Environmental Science & Policy 63 (2016) 143–150

Contents lists available at ScienceDirect

Environmental Science & Policy

journal homepage: www.elsevier.com/locate/envsci

A multiple timescales approach to assess urgency in adaptation to climate change with an application to the tourism industry

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ARTICLE INFO

Article history:
Received 6 January 2016
Received in revised form 11 May 2016
Accepted 23 May 2016
Available online 6 June 2016

Keywords:
Climate change
Adaptation
Climate vulnerability
Timescale
Tourism industry

ABSTRACT

As climate change adaptation is increasingly discussed and becoming a mainstream concept, different types of users are asking themselves if and when they should develop an adaptation strategy, often not knowing where to begin. Climate experts, on the other hand, have access to an enormous amount of data that could be useful to users but often do not know how to translate it into something practical. Both users and experts can be linked through two timescales, the system lifespan and climate vulnerability. While the system lifespan relies on the user's estimation of his planning timeframe, the climate vulnerability is estimated from climate model projections and observations. We propose a simple tool to relate user and climate expert knowledge by combining the two timescales. To be reliable, the interconnection implies a dialogue to first identify what sensitive climate variable will impact the system and subsequently the extent of the impact. Climate data can then be used to identify, with the use of a simple graph, how sensitive a system is likely to be and help users position themselves about the urgency of adaptation. The concept has been successfully presented and applied to the tourism industry, notably the ski industry, which is showcased in this paper.

1. Introduction

The threat of a changing climate due to greenhouse emissions during the present century has not only attracted the attention of scientists in diverse domains, but has also affected international politics and moved to action national governments, institutions, companies –from large businesses to small and medium size enterprises (SMEs) – and even private citizens. Increasingly, those presumably at risk are reaching out to climate change and adaptation specialists inquiring about how to better evaluate their vulnerabilities. The spectrum of situations is vast and ranges from cases where actions are necessary –and even urgent–, to cases where no action is required.

For the user of climate information, pinpointing where their situation fits within a spectrum of possibilities is surely a complicated task: overestimations or underestimations of overall risks are both common and undesirable due to their probable consequences. On the other hand, a climate expert providing information (data or analysis) for decision-making or planning may only have a superficial understanding of a given activity, and may hence fail in adequately estimating the risks by assuming characteristics of the activity that (s)he in fact knows very little about.

Proper answers to questions such as "Do I need to adapt right away? ' or "When will climate change have an important enough impact to require adaptation?' can only be obtained through comprehensive collaborative interactions between climate experts and users. *There are, however, situations in which a more or less rapid screening of both the user's activity and the climate information can help to elaborate a preliminary answer.* Moreover, the importance of a first screening, before going further with more sophisticated approaches if needed, has been emphasized by Maraun et al. (2015).

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http://dx.doi.org/10.1016/j.envsci.2016.05.018
1462-9011/

In this paper, we propose to simultaneously use climate information expressed in commonly used units of time (years) produced by climate experts and knowledge of vulnerabilities from users to obtain a sense of their risk. In addition to this, information regarding their business-planning horizon will point to the need or urgency to adapt to climate change. The final conclusion can be reached by inspecting information presented on one simple easily understood graph. Developing such a visual tool can support governmental organizations dealing with multiple requests, as well as users having difficulty obtaining tailored information from climate institutions saturated with demands.

Others tools for decision-making in climate change adaptation have been developed during the last decade or so (Brown et al., 2012; Kalra et al., 2014). The novelty of our approach is to present timescales in such a way as to make them intuitively understood by non-specialists. The timescale approach applied to climate change has been used previously (Jones and Mearns, 2005; Hallegatte, 2009; de Elía et al., 2014) but to our knowledge it is the first time that multiple timescales are combined in a single, simple tool for preliminary decision-making.

In the next pages the methodology will be explained, first describing the two timescales (Section 2) and the prioritization process (section 3). Exampls will be illustrated in Section 4, first with some hypothetical cases from Québec's tourism industry and then with a preliminary real-case application to a ski resort in southern Québec. Note that the question of adaptation to climate change will be examined under a constant paradigm, assuming that important drivers such as economic development, population growth and other major factors remain unchanged.

2. The issue of timescale

Climate change is an ongoing process that affects the planet in multiple ways, but it concerns humanity mainly because its associated timescale is comparable to the length of a human life *and* because we are vulnerable to such changes. In this sense, it is important to grasp the double nature of human dependency: we may be vulnerable to a given change but this change may happen so slowly that major civilization changes could happen before any threatening event occurs (think, for example, of the next Ice Age coming perhaps in the next 20 thousand years). On the other hand, changes can occur promptly without us being vulnerable to it; or changes can also have immediate consequences without allowing any time to react.

