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ANALYSIS OF EXTREME WILDFIRE BEHAVIOR IN EAST-CENTRAL ALBERTA: A CASE STUDY

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1. INTRODUCTION

A large region of central and western Canada experienced a particularily severe forest fire season during 1980 in terms of the number of fire starts, area burned, and suppression expenditures*. In Alberta, most of the fire activity occurred during April and May in the northern half of the province. A total of 1356 fires burned over 639,807 ha. This represents ≃ 1.5% of northern Alberta (defined here as roughly the area above 54°N latitude). Fire protection costs, fixed and variable, totaled 46 million dollars in the province.

There were 42 "Class E" fires (> 200 ha) in Alberta during the 1980 fire season. The purpose of this paper is to document the environmental conditions associated with the extreme behavior exhibited by a single Class E fire during its first burning period. The particular fire under examination here, referred to in the official records of the Alberta Forest Service (AFS) as DND-4-80, occurred in the Cold Lake Air Weapons Range and Lac La Biche Forest of east-central Alberta (Fig. 1). On May 2, 1980, it advanced nearly 18 km to the north from its point of origin, in a period of five hours. The fire eventually covered an area of 137,313 ha in Alberta and an estimated 40,500 ha in Saskatchewan (referred to in that province as the Victor Fire). The initial run of the DND-4-80 Fire was selected for a case study analysis because of its rapid rate of spread and the availability of a rather complete set of weather data.

2. FIRE CHRONOLOGY AND DESCRIPTION

The DND-4-80 Fire was first detected by the Winefred Lookout (LO) towerman at 1438 MDT on May 2. Smoke was observed 3.2 km southwest of the tower site within the Cold Lake Air Weapons Range (Fig. 2), a restricted area administered by the Department of National Defence. The fire was thought to have started at approximately 1315 MDT and estimated to be 0.8 ha at discovery (the area of origin was screened from Winefred LO by a ridge). The cause of the fire was thoroughly investigated and although it was strongly suspected to be man-caused, the specific causative agent remains unknown. The smoke report was relayed by radio to the Beaver Lake Ranger Station (RS) (Fig. 1) at 1440 MDT.

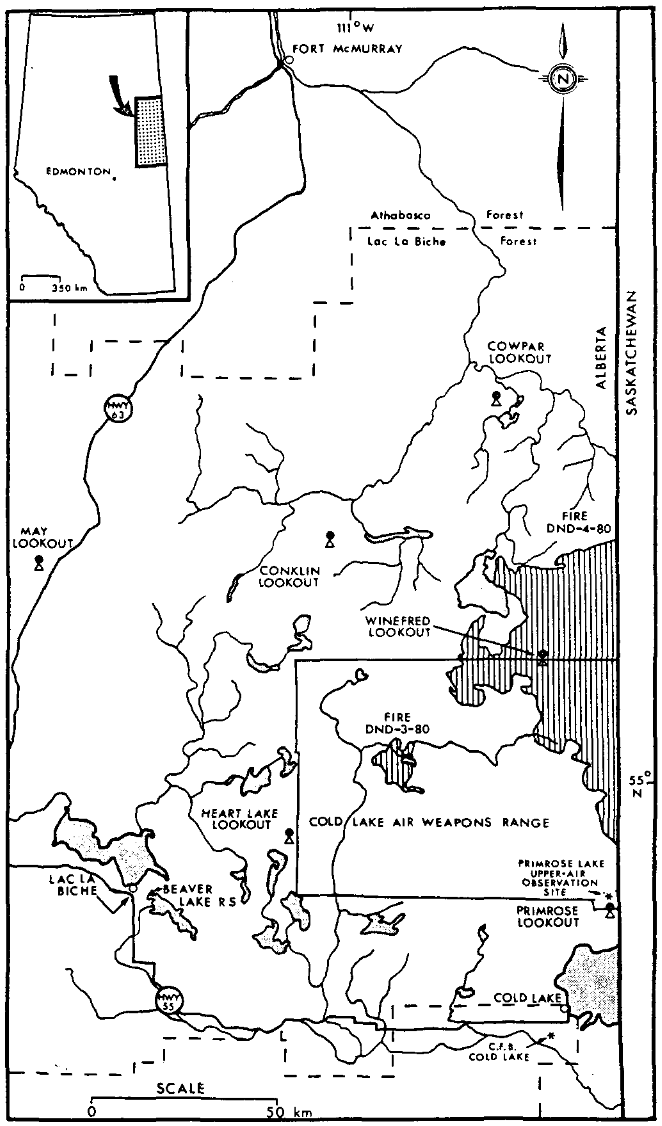

Fig. 1. *Location of the DND-4-80 Fire in east-central Alberta and weather stations referred to in the text.*

*Stocks, B.J., C.E. Van Wagner, W.R. Clark, and D.E. Dube, 1981: The 1980 forest fire season in west-central Canada -- social, economic, and environmental impacts. Environ. Can., Can. For. Serv., unpubl. rep., 27 pp.

