

Length of the fire season in a changing climate

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The Canadian Climate Centre's General Circulation Model provides two 10-year data sets of simulated daily weather for a large array of gridpoints across North America. A subset of this data, comprised of only those points within the forested part of Canada, was selected for study. Fire season length was calculated from data sets of both the $1\times\text{CO}_2$ and $2\times\text{CO}_2$ runs of the model as well as for the actual climate, using observed data from weather stations. A comparison made between the results of the $1\times\text{CO}_2$ and $2\times\text{CO}_2$ runs indicated a significantly longer fire season across the country under a doubling of atmospheric CO_2 levels. Implications of this result, such as a fall fire season in Canada's east and greater strains on management agencies, are discussed.

Le Modèle de circulation générale du Centre climatique canadien fournit deux séries de données réparties sur dix ans qui simulent la température quotidienne d'un grand ensemble de points répartis sur un réseau couvrant l'Amérique du Nord. Un sous-ensemble de ces points, représentant seulement les points faisant partie du territoire forestier du Canada, a été sélectionné pour fins d'étude. La durée de la saison de feux a été calculée à partir des données simulant une fois le taux de CO_2 et deux fois le taux de CO_2 , ainsi que pour le climat actuel, en utilisant les données recueillies à partir des stations météorologiques. Une comparaison établie entre une fois le taux de CO_2 et deux fois le taux a démontré une saison de feux significativement plus longue partout au pays lorsque le taux de CO_2 atmosphérique est doublé. Les implications de ce résultat, à savoir par exemple la saison de feux à l'automne dans l'est du Canada et les plus grandes pressions exercées sur les organismes de lutte, sont discutées.

Introduction

Speculation abounds over the potential impacts of so-called greenhouse warming. The problem in making quantitative statements about this subject is the enormous complexity of the system involved. Indeed, we would need a spare biosphere with which to experiment in order to obtain accurate quantitative results. However, because we do need information about what might happen under a doubling of greenhouse gas levels in the atmosphere, we can do the next best thing, model the biosphere with powerful computers. These numerical simulations involve complex mathematical equations describing global circulation patterns and processes. First, a general circulation model (GCM) is built to match present day conditions as best as possible, and then the amount of carbon dioxide in the model's atmosphere is effectively doubled. This effective doubling of the concentration of carbon dioxide in the atmosphere is expected to happen by the year 2040. Carbon dioxide (CO_2) is the main greenhouse gas (in volume) being added to the atmosphere, but other gases such as methane, chlorofluorocarbons (CFS's) and water vapour also play a large role in contributing to the greenhouse effect. The results of this new run, called a $2\times\text{CO}_2$ scenario, are then debated as to their relevance and validity.

What could rapid climate change mean to the forest? A several degree Celsius rise in average global temperature is predicted by most models. However, regional and seasonal changes in climate could be much more dramatic. With respect to forest fires, this temperature rise could, if there is no accompanying increase in rainfall amount, lead to a much drier forest, one in which fire ignition is easier and fire control becomes more difficult. Overpeck *et al.* (1990) predicted that global warming will cause weather conditions to be more conducive to forest fire occurrence through an increase in the frequency of "disturbance weather" such as

summer/autumn drought and thunderstorms. Flannigan and Van Wagner (1991) used the output from three GCM's to suggest a nearly 50% increase in the area burned by forest fires in Canada in a $2\times\text{CO}_2$ world. Their study did not consider the lengthening of the fire season, however. In this regard, Street (1989), in a study of the effect of climate change on the Ontario forest fire situation, suggests that the fire season will become longer and that there will be a shift in the severe fire months to later in the season. This shift in the fire season is due to an expected increase in precipitation in the spring months and a decrease in the later summer months. The purpose of the present study was to look at the change in fire season length quantitatively in a $2\times\text{CO}_2$ world and to discuss the implications of these changes for fire management in Canada.

Data and Methods

The numerical climate change information used in this study was from a GCM running at the Canadian Climate Centre (McFarlane *et al.* 1991). The Centre's present model can provide monthly or daily data sets containing averages or samples of many different familiar climatic variables such as temperature, precipitation, etc. These data sets span 10-year periods and exist for both a $1\times\text{CO}_2$ and $2\times\text{CO}_2$ run of the model. They contain data from an array of 570 gridpoints covering North America (Figure 1).