In terms of human activities, the situation is similar. For example, for tourists thinking about their next winter holiday or vacation destinations and government agencies worried about seasonal occupancy rates, climate change may seem trivial compared to other clear and present concerns affecting tourism development such as landscape degradation by coastal erosion, natural resources scarcity, shifting travel patterns, destination attractiveness or volatile economic conditions. However, this situation can evolve when risk management and strategic decision-making are framed to adopt a long-term vision. In that context, climate change impacts should be included in their assessment of financial and environmental vulnerabilities as well as financial and environmental vulnerabilities. For example, those planning to sell or invest in businesses, or assets such as infrastructures (e.g. resorts, land, trails, properties) must consider cumulated seasonal peak income and should be aware of climate change and its positive or negative effects on supply and demand.

Two timescales emerge from these examples, one describing the lifespan of a given activity, infrastructure, organism or planning horizon of a business, and the other describing the timescale associated with climate change and how it may put the activity at risk. In what follows, we will discuss both timescales labeling them *lifespan* and *vulnerability* timescales, respectively.

2.1. System lifespan

All institutions, businesses and structures possess their own lifespan depending on their field of activities. Table 1 (adapted

Table 1
Planning horizons relevant to climate risk assessments.

Planning scale/ lifespan (years)	Institutions, businesses and structures	Tourism interests
0–5	Election cycles	Disaster risk management, business & management strategies, market development, climate image branding and marketing, innovation & technology, insurance and financial products Disaster risk management
5–10	Profit and loss Agriculture (farm planning)	Tourism Small and medium size enterprises Cruise ship routing
10–20	Plant breeding (new crops) Forest lease agreements Pulp plantation Generational succession	Tourism development planning and master plan, recreation and visitors facilities maintenance, tourism policy & regulations
20–40	New irrigation projects Coastal infrastructure	Tourism structural investments (e.g. accommodations, access roads, marinas, etc . . .) National and provincial parks development strategies Tourism behavior: visitation and travel patterns (intra, inter-regional and international) Insurance needs Location analysis and land-use planning Developing climate competitive advantage Landscape, natural resource supply and services (e.g. water, ecosystems & biodiversity)
40–60	Tree crops Long-term biodiversity	Airport design life Site location Regional policy and planning
50 and up	Intergenerational equity Coastline and flood defences Large dams Bridge design life Land-use planning	Conservation New protected area planning

Adapted from Jones and Mearns (2005), Scott and Jones (2006); Hall (2009), Hallegatte (2009), Scott and Lemieux (2009) and Scott et ?al. (2011b).

from Jones and Mearns, 2005; Hallegatte, 2009; Scott and Lemieux, 2009; Scott et al., 2011b) illustrates approximate lifespans for different activities with a special focus on the tourism industry. Even if these values are indicated with apparent precision, they are in fact rather vague and dependent on multiple factors. It is preferable to take them as approximate, disputable values for which more in-depth knowledge is needed. In what follows, we will refer to this planning scale by the symbol n_{ls}.

Some activities can adapt quickly to changes while others –like those depending on massive investments in infrastructure—cannot do so and hence the consideration of threats such as climate change becomes necessary.

As discussed above, knowledge of the planning timescale is fundamental for understanding risk vis-à-vis climate change. Only experts in a given activity have the knowledge to estimate this timescale for their own system, but even for them the situation is not trivial: each activity could be described in terms of different fundamental timescales according to the particular aspect that is under study. For example, in agricultural production, different timescales coexist such as the short-term annual planning for planting purposes, the mid-term planning of loans for certain investments needed for new crops, and even the longer term planning (few decades) that is imposed by generational change. The planning scale for outdoors tourism and for small and medium sized recreational enterprises (SME's) is generally relatively short, but can span a few decades for the largest investments and is much longer for infrastructures that support tourism services (e.g. coastal or mountain infrastructures), as illustrated in Table 1. The biggest challenges will then to relate imprecise lifespan information to climate information having its own uncertainties, and to bridge this gap between providers and users to arrive at usable figures. This implies creating a relationship of trust that takes time to develop.

2.2. System vulnerability timescale

Almost all human activities have some form of relation to weather and climate –some through a vague dependence, some more direct. This relation or dependence on weather and climate may not necessarily transform into a large vulnerability to climate change –not even for activities that are impacted by weather disturbances.

