-country skiing

### **Management Implications**

The U-C-IAV mapping tool can help to make the complexities of climate change impacts more recognisable, increase communication and awareness of climate change among decisions-makers and the general public and improve understanding of possible adaptation responses. The public sector still holds a key role in providing ski services for the population in Finland, and the tool could provide insights into the factors influencing vulnerability to climate change. This may assist stakeholders' decisions for designing strategies or developing policies to reduce vulnerability. The tool showcases cross-country skiers, representing an example of recreationists who already have experiences of adaptation to a changing climate and are expected to be affected even more in the future. As such, this study provides information that is potentially applicable or can serve as an example when investigating adaptation options for other winter activities in response to changing climate.

## **1. Introduction**

Climate change is likely to be one of the crucial environmental determinants of outdoor recreation demand and the behaviour of those seeking recreation (recreationists) in the future. Ski-tourism in general, and ski resorts in particular, are expected to face negative impacts of climate change (IPCC et al. in press, pp. 20–21; O'Brien et al., 2006; Scott and McBoyle, 2007), including monetary losses (e.g. Moen and Fredman, 2007; Elsasser and Messerli, 2001). Such impacts are also of importance in the Nordic countries (Saarinen, 2014), but systematic research on the topic is scarce (IPCC et al. in press, pp. 20–21, Scott et al., 2007). For example, little is known about climate change impacts on skiing demand (e.g. Dawson et al., 2013), and most research that has been conducted focused on downhill rather than cross-country skiing (Landauer, Sievänen, & Neuvonen, 2009). Climate change impacts on cross-country skiing demand have been evaluated at the population level in Finland by Pouta et al. (2009), who projected a reduction in participation that could be expected particularly among females, individuals with a lower socioeconomic status, and inhabitants of urban environments. Some of the previous research has identified skiers' adaptation strategies in response to climate change (Dawson et al., 2013, Landauer et al., 2012, Landauer, Sievänen, & Neuvonen, 2009; Scott & McBoyle, 2007; Behringer et al. 2000). Although "supply-side" research indicates a range of potential outcomes for ski resorts (e.g. Scott & McBoyle), there is a growing sense, at least in Finland, that information on adaptation to climate change is currently lacking for the tourist industry and that innovative research activities are called for (Tervo-Kankare, 2011).

In Finland, cross-country skiing is an important leisure activity, with a participation rate of over 40 percent of the adult population surveyed in 2009–2010 (Sievänen and Neuvonen, 2011). Cross-country skiing is regarded as both a physical activity – a popular way of exercising and of gaining health benefits – as well as part of the cultural identity of Finns (Landauer et al. 2009; Landauer et al. 2014). Participation in physical exercise and an active lifestyle are known to have positive health effects (World Health Organization, 2010; Kaczynski and Henderson, 2007; de Vries et al., 2003). Traditional cross-country skiing in Finland relied on natural snow over extensive areas, with trips often made for the activity. Hence, compensating for poor snow

conditions through artificial snow making is not a viable proposition over such large areas. Moreover, recreational facilities for cross-country skiing represent one of the most important local municipal sports infrastructural services. Ski tourism (offering both downhill and cross-country skiing) is also a significant business in Finnish Lapland where the largest ski resorts are located.

On the supply side, the majority of ski tourism enterprises so far do not have any particular adaptation strategy to account for warming winter conditions, although the issue of climate change – adaptation and/or mitigation – was generally included in development plans as a component of their sustainable development targets (Tervo-Kankare, 2011). In Finland, many ski tourism and sport enterprises as well as municipal agencies have some experience of coping with adverse weather conditions, such as snow-making, transporting snow from ice hockey halls, storing snow from the previous winter, and providing indoor ski halls and ski tunnels (e.g. Lépy et al., 2014).

In this study we are concerned about the vulnerability of cross-country skiing as an activity under a changing climate in Finland. In general, vulnerability has emerged as a central concept in framing climate change impacts on human-environment systems (Adger, 2006; Fussler, 2007), though its definition and interpretation have evolved over time (e.g. see Lavell et al., 2012). The most recent definition by the Intergovernmental Panel on Climate Change (IPCC) describes vulnerability as "the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt." (IPCC et al. 2014, p. 5).

One of the most common methods of representing differences in regional vulnerability to climate change is through the use of maps. Such maps typically depict sets of indicators that are believed to be contributory factors in the overall vulnerability to climate change of the system under study (such as a population, institution or ecosystem). Indicators are measured or modelled attributes for which data are available for geographical units across a region. The indicators are commonly combined into a vulnerability index, a composite measure that can also be mapped (Malone and Engle, 2011; Preston et al., 2011; Polsky et al., 2007). Many examples of vulnerability maps at

various geographical scales have been documented, ranging from global (e.g., Füssel, 2010b), through continental (Metzger et al., 2008; Lung et al., 2013), to national (O'Brien et al., 2004) and sub-national (Rød et al., 2012). However, vulnerability mapping has also been challenged as a credible analytical method, due to the subjective nature by which indicators are selected (commonly based on subjective inference of causality), and the often arbitrary manner by which they are combined into indices (Füssel, 2010a; Hinkel, 2011). While recognising this critique, we argue here that as long as the underlying purpose, data and assumptions are fully transparent to the target audience, such mapping exercises can still offer a potentially useful and informative analytical method. In particular, mapping can provide a means of visualising those different factors thought to influence vulnerability to climate change, which so far may have received little attention, and may not otherwise be accessible to decision-makers facing the challenge of responding to climate change (Carter et al., 2014).

In the present study, the vulnerability of cross-country skiing in Finland has been assessed by combining indicators derived from survey information on the attitudes and intentions of cross country skiers (Landauer et al., 2015) with indicators of prevailing and projected snow conditions. Our study focuses on skiing as a "close-to-home" activity, and the likely responses of skiers in different Finnish regions to changing conditions as winters become warmer. The study introduces a mapping tool for exploring the possible impacts of changing winter climate on skiing conditions and skiing behaviour. It is intended to be used by actors involved in cross-country skiing as business and service providers as well as professionals and decision makers concerned with policy and planning of land use and natural resources, with a view on helping these groups to assess adaptation needs and actions, and to promote discussion among different actors in their respective regions.

In the following sections we first outline the methods used to select, combine and map indicators of vulnerability to climate change for cross country skiing in Finland. Second, we describe the measured, modelled and survey-based data used to quantify the indicators. Third, we present an interactive web-based tool (U-C-IAV) that allows users to map the indicators and to combine them into vulnerability indices. Next, we illustrate the types of results that can be visualised

using the mapping tool and finally, we offer some conclusions on the utility of the web tool and its possible application and further development in the future.

## **2. Selecting indicators of vulnerability and potential impact**

Following Metzger and Schröter (2006), vulnerability to climate change can be defined as a function of exposure, sensitivity and adaptive capacity. In the case of cross country skiing, the exposure (E) is defined as the expected change in skiing conditions under a changing climate, sensitivity (S) is the degree to which skiing participation would be affected by a given change in skiing conditions, and adaptive capacity (AC) describes the willingness of skiers to adapt, using different options, to anticipated changes in conditions.

Sets of indicators have been identified that describe exposure, based on estimates of future snow conditions using a hydrological model, and sensitivity and adaptive capacity, based on responses from a national survey of outdoor recreation. Sensitivity is characterised by a single indicator – the proportion of the population between 15 and 74 who skied during the previous 12 months, which varies regionally. The adaptive capacity set is sub-divided into indicators of technical adaptation (describing skiers' willingness to upgrade their equipment), indicators of locational adaptation (reflecting skiers' willingness to use indoor ski areas such as ski tunnels or halls), and indicators of activity-level adaptation (describing skiers' anticipated responses to deteriorating snow conditions or actual behaviour). The specific indicators are listed in Table 1 and described in more detail in the following section.

While individual indicators are of interest in their own right, it is by combining them into composite measures (indices) that their joint contribution to exposure and adaptive capacity can be explored. A number of methods may be applied to develop such indices, all requiring that the original indicators first be converted into standard measurement units. In this study, vulnerability indices are simply a combination of normalised exposure and adaptive capacity indices, with the highest vulnerability associated with high levels of exposure and/or sensitivity combined with low adaptive capacity.

In contrast to causal models, which can be used to predict impacts on the basis of a given change in explanatory variables, an index necessarily describes a potential rather than a realised outcome. Vulnerability is an estimate of the propensity to be adversely impacted (Lavell et al., 2012) rather than an estimate of actual impact to be expected. Likewise, adaptive capacity describes the potential for adaptation based on the resources available, rather than the actual readiness and ability to adapt (Carter et al. 2014). In this study we acknowledge this distinction by separating survey responses that relate to potential adaptation measures for adjusting to a changed climate in the future from those responses that indicate an anticipated impact (i.e. number of ski trips per year). This is treated as a potential impact, though here the estimate provided is based on a perceived (by the skiers surveyed) rather than a modelled impact.

Table 1. Indicators of exposure, adaptive capacity and perceived impact applied in the study.

