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AN EXAMPLE OF MULTI-FACETED WILDLAND FIRE RESEARCH: THE INTERNATIONAL CROWN FIRE MODELLING EXPERIMENT

M.E. ALEXANDER[1], B.J. STOCKS[2], B.M. WOTTON[2] and R.A. LANOVILLE[3]

[1]Canadian Forest Service, Northern Forestry Centre, 5320-122 Street, Edmonton, Alberta, Canada, T6H 3S5; E-mail: malexand@nrcan.gc.ca

[2]Canadian Forest Service, Great Lakes Forestry Centre, P.O. Box 490, Sault Ste. Marie, Ontario, Canada P6A 5M7; E-mails: bstocks@nrcan.gc.ca and mwotton@nrcan.gc.ca

[3]Department of Resources, Wildlife and Economic Development, Forest Management Division, P.O. Box 7, Fort Smith, Northwest Territories, X0E 0P0;

E-mail: lanoville_rick/smith_00@minus40.gov.nt.ca

SUMMARY

The International Crown Fire Modelling Experiment (ICFME) constitutes a major, cooperative, global undertaking involving coordination by the Canadian Forest Service Fire Research Network and the Government of the Northwest Territories' Forest Management Division combined with participation of collaborating scientists and operational fire personnel, principally from Canada and the USA, but with representation from several other countries as well. The initial impetus for the ICFME was oriented towards the testing and calibration of a newly developed physical model for predicting the spread rate and flame front intensity of crown fires. However, the ICFME has also provided the opportunity to examine other aspects or implications of crown fire behaviour, without comprising this primary objective, including linkages to fire-fighter safety/personal protective equipment (PPE) and wildland-urban interface or intermix issues as well as certain ecological and environmental impacts or effects, including concerns about atmospheric chemistry from biomass burning. The five experimental crown fires that have taken place in the last two years are providing valuable new data and insights into the nature and characteristics of crowning forest fires

needed for dealing with the fire management problems and opportunities that will be affecting both people and ecosystems in the coming century.

INTRODUCTION

The International Crown Fire Modelling Experiment (ICFME) is a major field campaign being carried out in part under the auspices of the International Boreal Forest Research Association's (IBFRA) Stand Replacement Fire Working Group (SRFWG). The SRFWG was, as the first working group of the IBFRA, established in 1992 to foster cooperative research with the general goal of better understanding global climate change and ecosystem function with respect to the role of fires of lethal intensity in northern circumpolar boreal forests (Fosberg 1992; Goldammer and Furyaev 1996, pp. 516-517).

The ICFME also represents a core research activity of the International Geosphere-Biosphere Programme's (IGBP) International Global Atmospheric Chemistry (IGAC) project dealing with the Biomass Burning Experiment (BIBEX) (Goldammer 1994; Goldammer and Furyaev 1996, pp. 1-20 and 518-524). The first burning associated with the IBFRA-SRFWG's experimental program of fire behavior was the Bor Forest Island Fire Experiment which took place in north-central Siberia in July 1993 and involved a 49-ha stand of mature Scots pine (*Pinus sylvestris*) as documented and reported on by the Fire Research Campaign Asia-North (FIRESCAN) Science Team (1994, 1996).

A third project initiated in 1995, referred to as the FROSTFIRE involves the burning of 809 ha of boreal conifer and hardwood forests in the Caribou-Poker Creeks Research Watershed located 40 km north of Fairbanks, Alaska, USA (*see* http://www.fsl.orst.edu/home/usfs/gepp/alaska/frstfire.htm). The broad aim of all three of these experimental burning projects is to investigate the behavior, ecological and atmospheric chemical effects of high-intensity, stand replacement or stand killing fires in boreal forest ecosystems.

The purpose of this paper is to provide a broad overview of the ICFME and to summarize its current status thereby updating previously published accounts (Stocks and Alexander 1996; Alexander et al. 1998) of this global wildland fire research effort for broader distribution via inclusion in these conference proceedings. As a matter of possible interest,

several popular articles dealing with the ICFME have also appeared (Shilts 1997; Andersson 1998, Anon. 1998; Holloran 1998; Klasseen 1998; Samoil 1998).

BACKGROUND INFORMATION

Wildland fire research scientists in Canada and the United States have been working for many years on the development of fire danger rating and fire behavior prediction systems, which are now in widespread use across North America and overseas (Andrews 1991; Alexander et al. 1996). These systems are used daily by fire management agencies in these countries, forming the basis for decision support systems pertaining to fire control and fire use activities. Although much progress has been made to date, much more remains to be accomplished, including the formulation of a predictive physical-based model of wildland fire behavior that can encompass the full range of the types and intensities of free-burning fires encountered in nature for any combination of fuel, weather and topography.

Despite the fact that high-intensity crown fires currently account for an overwhelming proportion of the annual area burned in Canada, a full understanding and the subsequent ability to model the initiation, propagation and spread of crowning forest fires remains an elusive goal for fire research scientists in this country and throughout the world. The Canadian Forest Service (CFS) approach to the prediction of crown fire phenomena has been largely empirical in nature (McAlpine et al. 1990). An extensive experiment burning program carried out in several major fuel types, involving both gentle surface fires to high-intensity crown fires (Alexander and Quintilio 1990), coupled with observations obtained from monitoring selected wildfires (e.g., Alexander and Lanoville 1987), created a large data base that is the foundation for the system of quantitatively predicting fire behavior used in Canada today (Forestry Canada Fire Danger Group 1992; Taylor et al. 1997). Conversely, the development of systems for rating fire danger and predicting fire behavior in the United States has been based largely on a semi-theoretical, laboratory-based fire spread model, which has proven limited in the prediction of crown fire behavior, resulting in the necessity to resort to empiricalism as well, at least for the interim (Rothermel 1991). At the same time, CFS fire behavior researchers have come to realize that it would be virtually impossible to carry out a series of experimental fires over a range of burning conditions in all the important fuel types found in Canada for a number reasons (e.g., time, expense, logistics, shortage of personnel).

Within this context, CFS fire behavior researchers began cooperating with Dr.Frank A. Albini of the Department of Mechanical and Industrial Engineering, at Montana State University in Bozeman, Montana, a leading wildland fire modeller, on the extension of a some-what limited crown fire spread model developed and tested in the mid-80s (Albini and Stocks 1986). This process, initiated in late 1992, was to involve a large amount of theoretical model development coupled with specific experimental fires carried out in a field setting for testing and validation purposes. This initiative was financially as well as intellectually supported by the CFS using Green Plan funds (Anon.1994) and by the USDA Forest Service's Intermountain Fire Sciences Laboratory at Missoula, Montana. The final report for Dr. Albini's research on a "physical modell of crown fire behavior" was completed in May 1997. Component parts of the research effort have also been separately reported on (Albini 1996; Call 1997; Call and Albini 1997)

STUDY AREA DESCRIPTION

The ICFME study area, located about 40 km northeast of the town of Fort Providence in Canada's Northwest Territories (NWT) (61.6 °N latitude, 117.2 ° W longitude), was selected following a reconnaissance of potential candidate sites by CFS and Government of NWT Department of Resources, Wildlife and Economic Development (DRWED) personnell in June 1994. The terrain in the study area is flat (elevation: 159 m above MSL). A preliminary fuel survey of the area was carried out in September 1994. The fuel complex consists of a 65-year-old jack pine stand (*Pinus banksiana*) with the overstory canopy averaging 12 m in height and 4100 stems/ha with an understory (4600 stems/ha) of black spruce (*Picea mariana*), and was viewed as ideal for supporting high-intensity crown fires in normal summer weather based on experimental burning experience in other comparable fuel complexes (Stocks 1987, 1989). The study area is surrounded by shrub-dominated meadows varying from ~ 0.5 – 1 km in width that were burnt off in May 1995 and portions of it again in May 1997 with a view to begin securing the area from the possibility of "escapes" or excursions from the planned experimental fires.

