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Résumé de l'article

À l'aide des deux scénarios de variation climatique retenus par le Centre d'étude canadien sur le climat, les auteurs tentent de cerner quel serait l'effet, sur la pratique du ski alpin dans les basses Laurentides, des changements de température et de précipitation prévisibles selon ces scénarios. Ces derniers prévoient une augmentation de la moyenne hivernale des précipitations et des températures s'échelonnant respectivement entre 0 et 16% et 7,6 et 9,3° F (4,2 et 5,2° C). De tels changements pourraient abréger la saison de ski et occasionner des pertes monétaires substantielles voire même entraîner la disparition de cette industrie dans la région. Il semble par ailleurs que la pratique du ski alpin soit moins sensible aux conditions appréhendées dans l'un des deux scénarios. Signalons également que certaines analyses de sensibilité montrent que la durée de la saison de ski n'est que peu affectée par une augmentation de la température moyenne hivernale inférieure à 4° F (2,2° C).

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THE IMPACT OF CO_2 — INDUCED WARMING ON DOWNHILL SKIING IN THE LAURENTIANS

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ABSTRACT

Using the two climatic change scenarios selected by the Canadian Climate Centre, an attempt has been made, using snowcover suitability percentiles, to estimate the resilience and sensitivity of downhill skiing in the Lower Laurentians to the suggested changes in temperature and precipitation. The scenarios suggest an average winter increase in the range of 0 to 16 percent for precipitation and 7.6 to 9.3° F (4.2 to 5.2° C) for temperature. These changes could possibly result in a reduction of the marginally reliable and reliable ski seasons in the Laurentians by 40 to 89 percent respectively with a minimum financial loss of 10 $ million and a maximum loss of virtual elimination of the ski industry in this area. It would appear then that downhill skiing in the Lower Laurentians has some resilience to the suggested conditions of one scenario but not the other. In addition, the sensitivity analyses indicate that the ski season length in this part of Canada is little affected until the average winter temperature increases by 4° F (2.2° C).

KEY WORDS: Climate change, scenarios, snowcover suitability percentiles, skiing, sensitivity analysis, Sainte-Agathe-des-Monts.

RÉSUMÉ

L'influence de l'« effet de serre » sur le ski alpin dans les basses Laurentides du Nord de Montréal

À l'aide des deux scénarios de variation climatique retenus par le Centre d'étude canadien sur le climat, les auteurs tentent de cerner quel serait l'effet, sur la pratique du ski alpin dans les basses Laurentides, des changements de température et de précipitation prévisibles selon ces scénarios. Ces derniers prévoient une augmentation de la moyenne hivernale des précipitations et des températures s'échelonnant respectivement entre 0 et 16 % et 7,6 et 9,3° F (4,2 et 5,2° C). De tels changements pourraient abréger la saison de ski et occasionner des pertes monétaires substantielles voire même entraîner la disparition de cette industrie dans la région. Il semble par ailleurs que la pratique du ski alpin soit moins sensible aux conditions appréhendées dans l'un des deux scénarios. Signalons également que certaines analyses de sensibilité montrent que la durée de la saison de ski n'est que peu affectée par une augmentation de la température moyenne hivernale inférieure à 4° F (2,2° C).

MOTS-CLÉS: Changements climatiques, scénarios, couverture neigeuse en centiles, ski alpin, analyse de sensibilité, Sainte-Agathe-des-Monts.

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Because of rising levels of carbon dioxide (CO_2) and other trace gases in the atmosphere, climatic change models project by the year 2050 an increase in the mean global temperature by 1.5° C to 4.0° C. These models also suggest that the latitudinal effect will be differentiated with the response in the polar regions in the Northern Hemisphere being greater than the average by a factor of about two or three, and greater in winter than in summer (Kellogg and Schware, 1981). Using the scenarios from two such models selected by the Canadian Climate Centre for use in their impact studies — Scenario A developed by Princeton University's Geophysical Fluid Dynamics Laboratory (GFDL) and Scenario B developed by the National Aeronautical and Space Administration's Goddard Institute of Space Studies (GISS) (Hengeveld and Street, 1985) —, an attempt has been made, using the case study approach, to consider the resilience and sensitivity of downhill skiing in the Lower Laurentian area of Québec to the possible climatic changes being suggested as feasible.