Identifying this dependence may not be a simple matter. Hallegatte (2009) presents a list of generic activities with their associated level of exposure to climate change. To develop the idea further and evaluate specific cases, we propose that the vulnerability of a system should take into account both the degree to which the system is susceptible to the adverse effects of climate change and the ability to cope with these impacts. It is therefore a function of the magnitude and rate of change to which a system is exposed and of the sensitivity and adaptive capacity of that system. For example, most infrastructures are insensitive to a 4 °C change in average temperature. The same is true for many activities, such as professional sports. That is, if today's climate projections happen to be accurate, in 100 years from now, events like the Indy 500 car-racing competition could be celebrating their 200th anniversary unharmed by climate change. On the other hand, seasonal winter sports like alpine and cross country skiing, skating or ice fishing may become restricted to fewer world locations and operational days. Some researchers even question whether past suitable climate locations, such as Vancouver, Canada, will still have the capability of hosting future winter Olympic Games (Scott et al., 2015). The difference between these examples is the respective vulnerability of recreational or sport activities to a change in climate conditions (Scott et al., 2004).

Most institution leaders are well aware of their sensitivity to climate –through their experience of climate variability–, but they ignore how the climate is going to be changing in the next decades. For example, they may know that more rain would be bad for their businesses, but they usually ignore whether climate change projections in their region predict more rain for the future. Furthermore, they ignore the timing of the change in the future and which form this potential change in precipitation is going to take (more severe thunderstorms, more heavy snow, all of which can occur even as there are more dry spells). As for climate experts, they do have access to information regarding climate change but are typically unaware of the vulnerabilities or sensitivities of a given user or sector. Is an increase of 2 °C in average surface temperatures hazardous or likely to have a negative impact for a given user? Or is the relationship rather more complex, like the number of times a year a certain temperature threshold will be crossed? Or is another climate variable, such as precipitation more important?

The vulnerability timescale can only be estimated with the contribution of both climate specialists and users (e.g. from the tourism industry). To clarify these issues, a survey of the weather and climate variables that can affect the activity must first be carried out (e.g. summer temperature, rainy days). This analysis should also consider which statistics is of more concern (average over a given period, extremes, etc.). Unfortunately, this identification may not be as trivial as it may appear: first, one may inadvertently confuse one variable with another. For example, most farmers naturally think of precipitation as a key element when they worry about their productivity. But in a future, warmer climate, increased evaporation is going to produce drier soils for the same amount of precipitation. So it is important to uncover the users' real issue, which in this example may in fact be soil moisture.

Another reason that makes this exercise non-trivial is that sensitivities to climate change usually cannot be simply described using single statistics (for example the mean) and that vulnerability's threshold must be defined for each user. For example, one business activity may depend on winter temperatures. The way the temperature affects the business must then be known: the average temperature is a different statistic then the annual extreme. And finally, a threshold must be defined, as for example if three consecutive years out of four with extreme conditions may be enough to derail plans even if the long-term average has barely changed. The user could confidently claim that he had bad luck, but we can also think that their vulnerabilities were underestimated. And what's more, if there is more than one important variable, you will need to know all the thresholds, which will term here vulnerability thresholds.

Once analysis portrait of the climate indices that may have important impacts to a user is available through climate variable thresholds, it is up to the climate expert to provide the information about whether that change is to be expected and when. As the user faces difficulties in defining with some precision their vulnerability thresholds and the lifespan of their activity, climate experts are equally confronted with important problems, as dealing with imperfect models and climate variability that make their task complex. Nonetheless, when all the necessary information is collected, an idea of the vulnerability timescale can be obtained through the following expression (see de Elía et al., 2014)

$$n_v = 100 * s/\beta \quad (1)$$

where s and β are as defined in Fig. 1, with the former being the user-defined (vulnerability) threshold and the later the centennial trend of the normal distribution of a variable. The factor 100 converts the vulnerability time scale n_v to year units. With this definition, an activity vulnerable to an increase of 2 °C in a region

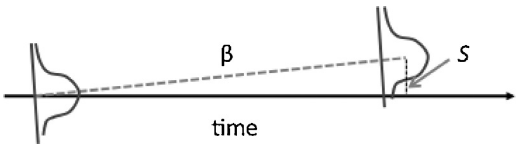

Fig. 1. Schematic representation of change trough time of a normal distribution of a variable with a vulnerability threshold of s and a trend β.

where the projected trend is 5 °C/century will result in a vulnerability timescale of $n_v = 40$ years. From this expression, one can see that the larger the threshold, the less sensitive a system is. In addition, the larger the trend, the larger the climate change impact will be for a fixed period of time. Finally, when the vulnerability timescale (n_v) is high, it implies that the system is less vulnerable.