INTERNATIONAL CROWN FIRE MODELLING EXPERIMENT
NORTHWEST TERRITORIES, CANADA
Study Area Plot Layout

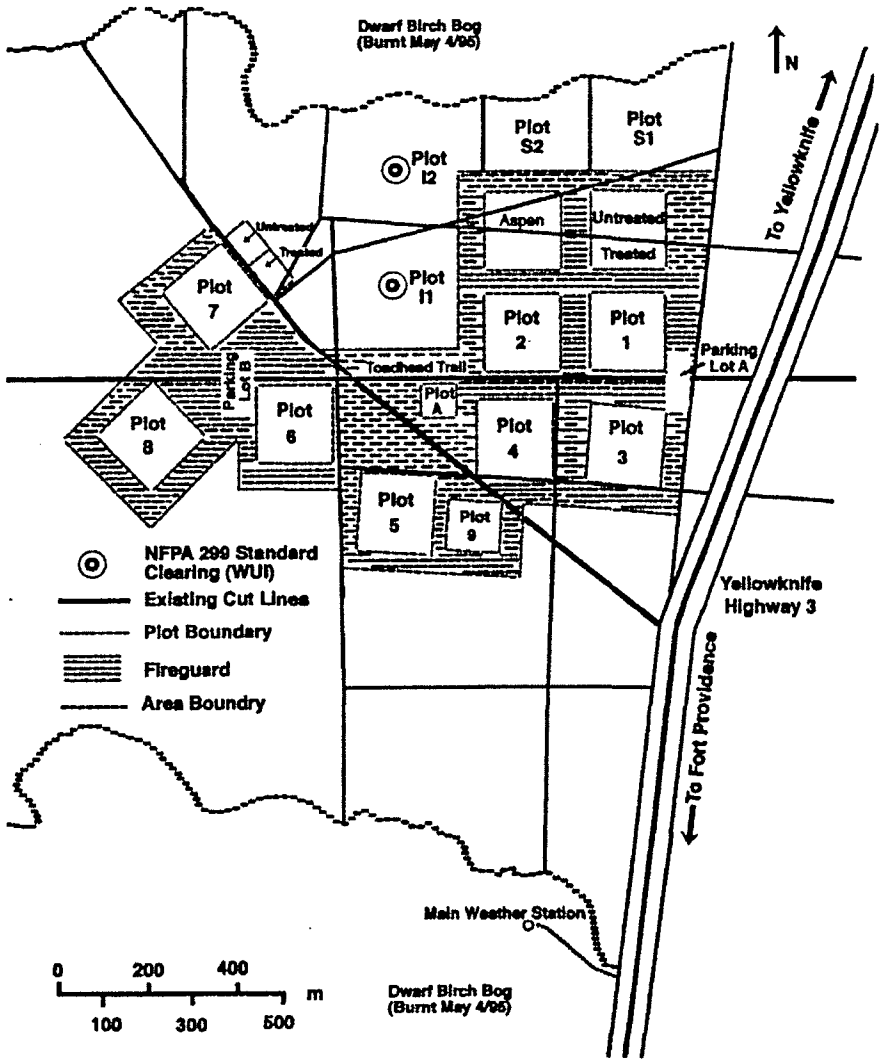

Figure 1: Plot layout for the International Crown Fire Modelling Experiment (ICFME) study area. To reference the location of the study area in relation to the geography of the Northwest Territories visit the ICFME homepage.

Ten experimental burning plots were surveyed in the summer of 1995 (Figure 1). Eight of the ten original plots are 150 x 150 m in size; the other two are smaller (75 x 75 m and 100 x 100 m). Plot orientation has been purposely varied to account for some likely variation in predominate wind directions during the "burning window", which was selected on the basis of day length, local climatological knowledge, and an analysis of historical fire danger records available for the DRWED fire weather station in Fort Providence. In 1996, three additional plots were established adjacent to the primary plots in order to analyze various aspects of fuel

management treatments on potential fire behavior such as the effects of thinning/pruning and the value of trembling aspen (*Populus tremuloides*) stands as a fuelbreak. Following the first phase of ICFME burning, four additional plots were established in July 1997 to further examine the effectiveness of: (i) protective fire shelters (Putnam 1995, 1996; Roth 1997) on a seismic line and in small clearings as opposed to a cleared break such as represented by the firegaurds (Plots S1 and S2) and (ii) the NFPA (1991) 299 Standard for community home protection from wildfires (Plots I1 and I2 complete with simulated houses).

METHODOLOGY

Preburn sampling of the ground, surface and crown fuel characteristics load, depth and bulk density (*cf.* Walker and Stocks 1975) was undertaken during the summers of 1995 and 1996 using standardized techniques (e.g., Stocks 1980; Nalder et al. 1997). Construction of 50-m (minimum) wide fireguards around each of the plots in order to facilitate access and fire control considerations (i.e., to compensate for the lack of surface water in the area) was begun in 1995 and completed in the fall of 1996. Two ICFME preburn planning meetings were held in Calgary, Alberta, Canada, during December 1995 and again in January 1997 in order to bring together the participating researchers from Canada and the United States together with DRWED staff and native community leaders from Fort Providence. These meetings resulted in the development of logistical and research plans that were acceptable to all parties involved in the ICFME project.

A World Wide Web homepage (address: http://www.nofc.forestry.ca/fire/fmn/nwt/) for the ICFME initially developed in the spring of 1997, has gradually expanded in scope and attained a certain degree of notoriety within the wildland fire community (Hogenbirk 1998).. This use of the internet's capability has greatly facilitated effective communication at various levels and aided in certain operational aspects of the project as well, constitutes another example of how computer technology has help to advance wildland fire research globally (Weber 1995). A fully-instrumented fire weather station was established adjacent to the plots in the large, open meadow area south of the plots (Figure 1) as soon after snow-free cover each spring as possible. The daily 1300 MDT fire weather observations from this station permitted the calculation of the six standard components of the Canadian Forest Fire Weather

Index System (Van Wagner 1987) which were in turn used along with the fire weather forecast to determine the suitability of burning on any given day.

Spot fire weather forecasts for the ICFME were prepared twice daily at around 0800 and 1500 MDT (Figure 2) and posted on the ICFME homepage. The 0800 forecast predicted the weather for the current day including hourly predictions of temperature, relative humidity, probability of precipitation, wind speed and direction as well the sky condition. The 1500 issue was the forecast for days 2 to 4 and included maximum temperature, minimum relative humidity, probability of precipitation and predominate wind speed and direction.

Forecast Issued at 0815 MDT 04 July 1997, Forecast for Friday 04 July 1997

Synoptic Discussion

At the surface High pressure area over the Beaufort with a ridge extending to Great Slave Lake. Mostly sunny skies and light winds accompany the ridge.

At 500 mb Upper high over southern Alaska with ridge eastward to extreme western sections of the southern Mackenzie. Upper low along the Arctic coast with a trough southeastward to northern Saskatchewan. Moderate northwest flow over the southern Mackenzie.

Time MDT	Sky	RH (%)	Temp. (^{0}C)	Direction/ Speed (km/h)
1300	Sunny	30	20	Light + variable
1400	Sunny	28	21	L+V
1500	A few clouds	25	22	L+V
1600	A few clouds	25	22	L+V
1700	A few clouds	25	22	L+V
1800	A few clouds	28	21	L+V
1900	Sunny	28	21	L+V
2000	Sunny	30	20	L+V

Comments and Confidence

Winds....light northeast this morning becoming light and variable by noon. Best guess as to direction would be NE this morning becoming E or SE this afternoon. Wind-speed will be light but variable as well with winds up to 15 km/h on occasion. One model- the Canadian Spectral Model has a high pressure cell developing just south (100 km) of the fire site this afternoon. If this happens then outflow from the high could push the direction to a more southerly direction. Probability of prec..... 0% Steering Flow (500 mb).... Moderate northwest.

Day 2-4 forecast issued at 1415 MDT Friday 04 July 1997

Synoptic Discussion/Remarks

Upper air features... Upper high and ridge in Alaska moves west. Ridge over Alberta - southern Mackenzie weakens and moves southeast. This results in a broad trough extending from a low over the Arctic Islands to a low in the Gulf of Alaska.

At the surface....High pressure area moving into Saskatchewan with a ridge extending to Great Slave Lake on Saturday. Low pressure area developing over the extreme southwest corner of the Mackenzie. Saturday...increasing cloud with a chance of an afternoon shower. Sunday and Monday....Mainly cloudy with a chance of an afternoon shower.

Saturday..40% pop Temp 23C Min RH 40% Winds SE 20 km/h

Sunday....40% pop Temp 23C Min RH 40% Winds E 15 km/h

Monday...40% pop Temp 23C Min RH 40% Winds E 15-20 km/h

Forecasts prepared by Mike Flannigan

ph.403 435-7338 (office)

403 436-1626 (home)

e-mail mflannigan@nofc.forestry.ca

Figure 2: Sample weather forecast issued daily during the burning phases of the International Crown Fire Modelling Experiment.

For both forecasts a synoptic discussion of the key features in the upper air and surface was included. The forecasts were prepared by a CFS meteorologist based in Edmonton, Alberta, using information obtained from a variety of internet sites. Surface analysis, upper air charts, skew-T thermodynamic diagrams (tephigram) from three nearby upper air stations (Fort Smith, Norman Wells and Fort Nelson), satellite images (GOES and NOAA, visible, infrared, enhanced and animations (loops)), and hourly surface observations were all available on the internet in a timely fashion. Also, available on the ICFME internet site were output from a wide variety of numerical weather models (ECMWF, MRF and CMC products) as well as forecasts prepared by the Canadian Atmospheric Environment Service. No radar data was used as there is no radar operating in this region. In 1998, a portable radiosonde will be used on potential burning days to provide a detailed vertical structure of the atmosphere over the ICFME site for both forecast purposes and for quantifying the upper air component of the fire environment associated with each experimental crown fire. Updated forecasts and consultations were provided as required on potential burning days via communication through a satellite phone link right at the ICFME study area.