LIMITATIONS OF STUDY

First and foremost, it should be recognized that the scenarios are uncertain and cannot be verified. Secondly, the above atmospheric scenario models consist of a number of component parts, for example, the GFDL model (Manabe and Stouffer, 1979, 1980) has three parts — an atmospheric section, a landmass heat and water balance section and an oceanic factor — each with its own inbuilt assumptions. Again, for illustrative purposes, one assumption made in the oceanic component of the GFDL model is that oceanic heat storage and movement will be ignored (Schlesinger, 1986). Because each model has its own assumptions, values obtained may be different, that is why the results of two different model attempts are being considered in this study. The normal procedure is for the initial values of the model's parameters to be integrated forward in time (the experiment run) for a specified level of atmospheric CO_2, usually two times a preindustrial level of 300 parts per million (Palutikof, 1986). The results obtained from this integration procedure are compared with those from a control run using present-day CO_2 levels and the differences obtained in temperature and precipitation values for set locations represent the changes that might occur in a CO_2-warmed world. Thirdly, because the models utilize a coarse grid (Scenario A has a grid of approximately 4.4° latitude and 7.5° longitude while Scenario B has a grid of 4° latitude by 5° longitude) output data are not completely comparable and extrapolations using slopes between points have to be used to obtain information for specific locations. Lastly, it has been assumed that other than the changes in climate all other things are considered to remain as they are today.

CASE STUDY

Downhill skiing was selected for investigation because it is an important winter recreation activity which is sensitive to climate. Within Québec, the Lower Laurentian area was selected with data from Sainte-Agathe-des-Monts being used as representative of the region.

For the Lower Laurentians, then, suitable snow cover periods for downhill skiing and periods for snowmaking were determined for present-day conditions as well as for conditions suggested by scenarios A and B using the Sainte-Agathe-des-Monts' data and the method presented by Crowe *et al* (1977). They define a snow cover

suitability percentile as the percentage probability of a day with a snow cover of at least 5 cm, no measurable liquid precipitation (freezing rain, drizzle, or rain), and a maximum temperature less than 40° F (4.5° C). If this percentile is less than 50, then the conditions are considered unreliable; 50 to 74, marginally reliable; and 75 or greater, reliable. For the purposes of this study, the suitable snow cover season for downhill skiing is considered to be the period when the snow cover is deemed to be marginally reliable or better, i.e. a value of 50 and higher. Of course, snowmaking could extend the ski season outside of the marginally reliable or better period. The snowmaking season which begins on the first day in the fall when the mean temperature falls to 28° F (-2.2° C) and ends on the last day in spring when the mean temperature rises to 28° F, (-2.2° C), was calculated. The threshold of 28° F (-2.2° C) is used since Crowe *et al* (1977) stated that snowmaking is usually considered practical from an economic viewpoint when the daily mean temperature is 28° F (-2.2° C) or less.

It should be noted that since Crowe *et al* used Fahrenheit all calculations in this case study were initially done in Fahrenheit and then converted to Celsius.

RESORT CLIMATE AND SKIING SEASON

Changes to the average monthly values for temperature and precipitation for each scenario for the months of November to April inclusive, the winter season, are presented in table 1. Both scenarios suggest that winter temperatures will increase while precipitation totals will remain the same or increase by 16 percent over the season.

Table 1

Changes in Average Monthly Values for Temperature and Precipitation for the Winter Season Suggested by Scenarios A and B for the Lower Laurentian Area of Québec

	Present-Day		***Scenario A***			***Scenario B***	
	Normal Monthly Temp.	*Change in Temp.*	*Future Average Monthly Temp.*	*Change in Precip.*	*Change in Temp.*	*Future Average Monthly Temp.*	*Change in Precip.*
	°C	*C°*	*°C*	*%*	*C°*	*°C*	*%*
November	-1.5	+6.7	5.2	106.5	+5.0	3.5	81.8
December	-10.4	+2.1	-8.3	102.3	+5.7	-4.7	91.7
January	-13.4	+2.7	-10.7	103.0	+5.8	-7.6	104.3
February	-12.1	+5.6	-6.5	166.8	+5.2	-6.9	104.3
March	-5.7	+5.0	-0.7	99.2	+4.8	-0.9	104.2
April	2.2	+3.2	5.4	118.2	+4.4	6.6	103.8
Average	-6.8	+4.2	-2.6	116.0	+5.2	-1.6	98.4

In more detail, Scenario A suggests that, for the winter season, mean monthly temperatures will increase by 7.6° F (4.2° C) with the largest increase, 12.1° F (6.7° C) in November followed in December by the smallest increase, 3.8° F (2.1° C). Mean monthly temperatures will be below freezing from December to March inclusive. Average winter precipitation totals will increase to 116 percent of normal. Much of this increase is accounted for by changes in February and April when precipitation values will be 167 and 118 percent of normal respectively. The remaining months of the winter season will have precipitation totals of within 7 percent of normal.