<b>Indicators of exposure (modelled changes in snow conditions for the period 2010-2039 relative to 1971-2000, and population exposed in 2010)<sup>1</sup></b>	
<i>Change in snow depth</i>	
	Change in 30-year mean snow depth (cm)
<i>Change in snow cover duration</i>	
	Change in mean duration of period with > 10 cm snow depth (days)
	Change in mean duration of period with > 20 cm snow depth (days)
	Change in mean duration of period with > 30 cm snow depth (days)
<i>Change in snow cover reliability</i>	
	Change in proportion of years with < 100 snow days <sup>2</sup> (%)
	Change in proportion of years with < 50 snow days <sup>2</sup> (%)
	Change in proportion of years with < 30 snow days <sup>2</sup> (%)
<b>Indicator of sensitivity (survey-based data from winter 2010, units: %)<sup>1</sup></b>	
<i>Ski activity level</i>	
	Proportion of population aged 15-74 who ski
<b>Indicators of adaptive capacity (survey-based data from winter 2010, units: %)<sup>3</sup></b>	
<i>Indicators of technical adaptation</i>	
	Proportion of skiers willing to upgrade their equipment
	Proportion of skiers willing to develop their skiing technique
	Proportion of skiers prepared to learn new waxing methods
<i>Indicators of locational adaptation</i>	
	Proportion of skiers prepared to ski in a different area nearby <sup>4</sup>
	Proportion of skiers prepared to ski on artificial snow
	Proportion of skiers prepared to use ski halls or ski tunnels with artificial snow
	Proportion of skiers prepared to travel more than 300 km to find natural snow <sup>5</sup>
	Proportion of skiers prepared to make a special visit to a region with natural snow
	Proportion of skiers prepared to acquire a recreational home in a ski-secure area
	Proportion of skiers prepared to move to a ski-secure region
<i>Indicators of activity-level adaptation</i>	
	Proportion of skiers who would switch to renting skis if snow conditions deteriorate
	Proportion of skiers who would give up skiing if snow conditions deteriorate
<b>Perceived impact</b>	
	Anticipated number of ski trips per year under changed conditions
<sup>1</sup> The higher the level of exposure or sensitivity, the higher the vulnerability	
<sup>2</sup> Days with snow depth exceeding 20 cm	
<sup>3</sup> The higher the level of adaptive capacity, the lower the vulnerability	
<sup>4</sup> Close enough to be easily accessible for a daytrip	
<sup>5</sup> A trip of more than 300 km is assumed to require an overnight stay.	

### 3. Quantifying the indicators

The exposure indicators adopted in the study comprised data on snow depth, snow cover duration, and snow cover reliability across Finland. These were simulated with the WSFS hydrological model (Veijalainen, 2012) using observed climate data for the period 1971-2000 and five climate scenarios for the period 2010–2039, selected to cover the range of projected climate changes in Finland from a larger ensemble of climate model-based projections (Jylhä et al., 2009). The change in snow conditions was simulated for catchments in Finland, from which area averages were calculated for municipalities. Guidelines suggest that the minimum snow depth for track grooming is 20 cm (Pylväs et al. 2006), but 10 cm (typically the first snow of the winter) may be sufficient for skiing on fields or on frozen lakes, while 30 cm might be required in forested terrain. Changes in snow cover reliability refer to snow depths exceeding 20 cm. The scenario simulations for future climate suggest shorter periods of snow and a reduced snow depth across the whole country, in accordance with previous studies (e.g. Jylhä et al., 2008). Snow conditions suitable for cross-country skiing are expected to be most severely affected in southern Finland and coastal regions (Figure 1). *A priori*, these trends are likely to affect participation in cross-country skiing, which could result in a decline of the annual number of skiing occasions for those who participate in skiing.

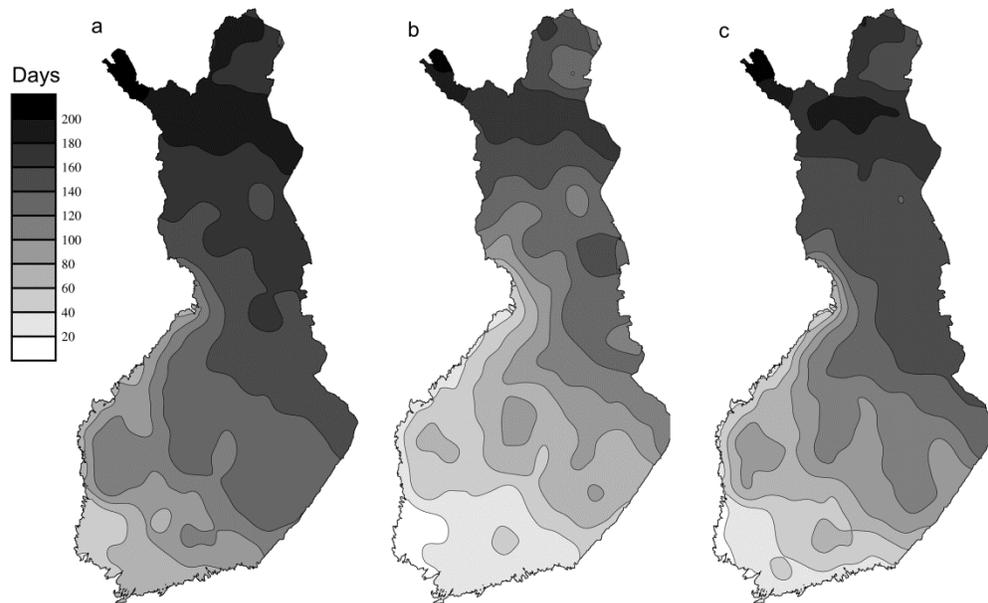


Figure 1. Number of days per year with more than 20 cm snow depth in Finland simulated with the WSFS hydrological model a) for the reference period 1971–2000; b) change for the period 2010–2039 with the ensemble average of 19 General Circulation Models (GCMs) that simulated the response to the SRES A1B (moderate) emission scenario; and c) change for the period 2010–2039 for an example from a single GCM (ECHAM5/MPI-OM), also for SRES A1B. Differences in near-term projections are minimal for alternative emissions scenarios, so only SRES A1B is shown; much greater uncertainties originate from differences between GCMs. Source: Finnish Environment Institute SYKE; for WSFS hydrological model see Veijalainen (2012).

The sensitivity and adaptive capacity indicators were drawn from the Finnish National Survey of Outdoor Recreation 2009–2010, which provides a database of cross-country skiers' behaviour (Sievänen and Neuvonen, 2011). Data on past skiing behaviour (interpreted as a sensitivity indicator) and willingness to participate in skiing activities at present and under climate change (indicators of adaptive capacity) were collected from cross-country skiers during the winter of 2010. Altogether 769 responses were received (response rate of 35%), which were analysed separately for the four main geographical regions of Finland: South Finland, West Finland, North and East Finland and the Helsinki-Uusimaa region. Skiers were asked either to predict their likely behaviour over the next five years (near future) or in relation to a more hypothetical longer-term future situation under which conditions had deteriorated, hence offering alternative temporal references of perceived vulnerability (cf. Füssel 2007). These alternative questions were offered because it was assumed that respondents would perceive the impacts of climate change individually, mainly due to differences in their age and personal lifetime prospects as

skiers. The response to one question, related to the skiers' anticipated number of ski trips per year under a hypothetical halving of snow days, was interpreted as a potential (i.e. perceived) impact rather than as an adaptive capacity indicator.

#### **4. An interactive tool for mapping vulnerability of cross-country skiing to climate change**

An interactive web-based mapping tool was developed to allow users to depict the above indicators of exposure, sensitivity and adaptive capacity and to combine them into composite indices for exploring climate change vulnerability. The tool was first developed to represent vulnerability to climate change of the agricultural sector and of the elderly at the municipal scale in the CARAVAN<sup>1</sup> and MEDIATION<sup>2</sup> projects for the Nordic region (Carter et al. 2010; 2014). It has since been adapted for Finland to represent both vulnerability and potential impacts, as the User-based Climate change Impacts, Adaptation and Vulnerability mapping tool (U-C-IAV)<sup>3</sup>. The tool currently addresses the elderly (Carter et al., 2014) and cross-country skiing (presented here), but the tool will be extended in the future to cover other sectors such as agriculture and biodiversity.

When combining indicators, compositing involves first converting indicators to standard units through a normalisation procedure, applying linear scaling to values for each regional unit relative to the regional range and re-scaling values to a range between 0 and 100. Composite indices are produced by averaging the normalised values. These computations are carried out automatically, as soon as multiple indicators have been selected. If users regard one indicator as more important than another, differential weighting of individual indicators can also be applied (up to a weighting factor of 10). The user-interface is divided into three mapping panels. The left hand panel depicts exposure and sensitivity, either as individual indicators in their original measurement units, or as a composite index if several indicators are selected together. Note that indicators are grouped into similar categories and only one can be selected at a time, to avoid

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<sup>1</sup> Climate change: a regional assessment of vulnerability and adaptive capacity for the Nordic countries (CARAVAN – 2008-2010) was funded by the Academy of Finland, Research Council of Norway and Swedish Environmental Protection Agency in the Nordic-Call of CIRCLE (Climate Impact Research Coordination for a Larger Europe), an ERA-Net project established under the European Commission's Sixth Framework Programme.

<sup>2</sup> Methodology for Effective Decision-making on Impacts and Adaptation (MEDIATION – 2010-2013) was funded by the European Commission's Seventh Framework Programme.