The experimental plots were ignited as a 'line source' using a truck-mounted pressurized flame thrower or "terra-torch" (Bradshaw and Tour 1993). Typically, the length of a 150 m plot edge could be "fired up" in less than a minute. Permanent DRWED staff or contractors and fire suppression crews on contract to DRWED provided all the necessary logistical support for conducting the experimental fires, including the establishment of a temporary base camp at the study area.

A vast array of ground-, tower- and helicopter-based instrumentation was employed to quantify numerous fire characteristics in the most detailed manner possible. All of this equipment worked extremely well, permitting measurements of smoke chemistry, flame size and geometry, radiant heat flux, gas temperatures and fire spread using visible and infrared cameras, radiometers and thermocouples (e.g., Butler 1994; Kautz 1997).

ICFME PHASE I - 1997 PROGRESS REPORT

After three years of planning and preparation, the first phase of ICFME burning took place in June-July 1997. Although designed primarily to develop knowledge and data

essential to predicting the physical behavior and impacts of high-intensity crown fires, ICFME-I brought together a diverse group of environmental and wildland fire scientists as well as managers from various parts of North America and overseas in a truly cooperative research undertaking. A total of 45 individuals from outside of the NWT participated, for varying lengths of time, in the first field phase of the ICFME. This included a group of 20 from Canada (principally members of the CFS Fire Research Network based at Edmonton, Alberta, Sault Ste. Marie, Ontario and Victoria, British Columbia, as well as representatives from Canadian universities and a provincial fire management agency), a group of 23 from the United States (principally from federal government agencies although universities and private industry were represented as well), and two grassland fire scientists from South Africa (*see* ANNEX I).

After a wet spring in the Fort Providence area, fire researchers began arriving on June 19 in preparation for three weeks of experimental burning in 1997. Over the next three weeks, a gradual drying trend produced some ideal burning conditions at the ICFME site (Figures 3 and 4). The weather experienced during this three-week period was unusual in several respects. Typically, in the upper atmosphere (500 mb) the experimental site is on the east side of a upper ridge that extends along the west coast of North America. However, in 1997 the 500 mb level was dominated by two well-developed upper lows, one over the Gulf of Alaska and the other over the Arctic Islands, which resulted in a broad trough over the Southern Mackenzie District. At the surface, a trough usually extends along the Mackenzie River valley at this time of year. During the 1997 burning window, surface pressure highs and ridges were common over the Mackenzie District. Daily rainfall was very light through this three-week period. Rainfall totals (24-h) exceeded 0.5 mm on June 26/97 (5.3 mm) and again on July 11/12 (10.1 mm). A cold front was responsible for the rain on June 26 while an upper disturbance (cold low) brought rain to the site on July 11/12. In a typical summer airmass showers/thunderstorms triggered by daytime heating are common. Winds were light during most of the period, with wind speeds over 20 km/h observed on only three days.

After a few small test fires, the first full-scale crown fire was ignited on July 1 Canada Day! This was followed by two additional successful high-intensity crown fires on July 4 and July 9. A number of other potential burning days had to be cancelled due to largely unfavourable wind directions. The 1997 burning window effectively ended with rains beginning on July 10. The burning conditions associated with the three 1997 fires are documented in Table 1. Postburn fuel sampling and clean up was completed by July 12.

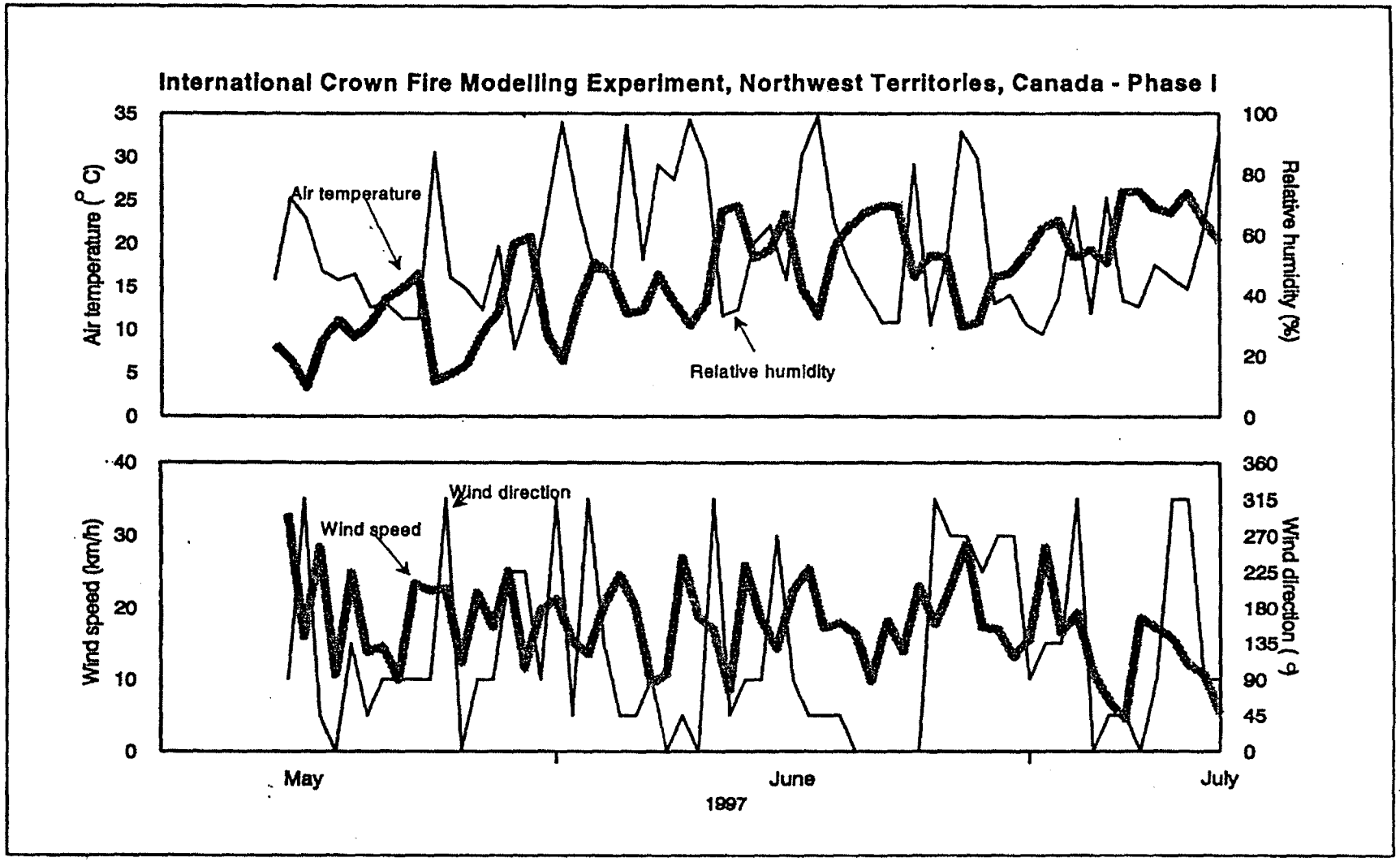

Figure 3: Daily trends in 1300 MDT fire weather observations prior to and during the first phase of the International Crown Fire Modelling Experiment in 1997.