The above values may suggest a short transition period from unreliable to reliable skiing conditions ; the maintenance of reliable ski conditions during February ; and a longer "fall off" in the season in March because of the 167 percent increase in precipitation in combination with a mean monthly temperature below freezing.

Scenario B, on the other hand, suggests a greater warming for the winter season, 9.3° F (5.2° C), with a range of 7.9° F (4.4° C) to 10.4° F (5.8° C), associated with precipitation values similar to the present except for November and December which will have 82 percent and 92 percent of present-day precipitation totals respectively. This will again result in a period from December to March inclusive when the mean monthly temperatures will be below freezing. However, with the uniform warming of approximately 9° F (5° C) a month with little change in precipitation, the skiing season would likely be greatly reduced.

Using the procedure developed by Crowe *et al* (1977) snow cover suitability percentiles for downhill skiing were calculated for the winter season (figure 1). The figure displays the downhill ski season divided into three major categories :

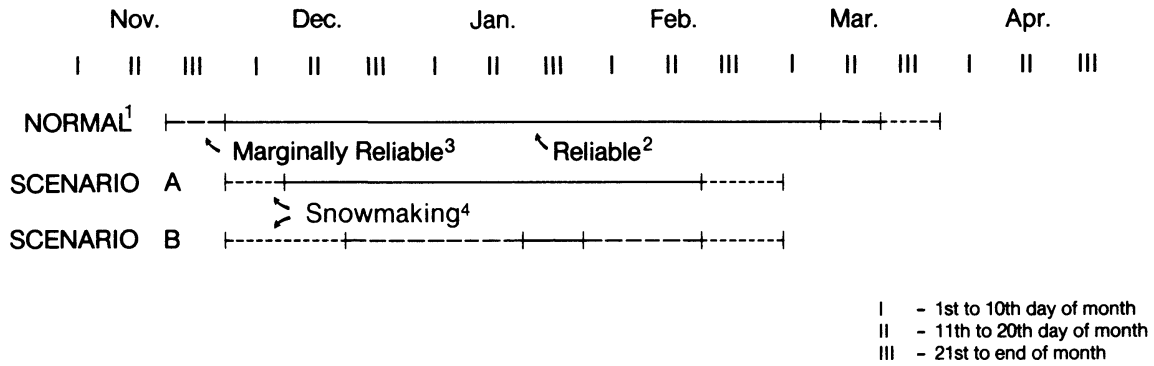
1) the "reliable snow cover season" (hereafter called the reliable season) in which there is a 75 percent or greater probability of there being suitable snow cover for downhill skiing ;
2) the "marginally reliable snow cover season" (hereafter called the marginally reliable season) in which there is a probability of between 50 and 74 percent of there being snow cover for downhill skiing ;
3) the period available for snowmaking, outside of the marginally reliable or better season, which may extend or upgrade the ski season.

At Sainte-Agathe-des-Monts the marginally reliable or better skiing season extends at present from November 21 to March 20, a period of 120 days. The reliable season is shorter by 20 days, starting December 1 and extending to March 10. Snowmaking extends the season by about a week at both the beginning and the end of the ski season. Therefore, the possible ski season at present at Sainte-Agathe-des-Monts is 131 days from November 21 to March 31.

Because of the large increase in temperature under Scenario A in November, followed by the smallest monthly increase in December it is not unexpected to find that the Lower Laurentian area will go from conditions of no snow or unreliable skiing to reliable snow cover with no marginally reliable period. Similarly, at tne end of the season, with a monthly temperature in February of -6.5° C (20.3° F) and -0.7° C (30.7° F) in March, the situation will result again in the exclusion of a marginally reliable ski season. This means that under Scenario A there will only be a reliable ski season of 72 days duration running from December 11 to February 20, a reduction of 28 percent from the present-day situation. Snowmaking may extend this season to normal conditions. With only a reliable ski season the marginally reliable or better ski season under Scenario A conditions will be reduced by 48 days or 7 weeks.

Figure 1

Periods with Suitable Snow Cover for Downhill Skiing at Ste-Agathe-des-Monts, Québec



1 Normal snow cover suitability percentiles for downhill skiing at Ste. Agathe Des Monts for 1951-80.
2 Reliable: 75% or greater probability of suitable snow cover for downhill skiing.
3 Marginally reliable: 50 to 74% probability of suitable snow cover for downhill skiing.
4 Snowmaking: Snowmaking is usually considered practical, from an economic viewpoint, when the daily mean temperature is 28°F (-2.2°C) or less. Therefore the snowmaking season begins on the first day in the fall that the mean temperature is 28°F (-2.2°C) and ends on the last day in spring when the mean temperature is 28°F (-2.2°C).