We used a subset of the North American daily data set for this study, consisting only of gridpoints falling within the forested region of Canada. This amounted to only 61 gridpoints. To attempt to verify that the GCM was describing present weather patterns adequately, daily weather records were obtained from 41 Atmospheric Environment Service weather stations across Canada. These records spanned a period of 30 years from 1960 to 1989; station locations are listed in the Appendix.

When examining the output of GCM for effects caused by CO_2 doubling, note that many compromises and uncertainties are present in the model. Simulations must be kept

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computationally feasible and thus, simplified models of such processes as the role of heat transport within the oceans and the reflectivity of sea ice and cloud cover, to name a few, must be used. The spatial resolution of the models is also a limiting factor in keeping simulations at a reasonable level of computational complexity, and this can make regional simulation of climate change effects very uncertain (Grotch 1988). Also, processes such as SO₂ blocking as suggested by Charlson *et al.* (1992) are not included in simulations but may play a large role in determining just how fast and to what degree temperature may change in response to increased CO₂ in the atmosphere.

The first task, before any analysis of the data could proceed, was to devise a workable definition of fire season length. The start of the weather recording season is defined in the Canadian Forest Fire Danger Rating System (CFFDRS) (Canadian Forestry Service 1987) as beginning after: (1) three consecutive days of noon temperatures greater than 12°C for areas with no snow cover or (2) three consecutive days of no snow cover in areas with significant snow cover (Turner and Lawson 1978). This criterion, however, is used only for starting forest fuel moisture calculations and does not indicate the start of the fire season *per se*.

The United States National Fire Danger Rating System (NFDRS) (Deeming *et al.* 1977) does not have a set criterion for starting or ending the fire season either. Fuel moisture calculations are started four weeks before the first season is to start. A specific region will decide when the fire season is expected to start in their area, based on recent fire history. Simard *et al.* (1989) used a concept of burning-days to indicate the days of the fire season in areas with no snow cover.

They define the fire season as starting after three consecutive days of maximum temperatures greater than 7.2°C.

After looking at various methods, we decided to use a slight variation in the CFFDRS definition of the start of the fire season. The chosen approach had the fire season start in an area after three days of maximum temperatures greater than 12°C.

In the CFFDRS and NFDRS there is no official end to the fire season nor to the calculation of fire weather indices. In Canada, a fire management agency may consider a fire season as being over at the end of October, when there has been a long time with little or no fire activity and low fire indices, or simply when seasonal employees' contracts terminate in the fall. Needless to say, these definitions were not suitable for our study. Simard *et al.* (1989) end the season with the reverse of the criteria they use to start it, that is, after three consecutive days of maximum temperatures below 7.2°C.

After studying the merits of several end of season indicators, we decided to use a modified temperature criterion adapted from the CFFDRS start criterion and the end of season criterion of Simard *et al.* (1989). That is, a fire season was considered over after three consecutive days of maximum temperatures less than 5°C. Temperature is a simple variable that has a strong annual cycle and can be a good and reliable indicator for a season's starting and ending times. Temperature simulation through GCM's also seems to be the part of the modelling process in which modellers have the most confidence.

Using our temperature criteria, we calculated the actual start and end dates of the fire season for each year. This was