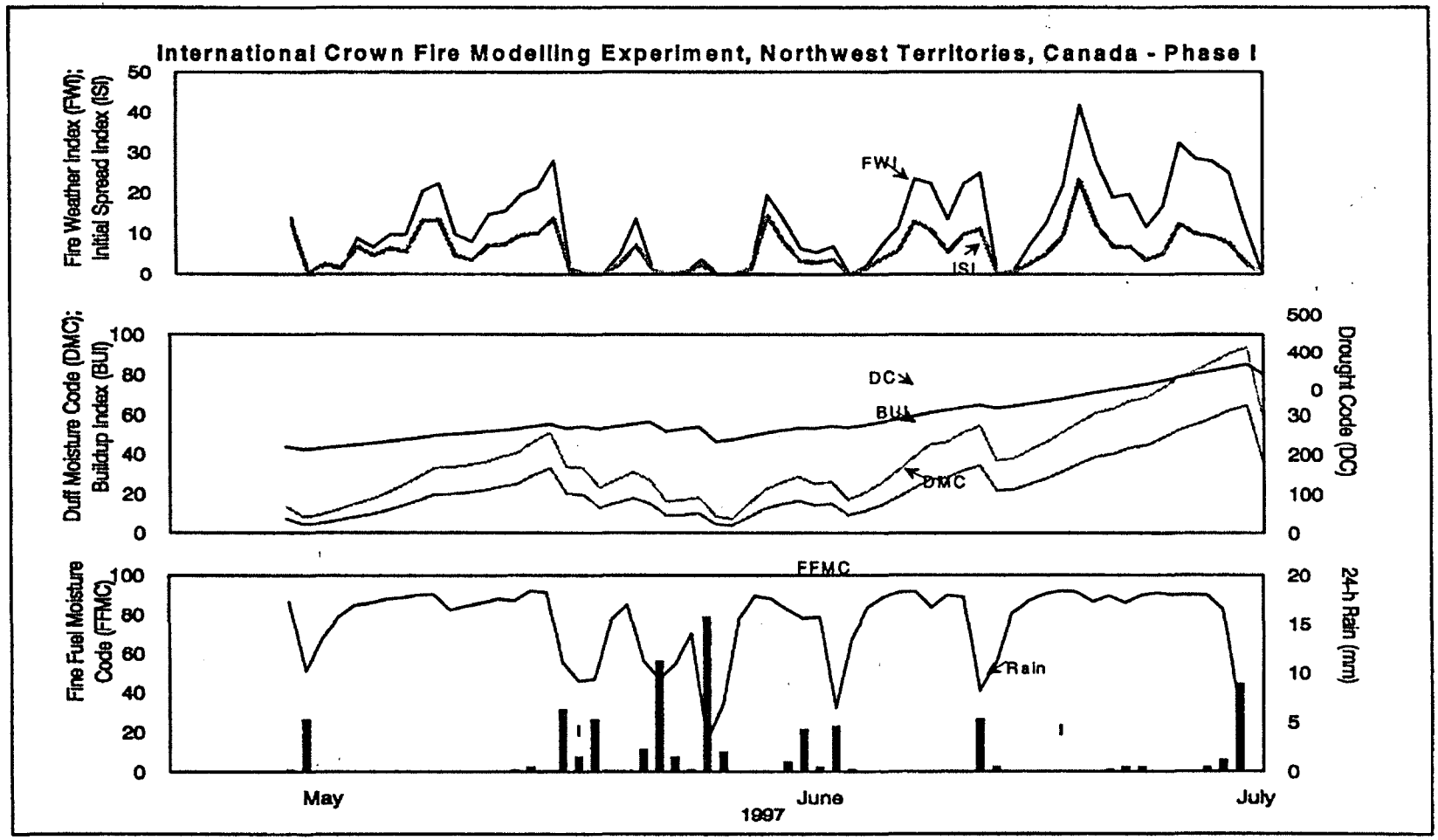

Figure 4: Daily trends in rainfall and the six standard components of the Canadian Forest Fire Weather Index System prior to and during the Phase I of the International Crown Fire Modelling Experiment in 1997.

The second phase of ICFME burning in 1998 during roughly the same period as in 1997. For the second year in a row, the ICFME brought together a diverse group of scientists and managers from Canada and the United States as well as Russia, France and Australia. ICFME-II participants began arriving in Fort Providence on June 22 in preparation for three weeks of experimental burning; a smaller advance group arrived on June 18. A total of 59 research and operational staff from outside the Northwest Territories participated, for varying lengths of time, in ICFME-II. This included a group of 28 from Canada, a group of 27 from the United States, one Australian bushfire research scientist, two Russian fire scientists and a PhD student from France. (*see* ANNEX I). Furthermore, film crews from Austria and England gathered imagery for various upcoming wildland fire documentaries on various aspects of wildland fire.

Snow-free cover occurred about two weeks earlier than normal in the spring of 1998. The main weather station at the ICFME site was established on May 7 (as compared to May 14 in 1997). In contrast to 1997, the spring of 1998 was relatively dry (the Duff Moisture Code reached a high of 84 on June 10). As participants arrived on June 22 they were greeted by a downpour in Fort Providence during the evening. Over the next several days a gradual drying trend produced conditions suitable for initiating crown fires (Figures 5 and 6). After a few small test fires, the first full-scale crown fire was ignited on the USA's Independence Day holiday, July 4 (Plot 8), followed by an additional successful high-intensity crown fire on July 5 (Plot 7). On July 6, ten minutes before igniting Plot I1, a "rogue" thunderstorm dumped 6.5 mm of rain directly on the plot in the space of about 20 minutes. This effectively ended any chance of burning within the remainder of the 1998 window (scheduled to end July 13) although hope was held out until as late as July 9 when the project had to be terminated due to the territorial wildfire situation. The fire weather and fire danger conditions associated with the two 1998 fires are given in Table 1.

Table 1: Fire weather observations and fire danger indexes associated with the various fires documented in the International Crown Fire Modelling Experiment to date.

ICFME plot. No	Date of burning (dd/mm/yy)	Time of ignition (MDT)	Dry-bulb temperature (°C)	Relative humidity (%)	10-m open wind speed (km/h)	Days since rain[2]	Canadian Forest Fire Weather Index (FWI) System components[1]					
							FFMC	DMC	DC	ISI	BUI	FWI
A	01/07/97	1426	22.3	28	15.9	5	91.8	35	348	12.2	56	27
5	04/07/97	1730	20.6	37	12.6	8	89.4	43	370	7.4	67	21
6	09/07/97	1406	24.0	44	17.2	13	89.9	59	410	9.9	86	29
8	04/07/98	1604	30.4	24	9.4	5	91.9	37	343	8.8	58	22
7	05/07/98	1642	29.2	41	16.4	6	92.5	42	352	13.6	65	41

[1] The three fuel moisture codes and three fire behaviour indexes comprising the FWI System are defined below (from Canadian Forestry Service 1984):

Fine Fuel Moisture Code (FFMC) – A numerical rating of the moisture content of litter and other cured fine fuels. This codes is an indicator of the relative ease of ignition and flammability of fine fuel.

Duff Moisture Code (DMC) – A numerical rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-sized woody materials.

Drought Code (DC) – A numerical rating of the average moisture content of deep, compact, organic layers. This code is a useful indicator of seasonal drought effects on forest fuels, and amount of smouldering in deep duff layers and large logs.

Initial Spread Index (ISI) – A numerical rating of the expected rate of fire spread. It combines the effect of wind and FFMC on rate of spread without the influence of variable quantities of fuel.

Buildup Index (BUI) – A numerical rating of the total amount of fuel available for combustion that combines DMC and DC.

Fire Weather Index (FWI) – A numerical rating of fire intensity that combines ISI and BUI. It is suitable as a general index of fire danger throughout the forested area of Canada.

[2] Based on an amount greater than or equal to 0.6 mm qualifying as a "rain day".

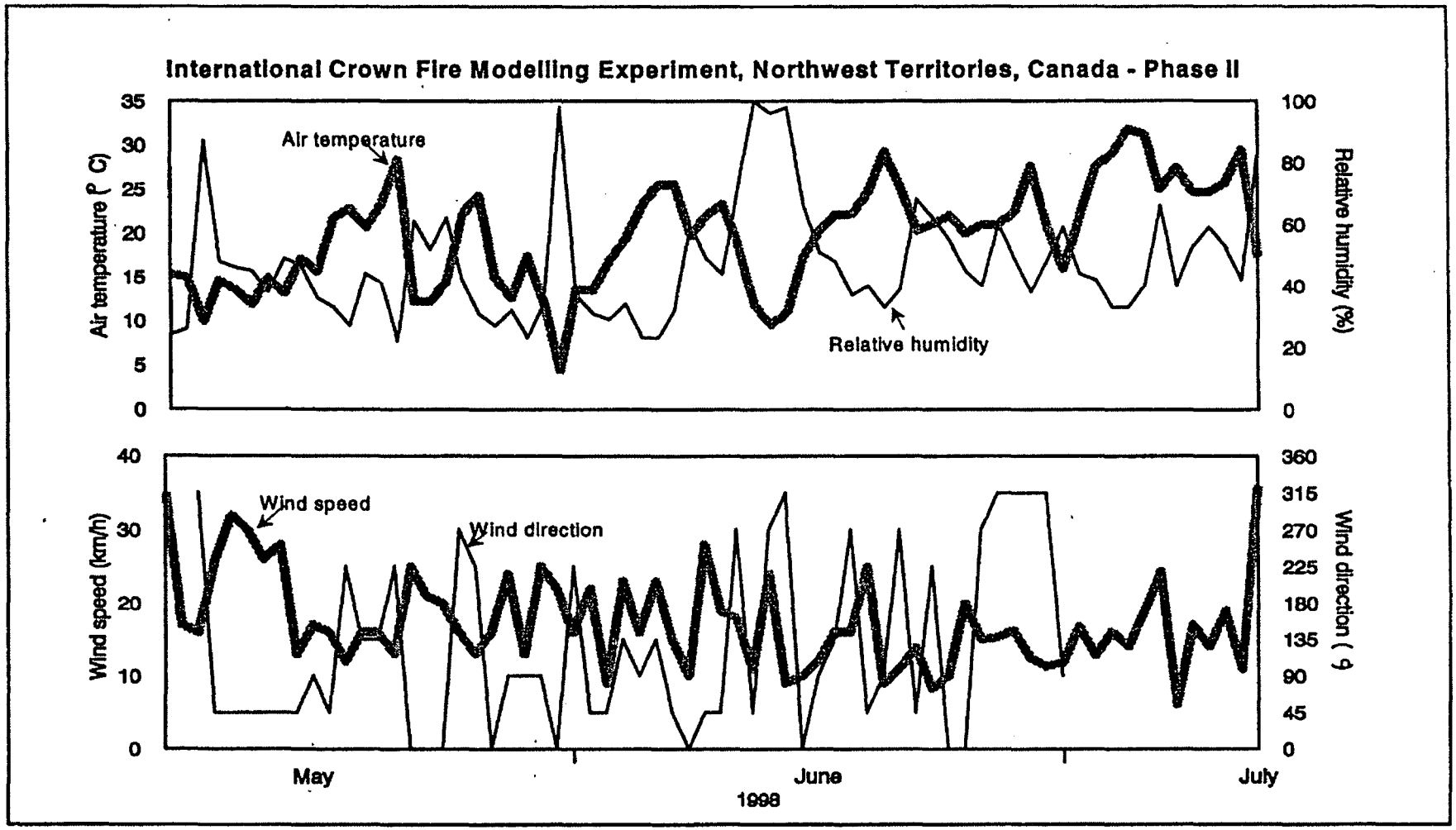

Fig. 5: Daily trends in 1300 MDT fire weather observations prior to and during the Phase II of the International Crown Fire modelling Experiment in 1998.

