J4.6 IMPACT OF CLIMATE CHANGE ON AREA BURNED IN ALBERTA'S BOREAL FOREST

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1. INTRODUCTION

The western boreal forest is a disturbance forest. Fire has been, and continues to be, the dominant disturbance agent in Alberta's boreal forest. For the period between 1961 and 2004, an annual average of 867 wildfires occurred in the province (Figure 1). These wildfires burned an annual average of 142,976 ha (Figure 2). Approximately 73 % of the total area burned during the 1961 to 2004 period occurred in the Boreal Forest Natural Region (Figure 3). Only 2 % of the wildfires in Alberta are "Class E" wildfires (> 200 ha), but they account for 98 % of the total area burned (Tymstra et al. 2005).

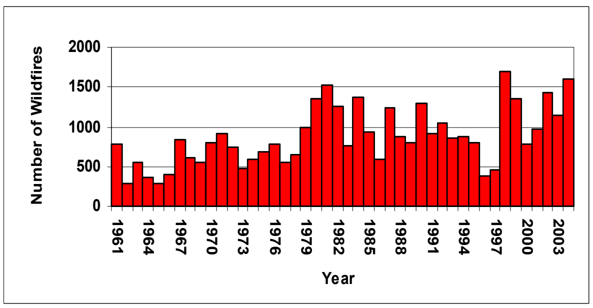

Figure 1. Number of wildfires in Alberta from 1961 to 2004.

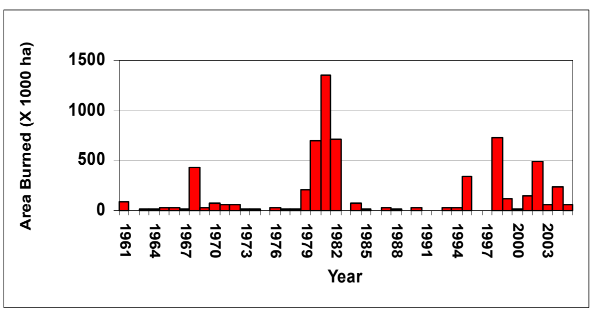

Figure 2. Area burned in Alberta from 1961 to 2004.

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Large fires are common in the boreal forest. However, wildfire management agencies across Canada are becoming increasingly concerned about the occurrence of longer fire seasons, and the increased frequency of very large, high intensity and high severity wildfires, that are expensive, dangerous, and challenging to contain. Significant increases in area burned and fire occurrence have occurred in Canada over the last four decades Podor et al. (2002, Gillett et al. 2004).

Some of these wildfires are very large in size. The 2002 House River wildfire, a classic boreal spring, wind driven fire, was for example, responsible for burning 248,243 hectares in northeast Alberta.

Using the Canadian General Circulation Model (GCM), Wotton and Flannigan (1993) predicted the fire season across Canada would be extended in length by 30 days as a result of a $2XCO_2$ scenario. Flannigan and Van Wagner (1991) predicted a 46 % increase in seasonal severity rating (SSR) in a $2XCO_2$ scenario. They also suggested a similar increase in area burned. Bergeron and Flannigan (1995) later concluded that climate change would result in a decrease of fire frequency in the southeastern boreal forest in Canada. Other research supports the conclusion that large regional variations occur across Canada (Flannigan et al. 1998, 2000).

Most projections of future fire activity and area burned are based on projecting fire danger indices (Flannigan et al. 1998, 2000, Brown et al. 2004). This study provides a more quantitative methodology to assess the impact