<sup>3</sup> <http://www.iav-mapping.net/U-C-IAV/>

over-representing one category in a situation where indicators from multiple categories are being combined into a composite index. The middle panel shows indicators of adaptive capacity which can also be selected separately or as combinations. These are also grouped into categories, but here the indicators within a given category are quite distinct from one another and can be selected in combination, if desired. The right hand panel offers two mapping options. One is labelled "index-based". If this is selected, when values are specified and mapped for both exposure and adaptive capacity they are normalised and mapped automatically on this panel, alongside the other two, with a black arrow appearing between them (Figure 2). A second option is labelled "perceived impact", which allows for a subjective estimate of a future impact outcome, in this case the estimated number of ski trips per year with a halving of snow days. This map is shown alone, as it is unrelated to the indicator maps in the other two panels.

Indicators of exposure (i.e. changes in snow conditions) can be shown for several scenarios. These indicators are provided as municipal averages, whereas indicators of sensitivity and adaptive capacity are provided for four larger regions in Finland (see above). The resulting indices of vulnerability therefore also show different values at the municipal level. Maps can be zoomed in to show smaller regions in more detail and indicator values of individual municipalities can be displayed. Rather than predefining the factors that influence vulnerability, users can test and explore alternatives by combining indicators into indices of vulnerability, including the possibility to apply weights to different indicators. The user-interface of the mapping tool contains extensive help and background texts which are easily accessible through information buttons and which guide users through the use of the tool and the interpretation of results. All items are supported with descriptions including the measurement unit, item definition, (default) interpretation of an indicator's effect on vulnerability and source of information.

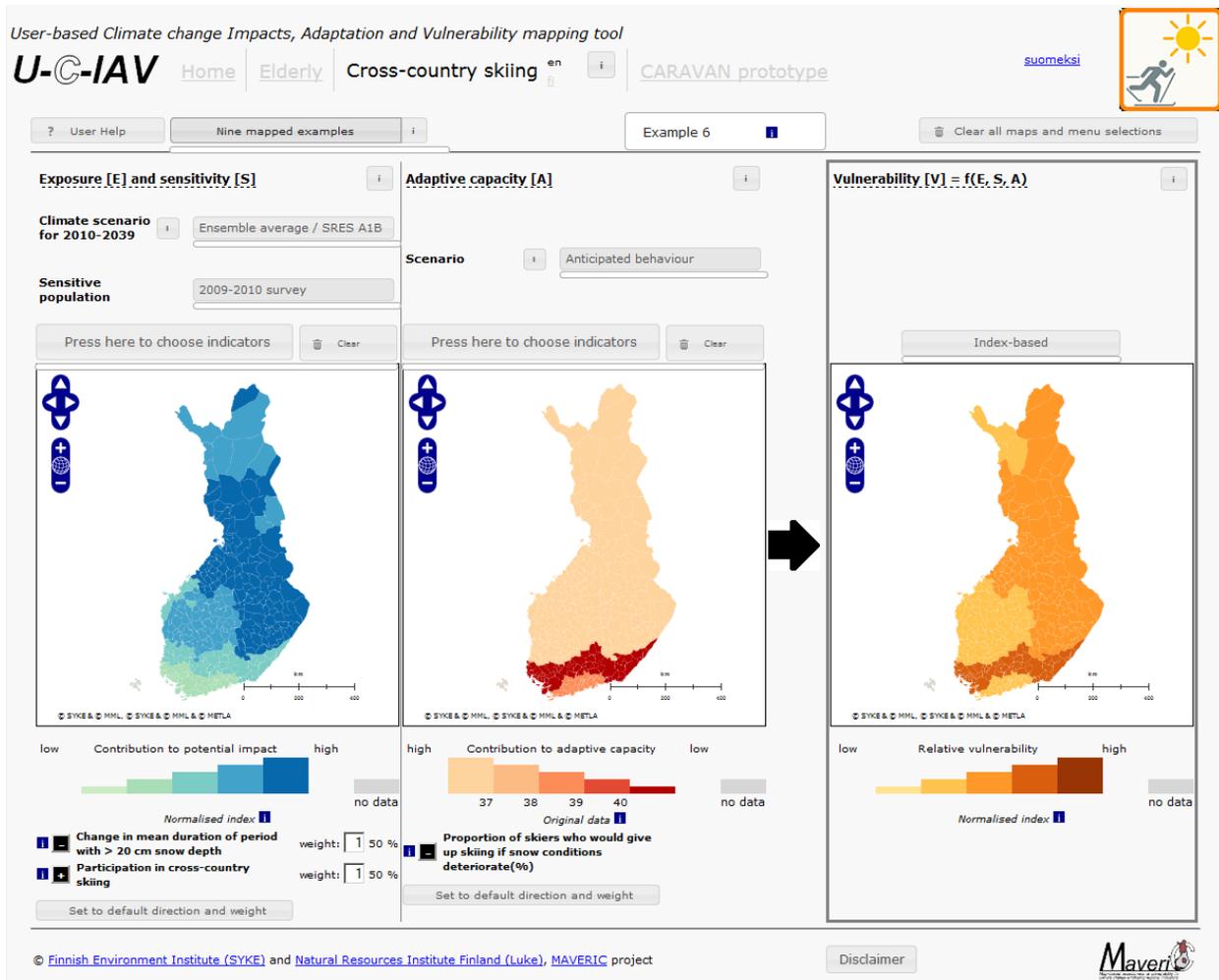


Figure 2. Screenshot of the vulnerability mapping tool for cross-country skiing. (Source: <http://www.iav-mapping.net/U-C-IAV/skiing/>).

In order to illustrate some different features of the tool and its functionality, nine example combinations of indicators, each resulting in a mapped vulnerability index, are presented as screenshots along with brief descriptions in Supplementary Material (Appendix 1). One of these combinations (Example 6) is repeated here and described in the text.

In this example, an indicator of exposure (change in mean duration of the period with >20 cm snow depth for the ensemble mean climate scenario) is combined with an indicator of sensitivity (proportion of the population aged 15-74 who ski) to form a composite index in the left hand panel. The map incorporates not only an objective estimate of how the snow conditions are projected to change in different regions in the future, but also the numbers of skiers likely to be affected in different regions, based on the survey data. The combination of exposure and

sensitivity is sometimes referred to as potential impact, so the composite map can be interpreted as a measure of the potential impact of climate change on cross country skiing as an activity. The combination of this indicator with an indicator of activity-level adaptation (proportion of skiers who would give up skiing under deteriorating snow conditions, also based on the national survey), shown in the middle panel in its original units of percent, results in the vulnerability map shown in the right hand panel. It shows that vulnerability is greatest in southern Finland, and least in the Helsinki region and western and north-west Finland.

Other examples in the supplementary material (Appendix 1) illustrate the versatility of U-C-IAV in exploring different indicators, alternative climate scenarios and a number of combinations of these. First, individual indicators that are mapped in their original units and combined into vulnerability indices: a sensitivity indicator combined with an adaptive capacity indicator (Example 1) and an exposure indicator with an indicator of activity-led adaptation (Examples 2 and 5, for different climate scenarios), locational adaptation (Example 3) and technical adaptation (Example 4). Second, Example 6 illustrates a combination of exposure and sensitivity indicators, themselves combined with a single adaptive capacity indicator into a vulnerability index. Third, three examples contain the same combination of exposure and sensitivity indicators combined with three different combination of two adaptive capacity indicators (Examples 7, 8 and 9). The last of these (Example 9) illustrates differential weighting of indicators, where one of the two indicators of adaptive capacity is assigned a weighting that is eight times that of the other indicator. The majority of vulnerability maps in these examples point to higher vulnerability in the south relative to the north of Finland, reflecting a combination of reduced duration of snow cover and lower willingness to adapt to deteriorating conditions. However, contrary examples that imply higher vulnerability in the north rather than the south also exist. For instance, skiers in the north are less willing to travel long distances in search of natural snow than skiers in the south. This result is not surprising, since around 30% of the skiing trips made by Finns are longer than 500 kilometres (Outdoor Recreation Statistics 2010), and most are from southern to northern parts of Finland where the large ski resorts are located.

## **5. Limitations and possible improvements of the tool**

The vulnerability mapping tool exhibits several limitations. First, the index-based approach offers a simplified description of vulnerability, with selected indicators representing only a limited number of aspects. For instance, one well-documented response to a restricted time period in which to ski is to compensate by skiing more often (temporal substitution). Neither temporal nor activity substitution (i.e. switching to another activity) are currently represented in the tool. In addition, the survey data focus only on the demand side of cross-country skiing. The tool could be improved by adding supply-side indicators, for example based on a survey of measures (actual or potential) offered by service providers for adapting to changing climate conditions.

Second, some limitations emerge with the use of survey data. These were collected at one point in time as part of recreation monitoring, based on a random sample of the Finnish population (Sievänen and Neuvonen, 2011). Not all responses are included in the mapping tool and some additional survey information might be included in the future (e.g. detailed questions about how skiing conditions affect the decision to ski). Moreover, respondents' reactions concerning their likely behaviour under a changed future climate should be interpreted only as a tentative answer, potentially influenced by the context in which the questions were posed (e.g. after a snowy versus a snowless winter). However, we have tried to refine the survey questions and validity of proposed measures by tailoring information on the future climate by using regionally-specific climate scenarios. Another limitation concerns the aggregation of the survey information for four regions, while snow information is presented on the more detailed municipal scale. Combining data held at different scales may cause mismatches in some individual municipalities.

