Some Pragmatic Thoughts on the Prediction of Spotting in Wildland Fires

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MITACS/GEOIDE Conference on Forest Fire Modelling
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Perspective of Presenter

- Observations of wildfires, experimental outdoor fires, prescribed fires – since 1972 – Canada, US, Australia and New Zealand
- Unit leader for Extreme fire behavior – CIFFC Wildland Fire Behavior Specialist Course (1996-2008); instructor for lecture and exercises on prediction of spotting
- PROMETHEUS Spotting & Breaching Sub-committee Chair
- Consider myself a “Dirt Fire Behavior Researcher” & a “Student of Fire Behavior”

Extreme fire behavior represents a level of fire activity that often precludes any fire suppression action. It usually involves one or more of the following:

- High Rate of Spread & Intensity

- Crowning

- Prolific Spotting

- Large Fire Whirls

- Well-developed Convection Column

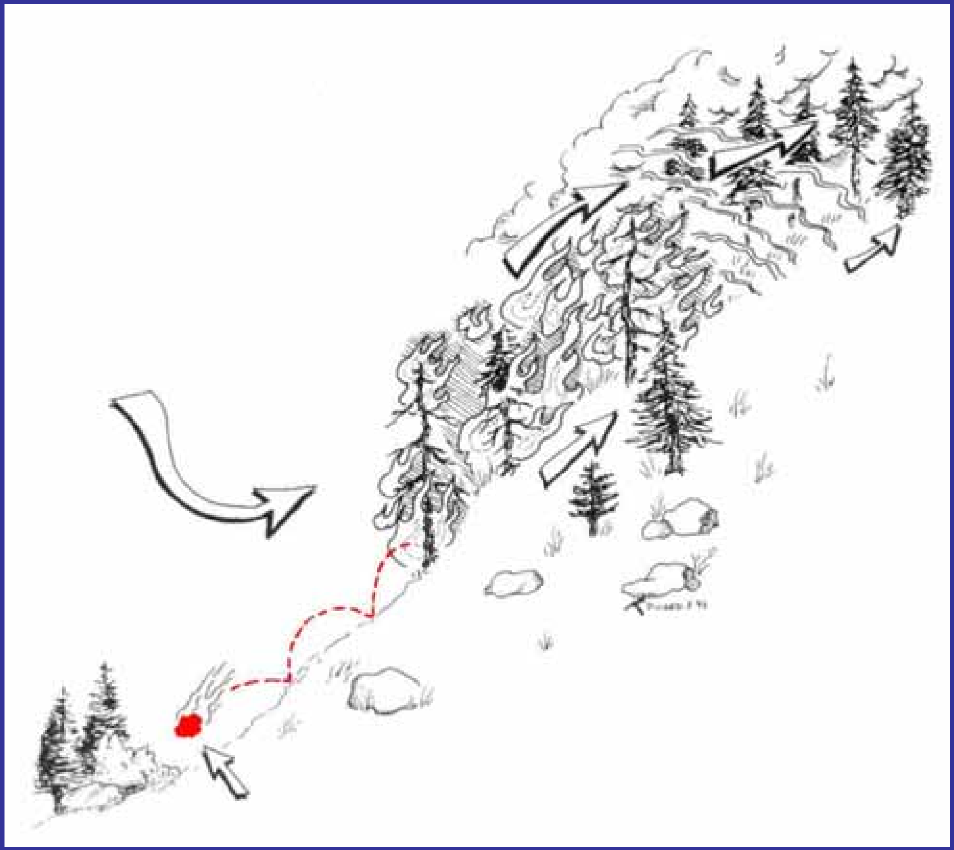
*“A fire should be regarded as capable of developing extreme fire behavior if in its early stages it has a tendency **to spot for any considerable distance, say, 600 feet** [183 m] **or more. Such spotting** indicates the presence of updrafts or whirlwinds capable of lifting up embers large enough to burn half a minute or longer before reaching the ground.”*

– George M. Byram (1959)