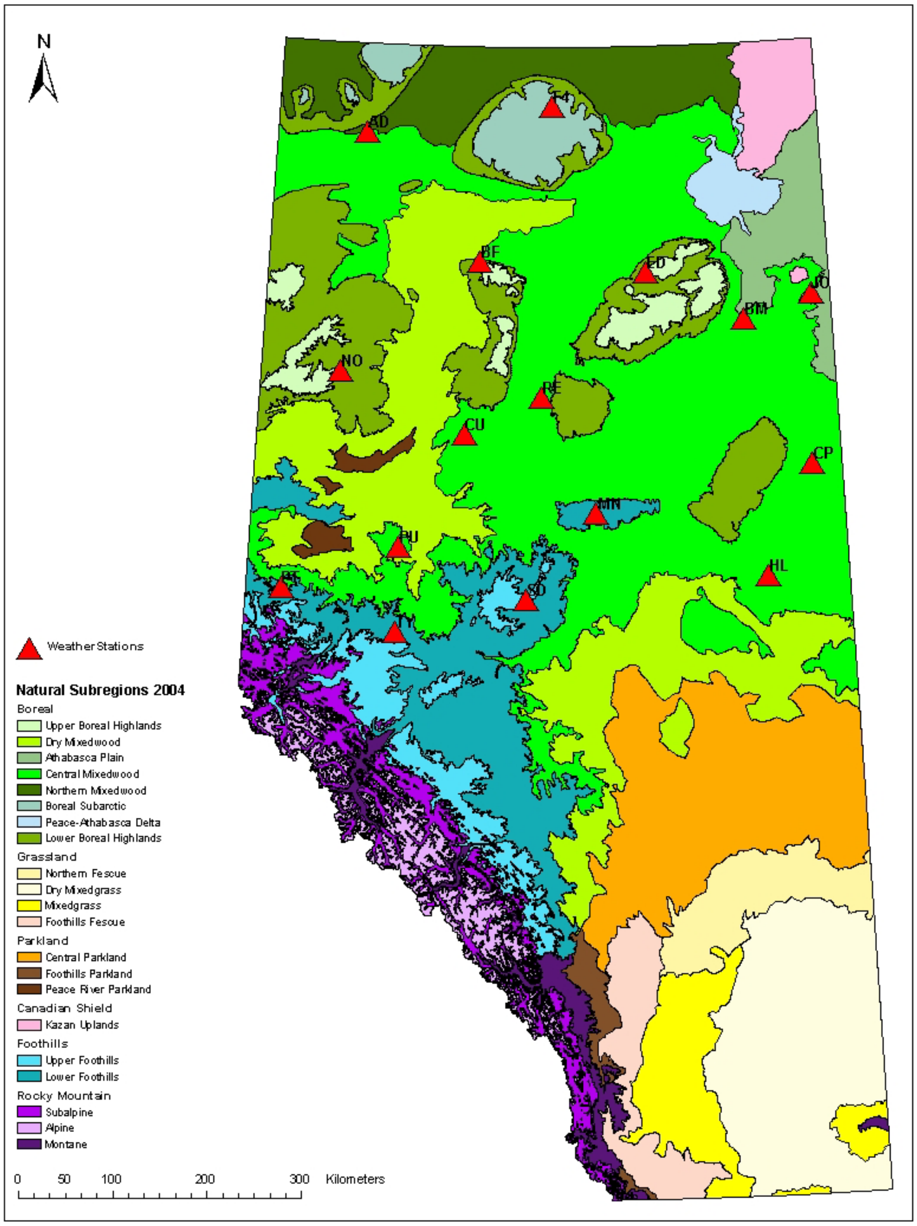

Figure 3. Natural Regions and Sub-Regions of Alberta and selected weather stations.

of climate change on area burned by integrating the use of fire growth simulations.

The ability to assess the biophysical, economic and social impacts of climate scenarios allows for the consideration of adaptation and mitigation options, and facilitates the development of a risk management framework.

2. STUDY AREA

The Boreal Natural Region is the largest Natural Region in Alberta. It is large, complex forest ecosystem characterized primarily by mixedwood forests consisting of white spruce, lodgepole pine, Jack pine, aspen and poplar tree species, and a mosaic of bogs, fens, rivers and lakes.

The greatest fire activity in Alberta occurs in the Boreal Natural Region. Fire has influenced the composition and structure of the boreal forest, and contributed to shape the landscape of this northern forest.