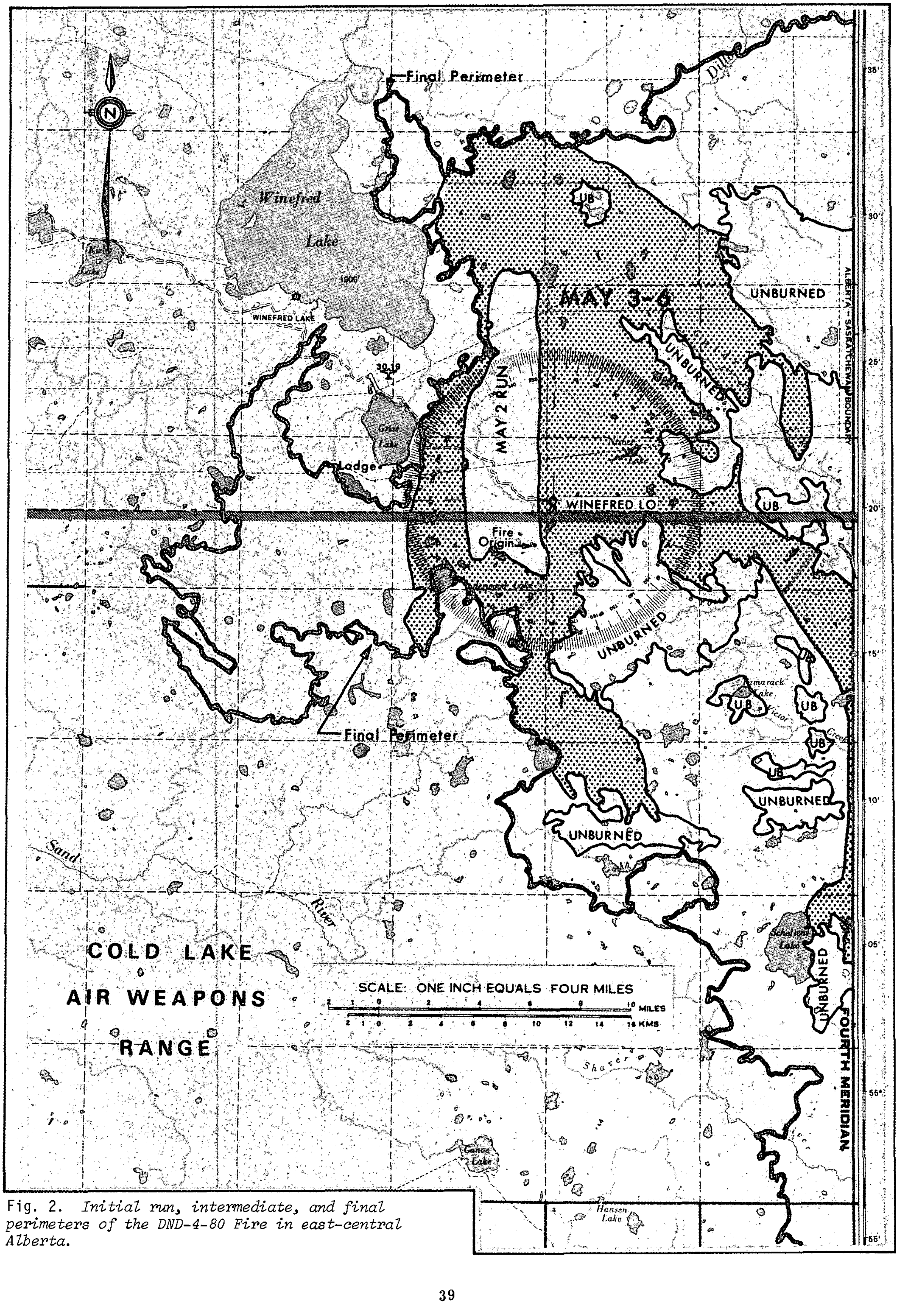

Fig. 2. *Initial run, intermediate, and final perimeters of the DND-4-80 Fire in east-central Alberta.*

The Department of National Defence does not have an initial attack capability and therefore it relies on AFS crews from the Lac La Biche Forest. The following is the chronological sequence of events that transpired during the next five hours (all times are MDT):

1505 - an AFS initial attack crew foreman flew over the fire and informed the Beaver Lake RS that it was heading in the general direction of the Grist Lake fishing lodge and "moving fast". He was informed to evacuate lodge residents.

1508 - fire estimated to be 800 ha in size.

1515 - all residents of the Grist Lake lodge were evacuated. Beaver Lake RS was advised that due to smoke, strong winds, and high spread rate, any action on the fire should be postponed.

1537 - Beaver Lake RS was informed by the crew foreman that the fire was approximately 1.2 km from Winefred LO.

1540 - helicopter dispatched to Winefred LO. Arrives at 1606. Winefred LO towerman evacuated at 1614.

1620 - fire had travelled past Grist Lake heading north along a strip approximately 3.2 km wide.

1727 - seismic crew camp was found near Grist Lake and a search for the men was started.

1925 - all seismic crew workers were located and evacuated. Due to intense fire front and time of day, suppression action was postponed until the following morning.

1930 - reconnaissance was made by the Lac La Biche Forest Superintendent and Forest Protection Officer to determine size and extent of fire area.

The initial run of the DND-4-80 Fire produced a narrow, elongated area approximately 20 km in length, by 3-5 km in width, and 7,500 ha in size.

3. FUELS AND TOPOGRAPHY

The fire area is located within the Boreal Mixedwood Forest Section (B.18a) of Canada (Rowe, 1972) and the Boreal Mixedwood Ecoregion (8) of Alberta (Strong and Leggat, 1981). The forest cover and topography is typical of east-central and much of northern Alberta.

An AFS forest cover type map of the area, as interpreted from 1950 aerial photography, shows a mosaic of jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* [Mill.] B.S.P.) stand associations, interspersed with minor amounts of trembling aspen (*Populus tremuloides* Michx.). Tree cover averaged 10-15m in height and fuels were uniform and continuous both vertically and horizontally.† The occasional open and sparsely treed muskeg as well as numerous small water bodies were the only interruptions in the continuity of tree cover. Aspen stands were in leaf during the first week in May and lesser vegetation was greening up rapidly, preceding the normal green-up period by a full two weeks.

