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METEOROGICAL AND FIRE BEHAVIOR CHARACTERISTICS OF THE 1989 FIRE SEASON IN MANITOBA, CANADA

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ABSTRACT

During the 1989 fire season, a record number of fires (1147) and area burned (3.28 million ha) occurred in the Province of Manitoba, Canada. These fires consumed over 9% of the provincial forested land base, forced the evacuation of 24,500 people from 32 different communities and cost $55 million (US) to suppress. The majority of the fire activity occurred during two distinct periods; the first in mid-May resulting from an outbreak of human-caused fires, and the second in mid to late July due primarily to lightning-caused fires. In both situations the synoptic weather pattern consisted of a 500 hPa blocking ridge centered over Manitoba that produced maximum temperatures of 30°C to 35°C, and minimum relative humidity values of 15% to 25%. As these ridges weakened wind speeds averaging 25 km/h to 35 km/h produced numerous high intensity crown fires in stands consisting primarily of black spruce and jack pine. Seven major wildfire runs were documented with headfire rates of spread and fire intensities ranging from 16.7 m/min (1 km/h) to 44.4 m/min (2.7 km/h) and 18057 kW/m to 40226 kW/m, respectively. A probability analysis estimating the return period of such an extraordinary fire season projected that this type of event could be expected in Manitoba only once every 400 years.

INTRODUCTION

The Province of Manitoba is located near the geographical centre of Canada (latitude 49° N - 60° N; longitude 90° W - 102° W). Approximately 50% of the province's 650,000 km^2 land base is classified as forested and 23% is considered productive forest land (Manitoba Natural Resources 1986). The majority of the province is located within the Boreal Forest Region of Canada (Figure 1) as classified by Rowe (1972). The dominant tree species within this area include *Picea glauca* (Moench) Voss (white spruce), *Picea mariana* (Mill.) B.S.P. (black spruce), *Pinus banksiana* Lamb. (jack pine) and *Populus tremuloides* Michx. (trembling aspen).

Fire is widely acknowledged as a natural component of the boreal forest ecosystem

(Wein and MacLean 1983). The fire cycle can vary between 40 and 250 years depending on the conditions of the local fire environment (Chandler et al. 1983). The fire behavior is generally characterized by high intensity, stand replacing crown fires which cover large areas. Records dating back to 1918 indicate that within Manitoba, prior to 1989, an average of 394 fires per year have produced an annual area burned of 128,600 ha (Hirsch 1990).

During the 1989 fire season, a record number of fires (1147) and area burned (3.28 million ha) occurred in Manitoba (Figure 2). These fires consumed over 9% of the province's forested area, burned an area six times larger than the 1988 Yellowstone National Park fires, and exceeded the province's total area burned for the previous 25 years combined. The fires also forced the evacuation of 24,500 people from 32 different communities and cost in excess of $55 million (US) to suppress. The Manitoba fires accounted for 43% of the 7.51 million ha burned in Canada in 1989 (Canadian Committee on Forest Fire Management 1990), which was also a 71-year record high value (Van Wagner 1988).

The majority of the area that burned in Manitoba in 1989 occurred during two distinct periods. The first was the result of an outbreak of human-caused fires in the central regions of the province in mid-May. The second took place in mid to late July due primarily to lightning-caused fires in northern Manitoba. The purpose of this paper is to provide a retrospective analysis of the fire weather and fire behavior that occurred during these two key periods. Where possible, documented wildfire runs have been used to substantiate the linkages between the extreme fire behavior and the severity of the fire weather and fire danger conditions. A short discussion on the historical perspective of the 1989 fire season is also presented.

ANTECEDENT WEATHER

The climate of Manitoba is classified as cool continental. Total precipitation averages from 400-600 mm per year (based on data for 1951-80) with most of the precipitation falling in the summer (Environment Canada 1982a). Mean annual daily temperatures for the 1951-80 period averaged between -7°C in the northern areas of the province to +3°C in the south (Environment Canada 1982b).