Third, we acknowledge that the tool might be more readily accessible to users who are familiar with climate change research and for those who can apply their local knowledge of skiing conditions and skiing culture in Finland. Without this experience, results may be difficult to interpret. Examples of how the tool can be applied are presented in supplementary material to this paper (Appendix 1), and further work could also explore vulnerability outcomes through sensitivity analysis.

Finally, more user feedback on the tool is required. Pilot versions of the general mapping tool were already released to key user groups (Carter et al. 2014), and the tool's current features and functionality reflect some of the feedback received from those groups as well as recent comments from independent researchers not involved in this study. A crucial next step is to invite experts from the relevant sectors like ski tourism resorts, municipal sport agencies, nongovernmental organizations, Metsähallitus, and decision makers from Ministries (e.g. Ministry of Education and Culture, Ministry of the Environment) to scrutinise and discuss the tool in a workshop environment. The aim of such meetings will be to receive feedback from key stakeholders to improve the relevance, usability and transparency of the tool.

## **6. Conclusions and management implications**

The U-C-IAV tool provides a flexible and interactive method for exploring potential regional impacts of climate change, by offering the opportunity to map key indicators separately as well as combining them into indices of vulnerability. Unlike most previous vulnerability mapping exercises in which indicators were both selected and combined by researchers, here, once the indicators have been defined (preferably by researchers in collaboration with experts), the decision on whether to map them separately or as combined indices is left to the user of the tool. This clearly requires that proper documentation be provided on the indicators presented as well as the assumptions made when combining them. Furthermore, appropriate caveats are needed to emphasise the subjective nature of the mapping exercise and to caution against over- or misinterpretation (Carter et al. 2014).

Little research has been carried out on the local vulnerability of cross-country skiing to climate change as a "backyard, close-to-home" activity. The tool can help to make the complexities of climate change impacts more recognizable at a local level (e.g. Lépy et al., 2014), to improve communication about climate change (cf. Neset et al., 2014) and to increase awareness of climate change among decisions-makers and the general public. The tool can assist stakeholders, including land use planners, managers of local and national sport facilities (such as skiing trails), state and municipal decision-makers providing funding for sport facilities, and ski tourism

entrepreneurs, and it can also be accessed by the general public to guide citizens towards a better understanding of the consequences of climate change on an activity in which many of them participate. For all of these interest groups, a common intention is to provide them with information that might assist their decisions when adapting to changing climate.

When mapping vulnerability in this way, it is interesting to reflect on the reasons why some regions appear to be more vulnerable than others. U-C-IAV does not provide any explicit explanations, although the subjective survey responses represented in the adaptive capacity indicators might provide interesting avenues for further research. For instance, differences in socio-economic structures and resources between regions may help to explain differences in capacity to adapt to changing conditions, for example the provision of snow storing facilities or ski tunnels. Some regions may also be more vulnerable to change if their regional economies depend more heavily on ski tourism (cf. O'Brien *et al.* 2006) or the areas are small and less diversified (Scott *et al.* 2006). On the other hand, regions or resorts which are able to continue to provide skiing facilities e.g. by investing more in snowmaking technologies (Scott *et al.* 2006) are less vulnerable as conditions change in the future, and might even gain from increasing numbers of visitors, if locational adaptation is successful (Dawson, Scott & Havitz, 2013; Saarinen, 2014). Such possible shifts in demand in the areas that remain operational underline the complexity and the uncertainty in planning processes both at regional and national levels. Since the results of U-C-IAV demonstrate that some regions may gain from a changing climate at the expense of other regions, this information could be valuable for informing national sports and recreation governance and planning, implying that policies will need to be tailored to divergent regional circumstances. Although the focus here is cross-country skiing, in principle the mapping tool could be expanded to encompass other recreational activities as well.

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## **Appendix 1**

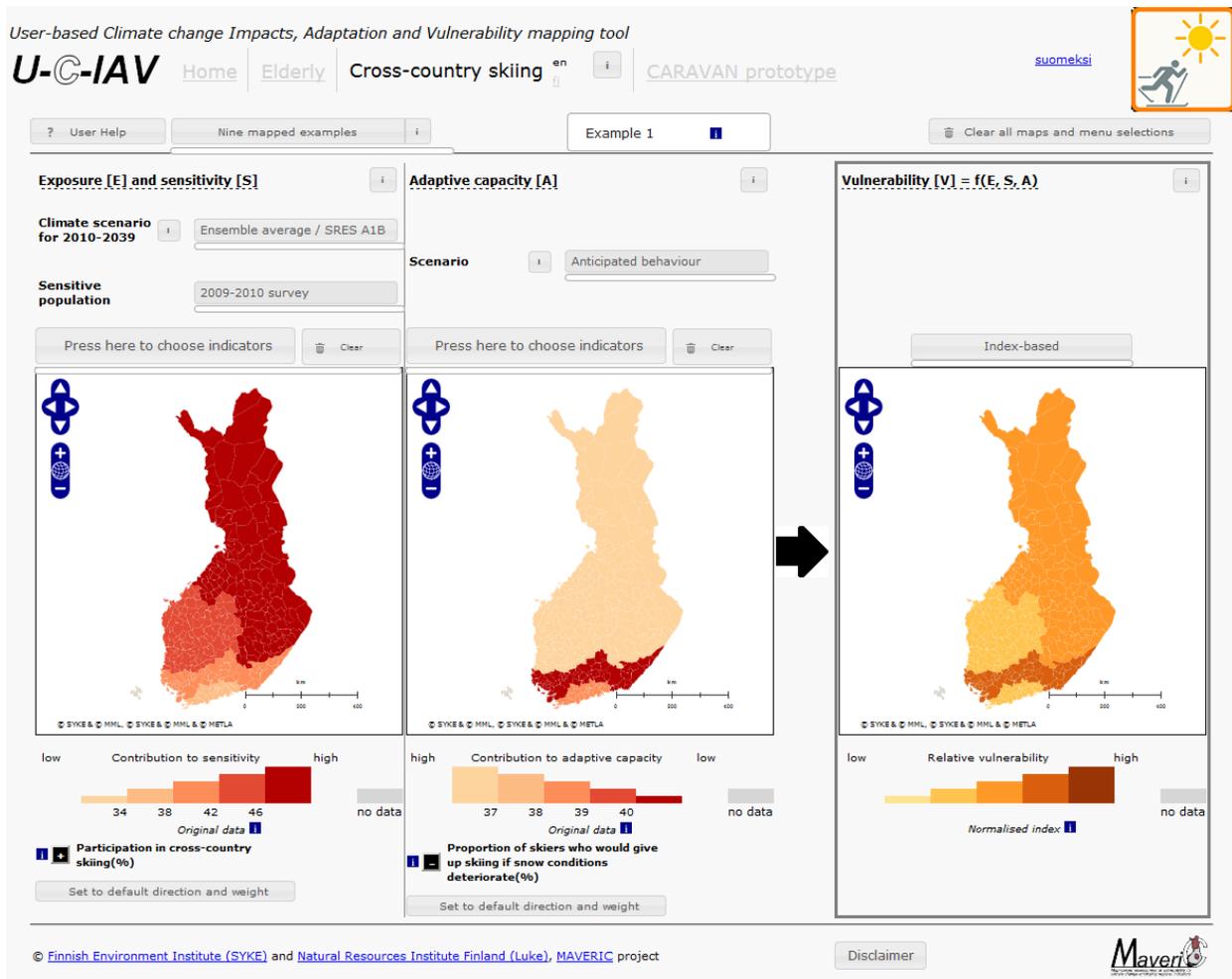
### **Vulnerability of cross-country skiing to climate change in Finland – an interactive mapping tool**

#### Supplementary Material

In order to illustrate various features of the vulnerability mapping tool and its functionality, nine examples of combinations of indicators are presented in Figures S1-S9 below, each resulting in a mapped vulnerability index.