†The third author served as a Fire Behavior Officer on the overhead team assigned to the DND-4-80 Fire between May 6-12.

The area burned during the initial run of the DND-4-80 Fire is situated at an elevation of 600-700 m ASL. Major elevational changes in the surrounding area are minimal; the difference between Winefred Lake (579 m) and Winefred LO (744 m) is only 165 m over a distance of 13 km (Fig. 2). Thus, the terrain would be classed as essentially level. Natural fuelbreaks were virtually nonexistent. Road access to and within the area is limited.

4. ANTECEDENT CLIMATIC AND METEOROLOGICAL CONDITIONS

Most of east-central Alberta had well below-normal precipitation during the 6-month period from November 1979 to April 1980 (Fig. 3). The three closest year-round climatological stations (Anon., 1981) to the fire area (Fig. 1) all indicated below-normal precipitation during this time: Fort McMurray (44%); Lac La Biche (30%); and Cold Lake (35%). A Sacramento storage gauge at May Tower (Fig. 1) recorded 119.4 mm of precipitation between September 13, 1979 and May 1, 1980, while Fort McMurray, Lac La Biche and Cold Lake reported 111.5 mm, 163.7mm and 104.8 mm, respectively, during this same time interval. A dry winter is not unique to this region as indicated by long-term records at Fort McMurray which shows that in the 60 years (since 1919-20) prior to 1980 there were at least seven winter/spring periods with significantly less precipitation than the winter and spring of 1979-80. Lac La Biche has witnessed at least 18 years with less precipitation in the last 35 years since 1944-45, whereas Cold Lake has experienced only one drier winter/spring in the 26 years since 1953-54. Air temperatures were almost consistently above-normal between November 1979 and April 1980.

In the spring of 1980, most of east-central Alberta was free of snow by the first week of April. Fort McMurray and Cold Lake reported only a trace of snow on April 6. This was about two weeks ahead of normal (Potter, 1965) and due in part to the above-normal temperatures and below-normal precipitation during the preceding five months. This was not a unique situation, as records indicate loss of snow cover as early as the last week of March (Potter, 1965).

During the third week of March, an upper level high pressure ridge became well-established over Alberta. This system persisted throughout April and the first three weeks of May. The strength of the ridge can be judged from the fact that the mean 500 mb height over Edmonton (Fig. 1) during April was 5560 m compared to a normal of 5460 m. This was reflected in record high surface temperatures over much of east-central Alberta. In April 1980, Fort McMurray, Lac La Biche, and Cold Lake reported monthly mean daily temperatures of 10.0°C, 9.4°C, and 9.3°C, respectively, compared to 1951-80 normals (Anon., 1982) of 2.1°C at the former two stations and 2.9°C at the latter. The monthly mean daily maximum temperatures at Fort McMurray (18.2°C), Lac La Biche (17.1°C) and Cold Lake (16.3°C) represent the highest reported April values since continuous climatological observations began in 1915, 1945 and 1953, respectively. Precipitation was almost absent during April 1980: Fort McMurray (0.2 mm); Lac La Biche (trace); and Cold Lake (1.6 mm). Except for one year, this represents the least amount ever recorded at Fort McMurray since 1922. Neither Lac La Biche or Cold Lake have ever recorded smaller amounts since the initation of recordkeeping in 1945 and 1953, respectively. Other years with warm, dry winters have had a relatively cool April with considerably more precipitation than April 1980.