The winter of 1988-89 (November 1, 1988 - March 31, 1989) was characterized as milder and drier than normal. Figure 3 shows that precipitation, as a percentage of normal for the winter period, was above average in the northwest and the extreme southwest sections of the province. Remaining portions of the province had below normal

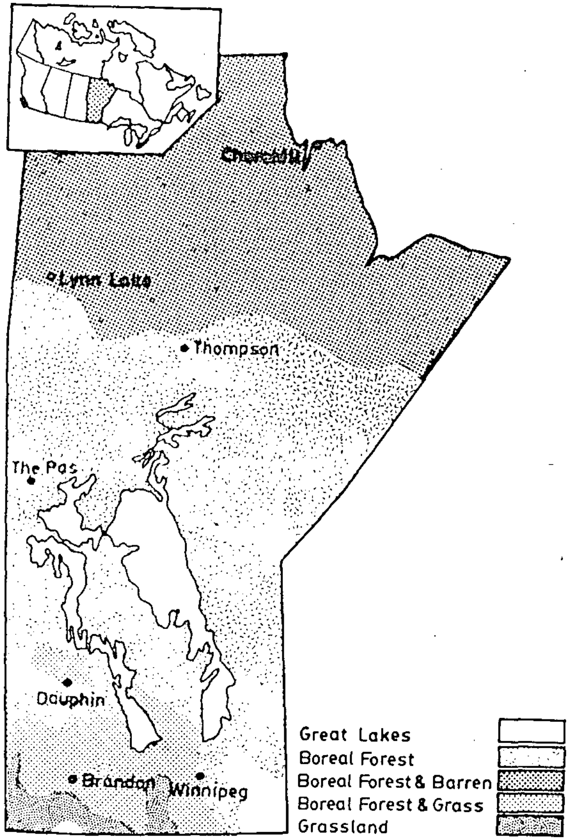

Figure 1. Forest regions of Manitoba (based on Rowe 1972).

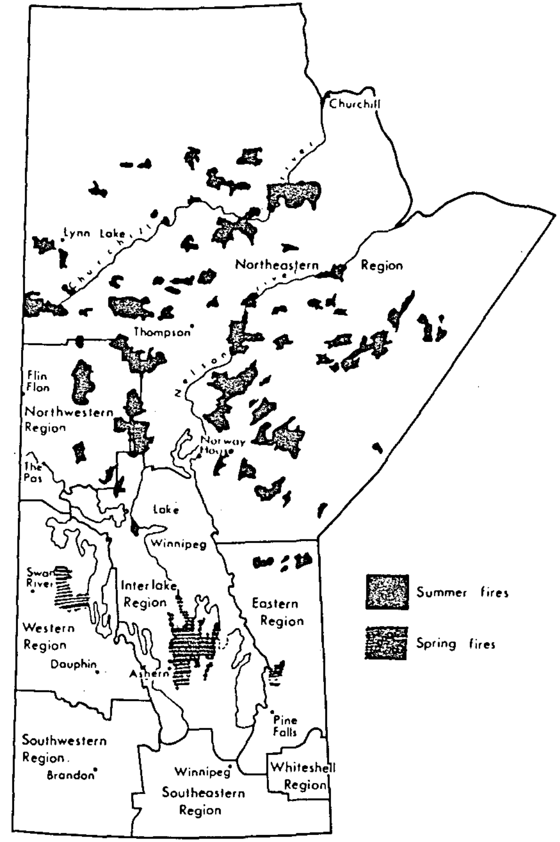

Figure 2. Area burned in Manitoba during 1989 by fires greater than 5000 ha in size.

precipitation with most stations receiving around 75% of normal. In April 1989, southern areas experienced a normal spring snowmelt however precipitation was only 25-50% of normal while in the north precipitation was, for the most part, above normal (Figure 4).

SYNOPTIC WEATHER CONDITIONS ASSOCIATED WITH THE ACTIVE FIRE PERIODS

Meteorological data for the two periods of major fire activity were obtained from the Canadian Atmospheric Environment Service (AES) in Winnipeg and the Manitoba Natural Resources (MNR) department. These data included mean sea level pressure analysis and surface data such as: temperature, atmospheric moisture (dewpoint temperature or relative humidity), wind speed and direction, and precipitation. Upper air data and analysis, also obtained from AES, included 850 hectopascal[1] (hPa) analysis, 500 hPa analysis, 250 hPa analysis and tephigrams[2] from The Pas, Shilo (near Brandon), and Churchill, Manitoba and Big Trout Lake, Ontario.

May 11-17, 1989

The weather in May prior to the 11th was warm and dry with very little or no precipitation across much of central Manitoba. During the entire period of intense fire activity a "blocking ridge" at 500 hPa was dominant. Blocking ridges in the upper atmosphere generally provide sunny and warm conditions at the surface and shunt any precipitation-bearing systems away from the region under the ridge. Temperatures were generally in the mid to upper twenties (°C) but did exceed 30°C on occasion with minimum relative humidity (RH) values as low as 15% and wind speeds on the critical days averaging 20-35 km/h.