In general, ordinary human activities are affected by climate variability and hence businesses, institutions and infrastructures are built to resist weather and climate variations to some extent, with the exception of the least common events. In other words, the climate is intrinsically variable (think for example of the fact that some winters are colder than others) and systems are intrinsically adapted to this natural variability. For this reason, it is natural to rewrite (1) with the threshold expressed as a function of the time standard deviation of the variable of choice, so that

$$n_v = 100 * k\sigma_{\mathbf{x}}/\beta \quad (2)$$

where k now represents the threshold as a function of standard deviations, and $\sigma_{\mathbf{x}}$ is the time standard deviation of the time average of the variable x. Expression (2) tells us that robust systems are those with a large k, namely a large threshold. In this case, the users are already adapted to important variability and under this current trend, it will take a long time before the system is destabilised. In other words, the change may not occur fast enough for the threshold to be reached in a timescale that matters for the user. But how do we know if the system is robust? For example, we can look at a ski resort concentrating on a relevant variable related to snow cover over an entire season, and a threshold of the of 10% of the distribution, which is associated with a minimum seasonal amount. Different resorts located in different regions already have infrastructures that are adapted to the current natural climate variability but thresholds will eventually be exceeded in the future as the snow season shortens. The time it takes to reach this threshold corresponds the vulnerability timescale n_v, described above (Eqs. (1) and (2)). An example of how climate vulnerability timescales may differ across North America can be found in Fig. 3 of de Elía et al. (2014), who computed the values based on nine NARCCAP regional model simulations (Mearns et al., 2009).

The vulnerability timescale should not be interpreted directly as 'years from now' because it depends on the question posed. However, the simplest interpretation refers to the time it takes for a variable (surface temperature in our previous example) to change by a given amount (one standard deviation), independent of starting time. By adding additional information, the goal is to highlight the rate of change in the climate over a time period that is relevant for a given system or activity.

2.3. Combining timescales

Having access to information regarding the lifespan of the system and its climate vulnerability timescale allows us to define the relative speed of the climate change for the activity of interest. Whether climate change is a fast or a slow process can only be decided with respect to the lifespan of a system. Fig. 2 shows a diagram that helps us visualize this relationship between the vulnerability timescale n_v (on the y-axis) and the lifespan n_{ls} of the system (on the x-axis). The scales, which in this case reach approximately 100 years, have to be long enough to detect a climate change signal in most of the variables, but short enough to correspond to a horizon that is relevant for humans. This is linked to the fact that the system lifespan n_{ls} does not go further in main literature while simulations can calculate the vulnerability timescale, n_v, for much longer periods, although they usually stop in 2100. We divided the graphical space into sections, each one being associated with a degree of urgency as to whether to take adaptation action or not. Adaptation is used here to refer to initiatives or measures that are meant to reduce the vulnerability of a system to climate change. The separation between the different sections are not clear-cut but rather blurred, marked only with different shades of colour, from greenish to represent no urgency towards a more reddish colour for pressing action. This colour gradient allows case-by-case interpretation. Interpretation of this diagram may be influenced by factors unrelated to the discussed timescales, such as funding availability or political agenda, and low cost or no regret actions may also be undertaken whatever result this diagram shows. The term redesign found on the graph is meant to be regarded as an adjustment or 'tweaking' of the system. Examples of redesign would be to shift the timing of the agricultural planting season as a rapid measure and to switch to a new crop species (after analyses and studies) for a longer-term measure.

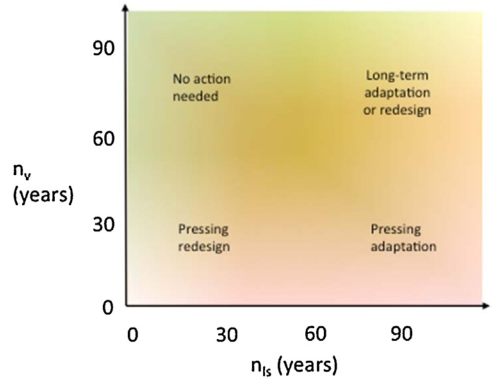

Fig. 2. Relationship between the vulnerability timescale n_v and lifespan n_{ls}. Both are expressed in years. Urgency in the adaptation response depends on the position on the graph.

Activities with very short lifespans or planning horizons compared with their climate vulnerability timescale (upper left section of Fig. 2) are not as concerned with the evolution of the climate. In other words, they are too short and will be finished by the time climate change starts to become a nuisance. At the opposite end of the spectrum, we find activities with long lifespans or planning horizons whose sensitivity to the climate puts them at risk over a relatively short time span (lower right section of Fig. 2). This section represents a typical example where an adaptation intervention is needed.

For users, this four-quadrant rule-of-thumb illustrated in Fig. 2 can be appropriate to produce a tentative answer to the question "Do I need to prioritize adaption to climate change?". The simplicity of the graph for non-scientists, and the fact that the main unit (years) independent of the variable used in the analysis, makes it we believe, a powerful tool for communication. The reality of this assumption is preliminary discussed in Sections 4.2 and 4.3.