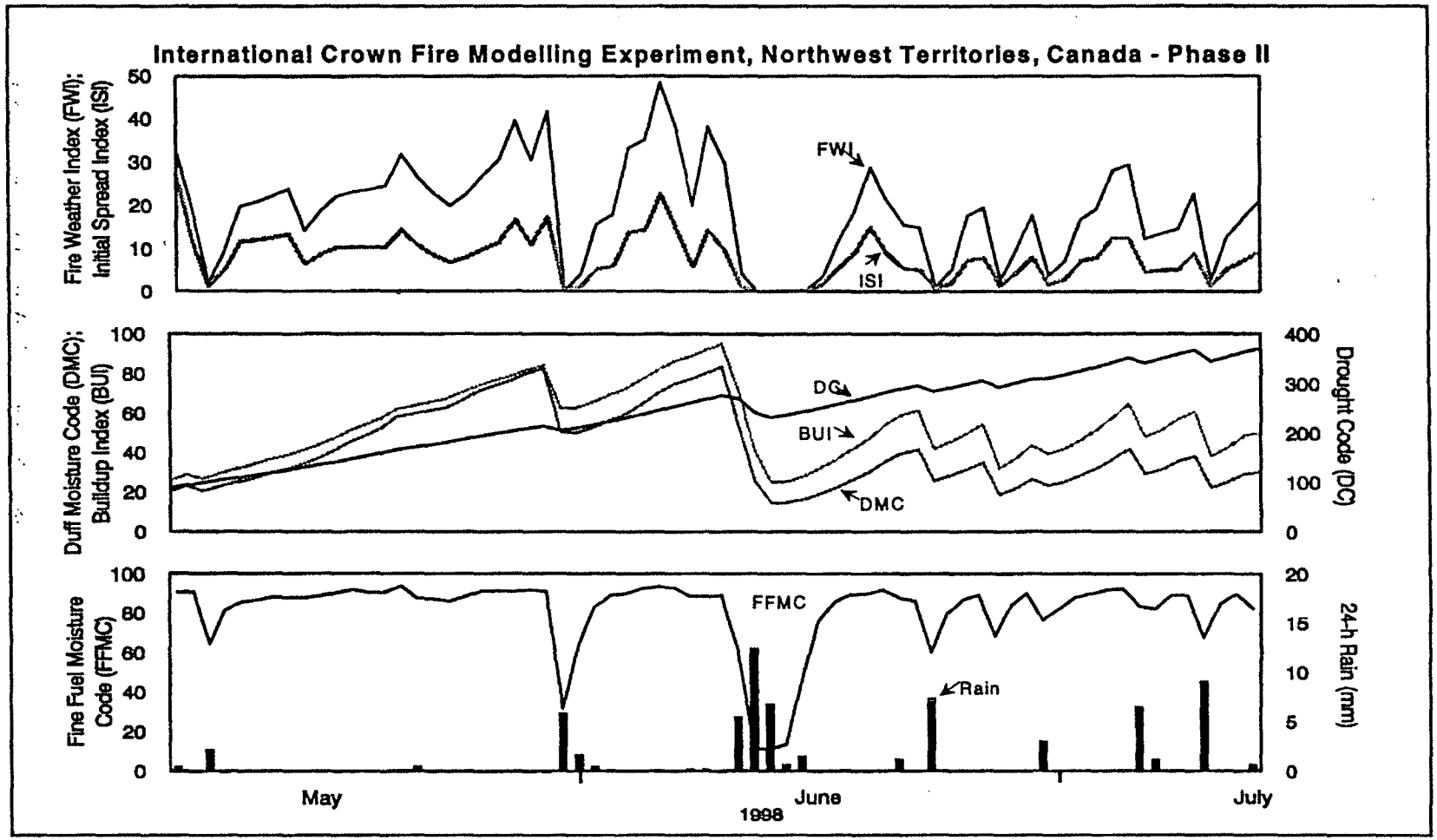

Figure 6: Daily trends in rainfall and the six standard components of the Canadian Forest Fire Weather Index System prior to and during the Phase II of the International Crown Fire Modelling Experiment in 1998.

PARTING THOUGHTS

The five ICFME fires conducted so far represent the most complex, heavily instrumented and documented experimental crown fires undertaken anywhere in the world to date. Spread rates and intensities were typically for crown fires in the boreal forest, advancing at around 2-3.5 km/h with energy release rates of 35,000-70,000 kW/m and flames at least twice the canopy height. Photographic images of all five fires can be viewed on the ICFME homepage; see also Shilts (1997). A recently released 8-minute videotape entitled "International Crown Fire Modelling Experiments - Northwest Territories - 1997" is available upon request in writing from: USDA Forest Service, Missoula Technology Development Center, Fort Missoula, Building 1, Missoula, Montana, USA, 59804.

ICFME researchers have been and are continuing to analyze the data colletcted to date. In January 1998 a meeting of most ICFME-I participants was held in Missoula, Montana, USA, to debrief on the 1997 fires and accordingly make plans for 1998. A similar debriefing/ /planning meeting will be held during this coming winter (1998-99). It is anticipated that again much will be learned from the results of this past summer's efforts and, armed with improved knowledge, the vast majority of researchers and managers that participated in the first two phases of the project will return to Fort Providence next summer for ICFME-III in order to burn the remaining plots. Phase III of the ICFME has tentatively been scheduled for June 16-July 7, 1999. A number of publications, inlcuding an overview document, will eventually be published upon completion of the ICFME burning.

The ICFME web site will in this regard periodically provide updates of newly released items.The ICFME is continuing to provide a unique opportunity to bring together some of the best wildland fire research scientists in the world to study fire behavior and fire impacts in an integrated, interdisciplinary field experiment that should result in a greater understanding of the physical mechanisms and ecological consequences of crown fires that will ultimately translate into improved forest fire management in the future. The information being gathered during the ICFME will form the basis for the next generation of fire behavior models be required by fire managers and other fire researchers a like (Taylor et al. 1998). As evident by the comments of the participants (Figure 7), the ICFME is enabling both researchers and managers to test and examine various models (Cohen 1995, Albini et al. 1996; Grishin 1997; Butler and Cohen 1998), management guidelines (IFFS Ltd. 1977; NFPA 1991; Anon. 1993;

The International Crown Fire Modelling Experiment (ICFME) has been invaluable to us in helping to design better protective fire enclosures and fire shelters with specific insulating performance for high-intensity crown fires in conifer fuel types. This would have not have been possible had the experimental burning associated with the ICFME not taken place. Jim Roth, Storm King Mountain Technologies, Los Angeles, California.

Understanding how structures ignite during wildland fires is critical for the development of effective, economically efficient and aesthetically acceptable methods of building homes in or near wildlands. Towards that end, the International Crown Fire Modelling Experiment (ICFME) offers an extremely unique opportunity to experimentally examine wood structures exposed to forest crown fires and verify structure ignition modelling calculations. None of this could be accomplished without the support of the Northwest Territories' Forest Management Division and Canadian Forest Service fire research. Without the site preparation for the experimental fires, the logistical arrangements for all the research personnel, etc. and the local community support, the ICFME would not be possible. Very importantly, it is this kind of study that provides the foundation for the understanding and basis for future management information tools. Jack Cohen, USDA Forest Service, Intermountain Fire Sciences Laboratory, Missoula, Montana.

Many of the ecological consequences of fire result from the effects of heating on plant regenerative organs (seeds, rhizomes, bulbs) in the soil, on the physical and chemical properties of the soil, and the soil fauna. A model for predicting soil heating during a fire has recently been developed although it has not been field validated under crown fire conditions. The International Crown Fire Modelling Experiment has provided a unique opportunity to determine the portion of a crown fire's energy budget that is impinging on the soil surface. The results of this experiment will allow researchers to develop improved fire effects models for use in planning and implementation of prescribed burning programs, and for assessing the need for post-wildfire rehabilitation. Kevin Ryan, USDA Forest Service, Intermountain Fire Sciences Laboratory, Missoula, Montana.