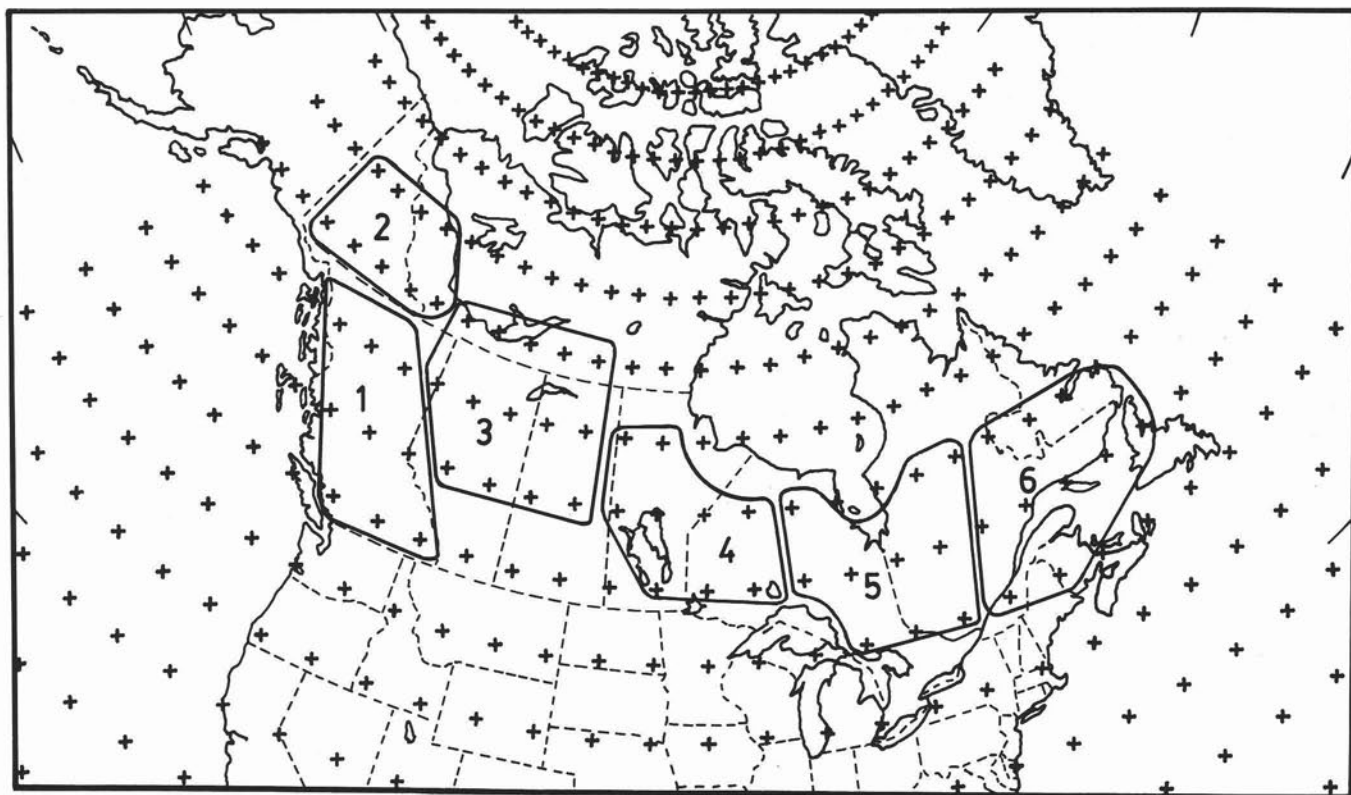


Figure 1. Gridpoints designating the six zones into which the forested region of Canada were separated. Each '+' marks gridpoint locations in the GCM model.

done for each gridpoint for both the $1\times\text{CO}_2$ and $2\times\text{CO}_2$ data sets and also for each weather station. We averaged these values over the number of years in the data set (30 years for actual data and 10 years for each GCM scenario) to provide a mean value of fire season start and end dates.

Our first objective was to compare results from the $1\times\text{CO}_2$ model to the actual climate data from the weather station records. Comparison of values between those at individual weather stations and those at gridpoints were useless in this case due to the spatial resolution of the GCM. The model averages the weather in a large area around the gridpoint to create a value at a particular point. Unfortunately, the small geographical and climatic features at individual points were lost in this process. A thorough discussion of this problem of regional analysis of climate change impacts can be found in Cohen (1990). In order to make reasonable comparisons, a number of gridpoints must be averaged together and then compared to the averages from a group of weather stations taken from the same area. With this in mind, we divided our set of gridpoints located within the forested region of Canada into six zones (Figure 1) based loosely on geographical regions, climatic zones, and forested regions (Rowe 1972). We then compared calculated fire season length from the $1\times\text{CO}_2$ and $2\times\text{CO}_2$ model runs.

Results

The average start and end date of the fire season in each zone for the $1\times\text{CO}_2$ data and weather station data are listed (Table 1). The fire season starts about 30 days earlier when it is calculated from the actual data than it does in the $1\times\text{CO}_2$ case. This discrepancy will be explained later. We do, however, believe that the earlier starts calculated from AES weather station records approximately correspond to the times we would say the current fire season starts in the various zones. This satisfied us as to the validity of our fire season starting criteria.