3. Prioritising adaptation measures

The method described above may be of interest to users wanting to know if or when climate change should be a concern for them. It may also be of use for those decision makers trying to prioritize whether or where climate change adaptation funds should be spent. Clearly some problems are more urgent than others, but the diagram presented on Fig. 2 lacks an important information, namely an indication of the importance of the activity: it may need urgent climate change adaptation, but may also be relatively unimportant. For decision makers, the societal importance of an activity is a dimension of utmost importance, regardless of the urgency of the problem in terms of the climate and its impact. Indeed, resources are not infinite and decisions must therefore be prioritized. While climate change will begin to impact a system given enough time, this does not mean that we need to take action right away. Proper prioritization and allocation of resources should ensure that prevailing risks are given the necessary attention.

In order to account for the societal relevance of an activity, an additional dimension can be added to Fig. 2 so that it better represents these additional concerns of decision makers. Such a scale should be dimensionless (although it may be tempting to use currency as a proxy for societal importance) and for the sake of simplicity we may only divide it in three categories: namely high (H), medium (M) and low (L) priority. Fig. 3 shows such a schematic with hypothetical extreme cases where prioritization should be easy: pressing adaptation is needed for a high priority activity and no action for a low priority activity. Of course, in reality, there may be some opportunities (or political needs) that will change the order of the execution, but with the help of Fig. 3, such choices could at least be made consciously. This three dimensional perspective can also be represented in a single expression:

$$\textbf{priority of adaptation} = \textbf{societal importance} \times \frac{n_{ls}}{n_v} \quad (3)$$

where prioritization increases with societal importance and lifespan of the system (n_{ls}), and diminishes for long vulnerability timescales (n_v). This expression by itself could be an informative discussion tool.

4. Some applications

As mentioned above, part of the challenge of this research was to find users willing to test some our ideas. To break the ice, we took advantage of a work meeting on climate change adaptation initiatives, held at the Laurentians regional county municipality (RCM), north of Montréal, during the spring of 2015. Numerous

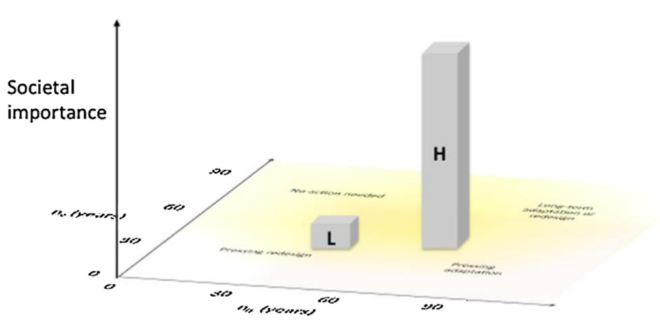

Fig. 3. 3-D relationship between the vulnerability timescale n_v, lifespan n_{ls}, and societal importance. The first two dimensions, n_v and n_{ls}, identicals to Fig. 2, are expressed in years, while the third axe, societal importance, is dimensionless. The letters H and L stand for high and low priorities. Urgency in the adaptation response depends on the position along the x and y axes as well as the height of the societal importance bars.

parties were in attendance, such as private and public tourism stakeholders, both climate and vulnerabilities, impacts and adaptation specialists from Ouranos – a Consortium on Climate Change, experts from the Transat Chair in Tourism from Université du Québec à Montréal, along with provincial government bodies that promote local and regional economic development and support entrepreneurship. This meeting was the starting point by using the tourism industry as a case-study for the application of the proposed framework. However, before going into the specifics of how this was done, a short introduction of the impacts of the climate on the tourism industry is required.

4.1. Climate and the tourism industry

From a traveller's point of view, climate has a broad significance to his decision-making and his vacation experience. Climate is of crucial importance in defining a particular destination's pull and as such, is a key factor in the selection of a holiday destination and timing of holiday. Climate may also influence the proportion of domestic and international holidays, tourism expenditures, and overall holiday satisfaction (Becken and Hay, 2012; Scott and Lemieux, 2009). This close relationship between climate and the tourism industry makes it particularly sensitive to climate change, although not all individual issues are equally sensitive (Kovacs and Thistlethwaite, 2014; IBC, 2012).

The second column of Table 1 illustrates different timescales of climate information for decision-making and planning as it applies to tourism. Historic climate information has in the past been the main source of information used for strategic planning of future tourism developments (Scott et al., 2011b). However climate change projections are now more frequently being utilized to anticipate and adapt to market risks and opportunities at the business, regional and national level. In fact, financial institutions are increasingly taking climate change into account when granting and guaranteeing loans since climate changes may potentially induce large financial consequences on a sector already considered a risky business due to its strong links with the economic situation. It is therefore in the best interest of tourism stakeholders and companies to put forward innovative climate change adaptation strategies to minimize climate change risks and take advantage of potential economic opportunities (Bleau et al., 2015).