Fortunately, from a financial point of view, the key ski business periods — the Christmas school break and the mid-February tertiary education breaks — will have reliable ski conditions. Therefore, the elimination of skiing in March, when approximately 20 percent of skier visits occur, is the major loss. Using the average Ontario skier expenditure at a ski area (lift tickets/equipment rentals/lessons/food/beverages) of $49 (Ruston/Tomany and Associates Ltd., 1985) as being equivalent to Québec skier expenditures, the value of the loss in skier expenditure at the Lower Laurentian ski resorts during March under Scenario A would amount to $10.6 million [20 percent of annual skier attendance, (1 081 761) (Association touristique des Laurentides, 1986) multiplied by average skier expenditure ($49)].

Relative to Scenario A, Scenario B results indicate a drastic reduction of 84.7 percent in the reliable ski season to 11 days during the last third of January. On the other hand, the marginally reliable or better season is only reduced by 13.9 percent to 62 days while the snowmaking period is the same as in Scenario A, namely 93 days. The drastic reduction in the reliable season is a result of the larger increase in mean monthly temperature under Scenario B conditions [10.3° F (5.7° C)] relative to Scenario A [4.3° F (2.3° C)] in the months of December and January in particular. It is possible, however, that snowmaking could upgrade the long marginally reliable season to the equivalent length of the reliable season under Scenario A. Yet with the marginally reliable season only starting on December 21 and ending on February 20 the busy Christmas school break and mid-February periods would be in jeopardy. Therefore, it may be concluded that there is every likelihood of the virtual elimination of the downhill ski industry in the Lower Laurentian area under Scenario B. The economy of the region would be hurt badly. The resorts themselves would lose approximately $53 million (annual skier attendance multiplied by average daily expenditure) while the area would lose an additional $50.8 million from accommodation, transportation and other sundry expenditures [calculated using the estimated average Ontario skier expenditures for accommodation ($21), transportation ($17) and other items ($9)].