3. FIRE WEATHER ANALYSIS

Sixteen weather stations were selected to complete the fire weather analysis (Table 1, Figure 3). These are the same weather stations used in a 1986 study to compare the fire weather severity in northern Alberta during the disastrous 1980 and 1981 fire seasons (Harvey et al. 1986). The daily weather records from 1995 to 2002 were collectively partitioned into 5 separate files based on the Fire Weather Index (FWI) value. Five FWI classes were used (Table 2). The fire season was established as starting on April 1 and ending on September 30.

The Fire Weather Index is a subsystem of the Canadian Forest Fire Danger Rating System (CFFDRS). Fire management agencies across Canada use the FWI system operationally to assess relative fire potential. The FWI system requires as input, daily noon measurements of temperature, relative humidity, wind speed and daily precipitation. The outputs of the system include three fuel moisture codes that account for, and track the relative effect of wetting and drying of the fuel layers. The Fine Fuel Moisture Code (FFMC) provides a measure of the fuel moisture content of the fine surface litter. The Duff Moisture Code (DMC) provides a relative measure of the moisture content of the loosely compacted upper duff, and the Drought Code (DC) provides a relative measure of long term drought, and the moisture content of the deep compact duff.

There are also two intermediate fire behaviour indices, and a final fire danger indice. The Initial Spread Index (ISI) provides a relative measure of the fire spread rate by combining the effects of wind (WS) and fine fuel moisture content (FFMC). The Buildup Index (BUI) combines the effects of DMC and DC, and indicates the amount of fuel available for combustion. The Fire Weather Index (FWI) is the final fire danger indice which gives an indication of the potential intensity of a fire assuming level terrain, and a standard fuel type (mature pine). The FWI combines the effects of BUI and ISI.

Station Name	ID
Adair	AD
Buffalo	BF
Bitumont	BO
Cowpar	CP
Cadotte	CU
Edra	ED
Heart Lake	HL
Johnson Lake	JO
Meridian	MN
Notikewan	NO
Pinto	PT
Puskwaskau	PU
Red Earth	RE
Swan Dive	SD
Tony	TY
Whitesands/F4	WS/F4

Table 1. Representative weather stations in the boreal forest selected for the weather analysis.

For each FWI class data set, the median was calculated. The median value and the 6 values above and below the median were averaged (N=13) for temperature, relative humidity, wind speed, Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC) and Drought Code (DC). The predominant wind direction was also obtained. These reference weather streams were then adjusted to create daily weather streams for input into *Prometheus* – the Canadian Wildland Fire Growth Model (Tables 4 - 6). *Prometheus* is a deterministic fire growth simulation model designed to run in Canadian fuel complexes. The *Prometheus* daily weather stream requires, maximum and minimum temperatures, minimum relative humidity, maximum and minimum wind speed and precipitation.

Precipitation was excluded for all scenario runs. The fire weather observations were collected at 1200 hours (1300 hours DST). To convert the noon temperature to maximum temperature, 3^{o} C was added to the noon temperature. To convert the noon relative humidity to minimum relative humidity, 7% was subtracted from the noon relative humidity. The minimum temperature was calculated by subtracting 10^{o} C from the noon temperature. The noon wind speeds were adjusted to maximum wind speeds by adding 2 km/hr. The minimum wind speed was set at 3 km/hr.

FWI Class	Values	% Frequency
Low	≤ 4.4	56.24
Moderate	> 4.4 and ≤ 8.4	14.88
High	> 8.4 and ≤ 16.4	18.64
Very High	>16.4 and ≤ 29.4	8.56
Extreme	> 29.4	1.68

Table 2. FWI class values and frequency of FWI days for all 16 weather stations.

Prometheus uses a diurnal routine to convert the daily weather streams into hourly weather streams which are required to complete fire growth simulations. The Lawson method of diurnal FFMC calculation was used (Lawson et al. 1996).