Figure 5 shows the 500 hPa analysis for May 11, 1989 0700 Central Daylight Time (CDT). A 500 hPa ridge extends from the central United States to Manitoba and northwestern Ontario and then continues northwestward to the Northwest Territories while a major trough extends southward from British Columbia. The upper ridge remained anchored over Manitoba between May 11 and May 17 before moving eastward to Ontario. The surface analysis for May 11, 1989 1300 CDT (Figure 6) shows a low pressure system

[1] 1 hectopascal (hPa) = 1 millibar = .1 kilopascal

[2] Tephigram - a thermodynamic diagram with temperature and logarithm of potential temperature as coordinates.

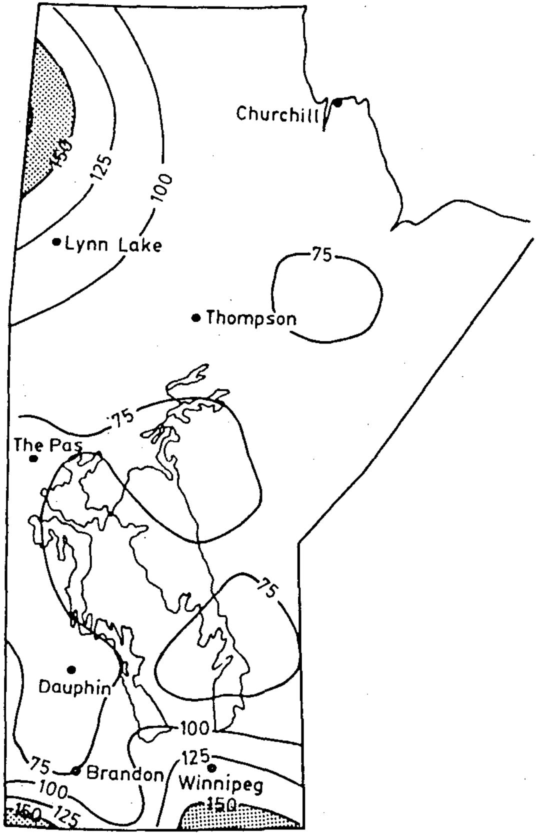

Figure 3. Precipitation as a percentage of normal for Manitoba, Nov. 1, 1988 - March 31, 1989 (percentages above 150% and below 50% are shaded).

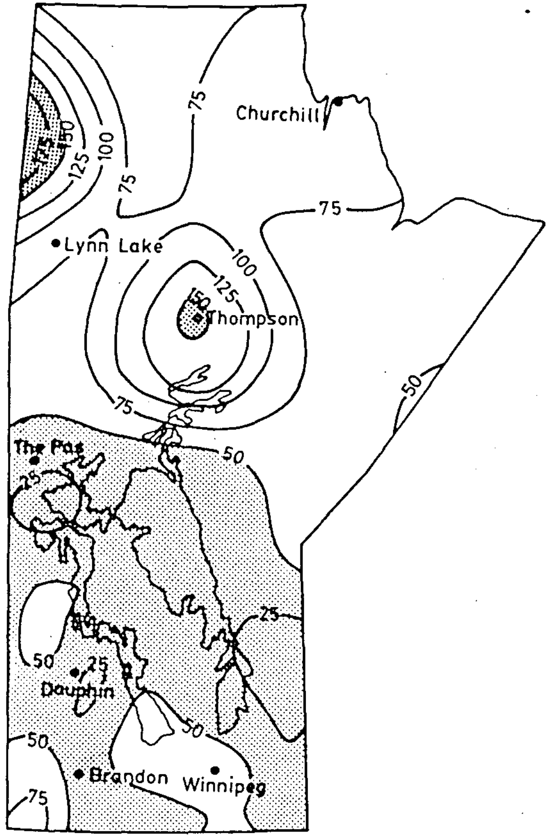

Figure 4. Precipitation as a percentage of normal for Manitoba, April 1 - 30, 1989 (percentages above 150% and below 50% are shaded).