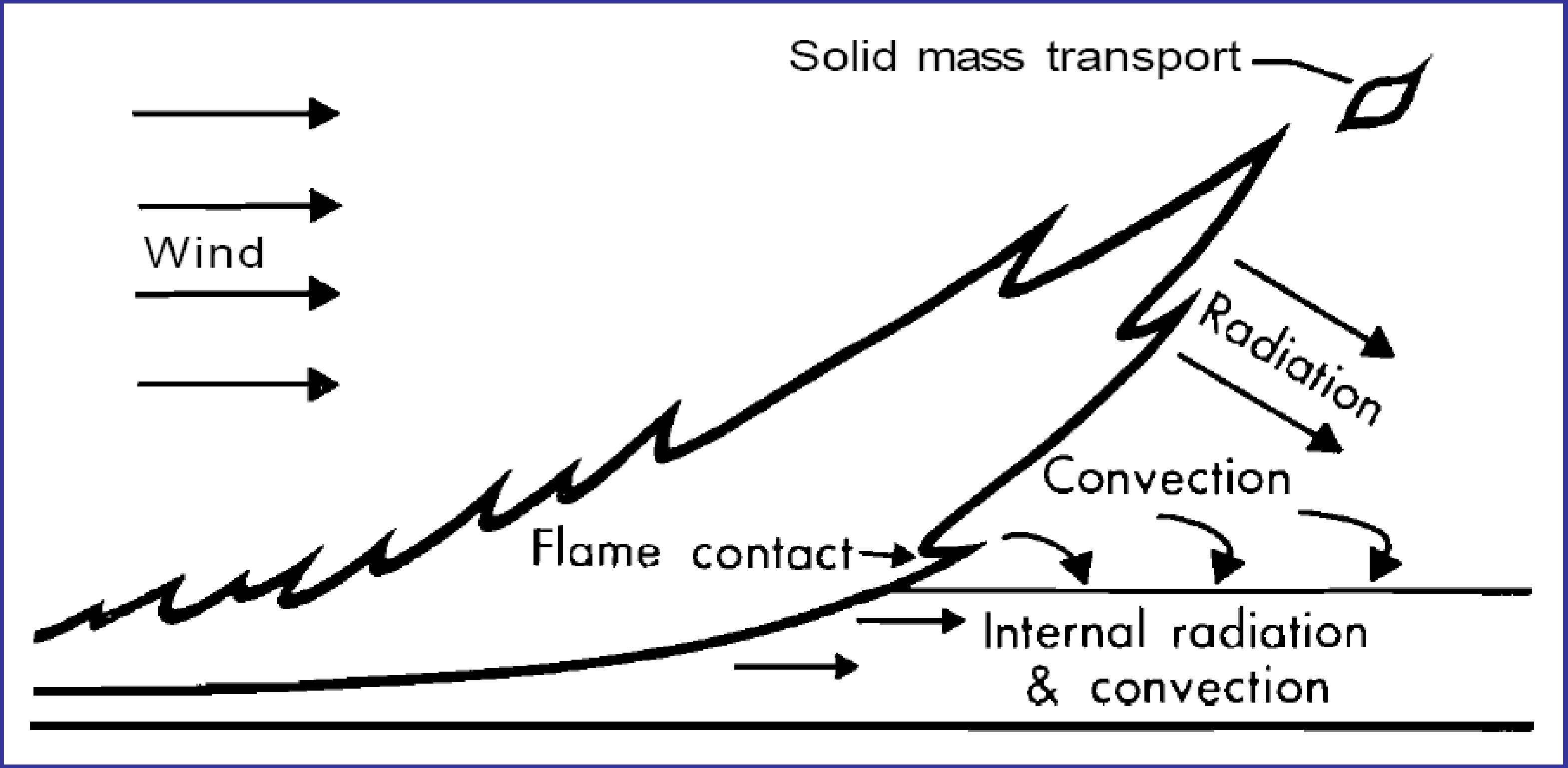
Definition

Spotting occurs when a fire produces sparks or embers that are carried by the wind and start new fires beyond the zone of direct ignition by the main fire.

Slope and gravity will cause burning material (e.g., logs, ponderosa pine cones) to roll downhill and cross control lines, possibly resulting in upslope "runs".