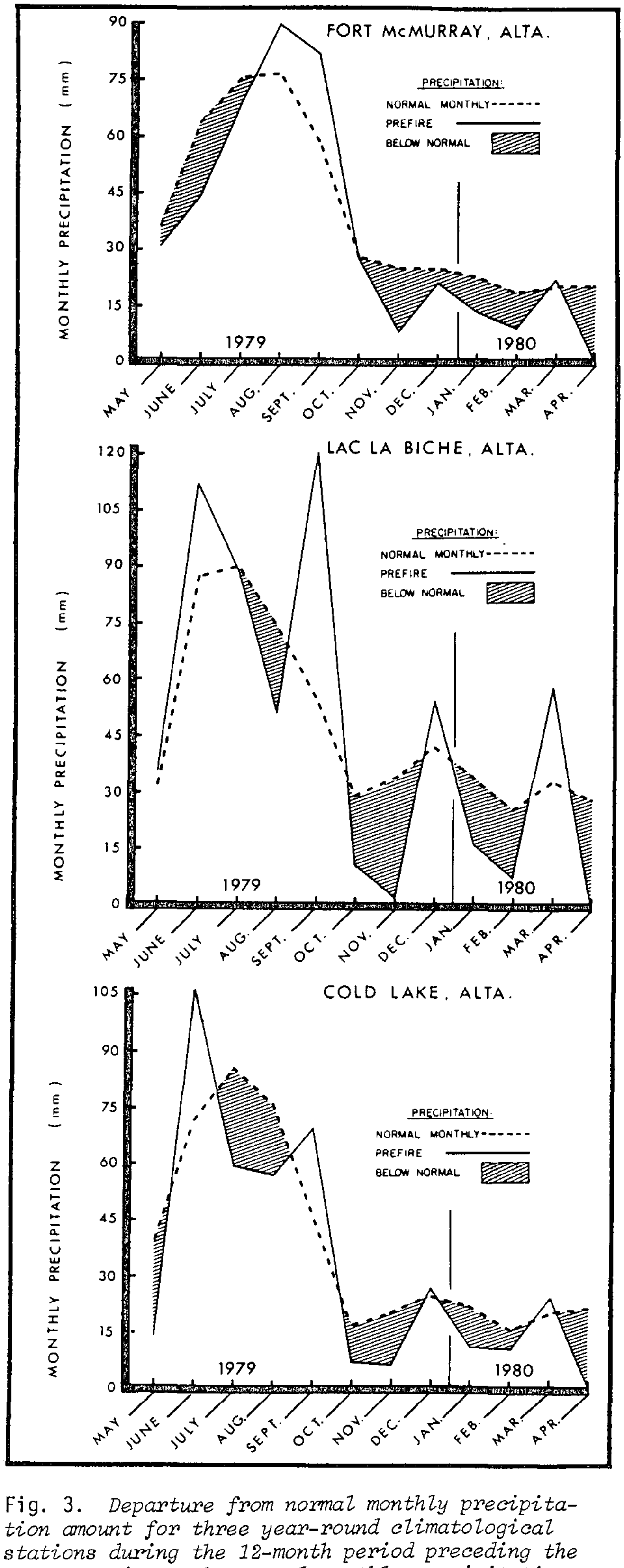

Fig. 3. *Departure from normal monthly precipitation amount for three year-round climatological stations during the 12-month period preceding the DND-4-80 Fire. The normal monthly precipitation (1951-80) is delineated by a broken line, the prefire precipitation by a solid line. Shaded areas represent periods when precipitation was below normal.*

5. FIRE WEATHER OBSERVATIONS AND FIRE DANGER RATINGS

Surface fire weather data for mornings and afternoons were obtained for five AFS LO stations closest to the fire area. Except for Winefred LO, the LOs lie within 65-85 km of the fire area (Fig. 1). The morning readings for May 2 are presented in Table 1. and reflect rather high minimum nighttime temperatures and low maximum nighttime relative humidities. The minimum overnight temperature at Winefred LO was 15.0°C.

The burning conditions during the initial run of the DND-4-80 Fire are expressed here in terms of the six Canadian Forest Fire Weather Index (CFFWI) components of the Canadian Forest Fire Danger Rating System (CFFDRS) (Van Wagner, 1974; Anon., 1978; Turner and Lawson, 1978). The standard CFFDRS fuel moisture codes representing the moisture content of fine surface litter, loosely compact duff of moderate depth, and deep organic matter are, the Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), and the Drought Code (DC), respectively. The relative fire behavior indexes of the CFFDRS representing rate of spread, fuel available for combustion, and frontal fire intensity are, the Initial Spread Index (ISI), Buildup Index (BUI), and the Fire Weather Index (FWI). More specifically, the ISI represents the combined effect of wind speed and FFMC on the fire spread rate. The BUI is a combination of the DMC and the DC which represents the total fuel available to a spreading fire. The FWI is a combination of the ISI and BUI, and represents the energy output rate per unit length of a spreading fire front. The FWI and its associated components, based on past and present weather observed daily at 1300 MDT, are presented in Table 2. All weather data were processed by computer (Van Wagner and Pickett, 1975). The spring DC starting values were adjusted for the 1979-80 subnormal overwinter precipitation (Turner and Lawson, 1978; Alexander, 1982a).

Except for Winefred LO, the 1300 MDT temperatures reported in Table 2 also represent the maximum observed temperatures for May 2. Because the

Table 1

Fire weather observations recorded between 0730-0745 MDT on May 2, 1980, for five surrounding Alberta Forest Service weather stations prior to the initial run of the DND-4-80 Fire.

Station name	Station elevation (m)	Dry-bulb temperature (°C)	Relative humidity (%)	Wind[a] direction	Wind[a] speed (km/h)
Conklin LO	695	17.0	41	SW	12
Cowpar LO	563	16.5	40	SE	22
Heart Lake LO	887	15.0	51	S	23
Primrose LO	678	14.0	36	S	18
Winefred LO	744	15.0	38	S	24

[a] As measured at a height of 10 m in the open on level terrain.

Table 2

Fire weather observations and fire danger conditions at 1300 MDT on May 2, 1980, for five surrounding Alberta Forest Service stations prior to the initial run of the DND-4-80 Fire.

Station name	Dry-bulb temperature (°C)	Relative humidity (%)	Wind[a] direction	Wind[a] speed (km/h)	CFFWI components FFMC	DMC	DC	ISI	BUI	FWI
Conklin LO	28.0	20	SW	19 (50)[b]	95	80	207	21	81	45
Cowpar LO	30.0	19	S	32	95	88	227	44	89	74
Heart Lake LO	26.0	22	S	35 (50)[b]	94	71	182	42	72	66
Primrose LO	27.0	18	S	18	95	70	275	21	86	46
Winefred LO	26.0	21	S	36	94	77	129	46	76	70

[a] As measured at a height of 10 m in the open on level terrain.

[b] Reported gusts in parentheses.

Table 3

Hourly weather observations and fire danger conditions for three synoptic stations prior to and during the initial run of the DND-4-80 Fire.

Fort McMurray, Alta. (elevation: 371 m)

Hour (MDT)	Dry-bulb temperature (°C)	Relative humidity (%)	Wind[a] direction (°)	Wind[a] speed (km/h)	FFMC	ISI
0800	16.7	37	120	15	91.9	11.6
0900	20.7	35	140	19	91.9	14.2
1000	24.4	33	140	22 (30)[b]	92.1	16.9
1100	26.8	26	170	32 (48)	92.6	30.2
1200	28.2	21	180	26 (61)	93.3	24.5
1300	28.8	22	200	28 (50)	93.9	29.2
1400	30.0	19	210	26 (48)	94.4	28.6
1500	29.9	16	210	32 (46)	95.1	42.1
1600	30.2	17	210	28 (41)	95.5	36.4
1700	30.0	16	210	28 (37)	95.8	38.2
1800	30.0	15	210	22 (37)	96.1	29.4
1900	29.0	16	200	19	96.2	25.7
2000	27.9	19	180	11	96.2	17.2
2100	24.4	23	150	13	96.2	18.8
2200	21.4	35	310	28 (43)	95.7	37.7
2300	18.9	44	270	28 (37)	95.1	34.5