Charcoal particles accumulating in lake sediments preserve a record of fire that allows us to interpret how fire regimes have changed with past changes in climate. Interpreting sediment charcoal records requires that we understand the relationship between fires and amounts of charcoal that settle in lake basins. Although understanding of charcoal production and transport is central to identifying past fires from lake sediments, only one

study to date (i.e., the 1993 Bor Forest Island Fire Experiment) has compared charcoal transport during fire with sediment charcoal records. The International Crown Fire Modelling Experiment has provided a second additional opportunity for us to measure the production and transport of charcoal particles and recovered sediment cores from nearby lakes. This was accomplished by placing particle traps in an array downwind of the experimental fires. The particles were recovered immediately after the burning and the samples taken to the laboratory for quantification by optical microscopy. Ultimately the results from this experiment will be used to interpret sediment charcoal records from Canada and Alaska. Jim Clark, Duke University, Department of Botany, Durham, North Carolina.

The experimental crown fires associated with the International Crown Fire Modelling Experiment are a natural extension of our work into protective fire clothing at the University of Alberta. In the past we have concentrated on flash fire hazards which produce heat fluxes on the order of 80 kW/m^2 for short durations and building explosions that produce fluxes in the neighborhood of 150 kW/m^2, again for durations of a few seconds. The International Crown Fire Modelling Experiment gives us an opportunity to measure hazards under real conditions and to evaluate personal protective equipment (PPE) under conditions that are extremely difficult to simulate in small scale laboratories. Mark Ackerman, University of Alberta, Department of Mechanical Engineering, Edmonton, Alberta. *The International Crown Fire Modelling Experiment provides an excellent opportunity to verify satellite fire detection theories as compared to actual free-burning fires in the boreal forest. The size of the flame fronts associated with the experimental fires would appear to be large enough for detection according to present theory. Furthermore, the determinations of the energy released from these heavily instrument fires provides invaluable input into model calculations.* Don Cahoon, NASA Langley Research Center, Atmospheric Sciences Division, Hampton, Virginia.

I have been privileged to collaborate with forest fire research personnel of the Canadian Forest Service in an effort to create, calibrate, and test a predictive physical model for the rate of spread and intensity of a crown fire. In June and July 1997, I took part in the first phase of the International Crown Fire Modelling Experiment as part of this research. The experiments were meticulously planned. Site preparation and prefire fuel inventories were the best I have ever seen in terms of thoroughness and professionalism of execution. These experiments must be thoroughly documented for they will become the standard against which

all models will be tested. Frank Albini, Montana State University, Department of Mechanical and Industrial Engineering, Bozeman, Montana.

The MTDC Fire Shelter Project has benefited tremendously from the foresight and analytical planning of the International Crown Fire Modelling Experiment (ICFME) organizational team. Laboratory test materials and testing of fire shelters near burning windrows of piled slash or in broadcast slash disposal burns does not adequately reflect the conditions experienced in the true thermal environment of high-intensity, free-burning wildland fires. The rapid development following ignition of the fast spreading, three-dimensional flame fronts associated with ICFME crown fires with their extreme level of turbulence has allowed us to test new, experimental protective fire shelters under realistic, near worst case wildland fire situations with all the inherent complexities involved. We have learned a great deal from the experience so far and are continuing to make improvements in prototype fire shelters. Ted Putnam, USDA Forest Service, Missoula Technology Development Center, Missoula, Montana.

As atmospheric scientists at NIST, participation in Phase II of the International Crown Fire Modelling Experiment (ICFME) in 1998 was an ideal "laboratory" for our research toward elucidating the complicated chemistry of black carbon and organic carbon in particles emitted from wildfires. Because emissions from various combustion sources differ substantially, we require samples from 'representative' fires. Our success in this regard is due in large part to the efforts of the ICFME organizers to closely monitor on-site environmental conditions and to adhere to environmental benchmarks that realistically lead to the development of crown fires. Joe Conny, National Institute of Standards and Technology, Surface and Microanalysis Science Division, Gaithersburg, Maryland. *Many thanks for allowing me to participate in the International Crown Fire Modeling Experiment (ICFME) the past two summers.To your credit you have been able to accommodate numerous research objectives that ranged from the theoretical or basic to the practical or applied. The results of testing fire shelters, personal protective equipment and defensible space standards for forest homes will have a direct impact on our most important fire management resource – our firefighters. The work being done in the Northwest Territories will help us in designing meaningful fire shelter tests in our Alaskan fuel types. The ICFME provides a unique opportunity to safely engage in research related to high-intensity crown fires. The video footage from inside and outside the experimental burning plots has had a definite impact on*

our perceptions of the crown fire phenomenon and is not lost on Continued even the most experienced of our firefighters. We now have truly new view of wildfire. John McColgan, USDI Bureau of Land Management-Alaska Fire Service, Alaska Smokejumpers, Fairbanks, Alaska.

My interest in the International Crown Fire Modelling Experiment as a fire ecologist conducting fire research in the savannas of southern Africa was to obtain first hand experience on the monitoring of crown fire behaviour under field conditions in Canada. Fire behaviour is a very neglected aspect of fire ecology in Africa and participating in this experiment provided the opportunity to achieve a whole host of objectives ranging from viewing the procedures for quantifying fuels, wind profiles and specific fire characteristics to interacting with leading research scientists studying fire behaviour. Participation in the experiment proved to be a great success and I have been able to adapt and improve the procedures for monitoring the behaviour of fires burning in southern African savannas. Witnessing the crown fires proved to be an awesome experience and I must express my admiration for the expertise with which the Canadian team tackled and successfully completed this daunting task. Winston Trollope, University of Fort Hare, Department of Livestock & Pasture Science, Alice, South Africa.

In Alberta, the use of protective fire shelters has been questioned for a number of years, both for and against. In 1995, after a fatality on the fire line, one of the safety questions to be addressed was whether we should adopt fire shelters or not. We therefore decided to take advantage of the Canadian Forest Service's invitation to participate in the International Crown Fire Modelling Experiment (ICFME) and their suggestion to utilize the University of Alberta's expertise in thermal testing to examine fire shelters, safety zones and personal protective equipment (PPE). What did we learn from the 1997 ICFME fires? First of all, shelters and PPE do not replace good fire behavior knowledge in avoiding fire entrapments. Secondly, more tests are needed in order to determine the size of safety zones required for survival and the limits of fire shelter effectiveness. Finally, the video footage of the fires obtained by ourselves and others involved in the ICFME will be extremely beneficial in our provincial fire training programs. Gary Dakin, Alberta Land and Forest Service, Northern East Slopes Region, Whitecourt, Alberta.

The main purpose of the infrared camera data that we acquired during first phase of the International Crown Fire Modelling Experiment in 1997 was an attempt to derive a data set

of temperatures and winds for assessing certain details of the thermodynamics and dynamics of wildland fires. I think the data we acquired is basically wonderful and that is primarily due to the good experimental design associated with fires. Terry Clark, National Center for Atmospheric Research, Boulder, Colorado.

One of my current research interests is determining the suitability of using post-fire live twig tip diameter from branches of standing trees as an integrated measure of fire severity. The measurements taken by the other participants in the International Crown Fire Modelling Experiment (ICFME) in the form of various instruments, sensors, video recorders and fuel consumption determinations provides the best possible data set for testing my hypothesis.The willingness of the ICFME participants to share their data, provide excellent helpful criticism and engage in useful discussions about my research makes participation a joy. Don Despain, U.S. Geological Survey, Greater Yellowstone Field Station, Bozeman, Montana.

Figure 7: Comments from selected collaborators who participated in the first two experimental burning phases of the International Crown Fire Modelling Experiment in 1997 and/or 1998.

Butler 1997), environmental processes (Cofer et al. 1996; Clark et al. 1998), and PPE for wildland firefighters such as fire shelters (Putnam 1995, 1996; Roth 1997). Such diversity illustrates that experimental burning projects like the ICFME can accommodate both applied or practial as well as more basic or fundamental studies, including client-driven and long-term R&D.

International endeavours like the ICFME are now viewed as how much of the world's wildland fire research will get done in the future through global partnerships(Goldammer 1994; McCaw and Alexander 1994; Weber 1995; Saveland and Thomas 1998). However, these kinds of projects don't just happen. The right unobtrusive atmosphere must be created so participants can do their work in as relatively unfretted manner as possible. In this regard, the success that the ICFME has achieved to date can be attributed to a number of factors, including thoughtful planning based on experiences with similar experimental burning projects (Stocks 1987, 1989, Alexander et al. 1991; Stocks and McRae 1991), good working relationships amongst the local community, operational personnell and researchers, and the support of senior management, coupled with a healthy dose of patience and perseverance by the participants. The fact that there was already an active prescribed burning program in the Fort Providence area (Gates et al. 1998) was also a definite contributing factor andshould not

be overlooked by any group or organization(s) contemplating an undertaking similar to the ICFME.