3. RCM OUTPUT

Output from the Canadian Regional Climate Model (CRCM) (Caya et al. 1995, Laprise et al. 2003) were used to simulate future conditions. The CRCM's spatial resolution is 45 km by 45 km, resulting in 174 grid cells over the study region in northern Alberta. Daily FWI values for the current time period and two future time periods were calculated from the grid cells. The current time period was modeled as 1975-1985 within the RCM. The 2x and 3x CO_2 scenarios correspond to RCM outputs for 2040-2049 and 2080-2089 periods respectively.

The RCM outputs 6 hour averages of screen height (about 1.5 m above ground) temperature, screen height specific humidity, surface wind speed, and precipitation. Since the FWI System requires inputs of daily noon temperature, relative humidity, wind speed, and daily rainfall, adjustments to the RCM outputs were necessary before calculating the daily FWI values.

The 6 hour average temperature spanning the local noon time at each grid cell was used to approximate the noon temperature. Relative humidity was approximated by estimating the dew point as the minimum temperature overnight, and then using the next day's noon temperature and actual dew point within the RH calculation. This method was checked against observed RH values, and appears to work well. Daily rainfall was also adjusted by an amount equal to 2.5 mm per day to correct for an unrealistically high rainfall frequency within the model.

A more detailed description of the data preparation can be found in Wotton et al. (1998). Wind values for the 1x CO_2 scenario were also compared against actual observations from weather stations and a calibration factor was calculated. Wind values for the 2x and 3x CO_2 scenarios were multiplied by the same factor. Once daily noon values were determined for the RCM data, the FWI indices were calculated. For this analysis the fire season was April 1 to September 30.

The daily RCM data were also partitioned into 5 separate files based on the FWI values (table 2). For each FWI class data set, the median value was calculated. The median value and the 6 values above and below the median value were averaged (N=13) for temperature, relative humidity, wind speed, FFMC, DMC, and DC. These calculations were completed for all of the time periods (Table 3).

The RCM output was only used to determine the relative differences in temperature, relative humidity, wind speed, FFMC, DMC and DC, between the current time period and the 2x CO_2 period, and the current time period and the 3x CO_2 period. The relative differences were then used to generate 2x CO_2 and 3x CO_2 *Prometheus* weather streams.

4. FIRE GROWTH SIMULATIONS

An actual fire day (July 20, 1999) in the Lac La Biche Wildfire Management Area was used for the fire growth simulations and area burned calculations. This day is considered a typical wildfire business day in the boreal forest under very high fire weather conditions. Eight of the 27 new wildfire starts that occurred on that day escaped initial attack (Figure 4). The ignition locations for 21 of the 27 wildfires were input into the *Prometheus* model. The growth of the 21 wildfires were simulated for 5 days for each of the five fire weather streams, using a standard burn period of 1000 hrs to 2200 hrs.

The total area burned for each fire weather stream and time period was then multiplied by the frequency of area burned by all wildfire starts

	1x						2x						3x					
	Temp °C	RH %	WS km/hr	FFMC	DMC	DC	Temp °C	RH %	WS km/hr	FFMC	DMC	DC	Temp °C	RH %	WS km/hr	FFMC	DMC	DC
Low	9	62	10	74	9	78	16	66	14	73	9	156	18	56	12	71	15	158
Med	17	62	15	83	18	200	17	56	15	81	23	162	20	56	14	80	28	269
High	19	41	9	88	30	180	17	48	13	87	30	209	21	47	12	88	30	185
Very High	18	50	18	88	47	371	24	45	13	90	51	296	24	43	13	89	56	388
Extreme	26	35	13	92	82	490	25	43	16	90	87	508	24	41	18	90	79	485

Table 3. Projection of future fire weather conditions for northern Alberta using CRCM output

	Temp °C	RH %	WS km/hr	WD	FFMC	DMC	DC
Low Fire Wx	15.5	61.6	9.1	NW (20.4 %)	63.4	9.5	109.4
Moderate Fire Wx	16.5	54.6	9.5	SW (20.7 %)	83.5	20.6	293.7
High Fire Wx	16.8	45.6	12.4	SW (24.6 %)	87.5	23.7	234.0
Very High Fire Wx	21.1	34.2	13.8	SW (28.2 %)	90.4	33.2	256.7
Extreme Fire Wx	21.4	30.7	24.5	SW (27.1 %)	91.4	38.9	318.0

Table 4. Reference (1X CO_2) fire weather for northern Alberta.