Lac La Biche, Alta. (elevation: 559 m)

Hour (MDT)	Dry-bulb temperature (°C)	Relative humidity (%)	Wind[a] direction (°)	Wind[a] speed (km/h)	FFMC	ISI
0800	16.7	43	140	16	92.4	13.1
0900	-	-	-	-	-	-
1000	22.8	31	140	21	92.5	17.1
1100	24.4	24	160	24	92.9	21.0
1200	27.2	19	170	31	93.6	32.8
1300	28.3	16	180	45	94.4	74.2
1400	29.4	15	180	31	95.1	40.1
1500	29.4	13	150	24	95.6	30.4
1600	30.0	12	180	26	96.1	36.1
1700	-	-	-	-	-	-
1800	-	-	-	-	-	-
1900	28.3	14	170	21	96.7	30.3
2000	24.4	17	150	11	96.7	18.3
2100	18.9	43	290	21	96.0	27.4
2200	17.2	50	290	21	95.2	24.6
2300	14.4	51	290	13	94.5	15.0

Cold Lake, Alta. (elevation: 544 m)

Hour (MDT)	Dry-bulb temperature (°C)	Relative humidity (%)	Wind[a] direction (°)	Wind[a] speed (km/h)	FFMC	ISI
0800	15.8	36	140	15	93.0	13.4
0900	20.0	30	170	20	93.0	17.2
1000	21.9	27	160	24	93.1	21.4
1100	24.2	24	160	22	93.3	20.1
1200	25.9	21	210	32	93.8	35.3
1300	26.9	16	170	39 (54)[b]	94.4	55.0
1400	27.7	15	200	33 (52)	95.0	30.8
1500	28.3	16	200	28 (46)	95.4	35.9
1600	27.8	16	170	39 (59)	95.7	65.1
1700	28.3	15	150	26 (44)	95.7	34.1
1800	27.9	13	200	33 (44)	96.1	51.0
1900	27.5	13	190	22 (39)	96.3	30.2
2000	26.3	15	160	17	96.3	23.6
2100	23.8	16	120	13	96.3	19.3
2200	21.1	21	130	11	96.3	17.3
2300	19.5	23	240	15	96.2	20.8

[a] As measured at a height of 10 m in the open on level terrain.

[b] Reported gusts in parentheses.

Winefred LO towerman was evacuated during the afternoon of May 2, the maximum temperature was not recorded at the morning observation on May 3.

Hourly surface weather data were acquired for the three closest synoptic observing stations (Anon., 1977) to the fire area (Table 3). Hourly computations of the FFMC (Van Wagner, 1977) and ISI were made for the period between 0800 and 2300 MDT on May 2 (Table 3). Weather readings from the synoptic stations were in good agreement with those from the LO fire weather stations (compare Table 2 with 1300 MDT data in Table 3).

6. SYNOPTIC WEATHER PATTERN AND CHARACTERISTICS

The strong upper ridge which was so persistent over Alberta during April reached its maximum development over Saskatchewan on May 2 (Fig. 4). A short-wave trough was moving northeastward on the west side of the ridge. This short wave was responsible for a temporary breakdown of the upper ridge. At the surface this was reflected by a Pacific cold front lying in a sharp trough which moved across Alberta from west to east on May 2 (Fig. 5). The southerly pre-frontal flow over the fire area was very warm, very dry, and unstable (Tables 1-3). The very dry air over the fire area, with dew point temperatures near 0°C and relative humidities of 15-20% (Fig. 5), probably was the

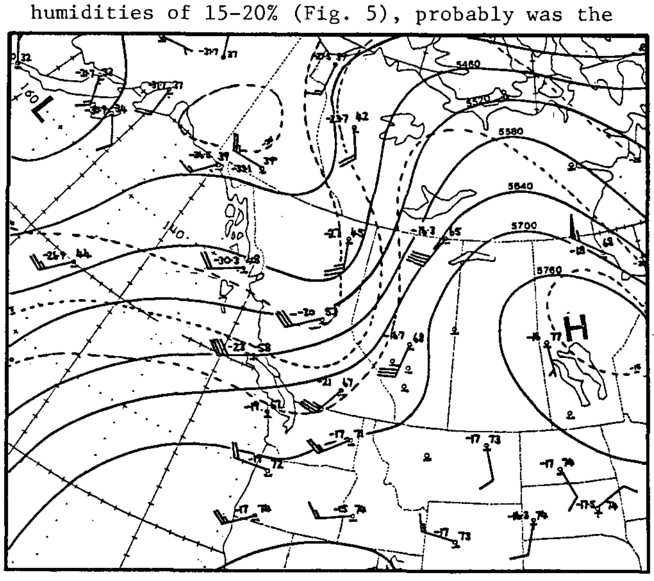

Fig. 4. *500 mb chart for 1800 MDT, May 2, 1980.*

result of a prolonged period of subsidence and a trajectory over the essentially bare fields of Saskatchewan and the Dakotas with little effective evapotranspiration. The cold front reached the fire area around midnight at which time there was a wind shift to the west-northwest, a drop in temperature, and an increase in humidity to about 50%. During the next 3-4 days, the fire continued to spread steadily southeast (Fig. 2) under the influence of northwesterly winds (< 20 km/h) and a sustained level of extreme fire danger.