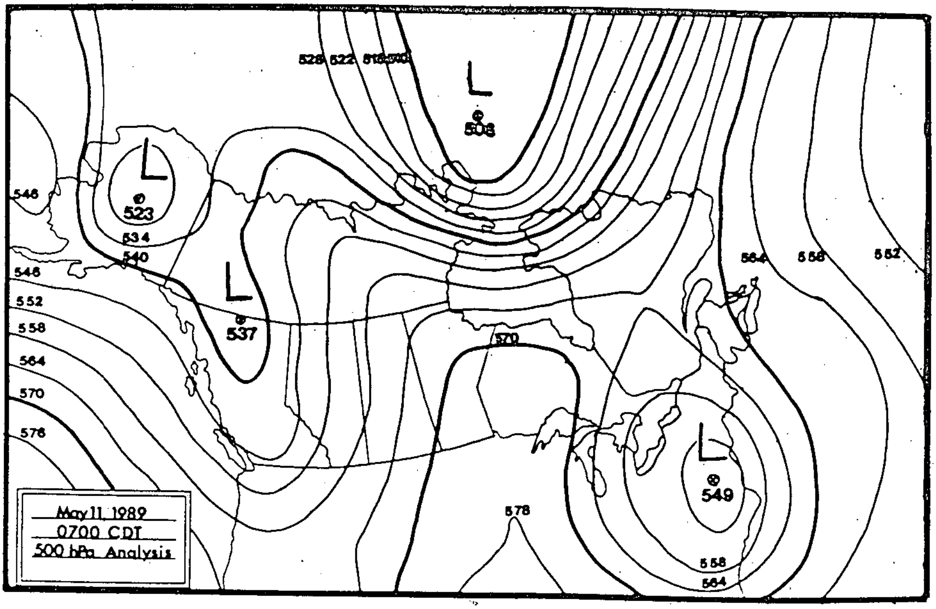

Figure 5. 500 hPa analysis valid for May 11, 1989, 0700 CDT (note: heights are in decameters).

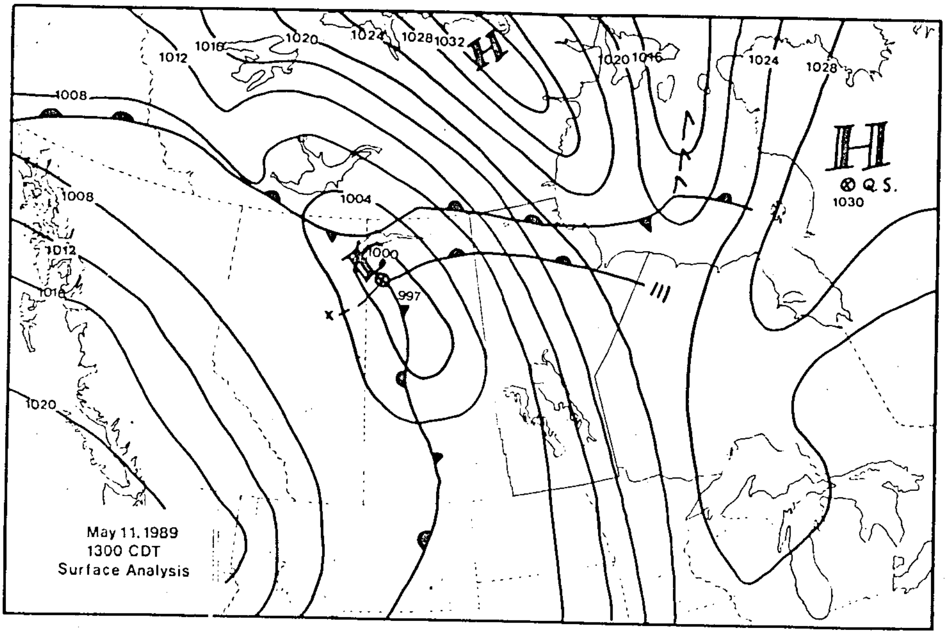

Figure 6. Surface analysis valid for May 11, 1989, 1300 CDT (note: isolines are in hectopascals).

moving over northern Saskatchewan with a trough and frontal system south to Wyoming. A strong southerly gradient in the pressure pattern was pulling warm and dry air from the south-central United States. Windy, warm and dry conditions associated with this weather pattern are conducive to rapid fire spread. Wind speeds dropped as the surface pressure gradient slackened by May 13 but the pressure gradient intensified once again on May 16 causing moderate wind speeds. By May 18 the extreme fire activity subsided as cooler, showery weather moved into the province.

July 21 - August 2, 1989

The weather in late May and throughout June was generally cool and wet across the province. In July, prior to July 21, the weather had been hot and dry in most of north-central Manitoba. On the evening of July 17 widespread lightning activity, accompanied by only spotty precipitation, occurred across north-central Manitoba contributing significantly to the 195 fire ignitions that were reported between July 18 and July 20. Once again an upper ridge played a major role during the active fire period. Figure 7 depicts a 500 hPa ridge extending from the southwestern United States to central Manitoba at 0700 CDT on July 21, 1989. This ridge held its position until July 24 when it was eroded by a disturbance from British Columbia. By July 28 another ridge located over the centre of the continent was influencing Manitoba. This ridge was eventually replaced by a moist, vigorous "Pacific" system on August 3.