	Temp °C	RH %	WS km/hr	WD	FFMC	DMC	DC
Low Fire Wx	26.7	65.5	12.9	-	62.5	9.3	218.9
Moderate Fire Wx	16.6	49.3	9.8	-	81.6	26.1	237.0
High Fire Wx	15.3	53.3	17.7	-	86.3	24.0	272.2
Very High Fire Wx	29.0	30.5	10.0	-	92.4	35.7	205.2
Extreme Fire Wx	21.2	37.4	31.2	-	90.2	41.2	329.8

Table 5. Projected 2X CO_2 fire weather for northern Alberta.

	Temp °C	RH %	WS km/hr	WD	FFMC	DMC	DC
Low Fire Wx	30.7	55.7	11.9	-	61.0	15.2	222.2
Moderate Fire Wx	19.6	49.7	8.9	-	80.7	30.9	394.0
High Fire Wx	18.5	51.7	16.0	-	87.0	23.7	241.0
Very High Fire Wx	28.5	29.4	10.0	-	91.8	39.8	269.0
Extreme Fire Wx	19.7	35.7	34.1	-	90.0	37.4	314.9

Table 6. Projected 3X CO_2 fire weather for northern Alberta.

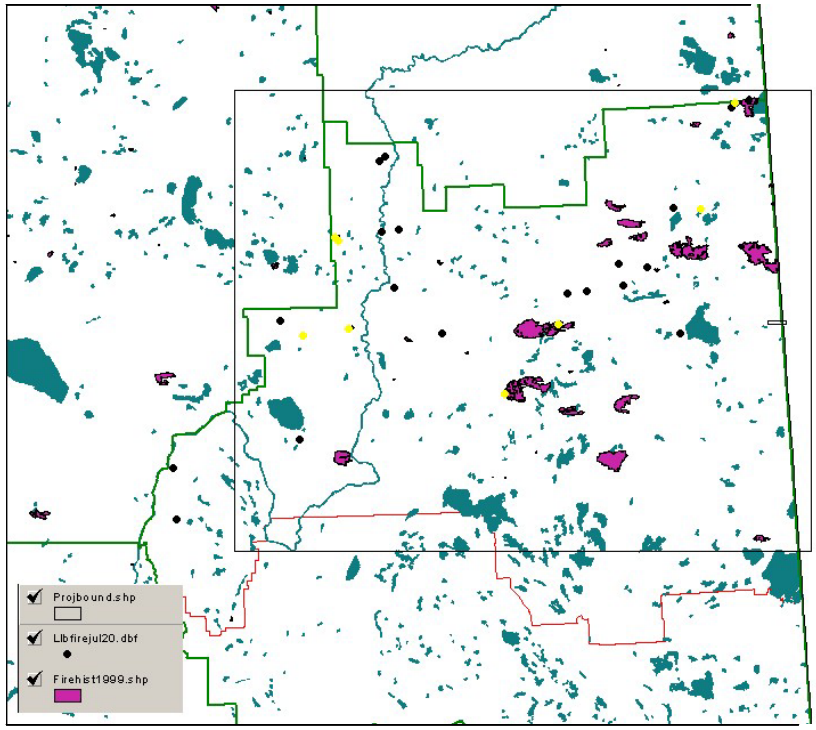

Figure 4. Wildfire starts on July 20, 1999 in the Lac La Biche Wildfire Management Area (escaped fires are coloured yellow, and the 1999 wildfire polygons are outlined in purple).