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A research project like the ICFME cannot be undertaken without the full support of many agencies and people, several of who are mentioned in ANNEX I. However, the authors would also especially like to thank the people of Fort Providence, B. Bailey, P. Johnson and T. Chowns of DRWED and D. Dube of the CFS. The assistance of C. Stefner in the preparation of this paper is gratefully appreciated.

REFERENCES

Albini, F.A. 1996. Iterative solution of the radiation transport equations governing spread of fire in wildland fuel. Physika Goreniya I Vzryva 32(5): 71-82.

Albini, F.A.; Amin, M.R.; Hungerford, R.D.; Frandsen, W.H.; Ryan, K.C. 1996. Models for fire-driven heat and moisture transport in soils. USDA For. Serv., Intermt. Res. Stn., Ogden, Utah. Gen. Tech. Rep. INT-GTR-335. 16 p.

Albini, F.A.; Stocks, B.J. 1986. Predicted and observed spread rates of crown fires in immature jack pine. Combust. Sci. Tech. 48: 65-76.

Alexander, M.E.; Lanoville, R.A. 1987. Wildfires as a source of fire behavior data: a case study from Northwest Territories, Canada. Pages 86-93 *in* Postprint Volume Ninth Conference on Fire and Forest Meteorology. Am. Meteor. Soc., Boston, Massachusetts.

Alexander, M.E.; Quintilio, D. 1990. Perspectives on experimental fires in Canadian forestry research. Math. Compu. Modelling 13(12): 17-26.

Alexander, M.E.; Stocks, B.J.; Lawson, B.D. 1991. Fire behavior in black spruce-lichen woodland: the Porter Lake Project. For. Can., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-310. 44 p.

Alexander, M.E.; Stocks, B.J.; Lawson, B.D. 1996. The Canadian Forest Fire Danger Rating System. Initial Attack 1996(Spring): 6-9.

Alexander, M.E.; Stocks, B.J.; Wotton, B.M.; Flannigan, M.D.; Todd, J.B.; Butler, B.W.; Lanoville, R.A. 1998. The International Crown Fire Modelling Experiment: an overview and progress report. Pages 20-23 *in* Preprint Volume Second Symposium on Fire and Forest Meteorology. Am. Meteor. Soc., Boston, Massachusetts.

Andersson, K. 1998. Crown fire experiments -- and trees as fire shields. Wildland Firefighter 2(1): 13-14.

Andrews, P.L. 1991. Use of the Rothermel fire spread model for fire danger rating and fire behavior prediction in the United States. Pages 1-8 *in* N.P. Cheney and A.M. Gill (eds.). Conference on Bushfire Modelling and Fire Danger Rating Systems Proceedings. CSIRO Div. For., Yarralumla, Australian Capital Territory.

Anonymous. 1993. Cabin owner's guide to fire prevention. Govt. Northwest Territories, Dep. Renewable Resour., Yellowknife, Northwest Territories. 15 p.

Anonymous. 1994. Canada's Green Plan forest fire research strategic plan. Nat. Resour. Can., Can. For. Serv., Ottawa, Ontario. 9 p.

Anonymous. 1998. A crowning achievement. Nat. Resour. Can., Can. For. Serv., Ottawa, Ontario. Solutions 1998(Spring): 1. [see also:http://nrcan/gc.ca/cfs/solutions/spring/art02.htm]

Bradshaw, S.; Tour, J. 1993. Ground ignitions systems: an equipment guide for prescribed and wild fires. USDA For. Serv., Missoula Tech. Develop. Cent., Missoula, Montana. Tech. Rep. 9351-2806-MTDC. 72 p.

Butler, B.W. 1994. Experimental measurements of radiant heat fluxes from simulated wildfire flames. Pages 104-111 *in* Proceedings of 12th Conference on Fire and Forest Meteorology. Soc. Am. For., Bethesda, Maryland. SAF Publ. 94-02.

Butler, B.W. 1997. Safety zones and fire shelters: some observations from Forest Service research. Wildfire 6(3): 36-40.

Butler, B.W.; Cohen, J.D. 1998. Firefighter safety zones: a theoretical model based on radiative heating. Int. J. Wildland Fire 8: 73-77.

Call, P.T. 1997. Run-time optimization of a radiation driven crown fire model. Mont. State Univ., Bozeman, Montana. M.Sc. Thesis. 86 p.

Call, P.T.; Albini, F.A. 1997. Aerial and surface fuel consumption in crown fires. Int. J. Wildland Fire 7: 259-264.

Cofer, W.R.III; Winstead, E.L.; Stocks, B.J.; Overbay, L.W.; Goldammer, J.G.; Cahoon, D.R.; Levine J.S. 1996. Emissions from boreal forest fires: are the atmospheric impacts underestimated? Pages 834-839 *in* J.S. Levine (ed.). Biomass Burning and Global Change, Volume 2: Biomass Burning in South America, Southeast Asia, and Temperate and Boreal Ecosystems, and the Oil Fires of Kwait. MIT Press, Cambridge, Massachusetts.

Clark, J.S.; Lynch, J.; Stocks, B.J. 1998. Relationships between charcoal particles in air and sediments in west-central Siberia. The Holocene 8: 19-30.

Canadian Forestry Service. 1984. Tables for the Canadian Forest Fire Weather Index System. Fourth ed. Can. For. Serv., Ottawa, Ontario. For. Tech. Rep. 25. 48 p.

Cohen, J.D. 1995. Structure Ignition Assessment Model (SIAM). Pages 85-92 *in* D.R. Weise and R.E. Martin (tech. coords.). The Biswell Symposium: Fire Issues and Solutions in Urban Interface and Wildland Ecosystems. USDA For. Serv., Pacific Southwest Res. Stn., Albany, California. Gen. Tech. Rep. PSW-GTR-158.

FIRESCAN Science Team. 1994. Fire in boreal ecosystems of Eurasia: first results of the Bor Forest Island Fire Experiment, Fire Research Campaign Asia-North (FIRESCAN). World Resour. Rev. 6: 499-523.

FIRESCAN Science Team. 1996. Fire in ecosystems of boreal Eurasia: the Bor Forest Island Fire Experiment, Fire Research Campaign Asia-North (FIRESCAN). Pages 848-873 *in* J.S. Levine (ed.). Biomass Burning and Global Change, Volume 2: Biomass Burning in South America, Southeast Asia, and Temperate and Boreal Ecosystems, and the Oil Fires of Kwait. MIT Press, Cambridge, Massachusetts.

Forestry Canada Fire Danger Group. 1992. Development and structure of the Canadian Forest Fire Behavior Prediction System. For. Can., Ottawa, Ontario. Inf. Rep. ST-X-3. 63 p.

Fosberg, M. 1992. International Boreal Forest Research Association, Stand Replacement Fire Working Group. Int. For. Fire. News No. 7: 68.

Gates, C.C.; Chowns, T.; Antoniak, R.; Ellsworth, T. 1998. Succession and prescribed fire in shrublands in northern Canada: shaping the landscape to enhance bison habitat. Pages 125-132 *in* K. Close and R.A. (Hartford) Bartlette (eds.). Fire Management Under Fire

(Adapting to Change), Proccedings of 1994 Interior West Fire Council Meeting and Program. Int. Assoc. Wildland Fire, Fairfield, Washington.

Goldammer, J.G. 1994. Interdisciplinary research projects for developing a global fire science. Pages 6-22 *in* Proceedings of 12th Conference on Fire and Forest Meteorology. Soc. Am. For., Bethesda, Maryland. SAF Publ. 94-02.

Goldammer, J.G.; Furyaev, V.V. (eds.). 1996. Fire in ecosystems of boreal Eurasia. Kluwer Acad. Publ., Dordrecht, Germany. For. Sci. Vol. 48. 528 p.

Grishin, A.M. 1997. Mathematical modelling of forest fires and new methods of fighting them. Translated by M. Czuma, L. Chikina and L. Smokotina. Edited by F. Albini. Publ. House Tomsk State Univ., Tomsk, Russia. 390 p.

Hogenbirk, J.C. 1998. Hot web sites. Wildfire 7(3): 15.

Holloran, C. 1998. CFS researchers study forest fire behavior. The Edge 1998(May): 3. [*see* also: http://www.mediamatch.com/may98/research1.html]

International Forest Fire System Ltd. 1977. Guidelines for settlement protection. Yukon Lands For. Serv., Whitehorse, Yukon Territory. 101 p.

Kautz, J. 1997. Appendix C -- insulated boxes for protecting video cameras. Pages 39-40 *in* R. Mangan. Surviving Fire Entrapments: Comparing Conditions Inside Vehicles and Fire Shelters. USDA For. Serv., Missoula Tech. Develop. Cent., Missoula, Montana. Tech. Rep. 9751-2817-MTDC. 42 p.

Klassen, C. 1998. Fire behavior studied. *Grande Prairie Daily Herald-Tribune*, 16 July 1998, p. 1.

McAlpine, R.S.; Stocks, B.J.; Van Wagner, C.E.; Lawson, B.D.; Alexander, M.E.; Lynham, T.J. 1990. Forest fire behavior research in Canada. Pages A.02:1-12 *in* Proceedings of International Conference on Forest Fire Research. Univ. Coimbra, Coimbra, Portugal.