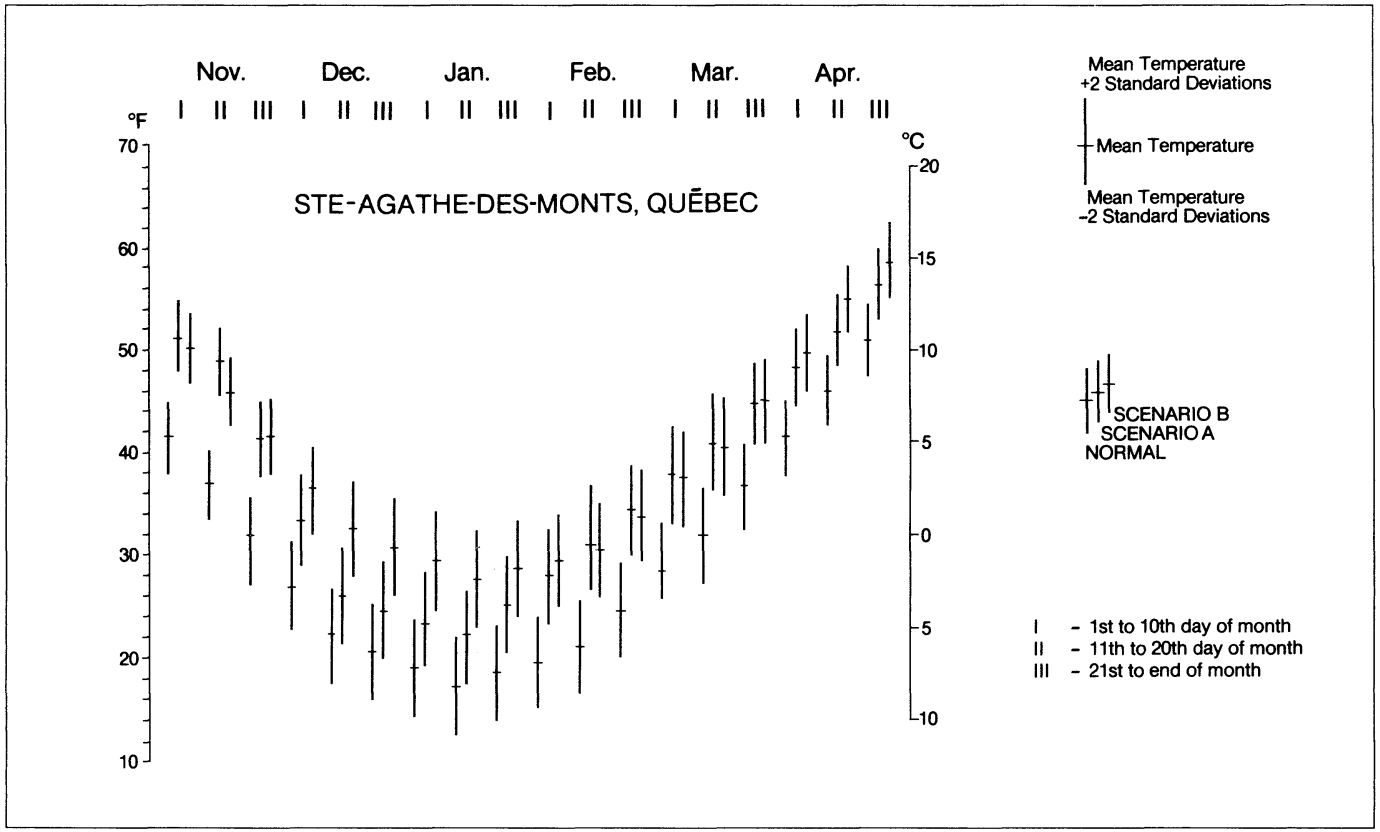
SENSITIVITY ANALYSIS

Are the above conclusions extreme? Yes and No. Assuming the scenarios will have the same standard deviation as at present, the temperature norms plus and minus two standard deviations were calculated for the winter period using 10-day intervals (figure 2). The means for each 10-day period from December 11 to January 20 for Scenario A are within plus two standard deviations of the present-day averages indicating that during this period the conditions suggested as possible occur at the present time though admittedly as extremes. Therefore, under Scenario A conditions this period would be the "most" reliable of the skiing season. Figure 2 also suggests that for the rest of the winter season conditions under Scenario A will be greatly warmer than present-day norms since the values of new mean temperatures minus two standard deviations are greater than the present norms plus two standard deviations. Because of the above similarity and difference from the present it is not surprising then that there is no marginally reliable ski season.

With a uniform temperature increase each month through the winter of approximately 10° F (5° C) conditions under Scenario B will be warmer than anything experienced at present. The mean monthly temperatures under Scenario B conditions are below freezing only during the period December 21 to February 20 which

Figure 2

Temperature Variability under Normal, Scenario A and Scenario B Conditions
Ste-Agathe-des-Monts, Québec



coincides with the marginally reliable or better season illustrated in figure 1. Similarly, the lowest temperatures, January 11 to 31, coincide with the 11-day reliable season from January 21 to 31 (figures 1 and 2).

Overall the scenarios suggest that all conditions will be extreme relative to present-day conditions except for the period December 11 to January 20 under Scenario A.

What then are the minimum temperature and precipitation increases required to produce situations similar to those suggested by the scenarios ?

If present-day Laurentian temperatures are increased incrementally by 1° F (0.6° C) while maintaining present-day precipitation totals it would take only an increase of 4° F (2.2° C) to obtain the reliable ski season length calculated under Scenario A conditions (figure 3a). This is 3.5° F (1.9° C) below what is forecast by the scenario. At this temperature increment, however, marginally reliable conditions extend the season significantly longer than under Scenario A conditions. To reduce the marginally reliable to the same season length as the reliable would require an increase by 9° F (5° C) at which temperature the reliable has been reduced to the same length as that of Scenario B. The reliable season drastically reduces in length with an increment of 7° F (3.9° C) and over. Similarly, the snowmaking season is reduced in length in a stepwise manner with key reductions at 2 to 3° F (1.1 to 1.7° C), 6° F (3.3° C) and 8° F (4.4° C).

Using the same procedure as in figure 3a, but with a precipitation base of 115 percent of normal (the suggested future winter average value from Scenario A) it would again require an increase of 4° F (2.2° C) to obtain the reliable ski season suggested by Scenario A (figure 3c). Again this is below the suggested temperature increase for Scenario A but is approximately the same value as two standard deviations of present-day mean monthly temperature [3.6° F (2° C)] indicating again that the shorter reliable ski season under Scenario A conditions is not fantasy but a present-day extreme. On the other hand, the season lengths suggested by Scenario B, irrespective of precipitation increases, is not obtained until the temperature has increased by 9° F (5° C).