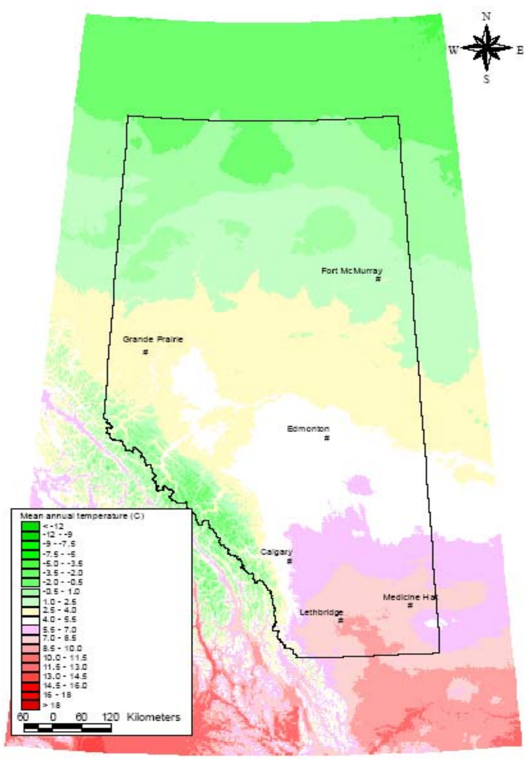

Figure 7. 2050s mean annual temperature output from the Alberta Climate Prediction Model.

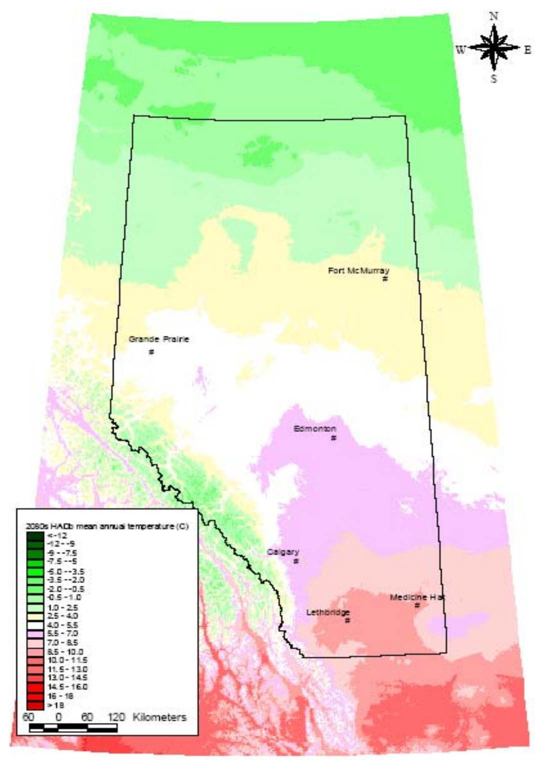

Figure 8. 2080s mean annual temperature output from the Alberta Climate Prediction Model.

FWI Class	Values	% Frequency
Low	≤ 4.4	19.82 %
Moderate	> 4.4 and ≤ 8.4	14.18 %
High	> 8.4 and ≤ 16.4	31.91 %
Very High	>16.4 and ≤ 29.4	26.60 %
Extreme	> 29.4	7.49 %

Table 7. Percent frequency of fire starts by FWI class.

FWI Class	Values	% Frequency
Low	≤ 4.4	2.01 %
Moderate	> 4.4 and ≤ 8.4	1.84 %
High	> 8.4 and ≤ 16.4	15.74 %
Very High	>16.4 and ≤ 29.4	28.48 %
Extreme	> 29.4	51.93 %

Table 8. Percent frequency of area burned by FWI class.

for the entire fire season for each FWI class (Table 8). The total weighted area burned is a relative measure used to compare the impact of a changing climate or fire management regime (i.e. budget). The frequency of area burned by FWI class was used rather the frequency of fire starts by FWI class (Table 7), because approximately 80 % of the area burned is a result of a small percentage of fires that occur during high to extreme fire weather conditions.