At the surface, warm, dry and windy weather prevailed over Manitoba between July 21 and July 23. Figure 8, the surface analysis valid for 1300 CDT on July 21, 1989, shows a broad low over the Northwest Territories with a frontal trough from the low southwards through Saskatchewan to the United States. A moderate south to southwest flow of hot air prevailed over Manitoba. Temperatures ranging from 30°C to 36°C were associated with this weather pattern. A disturbance from the west coast moved through northern Manitoba on July 25 and 26 bringing cooler temperatures and showery weather. Conditions were dry from July 27 until August 3 when a low pressure system brought widespread rains to northern Manitoba.

The persistence of a blocking ridge in the upper atmosphere was common to both periods of intense forest fire activity. This feature would intuitively be associated with forest fire activity since the persistent warm, dry weather is conducive to the drying of the forest fuels, resulting in an increased potential for ignition, greater fire spread and higher fire intensity. Newark (1975) showed a relationship between forest fire occurrence and the

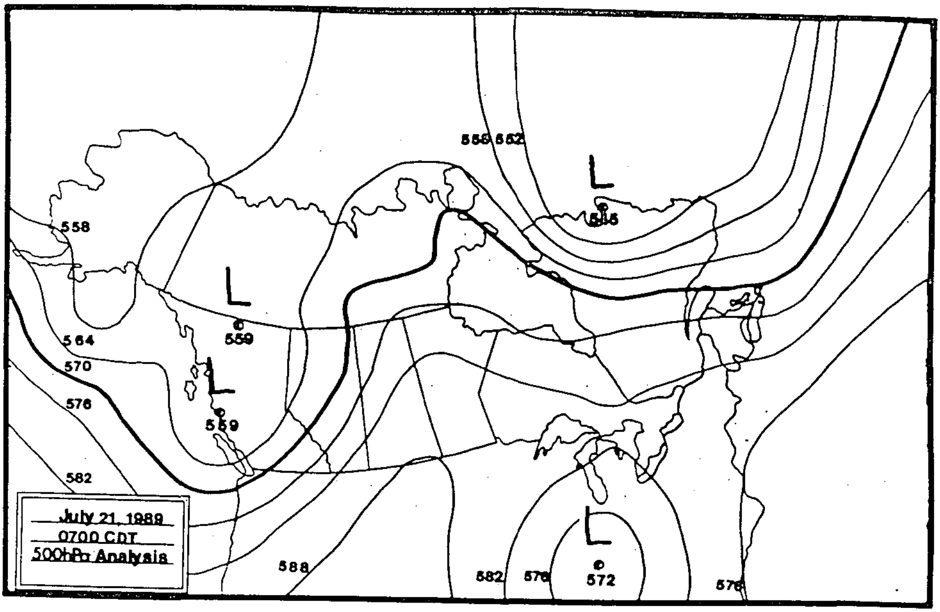

Figure 7. 500 hPa analysis valid for July 21, 1989, 0700 CDT (note: heights are in decameters).