The Department of National Defence intermittently operates an upper air observation site at Primrose Lake (Fig. 1), 65 km south of the fire area (elevation: 702 m), in support of military flight operations and research studies. Fortunately for this case study analysis, the Primrose Lake site was operational on May 2. A late morning radiosonde sounding shows instability from near the surface to approximately 3000 m (Fig. 6). The air was extremely dry, both at the surface and aloft, as evident by the wide range between the temperature and dew point. The shallow inversion near the surface was probably a remnant of the early morning inversion shown by the 0600 MDT radiosonde sounding from the permanent upper air observation site at Stony Plain, 30 km west of Edmonton. Surface weather observations from AFS LOs in the fire area suggest that this inversion was burned off by early afternoon, as these stations reported their maximum temperatures for the day at 1300 MDT (Table 2). High surface temperatures during the afternoon enhanced the atmospheric instability. The lapse rate during the afternoon was thus likely dry-adiabatic or super-adiabatic in the layer below 3000 m.

An afternoon pilot balloon (pibal) sounding from the Canadian Forces Base (CFB) Cold Lake, 100 km south of the fire area (Fig. 1), is presented in Figure 7. There is a suggestion of a pre-frontal jet at the 750 m level. The winds at this level were fairly strong, possibly as high as 65 km/h. A pibal sounding taken at Fort McMurray, 160 km north of the fire area (Fig. 1), and in the same relative position to the cold front as the fire area, showed a strong suggestion of a pre-frontal jet at a corresponding elevation earlier in the day (Fig. 8). There is thus every reason to believe that there may have been a low-level jet above the fire area prior to and during the initial run.

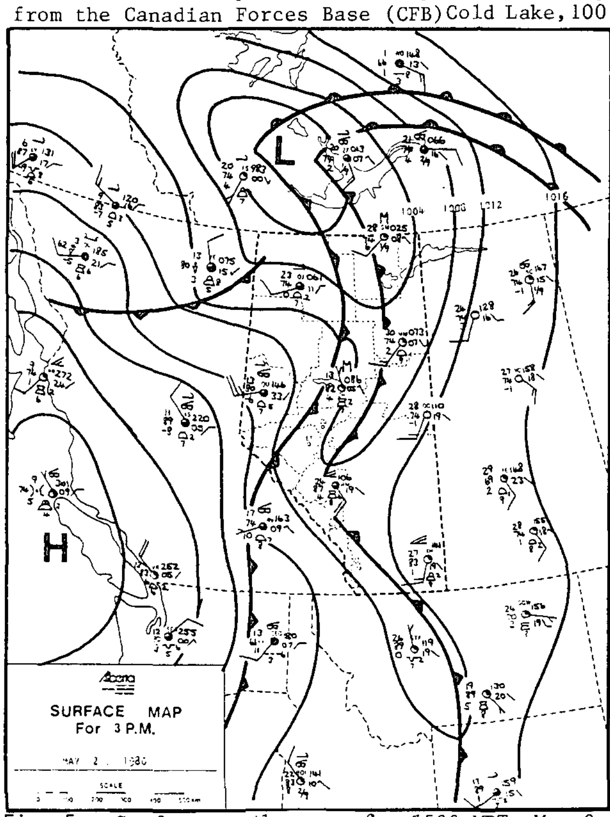

Fig. 5. *Surface weather map for 1500 MDT, May 2, 1980. Temperature in degrees C and wind speed in mi/h.*

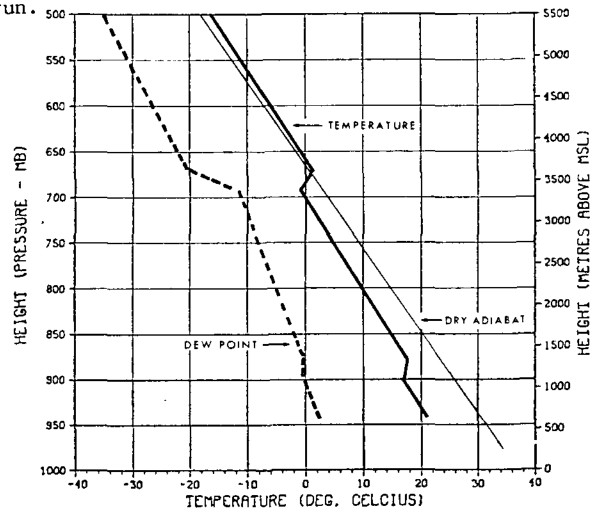

Fig. 6. *Vertical temperature profile over Primrose Lake, Alberta, at 1100 MDT, May 2, 1980.*

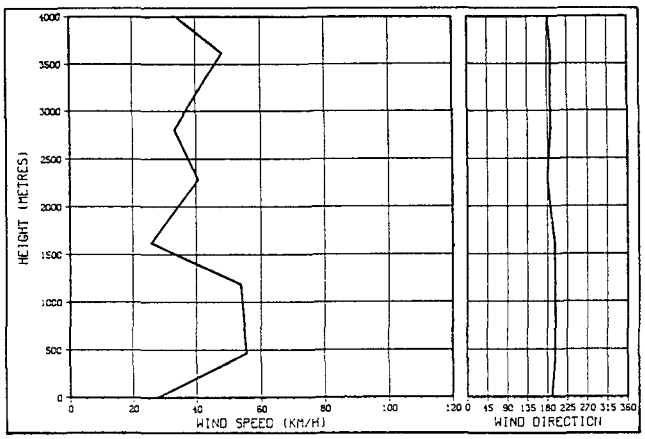

Fig. 7. *Vertical wind profile over Cold Lake, Alberta, at 1800 MDT, May 2, 1980.*