5. RESULTS

The 2X and 3X CO_2 scenarios resulted in a relative increase in area burned of 12.9 % and 29.4 % respectively from the reference 1X CO_2 scenario (Table 9). This increase is lower than the estimated increase in area burned suggested by Flannigan and Van Wagner (1991).

Approximately 34 % of the fire starts occurred during very high and extreme fire weather conditions (Table 7). However, about 80 % of the area burned occurred during very high and extreme fire weather conditions (Table 8).

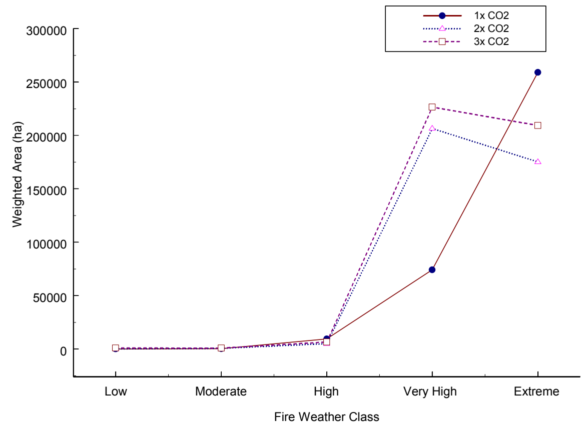

Figure 5. Weighted area burned by fire weather class and scenario.

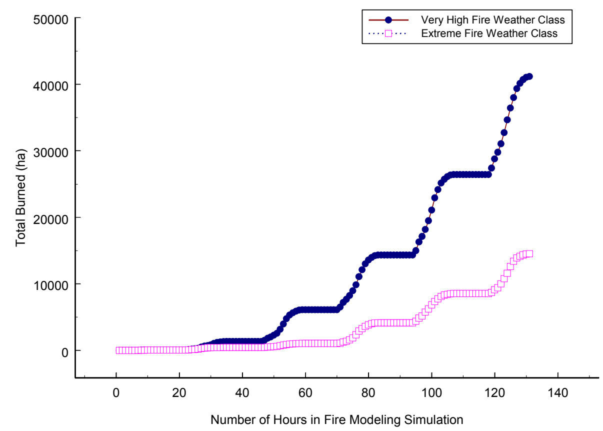

Figure 6. Area burned for wildfire E02094 using the very high and extreme fire weather classes for the 3X CO_2 scenario.

Fire Wx	$1XCO_2$	$2XCO_2$	$3XCO_2$
Low	94	141	1022
Moderate	444	691	950
High	9553	5083	6610
Very High	74272	206578	226627
Extreme	259216	175291	209439
Total	343579	387784	444648

Table 9. Weighted area burned by FWI class and CO_2 scenario.

There is no linear trend for each of the weather variables and fuel moisture codes for the CO_2 scenarios (Table 3). Nevertheless, there is a general overall warming and increased area burned trend. The greatest difference between the 1X CO_2 and the 2X and 3X CO_2 scenarios occurred during the fire growth simulations that used the very high weather stream (Figure 5).

Figure 6 illustrates the effect of the length of the simulation on the area burned for one wildfire (E02094) using the very high and extreme weather streams. The difference in area burned increases as the length of the simulation increases. The diurnal effect during the burning period is evident in the step-wise pattern of area burned. In this particular example, the very high weather stream resulted in more area burned than the extreme weather stream.

6. DISCUSSION

It is known that higher temperatures produce more cloud to ground lightning strikes. Although a warming climate may result in an increase in lightning caused fires, and a subsequent increase in area burned (Price and Rind 1994, Gillett et al. 2004), this study assumed a constant fire load for all scenarios. Our estimates of the increase in area burned for the 2X and 3X CO_2 scenarios may therefore underestimate the potential area burned, if more fire starts occur, and escape initial attack.