### Example 1: Percentage of skiers + risk of giving up.

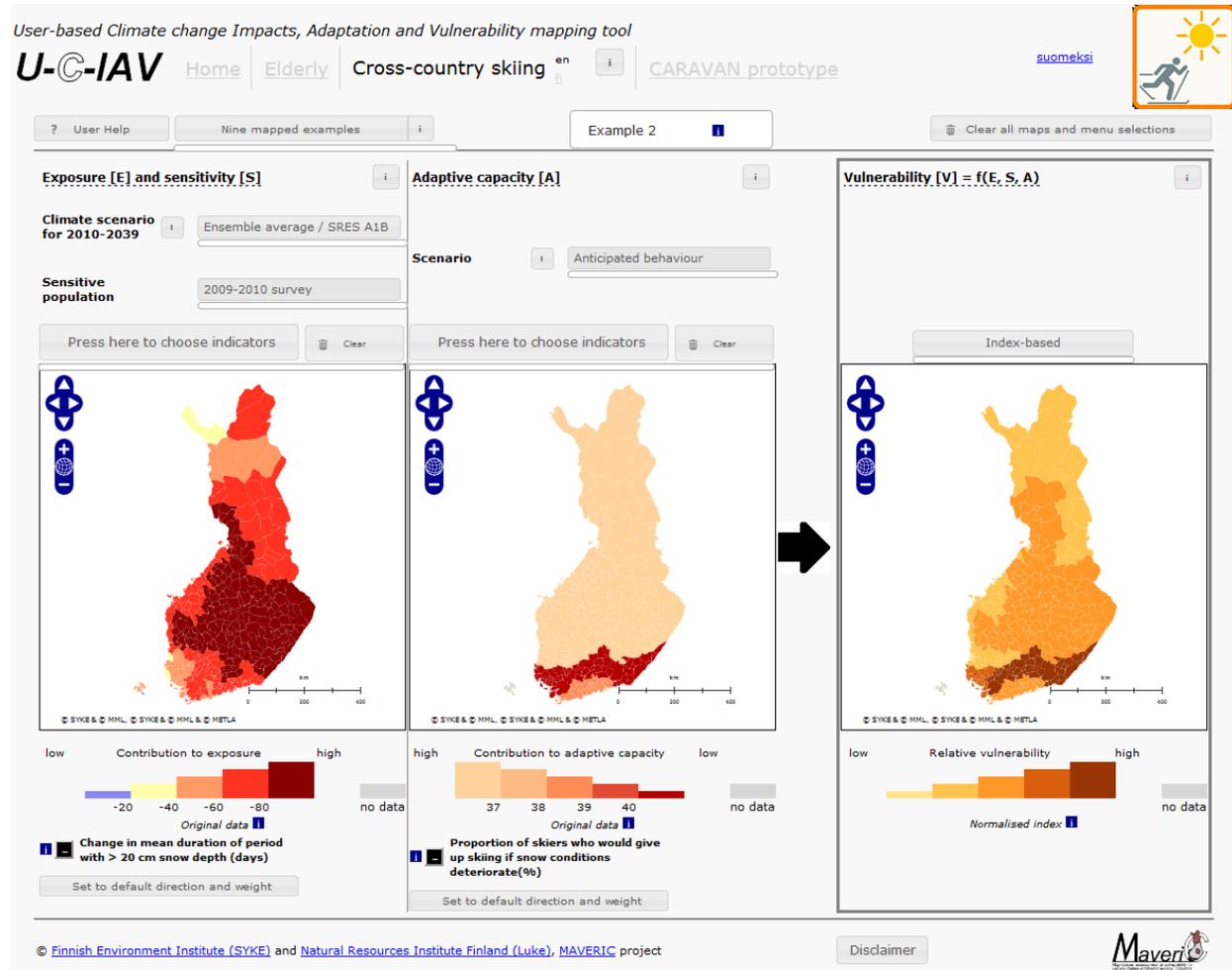
The proportion of the population aged 15-74 who ski (based on survey responses ) is mapped in original units as the only indicator of sensitivity in the tool. It shows a decline in reported skiing activity from north to south for the four regions surveyed, reflecting the duration and reliability of snow in Finland. In this example it is shown alongside the proportion of skiers who indicated that they would give up skiing if snow conditions deteriorate in the future, also in original units. The risk of skiers giving up the activity is larger in South Finland and the Helsinki Uusimaa region than further north. When these two indicators are combined (using equal weights) into the vulnerability index on the right, it becomes clear that cross-country skiing is most vulnerable in the south moderately vulnerable in the north and east and least vulnerable in the west and Helsinki regions.



**Figure S1:** Screenshot of the mapping tool for Example 1, showing the combinations of indicators describing the proportion of the population who ski (left, %) and the proportion of skiers who would give up if conditions deteriorated (centre, %) and the resulting vulnerability index (right, normalised).

### Example 2: Projected snow decline + risk of giving up.

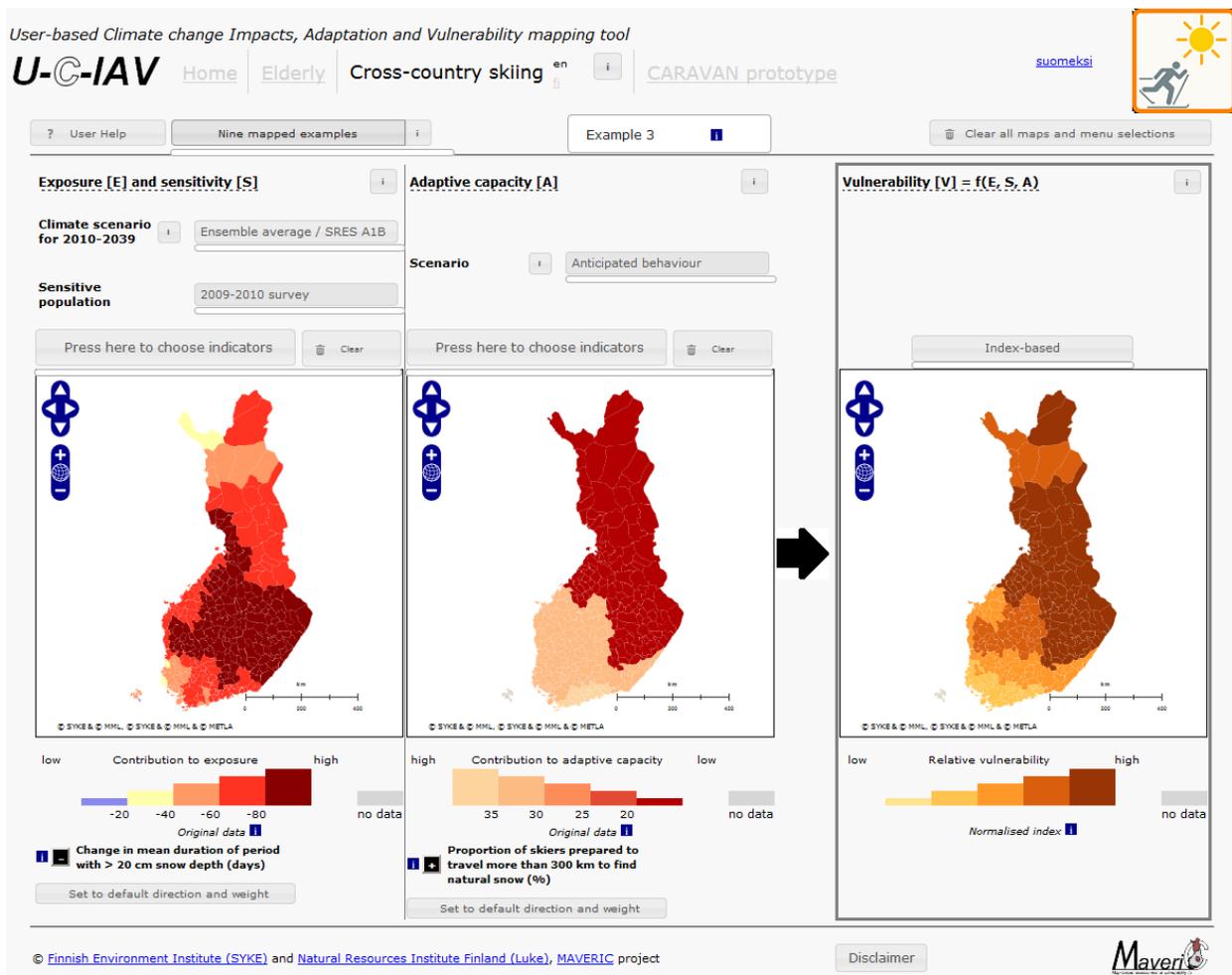
In this example, the sensitivity indicator from Example 1 is replaced by an exposure indicator – the change in mean duration of the period with >20 cm snow depth. This is shown in its original units (days) at the municipal scale, and assumes a scenario of future climate that is an average across an ensemble of 19 different climate model projections. A depth of snow of 20 cm is the threshold used to define suitable ski conditions over open terrain, and is projected to decline everywhere in Finland, but most severely in central Finland. Since no sensitivity indicator is selected here, the projected change in snow conditions is assumed to affect cross-country skiing activity in the same way everywhere. Here, it is combined (using equal weights) with the proportion of skiers who responded that they would give up skiing if snow conditions deteriorate in the future. The resulting vulnerability map is similar to that in Example 1, except that the greater exposure to snow decline in central than in northern Finland is reflected in relatively lower vulnerability of cross country skiing in northern Finland, and enhanced vulnerability in southern and central Finland.



**Figure S2:** Screenshot of the mapping tool for Example 2, showing the combination of indicators describing the change in mean duration of the period with >20 cm snow depth by 2010-2039 for the ensemble mean climate scenario (left, days) and the proportion of skiers who would give up if conditions deteriorated (centre, %) and the resulting vulnerability index (right, normalised).