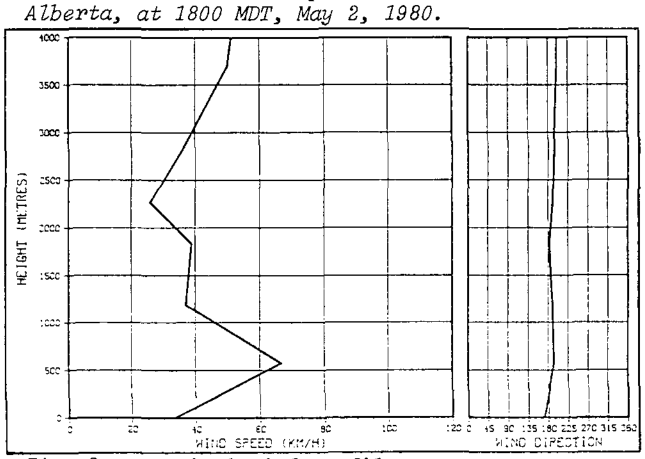

Fig. 8. *Vertical wind profile over Fort McMurray, Alberta, at 1100 MDT, May 2, 1980.*

7. RETROSPECTIVE ANALYSIS

The following summary is an interpretation of the environmental conditions responsible for the behavior of the DND-4-80 Fire during its first burning period:

Fuels and Topography- The quantity, size, and arrangement of forest fuels in southern boreal coniferous stands are conducive to fire spread. The topography had very little influence on the behavior of the fire.

Antecedent Climatic and Meteorological Conditions- Although not in themselves unusual, the combination of a warm, dry winter and early loss of snow cover contributed to low fuel moisture conditions in east-central Alberta during the latter half of April and first few days of May. The upper level ridge that became established in late March favored fuel drying.

Fire Weather Observations and Fire Danger Ratings- The incomplete overnight recovery of relative humidity affected dead fine fuel moisture. The similarity of the very high FFMC, DMC and BUI values as reported at 1300 MDT on May 2 by AFS LOs are indicative of prolonged and intense fuel drying over a large area. The FFMCs were especially high (maximum value is 99). The DCs, reflecting longer term weather, were unseasonally high. The ISI and FWI values were well into the extreme range. An FWI value of 30 or greater is considered to be an EXTREME level of fire danger in Alberta based on the frequency of occurrence (Kiil *et al.*, 1977). Sustained high surface temperatures, low relative humidities, and strong surface winds maintained this extreme fire danger condition during the afternoon and late into the evening.

Synoptic Weather Pattern and Characteristics- The combination of large-scale subsidence and the increase in the surface gradient of the approaching cold front discouraged the overnight recovery of relative humidity and encouraged high surface temperates. A temporary breakdown of the upper ridge was reflected at the surface over the fire area by high surface temperatures, highly unstable atmospheric conditions, low relative humidities, strong gusty surface winds and a vertical wind profile likely featuring a low-level jet. Recent fire meteorology studies in Alberta indicate that severe fire weather patterns are often associated with a breakdown of the 500 mb ridge.[††] It is interesting to note that the short wave trough responsible for the temporary breakdown of the upper ridge was also involved in the disastrous Mack Lake Fire in Michigan on May 5, 1980 (Simard, 1981).

The average forward rate of advance of the DND-4-80 Fire during the afternoon and early evening of May 2 was 3.5 km/h (or roughly 60 m/min). Based on experimental fire studies in Alberta (e.g., Kiil, 1975; Quintilio *et al.*, 1977), the fuel types involved, and the fuel moisture conditions indicated by the CFFWI codes, the available fuel consumed was probably at least 4.0 kg/m^2. Using a rate of spread figure of 1 m/s and a heat of combustion value of 18,700 kJ/kg, reduced somewhat for fuel moisture content, this translates into 74,000 kW/m as a conservative estimate of the frontal fire intensity (Byram, 1959a; Alexander, 1982b) during the DND-4-80 Fire's initial run. This level of intensity is certainly well into the class of extreme or blowup fire behavior characteristics.

[††] Nicholas Nimchuk, Meteorologist, Forest Protection Branch, Alberta Forest Service, Edmonton, personal communication (technical report in preparation).

8. DISCUSSION

Byram (1954) defined a "blowup" fire as one which suddenly and often unexpectedly multiplies its rate of energy output many times. Byram found that certain fuel and atmospheric conditions were conducive to extreme fire behavior. He concluded that a fire has the potential to blowup when:

(1) Fuels are dry and plentiful;

(2) The atmosphere is either unstable or was unstable for some hours, and possibly days, prior to the fire;

(3) The wind speed of the free air is 29 km/h or more at an elevation equal to, or not much above the elevation of the fire; and

(4) The wind decreases with height for a thousand or so metres above the fire with the possible exception of the first hundred metres.

The environmental conditions associated with the DND-4-80 Fire met all four of the above stated criteria as evident by the fire danger ratings (Table 2), the surface weather observations (Tables 2 and 3), and the upper air temperature (Fig. 6) and wind (Figs. 7 and 8) profiles.

Another fire (DND-3-80) in the Cold Lake Air Weapons Range, 50 km southwest of the DND-4-80 Fire (Fig. 1), was accidently started by military operations on the afternoon of the previous day, May 1. Extreme fire behavior was also exhibited by this fire during the afternoon of May 2 and all men and resources had to be withdrawn in the interests of safety. This fire did not exhibit any unusual behavior on the afternoon of May 1 or during the early morning of May 2. However, it literally "blew up" between 1100 and 1130 MDT on May 2 as it increased in size from 149 to 5087 ha. For all practical purposes, the fuels, topography, and fuel moisture conditions were similar on both days. The differences in fire behavior must then be explained on the basis of different meteorological conditions on May 1: (a) neutral stability in the lower levels of the atmosphere and (b) much lighter surface winds and a favorable vertical wind profile. No sign of a low-level jet was detected in the vertical profiles examined for Cold Lake or Fort McMurray on the day before and after May 2.