4.2. Our experience in a workshop with stakeholders of the tourism industry

One of the aims of the meeting was to provide tourism stakeholders with a greater understanding of climate change and climate information, and to showcase how scientists can provide insights for risks management and decision-making by providing timescales for processes. In order to facilitate the stakeholders' comprehension of the procedure, different hypothetical examples were derived from recreational and outdoor activities for most sections of figures shown on Figs. 2 and 3. The use of hypothetical examples instead of real case studies was at that point inevitable, since no case study could be built without substantial prior contribution from users.

Stakeholders sometimes mix the concepts of climate and weather, climate change and natural variability. The discussion attempted to facilitate explanations by climate specialists in order to focus on climate and climate change, as well as to determine who should adapt and finally to prioritize decision-making actions.

The first hypothetical example focused on a seasonal recurring outdoor festival sensitive to weather variations but mostly insensitive to slow climate changes. The kind of activity deployed and its administrative structure was presented as able to quickly react if climate change would become a nuisance. This was the prototypical example of activities where climate change was not a concern (upper-left quadrant of Fig. 2).

Secondly, a hypothetical example based on ski infrastructures was presented to demonstrate planning on a longer timescale. This climate change sensitive sub-sector, we argued, is very dependent on accumulated amounts of snow (artificial and natural) at critical peak periods, namely Christmas, Spring break and Easter holidays. In this particular case, given that investment planning is designed for a few decades and that snow accumulation is very sensitive to climate change, pressing adaptation is needed (lower-right quadrant on Fig. 2). An example of adaptation measures presented to owners of ski resorts was to further develop their summer activities.

The last hypothetical example focused on national park conservation. This vital issue needs to consider the sensitivity of the wildlife (fauna and flora) to climate change as well as the management of the national park, both resulting in long-term adaptation and redesign responses (upper-right quadrant). However, it is important to keep in mind that, as discussed by Holling (2001), ecosystems vulnerability thresholds are very difficult to estimate, and hence here the rule-of-thumb showed its limitations. Further research is needed to obtain a more satisfying answer.

The presentation was well received by participants and led to a transparent dialogue on sector planning horizon, focusing on its relationship with long-term climate change (previous meetings with the same kind of stakeholders had revealed their difficulty to grasp the climate scale outside climate natural variability). Local and regional impressions on vulnerabilities to climate change were exchanged during this session. Representatives of sectors and activities carried out during all four seasons (regional and provincial parks, regional tourism association cross-country and alpine skiing, camping, cycling, golf) each expressed impacts and adaptation solutions. It was obvious that for these users, the easy-to-understand figures clearly helped them rapidly position their own industry and region regarding prioritization of climate change adaptation versus other more pressing needs and concerns. We found this experience very encouraging but a much more personal and detailed approach will be needed to establish the full potential of our approach.

4.3. Application to southern Québec ski industry

In order to apply our approach to a real-world example, a mature ski resort in the North-American northeast industry has been selected for testing and a partnership has been developed between parties to better integrate business expertise in the research process. Located in the Eastern Towships, the ski area has observed large fluctuations in winter conditions and seasonality's during the last decades (Ouranos, 2015). In order to better cope with these changes, the resorts have adopted a number of strategies such as increasing snowmaking capacity in less snowy years, multiplying innovative marketing initiatives and developing four season market segments. At this stage of proof of concept, limited climate data were used, few variables were chosen, and consequently an in-depth uncertainty analysis has not been carried out. Also, the exercise does not imply prioritization since only one sector/project is studied.

Before our meeting with the stakeholders, the preparation was derived from the literature on hydroclimatic variables with the aim of enlivening the discussion (Olef et al., 2010; Marke et al., 2014; Scott et al., 2011a; Spandre et al., 2015). Table 2 shows the analysis of the two main variables highlighted in the literature – surface daily mean and maximum temperature above a given threshold– that we have used as examples for the vulnerability timescale n_v. Moreover discussions with ski resort managers helped to better define the planning scale n_{ls} related to normal lifespan for tourism investments such as ski lifts, snowmaking systems, and accommodations evaluated between 30 to 50 years.

As the user is adapted to the current historical natural variability, a first step involved determining a reasonable vulnerability threshold (s) is done through the use observed historical climate data. Two different sets of observations were used: Environment Canada's nearest weather station and Princeton University gridded data (Sheffield et al., 2006). This second dataset was shown to have large biases compared to station values in the upper tail of the daily maximum temperature distribution and consequently was not used for this indices. For each climate index (Table 2) a yearly number of events (i.e. days above defined thresholds) was determined from the observed data for the period 1951–2005. From these yearly values an empirical probability density function (pdf) was then estimated using kernel density smoothing and two values of s (see Eq. (1)) were arbitrarily determined as being the width between the median and the 85th percentile of the distribution, as well as the width between the median and 95th percentile. These two values represent extremes with recurrence intervals of approximately 6.5 and 20 years respectively.