The end of season as calculated from the weather records and the $1\times\text{CO}_2$ data set agreed fairly well (Table 1). The dates correspond to about the expected time for the end of the fire seasons in the specific zones with the exception perhaps of zone one.

We then compared the $1\times\text{CO}_2$ and $2\times\text{CO}_2$ data sets with each other, gridpoint by gridpoint, using a simple Student-t comparison. All gridpoints had significantly earlier starts in the $2\times\text{CO}_2$ scenario, with better than 99% confidence. The season in the $2\times\text{CO}_2$ world started an average of almost 20 days earlier. The $2\times\text{CO}_2$ fire season end also occurred later in the fall. This difference was less pronounced, however, averaging only about 10 days, but was still significant at a 99% confidence level for all but eight of the 61 gridpoints.

The start and end dates of the seasons were averaged over the six zones as before and compared in a similar manner (Table 2). There was a significant earlier beginning and a later end to the fire season for the $2\times\text{CO}_2$ scenario in all regions. The start averaged about 18 days earlier and the end averaged about 10 or 11 days later. Thus a lengthening of the fire season of almost 30 days is predicted on average.

Discussion

The discrepancy in fire season start dates (Table 1) is due to an artifact of the GCM. The later model start is caused by the temperature remaining at 0°C for a long period of time as it crosses from the freezing point. A plot of the average yearly temperature trend at a specific gridpoint illustrates this (Figure 2). When the weather cools in fall, the temperature corresponds to the end of season criteria before it reaches 0°C and thus, the end of season date is not changed. This effect is due to a connection in the model between reported screen temperature (the temperature 1.4 metres above ground) and the ground temperature. That is, when snow is on the ground but the atmospheric temperature is

Table 1. Average start and end of the fire season for $1\times\text{CO}_2$ scenario and weather station record

Zone	Weather station Average					$1\times\text{CO}_2$ scenario Average				
	Start	Std err	End	Std err	Season length	Start	Std err	End	Std err	Season length
1	APR 14	4.8	NOV 7	10	207	JUN 13	4.7	OCT 20	4.7	129
2	MAY 11	4.4	OCT 3	2.7	145	JUN 19	6.1	OCT 7	2.0	110
3	APR 27	1.8	OCT 17	1.9	173	MAY 30	3.5	OCT 16	2.2	139
4	APR 29	1.7	OCT 24	2.1	178	MAY 24	4.6	OCT 27	2.3	156
5	MAY 1	2.7	OCT 23	2.6	175	MAY 27	4.3	OCT 30	2.8	156
6	MAY 3	3.3	NOV 3	3.7	184	JUN 4	5.1	NOV 1	4.1	150

Table 2. Average differences in season starting and ending dates between $1\times\text{CO}_2$ and $2\times\text{CO}_2$ scenarios for each of the six zones in the forest subset (each t-value has 18 degrees of freedom).

Zone	Start of season		End of season		Season length		Percent increase
	Diff. ¹	t-value	Diff. ¹	t-value	$1\times\text{CO}_2$	$2\times\text{CO}_2$	
1	-26.5	-4.70	24.5	2.79	129	180	39
2	-20.2	-2.90	9.6	3.97	110	135	28
3	-14.4	-3.18	9.0	3.25	139	163	16
4	-15.7	-2.44	9.3	2.68	156	181	16
5	-14.4	-2.45	11.9	3.08	156	182	17
6	-17.1	-2.55	12.1	2.06	150	179	19
Canada	-17.8	-6.25	12.3	4.44	138	168	22

¹Difference is the $2\times\text{CO}_2$ starting or ending date average minus the $1\times\text{CO}_2$ starting or ending.