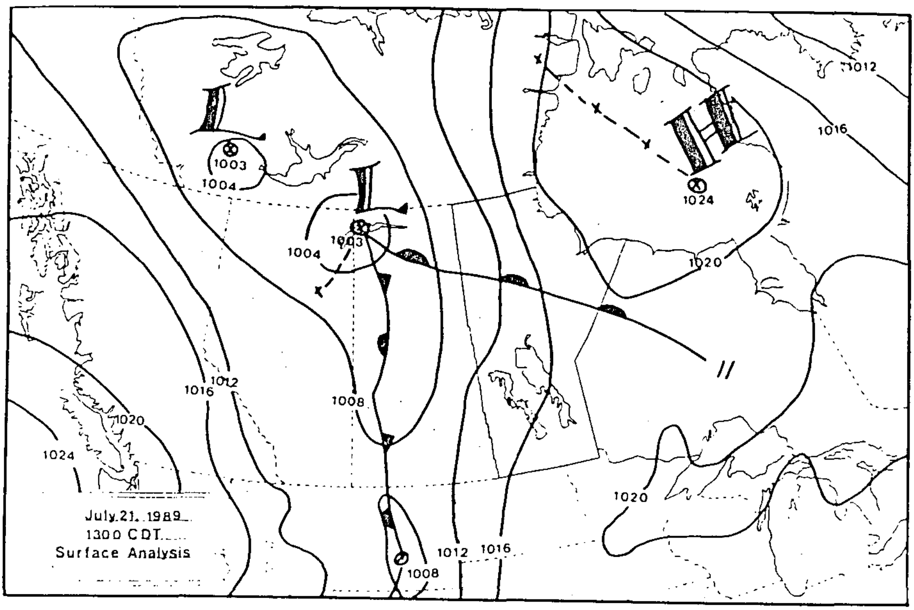

Figure 8. Surface analysis valid for July 21, 1989, 1300 CDT (note: isolines are in hectopascals).

500 hPa upper atmospheric ridging in northwestern Ontario. Stocks and Street (1983) found that these well entrenched ridges were a common denominator in critical fire periods in northwestern Ontario during 1974-80. Other authors (Flannigan and Harrington 1988; Nimchuk 1983; Schroeder et al. 1964) have also found relationships between upper atmospheric ridging and severe fire weather. The link between blocking ridges and extreme fire behavior has been documented and appears to have been operative during the 1989 fire season in Manitoba.

FIRE DANGER AND FIRE BEHAVIOR

The wide spread fire activity that transpired in Manitoba during the 1989 fire season was unprecedented in the province's recorded history. Numerous high intensity, continuous crown fires were the result of multiple fire ignitions occurring during periods of extreme fire weather. Many of the 75 fires that exceeded 5,000 ha in size (see Figure 2) experienced the majority of their fire growth as a result of major fire runs on just one or two days. Random observations by a number of MNR fire suppression staff have provided valuable descriptions of the fire behavior characteristics as well as headfire rate of spread data on seven of these conflagrations. This type of data, though not overly detailed, has been quite adequate for other recent case-studies of wildfires in this area of Canada (Alexander et al. 1983; Alexander and Lanoville 1987; Stocks and Flannigan 1987; Hirsch 1989).

Valuable insights concerning the extreme fire danger conditions and the associated fire behavior can be gained by examining the components of the Canadian Forest Fire Danger Rating System or CFFDRS (Stocks et al. 1989). The CFFDRS is used by all of the fire management agencies in Canada to indicate the potential for wildfire ignition, behavior and impacts. The two primary modules of the CFFDRS are the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987; Van Wagner and Pickett 1985) and the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1990). The FWI System consists of six components that provide "numerical ratings of relative fire potential in a standard fuel type (i.e., a mature pine stand) on level terrain" whereas the FBP System provides "quantitative outputs of selected fire behavior characteristics for certain major Canadian fuel types and topographic situations" (Merrill and Alexander 1987).

Table 1 lists the 1300 Central Daylight Time (CDT) fire weather observations and the values of the FWI System components[3] on the day of each of the well-documented wildfire runs. The indices reveal a number of key points. First, during all of the fire runs the moisture content of the surface litter and the top 5-10 cm of the duff layer was extremely low. Samples taken near Fire #64 showed the upper duff layers to have a moisture content between 30% and 50%. Second, the deeper duff layers (10-25 cm) were moist in May but were very dry during the July fires and contributed significantly to the amount of available fuel. Third, though the potential rate of fire spread varied substantially on days with major fire runs the potential fire intensity was consistently at a high or extreme level.

Table 1. Fire weather observations and fire danger indexes at 1300 CDT on the days of seven major wildfire runs in Manitoba during the 1989 fire season.

Fire Name	Location		Date (1989)	Temp. (°C)	RH (%)	10-m wind		FWI System components					
	Lat. (°N)	Long. (°W)				speed (km/h)	dir. (°)	FFMC	DMC	DC	ISI	BUI	FWI
Sandy River	51°05'	96°20'	May 11	25.3	23	37.0	180	93.5	40	82	40.6	40	51
			May 15	29.5	24	6.8	270	94.2	61	110	10.8	61	26
Cowan	52°05'	100°30'	May 13	27.0	20	10.0	180	94.3	46	220	12.8	61	29
Sherridon	55°00'	101°00'	July 21	36.0	24	33.0	205	93.1	75	575	34.6	113	73
Snow Lake	54°20'	99°50'	July 21	36.0	24	33.0	205	93.1	75	575	34.6	113	73
Norway House	53°55'	97°50'	July 22	30.9	40	24.0	190	92.6	94	516	20.5	129	55
Fire #64	54°15'	99°55'	July 25-26	23.0	56	15.5	225	89.1	91	610	8.2	133	31