The linear trend (β) portion of equation 1 was determined using a 150 year (1951–2100) simulation produced from version 5 of the Canadian Regional Climate Model – CRCM5 (Martynov et al., 2013; Separovic et al., 2013). The simulation was run at a 0.22° horizontal resolution over North America, driven by the first member of CanESM2 (Arora et al., 2011) with both regional and global models following RCP 8.5. Raw CRCM5 data was bias-corrected in order to ensure a similar frequency of climate index events for the period 1951–2005 to that seen in the observed data sets. Yearly numbers of events are then calculated for the entire corrected time-series (1951–2100). The linear trend β (equation 1) of this time-series is then calculated, and in combination with the previously calculated s values, allows for the determination of the vulnerability timescale n_v. The two timescales and their combination for the chosen ski resort are shown in the last column (vulnerability

Table 2
Sensitive variables for the ski industry in North-Eastern North America. Vulnerability timescale values are calculated using Environment Canada stations (bold) and Princeton university data (*italic*). Out of reach indicates that the vulnerability timescale is not attained within the simulated 150 years.

Variable	Vulnerability	Period	Motivation	Vulnerability timescale n_v (years)	
				85 perc.	*95 perc.*
Surface daily mean temperature	Number of days with $T_{mean} > -4\,°C$	November and December	Ski gun performs better if temperature is colder	**80** *50*	**120** *70*
Surface daily maximum temperature	Number of 2 consecutive days with $T_{max} > 10\,°C$	March	Preservation of the snow pack for spring skiing	**110**	**Out of reach**

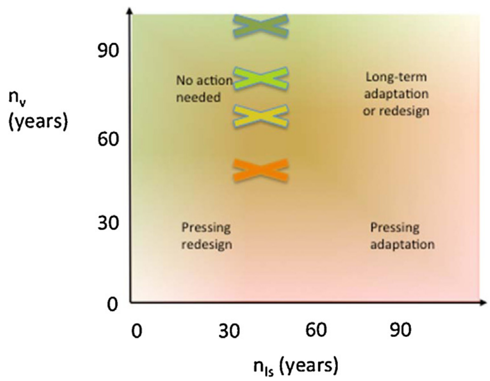

Fig. 4. Relationship between the vulnerability timescale n_v and lifespan n_{ls} for indices related to a ski resort. From green to red, the colors indicate the adaptation urgency. The vulnerability timescale n_v is calculated using CRCM5 data and observations while lifespan n_{ls} was determined by a ski manager.

timescale) of Table 2 and illustrated by "X" on Fig. 4 for vulnerability timescale up to 110 years ($n_{v.}$ of 120 years is not shown).

Under the mentioned assumptions results suggest that timescales are located in-between the sections "No action needed" and "Pressing redesign". The interpretation of results is not definitive but what seems clear is that the time required for infrastructure to become obsolete will more or less coincide with when projected changes in temperature will make the resort economically unsound.

The consensual societal importance (representing the third axis) has yet to be defined for ski stations in general and will depend on station type. Some stations are small family business that will invest substantial money and time to maintain their competitiveness, others are public facilities owned by municipalities with limited budgets that offer subsidies, and the rest are part of large conglomerates with clear financial goals that would likely sell the resort if it is predicted to underperform. In our case, the station is a small family business that brings visibility to the area, in addition to attracting large volumes of visitors in particular from a large city located 100 km away.

Methodology and results were presented to the ski station manager and to the Ouranos tourism program's direction committee, along with an analysis conducted for another resort located in a different region 350 km away. The concepts were rapidly grasped and pertinent questions illustrated their understanding and considerable interest. The following discussion centered on the relevance of the variables and thresholds chosen for this particular case, given the local and regional characteristics. For example, taking February instead of March for the number of 2 consecutive days with $T_{max} > 10\,^{\circ}C$ could help the station plan whether late winter snowmaking, which they currently do until the end of February, should be extended later in March. Regarding the chosen thresholds (85 and 95 percentiles, meaning that if the past 15% or 5% warm years would become the norm, business will be in difficulties), they appear too high for the direction committee, but appropriate for the station manager. A follow-up is planned with a small group of ski resorts to define the details of a more specific case study. The direction committee expressed their enthusiasm for the concept and requested the inclusion of additional climate variables, locations, and simulations in order to evaluate the uncertainty of the results.