### Example 3: Projected snow decline + resistance to travel.

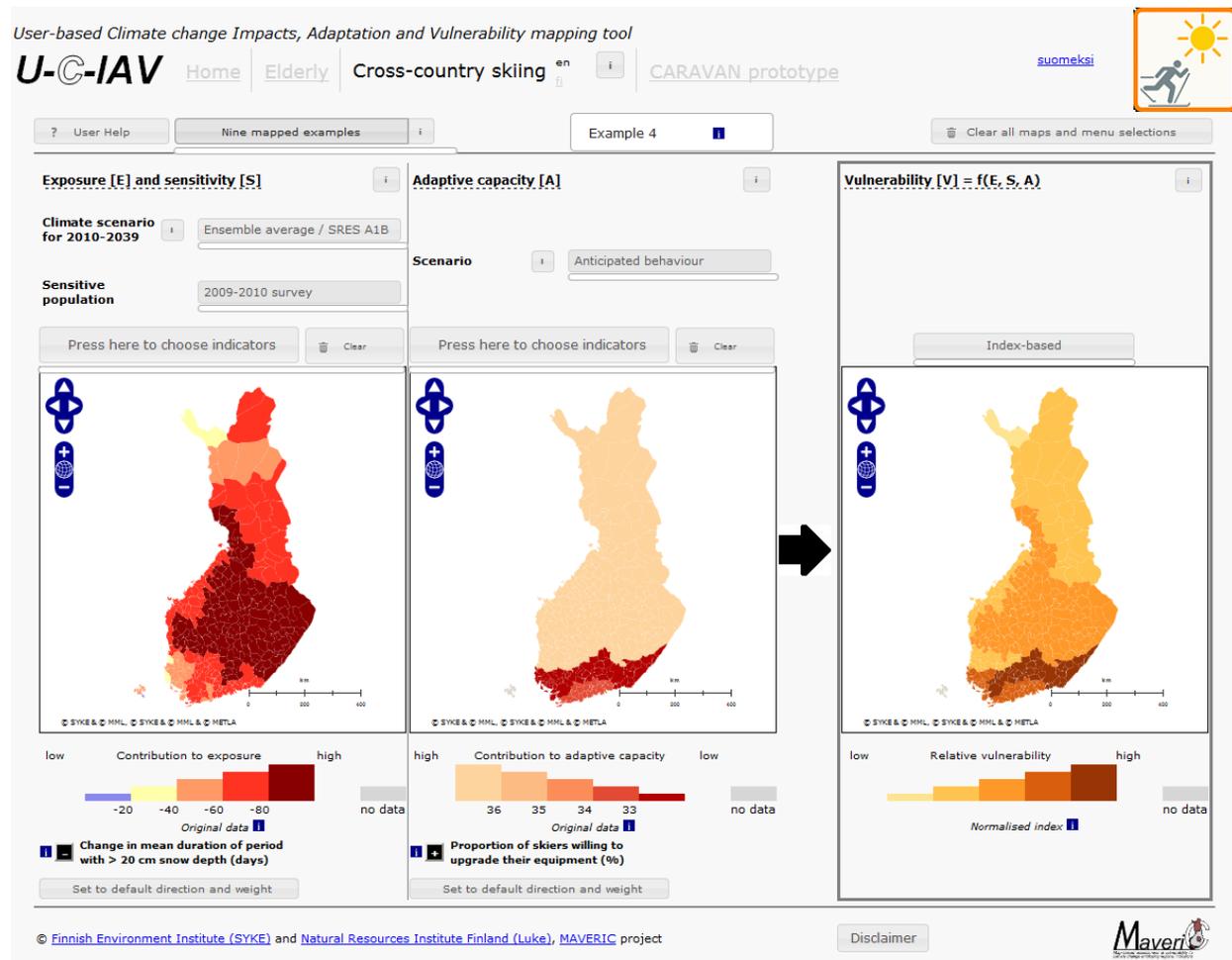
This example presents the same snow duration indicator as in Example 2, but a different adaptive capacity indicator of locational adaptation – the proportion of skiers prepared to travel more than 300 km to find natural snow, in original units of percent. Low values imply a lack of willingness to adapt to changing conditions by travelling, and hence contributing to a higher vulnerability of the activity. Here, a greater willingness to travel in the Helsinki region and least willingness to travel in northern and eastern Finland, so combined with projected snow duration, the resulting vulnerability map shows maximum vulnerability in central and northern Finland, and lowest vulnerability in southwestern Finland.



**Figure S3:** Screenshot of the mapping tool for Example 3, showing the combination of indicators describing the change in mean duration of the period with >20 cm snow depth by 2010-2039 for the ensemble mean climate scenario (left, days) and the proportion of skiers prepared to travel more than 300 km to find natural snow (centre, %) and the resulting vulnerability index (right, normalised).

#### Example 4: Projected snow decline + resistance to equipment upgrade.

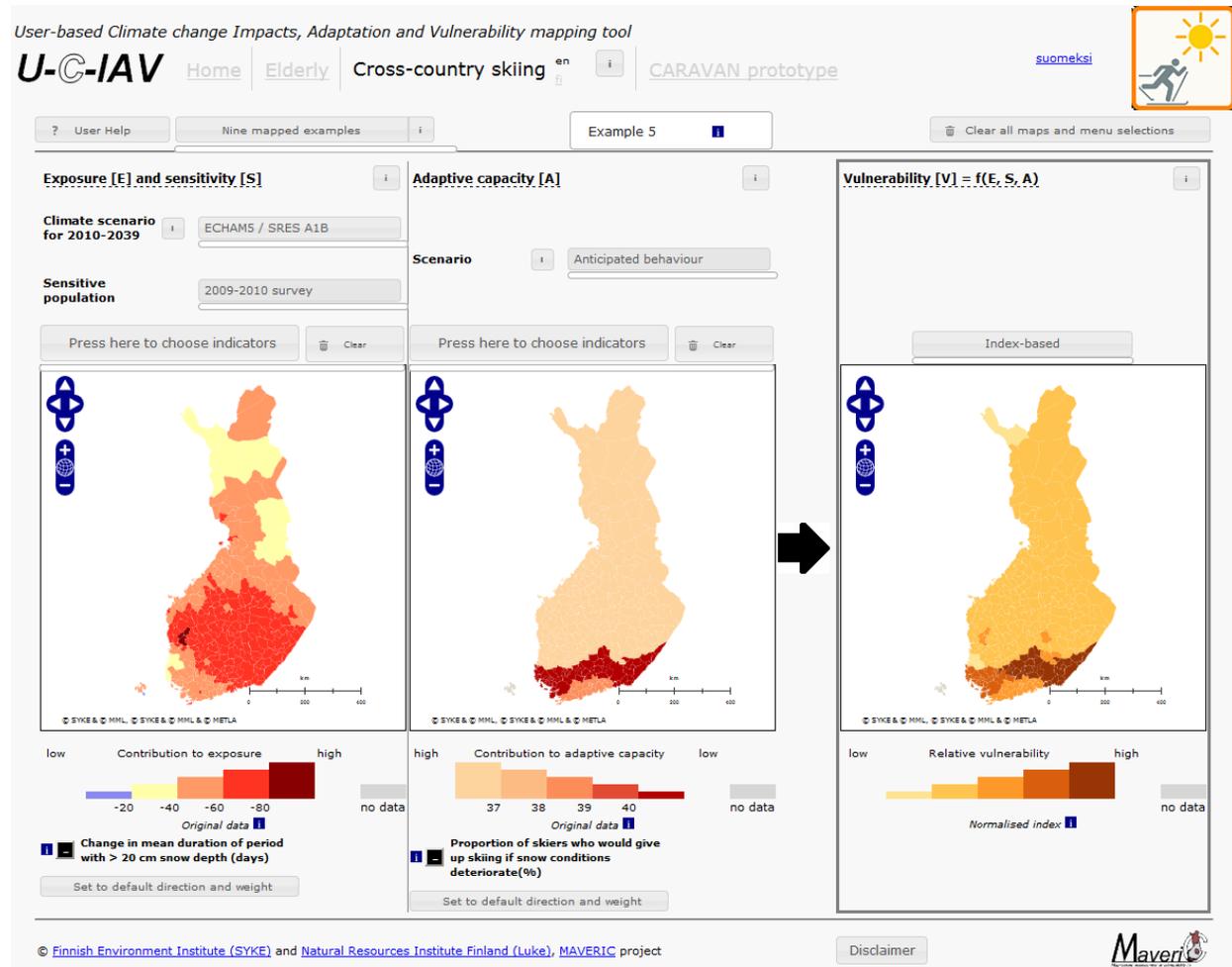
This example presents the same snow duration indicator as Examples 2 and 3, but this time an adaptive capacity indicator of technical adaptation is added – the proportion of skiers willing to upgrade their equipment, also expressed in original units of percent. Lower values indicate less willingness to upgrade equipment, which can be interpreted as contributing to greater vulnerability of skiing as an activity. Willingness to upgrade the equipment is lowest in southern Finland and the Helsinki region, and combined with projected snow duration, the resulting pattern of vulnerability is similar to that for the proportion of skiers indicating that they would give up skiing.



**Figure S4:** Screenshot of the mapping tool for Example 4, showing the combination of indicators describing the change in mean duration of the period with >20 cm snow depth by 2010-2039 for the ensemble mean climate scenario (left, days) and the proportion of skiers willing to upgrade their equipment (centre, %) and the resulting vulnerability index (right, normalised).