Table 2 provides specific fire behavior information on each of the well-documented wildfire runs. Undoubtedly a larger number of runs took place however, the necessary observations and weather data were only available for these seven fires. The average headfire rate of spread (ROS) over the period of the documented fire runs ranged from 16.7 m/min (1.0 km/h) to 44.4 m/min (2.7 km/h). These values are not unusually high for boreal forest fuel types however the overall length of some of the runs and the large

[3] The FWI System is comprised of three fuel moisture codes and three fire behavior indexes. The three moisture codes represent the moisture content of the fine fuels (Fine Fuel Moisture Code - FFMC), loosely compacted decomposing organic matter (Duff Moisture Code - DMC), and the deep layer of compact organic matter (Drought Code - DC). The three fire behavior indexes, which are derived from the moisture codes and the surface wind, indicate the rate of initial fire spread (Initial Spread Index - ISI), total available fuel (Buildup Index - BUI), and the intensity of a spreading fire (Fire Weather Index- FWI).

Table 2. Fire behavior characteristics of seven major wildfire runs in Manitoba during 1989.

Fire name	Calender date (1989)	Local time (CDT[6])	FBP System fuel type	Average wind speed[2] (km/h)	Average rate of spread (m/min)	Spread distance (km)	Fuel consumption[1] Surface[3] (kg/m^2)	Crown[4]	Total	Headfire intensity[5] (kW/m)
Sandy River	May 11	1140-1840	Boreal Spruce	29.8	22.8	9.6	1.84	0.80	2.64	18058
	May 15	1300-1530	Boreal Spruce	12.0	24.9	4.3	2.55	0.76	3.31	24726
Cowan	May 13	1700-2000	Immature Pine	20.0	44.4	8.0	1.82	1.20	3.02	40226
Sherridon	July 21	1230-2130	Boreal Spruce	24.6	27.8	15.0	3.64	0.80	4.44	37030
Snow Lake	July 21	1120-2143	Boreal Spruce	23.7	20.1	12.5	3.64	0.80	4.44	26773
Norway House	July 22	1500-2000	Boreal Spruce	29.8	16.7	5.0	3.87	0.80	4.67	23397
Fire #64	July 25-26	1400-0100	Boreal Spruce	21.0	19.4	12.8	3.92	0.69	4.61	26830

[1] Estimated values derived from the FBP System (Forestry Canada Fire Danger Group 1990).
[2] Wind speed observations (i.e., a 2 or 10 minute average of the 10-m open wind speed) were taken each hour during the fire run and averaged.
[3] Includes forest floor and woody fuel consumption.
[4] Includes only foliage (no woody material).
[5] Calculated according to Byram (1959) using a low heat of combustion of 18,000 kJ/kg. e.g. (22.8 m/min x 1 min/60 sec) x 2.64 kg/m^2 x 18000 kJ/kg = 18058 kW/m.
[6] Central Daylight Time.

number that were occurring simultaneously made the situation unique.

The overstory fuel consumed during the fire runs was a mixture of tree species with black spruce being the most dominant. Forestry Canada Fire Danger Group (1990) describes this as the Boreal Spruce (C-2) fuel type. The only exception to this was the Cowan Fire where the area was covered almost entirely with 25-30 year old jack pine (FBP System fuel type: C-4 Immature Pine). Topography in all of Manitoba's forested area could be considered gently undulating with very few steep slopes. Therefore, slope was not seen as an influential factor on the headfire ROS.

The fuel consumption data given in Table 2 are estimated values derived from the FBP System (Forestry Canada Fire Danger Group 1990) rather than actual field measurements. Clearly, the May fires did not produce the same level of fuel consumption as the July fires due to the differences in the moisture content of the deeper duff layers and the heavier woody fuels. Visual, post-fire inspections at some of the July fires showed complete consumption of all of the duff layers above mineral soil which in the Boreal Spruce (C-2) fuel type could be as deep as 30 - 50 cm.

Table 2 also provides headfire intensity values calculated according to Byram (1959) using an average low heat of combustion of 18,000 kJ/kg. The fire intensity levels during all of the fire runs greatly exceeded the point where suppression efforts would have been effective or even safe. Alexander and DeGroot (1988) state that when a fire's intensity is greater than 4000 kW/m the effectiveness of suppression (even with the use of airtankers, or backburning) is minimal. Therefore, when many of the fire runs were taking place suppression staff focused their efforts on evacuating residents of endangered communities. In total, 2000 people from 7 communities were forced to leave their homes in May and another 22,500 people from 25 communities were evacuated in July (Hirsch 1990).