5. Some additional difficulties

Aside from the difficulties already mentioned, particularly that none of the factors on the right hand side of Eq. (3) (lifespan of the system (n_{ls}) vulnerability timescales (n_v) and societal importance) are simple to estimate nor unique, other limitations to the proposed approach exist. It assumes that vulnerability is not going to evolve with time for reasons other than climate change. The vulnerability timescale n_v also presupposes an appropriate projection of the evolution of the variables, that is, that climate models are giving us good information. In addition, as discussed in de Elía et al. (2014), n_v is in fact an *expected* value that, due to the random nature of climate time-series, could be in reality a higher or lower value even if climate models were perfect. Difficulties may also arise if observed data are either not available or reliable for the sensitive variable(s). This was highlighted in the example presented above. The quality of the observations, as shown by the difference we obtain with two datasets for one common observed variable, namely daily surface temperature, was questionable. This will be particularly problematic in regions with sparse observations (and hence unreliable gridded datasets). The quality of observations is also relevant for the model data, as we have applied a post-processing method using those observations in order to eliminate model biases. Integrated discussions and knowledge transfer amongst the different interested stakeholders and partners are also required to correctly evaluate the lifespan n_{ls}, which defines the lifespan of an existing or future infrastructure or the planning horizon of a given institution, industry or activity of interest.

The question of covering the uncertainty of the vulnerability timescale n_v with an ensemble of simulations remains an issue and lack of observations may affect the interest of potential partners. This is comprehensible, as the tourism industry has limited resources to allocate to long-time research.

The third axis (societal importance) seems by far the one that can be most subjective and implies more personal choices. For example, an external evaluation of different possible situations may not apply the same societal importance to a ski resort as the owner of the ski station. For a regional evaluation, government priorities could help to establish the societal importance, for example from their own monetary concerns, strategic regional development and electoral opportunism.

Given the numerous reasons listed previously, we see that despite efforts to follow a quantitative approach, the nature of the problem only allow us to obtain results that are a coarse approximation of what users surely desire. In other words, the simplicity of Expression (3) hides a complex procedure and involves more work than simply plugging in three ready-made numbers. On the other hand, its simplicity could help trigger a constructive dialogue between climate experts and users, as our exercise has proven. The fact that the approach requires dialogue may be seen as a difficulty, but on the other hand it helps avoid an often inappropriate top-down approach from climate scientists and limits erroneous interpretations of climate information by users.

Another sensitive point is the fact that some of the information needed to perform the study may be considered confidential. It is not impossible that some results reflect on the long-term viability and hence on the marketability of a given business. This is uncharted territory for climate scientists.

6. Conclusions

Climate change is a long-term process whose manifestations are already visible for certain variables, while for others it will still take a few decades to discern their evolution from the natural variability. However, adaptation to climate change is often perceived as a general pressing need to avoid early impacts or take advantage of new opportunities, regardless of the climate variable or of the system of interest. In this paper we present a conceptual framework on timescale adaptation to climate change in order to provide a simple, easily understandable tool to non-scientific users to aid in determining the level of urgency of action. This framework is made up of three different dimensions that provide relevant information to users and government regarding the timing of climate change in relation to the vulnerability of their system and the societal importance of that system. These dimensions are the backbone of many adaptation decisions and their combination, either as a mathematical expression or as a diagram, can help decision-makers better estimate when they should act to limit the impacts of climate changes.

The first dimension is a user-defined climate vulnerability threshold, which has a timescale –the time it may take to exceed it– that is estimated from climate simulations and observations. The second dimension corresponds to the planning horizon, a timescale with a definition that is not as precise as the previous one. Rather, it entails an estimate of either the life span of the associated infrastructure, of the financial obligations or of the strategic planning horizon.

Since this framework needs a strong collaboration between climate scientists and users, many steps are involved before a thorough use and evaluation of the framework can be reached. After a first meeting where potential users were presented the methodology using hypothetical examples, a particular industry, a ski resort, was targeted to produce a case study. The choice of the ski industry involved gathering more in-depth knowledge for a specific (real) location and also a better overview of the general concerns of ski-resort managers. This study was subsequently presented to industry stakeholders who were interested in participating in the project.

After the presentation of the preliminary study, participants were invited to provide their feedback regarding the validity of the variables and thresholds that had been chosen. The main conclusion from this meeting was that the approach taken and the resulting diagram were easily understood, even though determining the value of each individual component may require a substantial amount of work.

We believe that this three-dimensional approach can help users prioritize their adaptation efforts, better understand inherent challenges associated with climate change adaptation, as well as provide insight to making targeted decisions on adaptive responses to climate change. More generally, this process leads to a visual outcome that can be used to promote general awareness and facilitate knowledge exchanges, therefore encouraging a continuous dialogue between climate scientists and different users.

Acknowledgements

The authors want to express their gratitude to Benjamin Désourdy, eng. manager, maintenance and development of Bromont ski station for the very helpful discussions. The CRCM5 data has been generated and supplied by Ouranos. Computations were made on the supercomputer guillimin from McGill University, managed by Calcul Québec and Compute Canada. The operation of this supercomputer is funded by the Canada Foundation for Innovation (CFI), NanoQuébec, RMGA and the Fonds de recherche du Québec – Nature et technologies (FRQ-NT).

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