What is the relationship between atmospheric conditions aloft and extreme fire behavior? Forest fires are influenced by vertical motions within the atmosphere. The energy released by the fire itself generates upward motion. This in turn influences the indraft into the fire at low levels and hence the intensity of the fire and so on. This principle of the reinforcement cycle between the fire and the atmosphere (Byram, 1959b; Brown and Davis, 1973) is simplistically, but, well-illustrated by Gaylor (1974, p. 132). At some point in the cyclic process, sufficient energy is released to allow for large-scale convection to begin and a blowup is then underway.

Air mass stability may either encourage or suppress vertical air motion (Schroeder and Buck, 1970). This can mean the difference between a "closed" or an "open" fire environment (Countryman, 1966). The stability of the atmosphere is determined by its lapse rate (i.e., the rate at which temperature decreases with an increase in altitude). On the average, the atmospheric temperature cools at a rate of about $10^{\circ}C/1,000$ m, which is referred to as the dry adiabatic lapse rate (DALR). At this rate of decrease the atmosphere is neutrally stable. When the lapse rate of the atmosphere is greater than the DALR, it is considered to be unstable. The greater the drop in temperature with height, the greater the air instability. Conversely, the less the drop in temperature with height, the less the instability. Brotak and Reifsnyder (1977) concluded that a temperature difference of at least $6^{\circ}C$ between the 950 and 850 mb height levels appears to be necessary for the occurrence of a major fire. The air temperature difference between the 950 and 850 mb levels during the afternoon of May 2, 1980, was likely of the order of $10-12^{\circ}C$ at the fire site.

Byram (1954, 1959b) considered that the most significant effects of atmospheric stability conditions on fire behavior are indirect, in that they operate through the vertical wind profile. Wind speed generally increases with height for up to several thousands of metres above the surface, which is characteristic of a well-mixed atmosphere. In flat country, the fire's convection column formed under such a profile is typically of the "fractured" variety. Byram felt that the most adverse profile from the standpoint of extreme fire behavior is that of a low-level jet in which there is a zone of decreasing wind speed above the fire, although winds immediately above the surface (< 450 m) may increase with height through a limited range. Byram and others (e.g., Steiner, 1976) have suggested that winds which decrease with height cause increased convergence of air at the base of the fire, resulting in an increased fire intensity. The downward transfer of momentum caused by the low-level jets observed at Cold Lake and Fort McMurray on May 2, 1980, resulted in strong, gusty winds at the surface during the afternoon. On level ground, the structure of the convection column over a fire under the influence of a low-level jet profile is of the "towering" type as illustrated by Countryman (1965, p. 316).

Can the potential for blowup fire behavior be anticipated? The transition from a surface fire to a crown fire is predictable to a large degree from the CFFWI and the particular fuel type. Forecasts of surface weather conditions can be used to yield a fire danger forecast of crown fire potential. However, the radical shift in fire behavior associated with crown fire and blowup fire conditions is very much a function of airmass stability and the structure of the wind field aloft. Forecasts of airmass stability are available from fire weather meteorologists (Davis, 1969) and these can be supplemented by monitoring the visible indicators (Schroeder and Buck, 1970) and indirect effects of stable and unstable atmospheric conditions. Helicopter soundings of temperatures aloft in the vicinity of project fires can be made (e.g., Johnson, 1964). Fire weather meteorologists have thus far not been able to forecast the occurrence of low-level jet winds which are often, but not always, associated with the passage of dry cold fronts (Byram, 1959b; Brown and Davis, 1973).** Their geographic extent and periodicity remain unknown. Thus, there is as yet no way of recognizing the presence of low-level jets without pibal or radiosonde soundings. Although winds aloft are sampled at several meteorological stations across Canada by the Atmospheric Environment Service and others (Anon., 1977), the applicability to forested areas is limited. The existing network could be increased by conducting pibal soundings (Ryan, 1976) at selected locations as fire danger conditions and fire activity dictate (Byram, 1959).

9. IMPLICATIONS FOR FIRE MANAGERS

The potential for the extreme behavior exhibited by blowup fires during their first burning period, such as DND-4-80, dictate the need for action and containment within a comparatively short time after ignition. Inaccessible areas, like the Cold Lake Air Weapons Range, decrease the effectiveness of fast and aggressive initial attack forces.

Traditionally, estimates of potential fire behavior have been based on surface weather observations and little attention is given to temperature and wind profile characteristics aloft. This is understandable since surface weather will usually account for the general aspects of a going wildfire (e.g., rate of spread). The less obvious effects of instability and winds in the lower and upper atmosphere, however, may trigger "blowups" when least expected, seriously disrupting the planning operations and jeopardizing the well-being of firefighters and the public. Practicing fire behavior specialists should recognize an important threshold once fires develop high surface energy outputs. Projections of fire behavior must consider that atmospheric conditions can limit or enhance the energy output rate of a free-burning fire with little or no warning. Once a fire becomes convective dominated, its behavior will be determined by the atmosphere and interactions with the fire itself. The job of prediction then becomes one of when and where a run can be expected to cease.

The environmental conditions associated with the DND-4-80 Fire as documented in this paper should not be construed as the only possible scenario under which blowup fires or extreme fire behavior can develop. This case study is simply a single, localized example that has value as a source of research data and as training material.

**The AFS Weather Section in Edmonton accurately forecasted the passage of the dry cold front through eastern Alberta on May 2, 1980, as well as the accompanying surface weather conditions.

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