Overall, figures 3a, b and c suggest that the seasons' lengths will be altered greatly with temperature increases of 3 to 4° F (1.7 to 2.2° C) irrespective of whether precipitation totals increase. This is well below the extreme 7.6 and 9.3° F (4.2 and 5.2° C) increases suggested for the winter months by Scenarios A and B respectively but close to two standard deviations of present-day winter mean monthly temperature suggesting that the Scenario results are present-day extremes rather than figures of fantasy.

CONCLUSION

The analyses suggest that the Laurentian ski season under conditions of Scenario A will be reduced by 28 to 40 percent but will still include the most important money generating periods — the Christmas school break and the mid-February break for college and university students. However, under Scenario B, the reliable season will be reduced to 11 days in late January although snowmaking would extend the season greatly. Financial losses could range from a minimum of $10 million under Scenario A to the virtual elimination of the ski industry with the resultant loss of over $100 million to the local economy.

Figure 3a

Sensitivity Analysis of Suitable Snow Cover For Downhill Skiing and Snowmaking Using Four Sets of Criteria Ste-Agathe-des-Monts, Québec

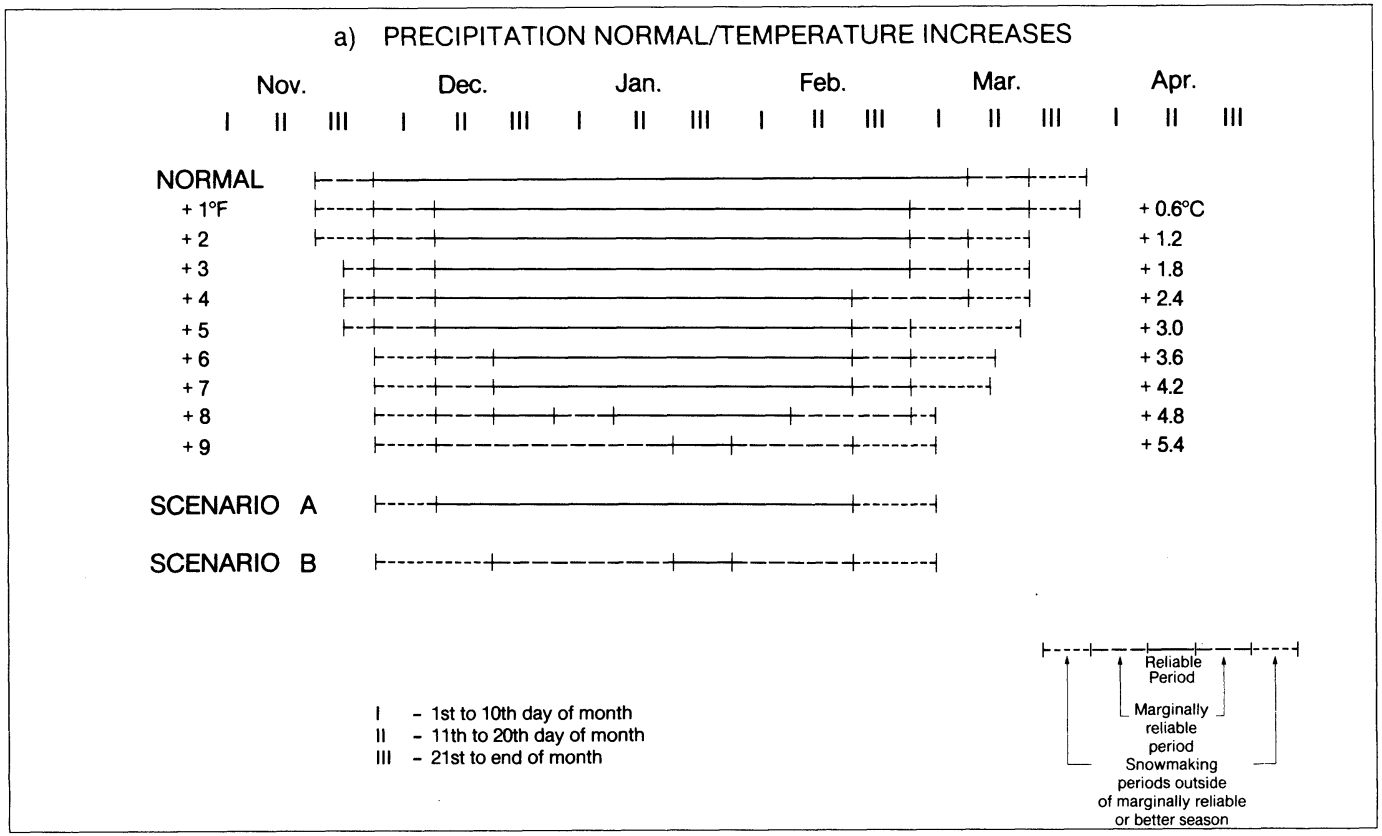


Figure 3b

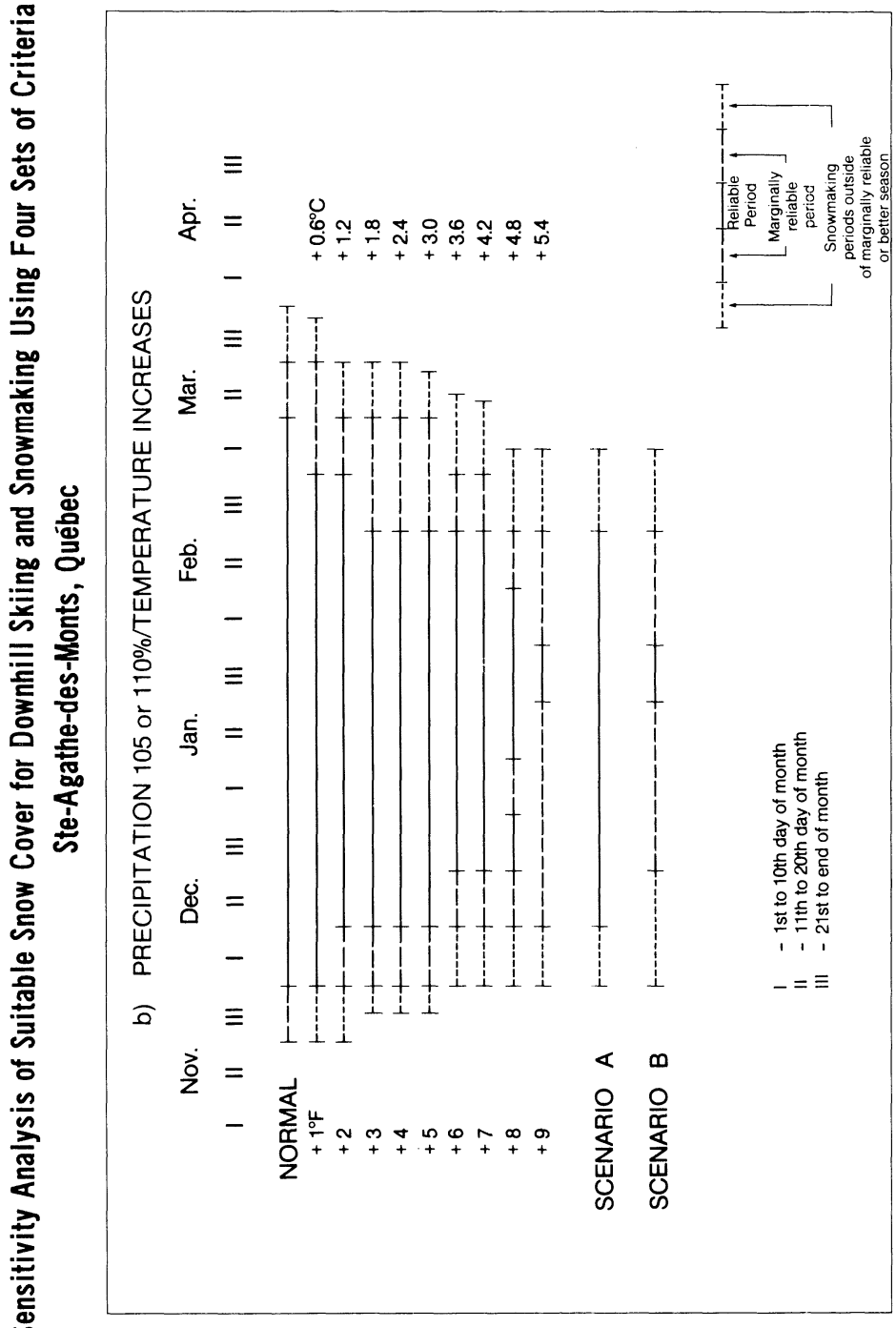
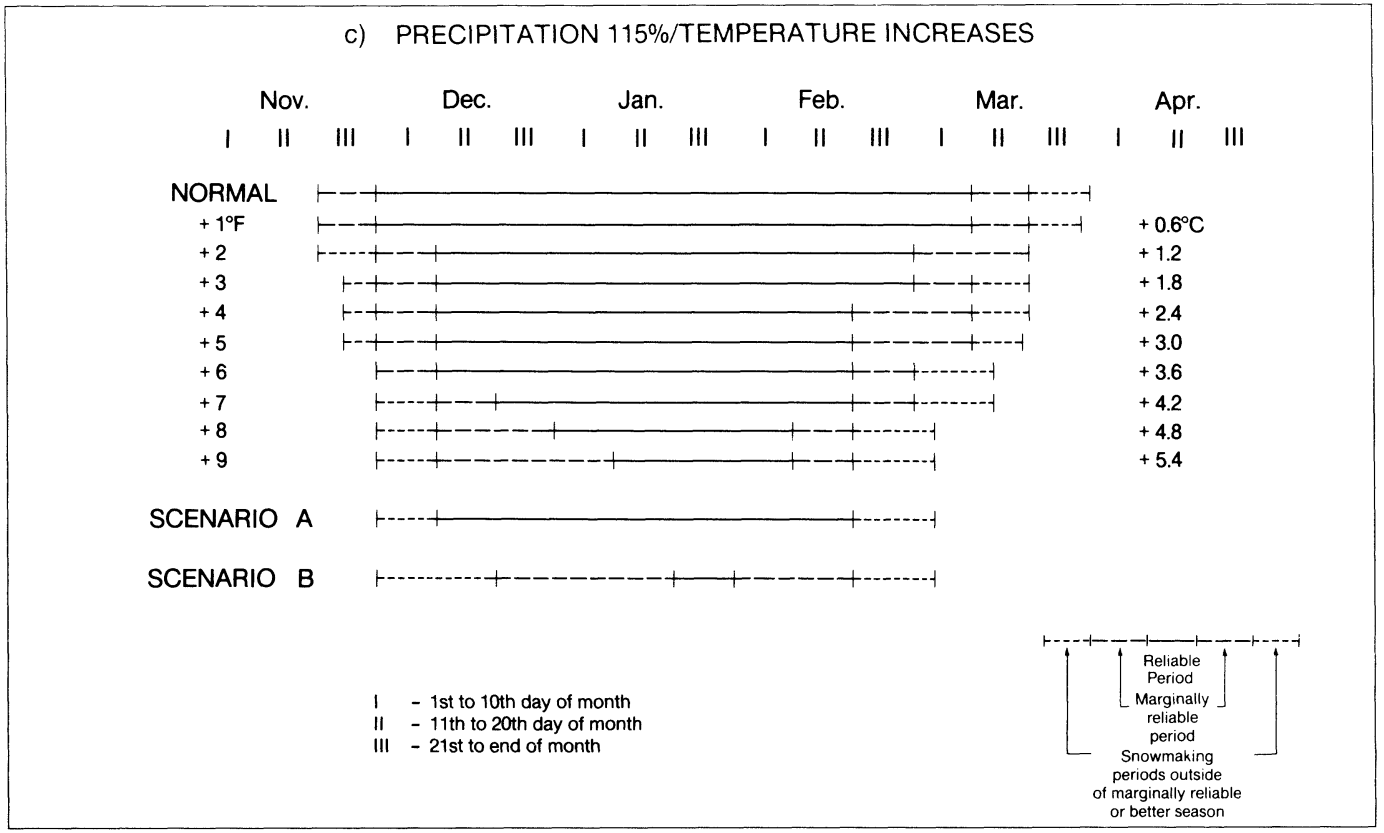

Sensitivity Analysis of Suitable Snow Cover for Downhill Skiing and Snowmaking Using Four Sets of Criteria
Ste-Agathe-des-Monts, Québec
b) PRECIPITATION 105 or 110%/TEMPERATURE INCREASES
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
I II III I II III I II III I II III I II III
NORMAL
+ 1°F
+ 2
+ 3
+ 4
+ 5
+ 6
+ 7
+ 8
+ 9
+ 0.6°C
+ 1.2
+ 1.8
+ 2.4
+ 3.0
+ 3.6
+ 4.2
+ 4.8
+ 5.4
SCENARIO A
SCENARIO B
I - 1st to 10th day of month
II - 11th to 20th day of month
III - 21st to end of month
Reliable Period
Marginally reliable period
Snowmaking periods outside of marginally reliable or better season

Figure 3c

Sensitivity Analysis of Suitable Snow Cover for Downhill Skiing and Snowmaking Using Four Sets of Criteria Ste-Agathe-des-Monts, Québec



It may be wise for resort operators involved with winter recreation in the Lower Laurentians to give consideration to incorporating climatic change into their decision-making. In addition, a program leading to diversification could be a wise investment for the future and one which need not wait until the real evidence of climatic change is upon us.

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CARTOGRAPHIE

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