### Example 5: Alternative projection of snow decline + risk of giving up.

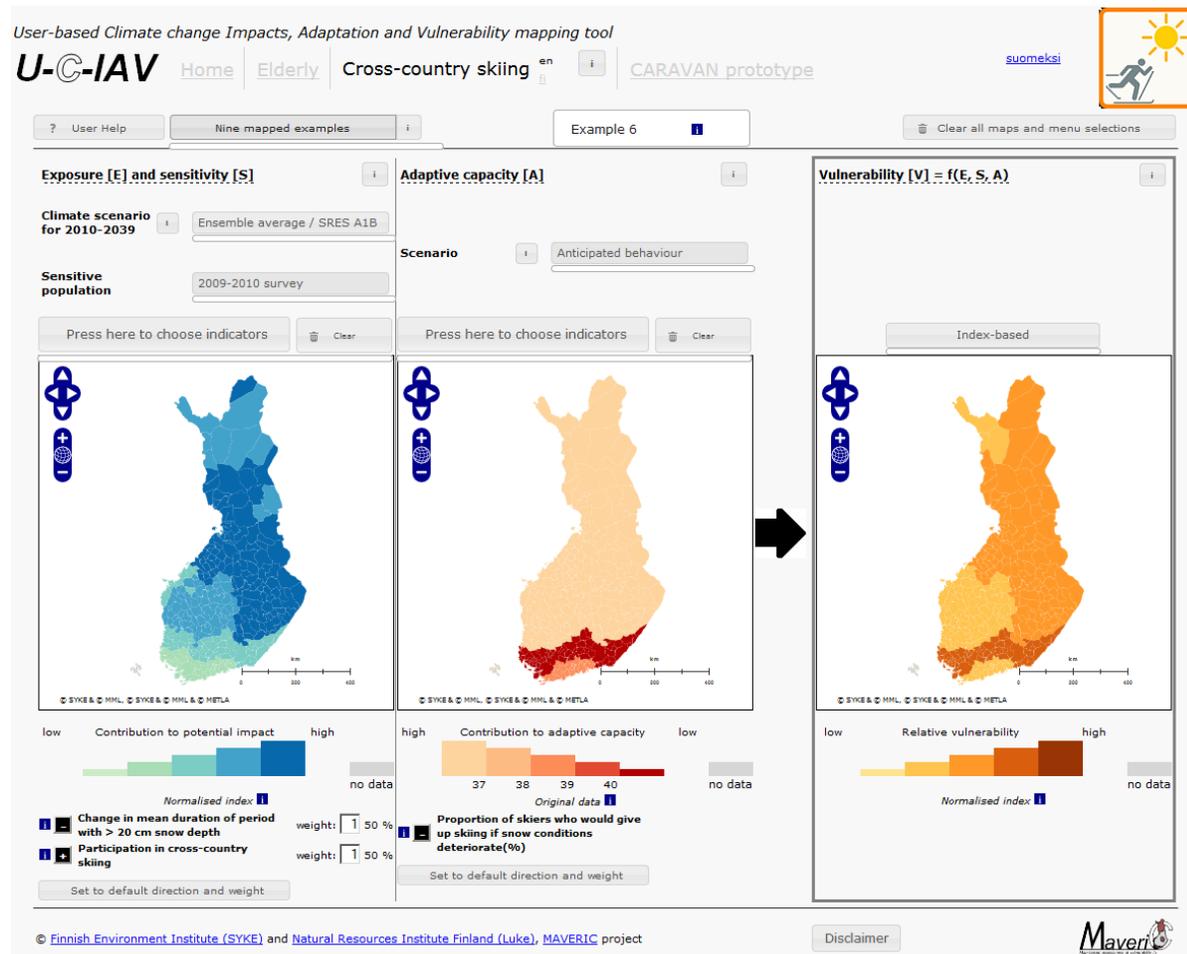
This example is a variation of Example 2, and combines the same indicator of snow duration with that of the proportion of skiers who would give up skiing under deteriorating snow conditions. In this case, the projected snow duration is evaluated assuming a different scenario of future climate, based on a single climate model projection rather than an ensemble average. Since this particular scenario shows smaller changes in duration than in Example 2, the resulting vulnerability map also shows lower vulnerability in many regions.



**Figure S5:** Screenshot of the mapping tool for Example 5, showing the combination of indicators describing the change in mean duration of the period with >20 cm snow depth by 2010-2039 for the ECHAM5 climate scenario (left, days) and the proportion of skiers who would give up if conditions deteriorated (centre, %) and the resulting vulnerability index (right, normalised).

### Example 6: Projected snow decline and percentage of skiers + risk of giving up.

In this example, the indicator of exposure (change in mean duration of the period with >20 cm snow depth for the ensemble mean climate scenario; also depicted in Examples 2-4), is combined with the indicator of sensitivity (proportion of the population aged 15-74 who ski; also depicted in Example 1), to form a composite index in the left hand panel. The map incorporates not only an objective estimate of how the snow conditions are projected to change in different regions in the future, but also the numbers of skiers affected, which also varies regionally. The combination of exposure and sensitivity is sometimes referred to as potential impact, so the composite map can be interpreted as a measure of the potential impact of climate change on cross country skiing as an activity. This potential impact is combined with the same indicator of activity-level adaptation (proportion of skiers who would give up skiing under deteriorating snow conditions; as used in Examples 1,2 and 5), resulting in the vulnerability map on the right hand panel. Here, vulnerability is greatest in southern Finland, and least in the Helsinki region and western and northwestern Finland.

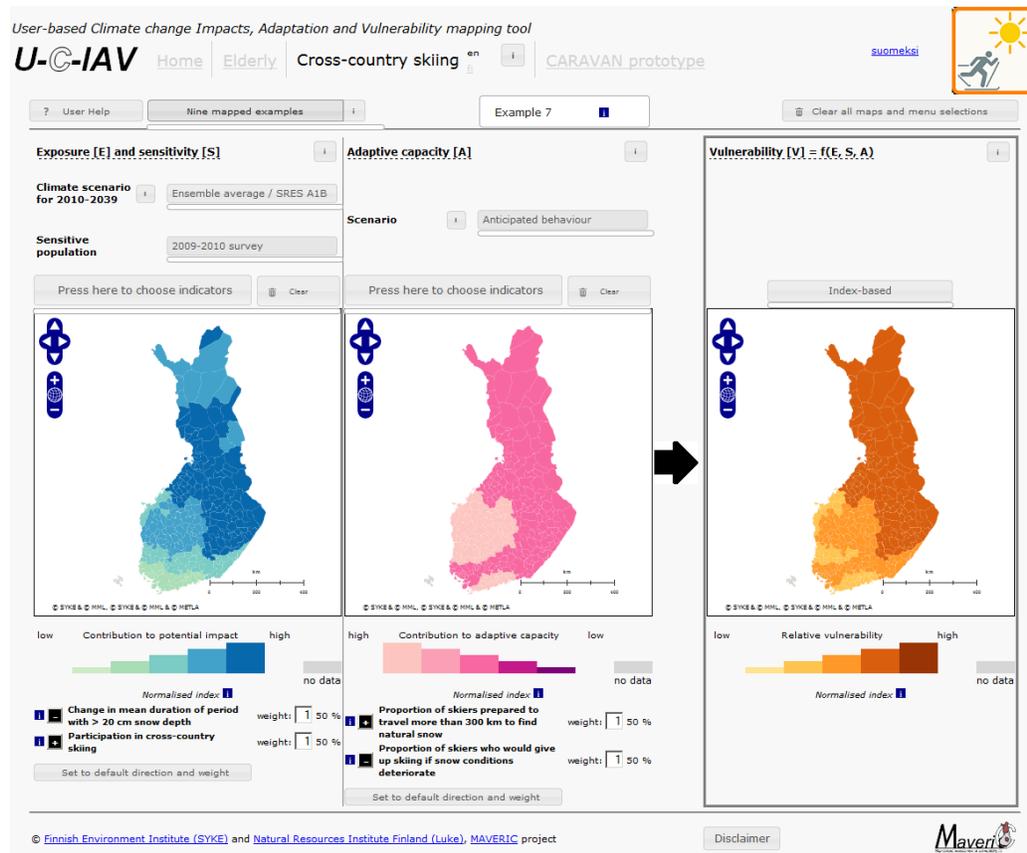


**Figure S6:** Screenshot of the mapping tool for Example 6, showing combinations of indicators describing the change in mean duration of the period with >20 cm snow depth by 2010-2039 for the ensemble mean climate scenario and the proportion of the population who ski (left, normalised) and the proportion of

skiers who would give up if conditions deteriorated (centre, %) and the resulting vulnerability index (right, normalised).

Example 7: Projected snow decline and percentage of skiers + risk of giving up and resistance to travel.

This example is similar to Example 6, with the same indicators of exposure (snow duration) and sensitivity (number of skiers) merged into a composite measure of potential impact in the left panel, but with the measure of adaptive capacity now consisting of a composite of two indicators. The first is the same indicator of activity-level adaptation (proportion of skiers who would give up skiing under deteriorating snow conditions) as used in Example 6. The second is an indicator of locational adaptation (the proportion of skiers prepared to travel more than 300 km to find natural snow) as used in Example 3. These two indicators show opposite gradients of adaptive capacity across Finland, so the composite index of the two presents a more even distribution (middle panel). Combined with the composite index of potential impact, the resulting vulnerability index shows somewhat greater vulnerability in northern and eastern Finland than in southern and western Finland.