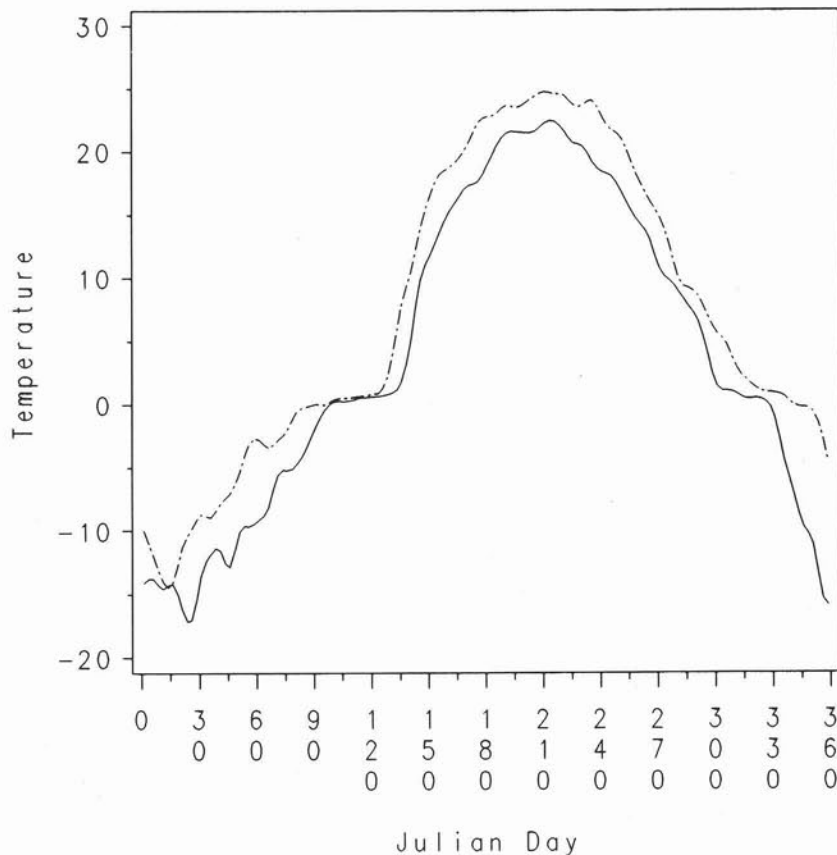


Figure 2. A plot of 10-year averages of maximum temperature for both the $1\times\text{CO}_2$ and the $2\times\text{CO}_2$ datasets from a gridpoint in Saskatchewan.

above freezing, the screen temperature is held down by the ground temperature, which stays at zero until all snow has melted. Because spring temperatures in both scenarios warm at roughly the same rate, the GCM develops a similar problem in both runs of the model and it takes approximately the same amount of time in both scenarios to overcome this screen/ground temperature coupling. Examination of temperature trend plots (Figure 2) verify that this is generally the case across the entire country. Thus, the effect is present to approximately the same degree in both runs of the GCM and, comparing the two runs, the effect only causes an equal shift in the absolute length of the season in both cases. While this does not affect comparisons in the present study, we must note the phenomenon with respect to the absolute fire season length as calculated from the GCM data.

Results (Table 2) show that there are absolute and statistically significant differences in the start and end dates of the fire season between the $1\times\text{CO}_2$ and $2\times\text{CO}_2$ data sets. Average standard errors (not shown) of fire season start and end for all zones were about 3 or 4 days in both scenarios. There appear then to be no significant differences in variability of fire season length between the scenarios.

The lengthening of the fire season is greatest for zone one which is essentially the province of British Columbia. Results suggest that the fire season in B.C. in a $2\times\text{CO}_2$ world will be just over 50 days longer, with the increase split evenly between spring and fall. British Columbia's present climate already makes it the area in Canada with the most significant fall fire season (Harrington 1982).

In zone three, primarily the forested sections of Alberta and Saskatchewan, our analysis indicates the fire season will start about two weeks earlier than at present. This is of concern especially in Alberta where, historically, the majority (63%) of the area burned has occurred in May. Thus an earlier start to the fire season would necessitate earlier dates for fire fighting preparedness. The extra length of the spring fire season may be slightly offset, however, by the shorter length of daylight in the earlier part of the season. The number of hours of sunlight during the day affects the drying time of exposed fuels; the shorter days earlier in the season would not allow as much drying to take place.

The results also seem to suggest a longer fall fire season in Eastern Canada. The fire season in zones five and six, already late ending, could be extended even further into fall. This would increase the period between leaf fall and the end of the fire season and could give rise to a more pronounced fall fire season similar to that of the Eastern United States.

Overall, a lengthening of the fire season would cause a larger demand on fire management agencies, as they would have to maintain a state of readiness for a longer time. Weather monitoring and the hiring of seasonal workers for fire suppression would have to start earlier and end later in the year.