McCaw, W.L.; Alexander, M.E. 1994. Tripartite agreement on wildland fire science research signed. Int. For. Fire News No. 11: 27-29.

Nalder, I.A.; Wein, R.W.; Alexander, M.E.; de Groot, W.J. 1997. Physical properties of dead and downed round-wood fuels in the boreal forests of Alberta and Northwest Territories. Can. J. For. Res. 27: 1513-1517.

National Fire Protection Association. 1991. NFPA 299 standard for protection of life and property from wildfire. 1991 ed. Natl. Fire Protection Assoc., Quincy, Massachusetts. 19 p.

Putnam, T. 1995. Your fire shelter. 1995 ed. USDA For. Serv., Missoula Tech. Develop. Cent., Missoula, Montana. Tech. Rep. 9551-2819-MTDC. 18 p.

Putnam, T. 1996. Your fire shelter -- beyond the basics. USDA For. Serv., Missoula Tech. Develop. Cent., Missoula, Montana. Tech. Rep. 9651-2829-MTDC. 30 p.

Roth, J. 1997. Fire shelter performance. Wildfire 6(3): 16-22.

Rothermel, R.C. 1991. Predicting behavior and size of crown fires in the Northern Rocky Mountains. USDA For. Serv., Intermt. Res. Stn., Ogden, Utah. Res. Pap. INT-438. 46 p.

Samoil, J. 1998. Lightning a forest fire all in a day's work for researchers. *Swan Hills Grizzly-Gazette*, 14 July 1998, p. 6.

Saveland, J.; Thomas, D. (tech. coords.). 1998. Wildland fire research future search conference notes. USDA For. Serv., Rocky Mt. Res. Stn., Fort Collins, Colorado. Proc. RMRS-P-1. 48 p.

Shilts, E. 1997. Managing crown fires in Canadian forests. Geos 1(1). [*see* also: http://www.bsl.com/geos/vol1_1/02main.htm]

Stocks, B.J. 1980. Black spruce crown fuel weights in northern Ontario. Can. J. For. Res. 10: 498-501.

Stocks, B.J. 1987. Fire behavior in immature jack pine. Can. J. For. Res. 17: 80-86.

Stocks, B.J. 1989. Fire behavior in mature jack pine. Can. J. For. Res. 19: 783-790.

Stocks, B.J.; Alexander, M.E. 1996. International Crown Fire Modelling Experiment. Pages CFS-31-33 *in* Reports Tabled at Forty Fourth Annual Meeting of Canadian Committee on Forest Fire Management. Can. Comm. For. Fire Manage., Winnipeg, Manitoba.

Stocks, B.J.; McRae, D.J. 1991. The Canada/United States cooperative mass fire behavior and atmospheric environmental impact study. Pages 478-487 *in* P.L. Andrews and D.F. Potts (eds.). Proceedings of 11th Conference on Fire and Forest Meteorology. Soc. Am. For., Bethesda, Maryland. SAF Publ. 91-04.

Taylor, S.W.; Baxter, G.J.; Hawkes, B.C. 1998. Modeling the effects of forest succession on fire behavior potential in southeastern British Columbia. *These proceedings*.

Taylor, S.W.; Pike, R.G.; Alexander, M.E. 1997. Field guide to the Canadian Forest Fire Behavior Prediction (FBP) System. Can. For . Serv., North. For. Cent., Edmonton, Alberta. Spec. Rep. 11. 60 p.

Van Wagner, C.E. 1987. Development and structure of the Canadian Forest Fire Weather Index System. Can. For. Serv., Ottawa, Ontario. For. Tech Rep. 35. 37 p.

Walker, J.D.; Stocks, B.J. 1975. The fuel complex of mature and immature jack pine stands in Ontario. Can. For. Serv., Great Lakes For. Res. Cent., Sault Ste. Marie, Ontario. Inf. Rep. 0-X-229. 19 p.

Weber, M.G. 1995. Fire research and the global village. For. Chron. 71: 584-588

ANNEX I: INTERNATIONAL CROWN FIRE MODELLING EXPERIMENT PARTICIPANTS[1]

1995 Preburn Sampling Phase

CFS: M. Alexander, G. Hartley, M. Maffey, J. Mason, C. Stefner, B. Stocks; MPIFU: G. Buchholz, S. Ing; USFS-IFSL: B. Butler; UFH: L. Trollope, W. Trollope; DRWED: R. Lanoville.

1996 Preburn Sampling Phase

CFS: M. Alexander, G. Hartley, M. Hobbs, M. Maffey, J. Mason, C. Stefner, B. Stocks, M. Weber, M. Wotton; USFS-IFSL: B. Butler, B. Schuette; DRWED: R. Lanoville; NASA: D. Cahoon.

1997 Experimental Burning Phase I

CFS: M. Alexander, K. Anderson, T. Blake, G. Dalrymple, B. de Groot, D. Dube, M. Flannigan, G. Hartley, K. Hirsch, M. Hobbs, M. Maffey, J. Mason, B. Mottus, C. Stefner, B. Stocks, S. Taylor, B. Todd, M. Weber, M. Wotton; MPIFU: J. Goldammer; USFS-IFSL: B. Butler, P. Call, J. Cohen, D. Latham, J. Reardon, B. Schuette, P. Sopko; UFH: L. Trollope, W. Trollope; DRWED: R. Lanoville, F. Lepine; NASA: D. Cahoon, E. Winstead; UA: M. Ackerman; ALFS: G. Dakin; USFS-MTDC: D. Gasvoda, J. Kautz, D. Mangan, T. Putnam, L. Weger, M. Wiggins; SKMT: J. Roth; AFS: K. Howard, J. McColgan, T. Pastro; USFS-NFS: M. Vanderpas; York University: M.A. Jenkins; National Center for Atmospheric Research: T. Clark, L. Radke; Duke University: J. Clark, J. Lynch; Montana State University: F. Albini.

[1] Abbreviations: CFS = Canadian Forest Service; MPICFU = Max Planck Institute of Chemistry-Freiburg University; USFS-IFSL = U.S. Forest Service-Intermountain Fire Sciences Laboratory; UFH = University of Fort Hare; DRWED = Department of Resources, Wildlife and Economic Development; NASA = National Aeronautical and Space Administration; UA = University of Alberta; ALFS = Alberta Land and Forest Service; USFS-MTDC = U.S. Forest Service-Missoula Technology Development Center; SKMT = Storm King Mountain Technologies; AFS = Alaska Fire Service; USFS-NFS = U.S. Forest Service-National Forest Systems

CFS: M. Alexander, B. Amiro, K. Anderson, T. Blake, R. Carr, D. Dalrymple, B. de Groot, M. Flannigan, G. Hartley, B. Hawkes, K. Hirsch, J. Ji-Zhong, T. Laengle, M. Maffey, J. Mason, D. McRae, B. Mottus, C. Stefner, B. Stocks, S. Taylor, B. Todd, M. Wotton; MPIFU: J. Goldammer; USFS-IFSL: R. Babbit, L. Bradshaw, B. Butler, J. Cohen, M.A. Davies, D. Latham, J. Reardon, K. Ryan, B. Schuette, P. Sopko, R. Susott; DRWED: R. Currie, E. Landry, R. Lanoville, F. Lepine, P. Rivard; NASA: E. Winstead; UA: M. Ackerman, N. Lavoie; ALFS: G. Dakin; USFS-MTDC: L. Anderson, J. Kautz, D. Mangan, T. Putnam; SKMT: J. Roth, W. Roth; AFS: J. McColgan; USFS-NFS: M. Linane, T. Petrelli, M. Vanderpas; Yukon Forest Fire Centre: A. Beaver; U.S. Geological Survey: D. Despain; U.S. National Institute of Standards and Technology: J. Conny, J. Slater; Arizona State University: B. Maddin; CSIRO Division of Forestry & Forest Products (Australia): J. Gould; E.I. DuPont Inc.: A. Swain; Russian Academy of Sciences-Sukachev Institute of Forestry & Timber: Y. Kisilyakhov, A. Sukhinin; Laboratory of the Sciences of Climate and the Environment (France): D. Lavoue; Ember Research Services: B. Armitage. B. Lawson; British Columbia Forest Service: J. Beck.

Fire Suppression Crews

The three Evergreen Forestry Ltd. fire suppression crews based at Fort Providence have provided much needed support to the ICFME, ranging from fuel treatments on selected plots to mop-up after the experimental fires to construction of the simulated houses in Plots I1 and I2. The senior crew supervisor is T. Matto. Crew "India" is comprised of J. Canadien, J. Matto (crew boss), W. Naldli, G. Sabourin and H. Sabourin. Crew "Juliette" consists of W. Bonnetrouge (crew boss), X. Bonnetrouge, A. Farcy, K. Minoza and S. Nadli. Crew "Kilo" is composed of M. Canadien, X. Canadien (crew boss), L. Elleze, P. Farcy and M. Nadli.

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COMPOSITION

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