Fire management agencies across Canada strive to continually strengthen their suppression capability to reduce the impact of wildfires on values at risk. In Alberta, the Department of Sustainable Resource Development (SRD) recently upgraded seven air tanker bases, and increased the overall air tanker capability by adding 3 contract B-2 aircraft. The turbo conversion of 3 Canadair CL-215 air tankers is also planned. Wildfire fighting crews were re-configured, and the number of Type I crews increased to strengthen the initial attack capability. Enhanced geomatics intelligence and decision support systems, community and landscape FireSmart initiatives, and a comprehensive community information and media program are also contributing to minimize the impact of wildfires. Quantifying the impact of these initiatives in a changing climate is, however, problematic.

Despite the on-going debate about the effectiveness of suppression (Miyanishi and Johnson 2001, Ward et al. 2001), the effect of fire management policies and suppression capability are factors that need to be considered. Using a controlled retrospective study of historical wildfire data, Cummings (2005) provided evidence that wildfire suppression significantly reduced the area burned in northeast Alberta. Projecting future wildfire suppression effectiveness remains a challenge. As a result, future changes in the effectiveness of suppression were not included in the analysis of this study.

Earlier and longer wildfire seasons are associated with climate warming (Wotton and Flannigan 1993, Beaubien and Freeland 2000). In this study, a standard 1000 – 2200 hr burning period was used. This is the active period of fire spread that typically occurs from 1000 hrs to sunset. Climate warming likely has a corresponding impact on the length of the burning period in the boreal forest, particularly during the spring season when the foliar moisture content is at a minimum (“spring dip”). Low humidity recovery at night was observed on the 2002 House River wildfire (Tymstra et al. 2005). The diurnal weather routine and hourly FFMC calculation routine in the *Prometheus* fire growth model do not account for changes in the diurnal and nocturnal patterns (e.g. time of sunset and sunrise, and minimum and maximum temperatures). The impact of climate change on the length of the burning period warrants further investigation.

In this study, the fire season was defined as starting on April 1 and ending on September 30. Further analysis using seasonal weather streams (i.e. spring, summer and fall) are recommended. Another suggested analysis for future study is the enhancement of the spatial resolution by dividing the study area into compartments, to capture regional variations in the fire environment, and climate change. The Boreal Natural Region is a large area (259,025 km^2). Within this study area there are regional differences in the fire regime (Tymstra et al. 2005), and regional variations in changes in climate (Anon. 2004). The Alberta Climate Prediction Model (ACPM) suggests a warming trend from the north to the south with (Figures 7 and 8).

Fuel moisture and wind are the main variables influencing area burned. Yet these are the most difficult outputs to model spatially, not only today, but also into the future. An increase in temperature does not necessarily result in large fires. In Alberta, wildfires occur every month of the year. Fuels must be available for burning (i.e. dry) and once a fire starts, it needs to spread (i.e. wind, slope). Most wildfires in the boreal forest are wind driven.

Although the *Prometheus* fire growth simulations did not include precipitation, it is accounted for indirectly in the fuel moisture codes. Precipitation was not included because of the inability to obtain spatially accurate estimates.

The use of percentiles is a preferred approach to analyze fire weather codes and indices because these variables increase exponentially. However, when multiple percentile variables are independently combined to construct weather streams, joint probabilities should be calculated (i.e. what is frequency of a day occurring with combined percentiles?). Future analysis using the methodology outlined in this study should consider evaluating joint probabilities.

Fuel, weather and topography are the main variables influencing fire behaviour. Fuel types were assumed to be constant between scenarios even though changes to the vegetation types and hence the fuel types may occur as result of climate warming. No attempt was made to model and incorporate the impact of climate warming on the fuel component of the fire environment.

Despite, the study assumptions and limitations, a trend towards an increasing area burned was estimated from the 1X CO_2 scenario to the 3X CO_2. Fire management agencies should subsequently plan accordingly to prepare for this scenario.

ACKNOWLEDGEMENTS

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