With an earlier start and later end to the fire season, there will, of course, be a longer "middle" to the season. With the increased temperature anticipated for this time, much drier forest fuels can be expected if rainfall patterns do not change significantly. However, confidence in rainfall

simulation by GCM's is much lower than that of temperature at this point in time. Rough estimates from the Canadian Climate Centre GCM indicate an increase in total annual rainfall across Canada in a $2\times\text{CO}_2$ world. This increase is not temporally uniform but seems to occur mostly at the start and end of the fire season. Rainfall amounts in the summer months in the $2\times\text{CO}_2$ scenario remained relatively unchanged from amounts in the $1\times\text{CO}_2$ scenario. This agrees with some of the findings of Street (1989). We did not, however, look at the frequency of rainfall events in the summer. It has been shown (Flannigan and Harrington 1988) that area burned in Canada is well correlated with sequences of dry days, and changes in this regard may play a key factor in the forest fire situation in a $2\times\text{CO}_2$ world. During an extended summer there is also the possibility of increased drought periods and consequent extreme fire danger.

We predict the length of the fire season will increase by an average of 22% across Canada in a $2\times\text{CO}_2$ world. If we assume that the number of fire starts and area burned are proportional to, or are at least positively correlated with, the fire season length, then even without considering the extra drying effect of higher temperatures on forest fuels, the forest fire situation in Canada would become more severe.

Summary

Using the Canadian Climate Centre's GCM, we found that the fire season length could increase by an average of 22% or 30 days across Canada in a $2\times\text{CO}_2$ world. The increase would be most pronounced in BC where the fire season could increase by 51 days or 39%. The increased fire season length would be due to the higher temperature regime across Canada over the year. It is unclear at this point, due to the limitations of the GCM, if the accompanying change in the rainfall regime will compensate for the effect of increased temperature on fire danger, or amplify it, or indeed if there will be any large change in rainfall patterns over the summer months. We do not intend to suggest that increased fire season length and the accompanying increase in forest fire occurrence and severity would be catastrophic for the Canadian forest. However, increases in the severity of fires and in fire occurrence frequency, and thus fire load, could make forest management a more difficult task. From a fire protection and suppression point of view, this could translate into significantly increased resource commitments by fire fighting agencies.

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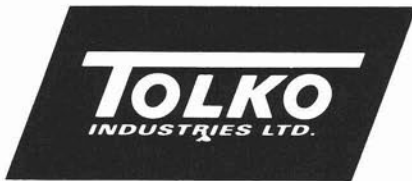
Appendix

The list of the Atmospheric Environment Service weather stations used in comparing the $1\times\text{CO}_2$ output from the GCM to actual observations.

Station location	Zone no.	Station location	Zone no.
Victoria, B.C.	1	Dawson, Yukon	2
Smithers, B.C.	1	Whitehorse, Yukon	2
Williams Lake, B.C.	1	Fort Simpson, N.W.T.	3
Cranbrook, B.C.	1	Fort Smith, N.W.T.	3
Fort Nelson, B.C.	1	Yellowknife, N.W.T.	3

Station location	Zone no.	Station location	Zone no.
Rocky Mtn. House, Alta.	3	Earlton, Ont.	5
Fort McMurray, Alta.	3	Kapuskasing, Ont.	5
Slave Lake, Alta.	3	Kapuskasing Airport	5
Whitecourt, Alta.	3	Timmins, Ont.	5
Cold Lake, Alta.	3	Chalk River, Ont.	5
North Battleford, Sask.	3	Maniwaki, Que.	5
Prince Albert, Sask.	3	Bagotville, Que.	5
Hudson Bay, Sask.	3	Val D'Or, Que.	5
Winnipeg, Man.	4	Roberval, Que.	6
Gimli, Man.	4	Campbellton, N.B.	6
Dauphin, Man.	4	Fredericton, N.B.	6
The Pas, Man.	4	Truro, N.S.	6
Thompson, Man.	4	Gander, Nfld.	6
Landsdowne House, Man.	4	Goose Bay, Nfld	6
Kenora, Ont.	4		
Sioux Lookout, Ont.	4		
Thunder Bay, Ont.	4		

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