Each major wildfire could in itself be an individual case-study of extreme fire behavior however, discussion has been limited to a few examples of highly unusual fire behavior. During the May fires, for instance, swamps and sloughs that are normally filled with water and serve as natural fuel breaks, were completely dry and burned rapidly throughout the night. Also, the Sandy River Fire, located next to Lake Winnipeg (the 5th largest lake in Canada) was influenced significantly by shifting winds (45°-90°) due to a "lake breeze" effect. This phenomena is rarely experienced in Manitoba and made the development and implementation of suppression plans very difficult.

The summer fire behavior was unusual primarily because of the high levels of fuel consumption and the volatility of the fine fuels. Fire #64 was the best documented example of a major fire run occurring under relatively moderate fire weather conditions. A possible reason for this type of fire behavior was the consumption of a large amount of available fuel on a day with good convective lift. Other examples of uncharacteristic fire behavior included indrafts being observed as far as 5 km ahead of major convection columns and significant crowning occurring at 3:00 a.m. with a humidity of 80%. This type of fire behavior rendered traditional suppression techniques ineffective leaving backburning by aerial ignition as the most utilized and effective suppression tool.

THE 1989 FIRE SEASON IN PERSPECTIVE

As stated previously, the 1989 fire season resulted in the highest area burned since records began in 1918. Was 1989 an anomaly or was it just part of the natural variability within the fire environment? The answer to this question is unknown. The large area burned may simply have been the result of multiple fire ignitions coinciding randomly with periods of below normal precipitation and short-term extreme fire weather. On the other hand, some individuals may wish to connect the severity of the 1989 fire season to greenhouse warming. This however cannot be stated with any certainty but, one should be aware that if significant climate warming does take place the events of 1989 could be a foreshadowing of things to come.

How unusual was the fire season climate of 1989 in Manitoba? Quite, in terms of temperatures for July. The mean July temperature in 1989 was the highest ever recorded for five stations in northern Manitoba. The new record July temperatures at these stations exceeded the previous records by an amazing 1.2°C-2.3°C. Otherwise, the climate during the remainder of the fire season was not that unusual except for a greater frequency of dry periods associated with the blocking ridge episodes. Precipitation for the entire fire season was near normal however, it appears that the timing of the precipitation and not the amount was most important in these critical fire weather situations.

How often could a fire season like 1989 (in terms of area burned) be expected in Manitoba? Depending on the analysis, it could be expected once every 400-770 years. This return period was calculated using the non-normal distribution of annual area burned in Manitoba for 1918-1989. The data was transformed to a normal distribution and the probability of a year like 1989 was determined to be 0.0025, producing a return period of 400 years (i.e., return period = 1/0.0025 = 400 years). The range of the return period is influenced significantly by one extreme year. In this case if 1989 is excluded from the distribution data the probability of a year in which 3.28 million ha is burned would be

0.0013 which yields a return period of about 770 years.

SUMMARY

The 1989 fire season will long be remembered as one of the most severe in Manitoba's history. The record number of fires (1147) and area burned (3.28 million ha) had a significant impact on the province's natural resources and its people. The majority of the fire activity occurred between May 11 - 19 in the central regions of the province and from July 21 - August 2 in northern Manitoba. The dominant weather feature during both situations was a blocking ridge in the upper atmosphere. These blocking ridges resulted in prolonged periods of warm, dry weather which significantly raised the fire danger conditions by lowering the moisture content of the forest fuels. Multiple ignitions of human-caused and lightning-caused fires during these periods overwhelmed suppression efforts and when the upper ridges began to weaken, strong winds produced numerous major fires runs. Many examples of extreme fire behavior were observed and a total of seven wildfire runs were documented. Observed headfire rates of spread and estimated headfire intensities ranged from 16.7 m/min (1.0 km/h) to 44.4 m/min (2.7 km/h) and 18057 kW/m - 40226 kW/m, respectively. A return period analysis based on area burned information showed that Manitoba can expect an extraordinary fire season like 1989 only once every 400 years.

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Contents

Preface

Subjects

Opening Conference 1 - 14

Closing Conference 1 - 19

Round Table 1 1 - 14

Round Table 2 1 - 5

List of Papers 1 - 9

Papers

Subject A *General and Institutional Aspects* A01 - A14

Subject B *Physical Aspects* B01 - B26

Subject C *Fire effects* C01 - C24

Sponsoring