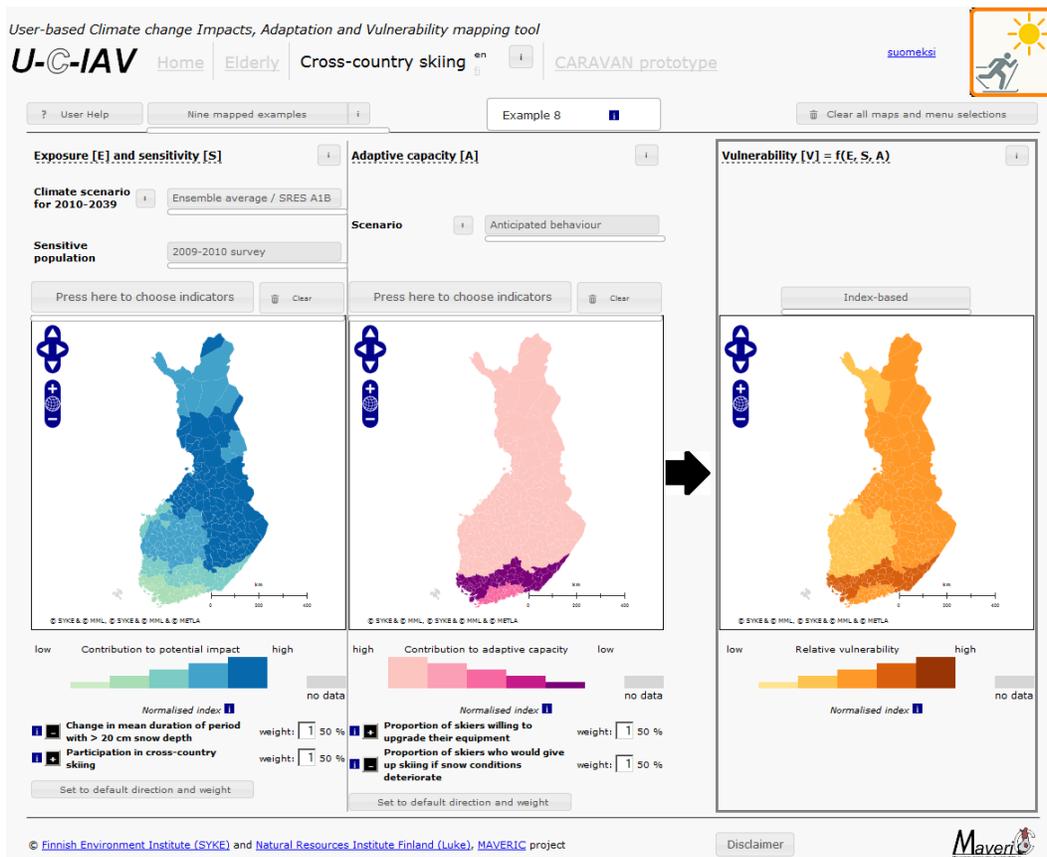


**Figure S7:** Screenshot of the mapping tool for Example 7, showing combinations of indicators describing the change in mean duration of the period with > 20 cm snow depth by 2010-2039 for the ensemble mean climate scenario and the proportion of the population who ski (left, normalised) and the proportion of skiers who would give up if conditions deteriorated and the proportion of skiers prepared to travel more

than 300 km to find natural snow (centre, normalised) and the resulting vulnerability index (right, normalised).

Example 8: Projected snow decline and percentage of skiers + risk of giving up and resistance to upgrade.

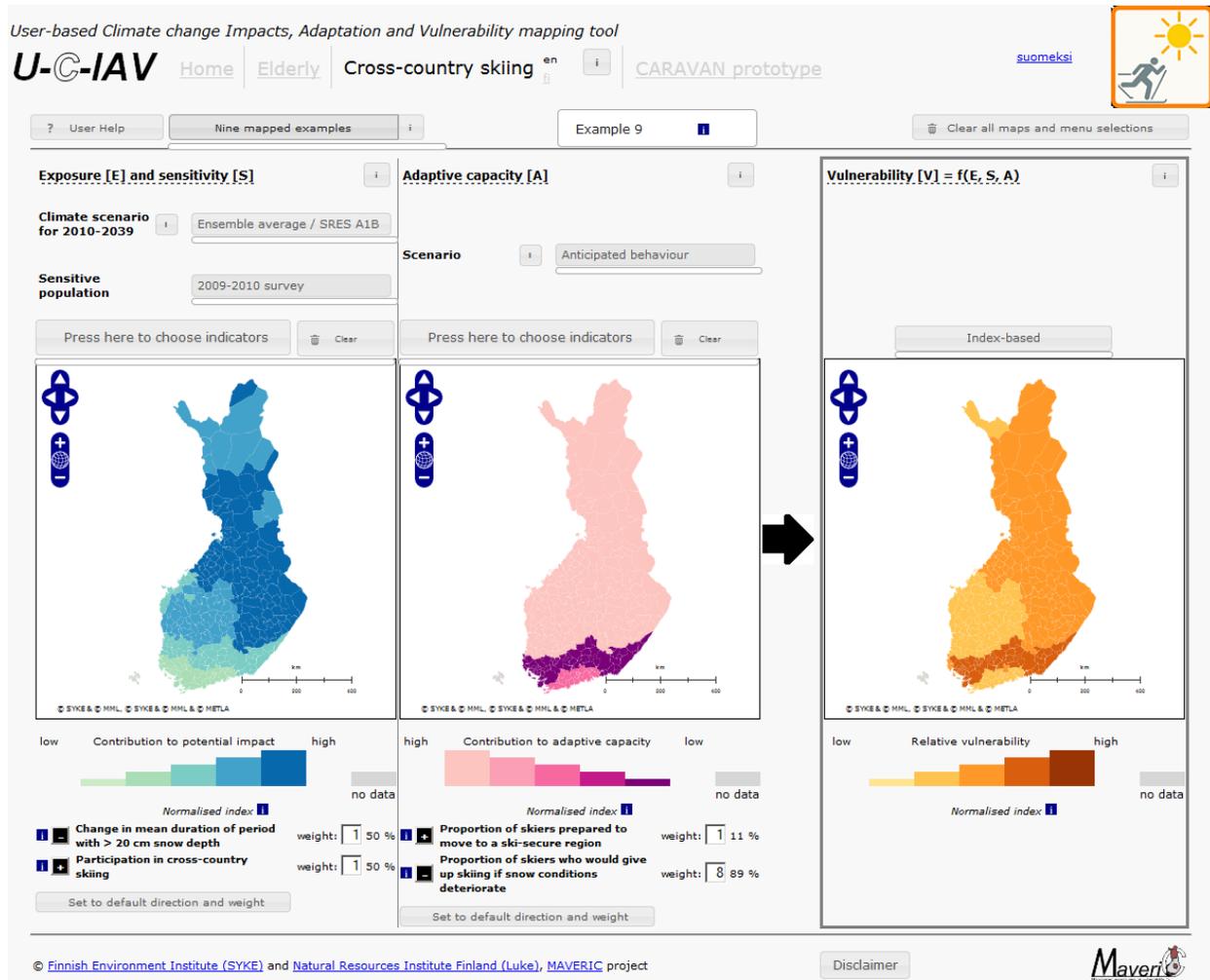
A similar example to Example 7, with the same indicators of exposure (snow duration) and sensitivity (number of skiers) merged into a composite measure of potential impact in the left hand panel, but with a composite index of adaptive capacity based on a different combination of two indicators. The first is the same indicator of activity-level adaptation (proportion of skiers who would give up skiing under deteriorating snow conditions) as used in Examples 2 and 6. The second is an indicator of technical adaptation (proportion of skiers willing to upgrade their equipment) as used in Example 4. These two indicators have very similar distributions, so the composite index of the two reinforces their patterns of adaptive capacity, with lower values in the south than the north (middle panel). Combined with the composite index of potential impact, the resulting vulnerability index shows greatest vulnerability in southern Finland and lowest values in the west and north-west, a pattern very similar to that presented in Example 6, but contrasting to that in Example 7.



**Figure S8:** Screenshot of the mapping tool for Example 8, showing combinations of indicators describing the change in mean duration of the period with >20 cm snow depth by 2010-2039 for the ensemble mean climate scenario and the proportion of the population who ski (left, normalised) and the proportion of skiers who would give up if conditions deteriorated and the proportion of skiers willing to upgrade their equipment (centre, normalised) and the resulting vulnerability index (right, normalised).

Example 9: Projected snow decline and percentage of skiers + risk of giving up (x8) and resistance to move.

Another example similar to Examples 7 and 8, with the same indicators of exposure (snow duration) and sensitivity (number of skiers) merged into a composite measure of potential impact in the left panel, but a composite index of adaptive capacity based on a different combination of two indicators. The first is the same indicator of activity-level adaptation (proportion of skiers who would give up skiing under deteriorating snow conditions) as used in Examples 2 and 6. The second is a different indicator of locational adaptation (proportion of skiers prepared to move to a ski-secure region). This is an example where weighting of indicators might be appropriate. Since the adaptive capacity indicators are based on survey information, they reflect responses to different questions. It can be seen from plots of the indicators in their original units that very few (up to about 5%) of the respondents would be prepared to move to ski-secure regions. Many more respondents (more than 40% in some regions) indicated that they might give up skiing. Compositing these two indicators requires standardising both between 0 and 1, so that a 5% response for one indicator would be accorded similar weight to a 40% response for another. Users have the possibility to account for such a disparity by attaching weights between 1 and 10 to each individual indicator. In this example, a weight of 8 is attached to the adaptation action of giving up skiing. As such, the composite index in the middle panel as well as the vulnerability index in the right hand panel are dominated by the pattern of the heavily weighted indicator – giving up skiing.



**Figure S9:** Screenshot of the mapping tool for Example 9, showing combinations of indicators describing the change in mean duration of the period with >20 cm snow depth by 2010-2039 for the ensemble mean climate scenario and the proportion of the population who ski (left, normalised) and the proportion of skiers who would give up if conditions deteriorated (weighted x8) and proportion of skiers prepared to move to a ski-secure region (centre, normalised) and the resulting vulnerability index (right, normalised).