Mechanisms of Heat Transfer and Fire Spread



Spotting is synonymous with solid mass transport

Significance

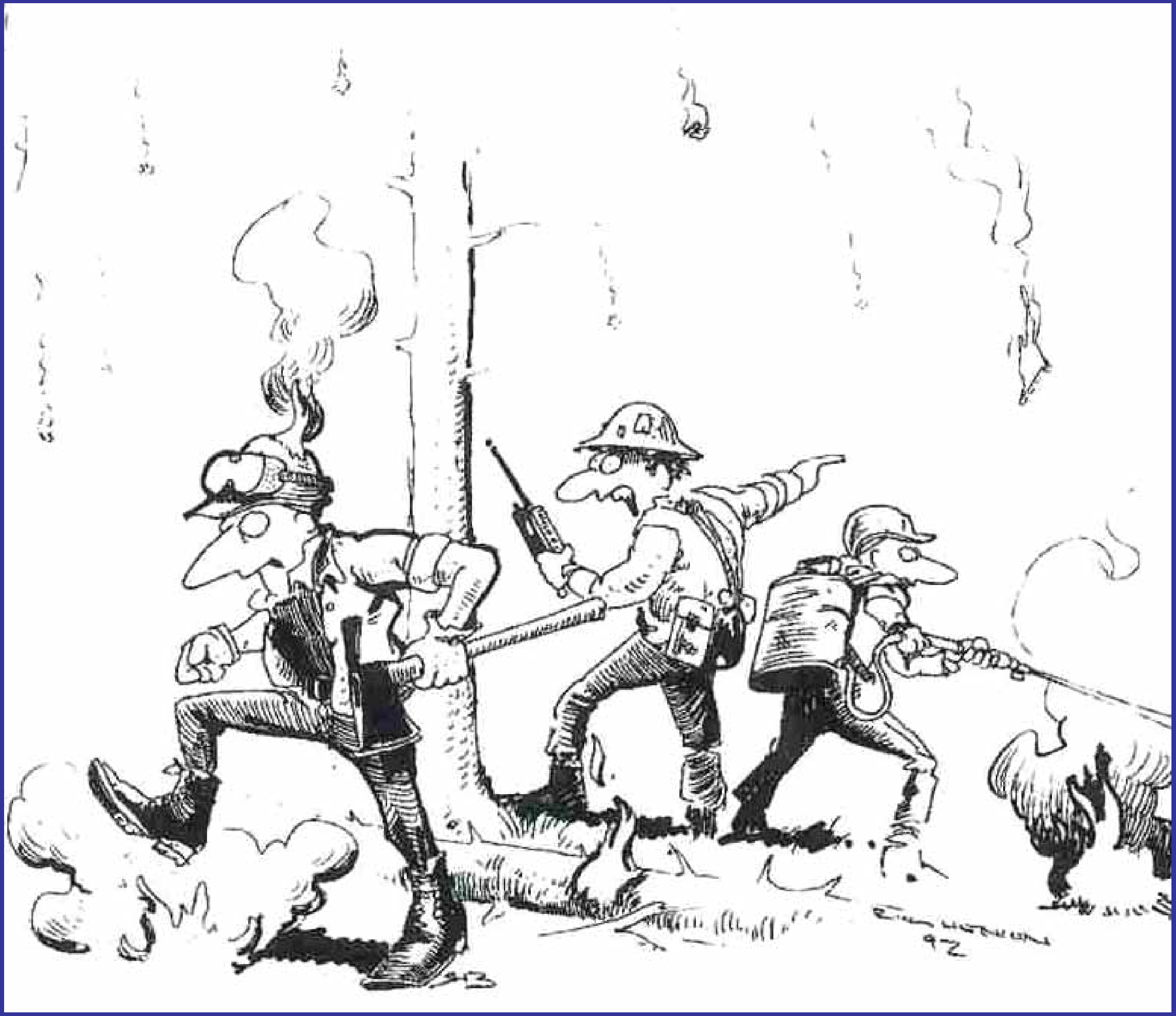
- Threat to the safety of human life (firefighters and the general public)

- Exacerbate fire suppression activities and plans

- Leading cause of structural losses in wildland-urban interface (WUI) fire disasters

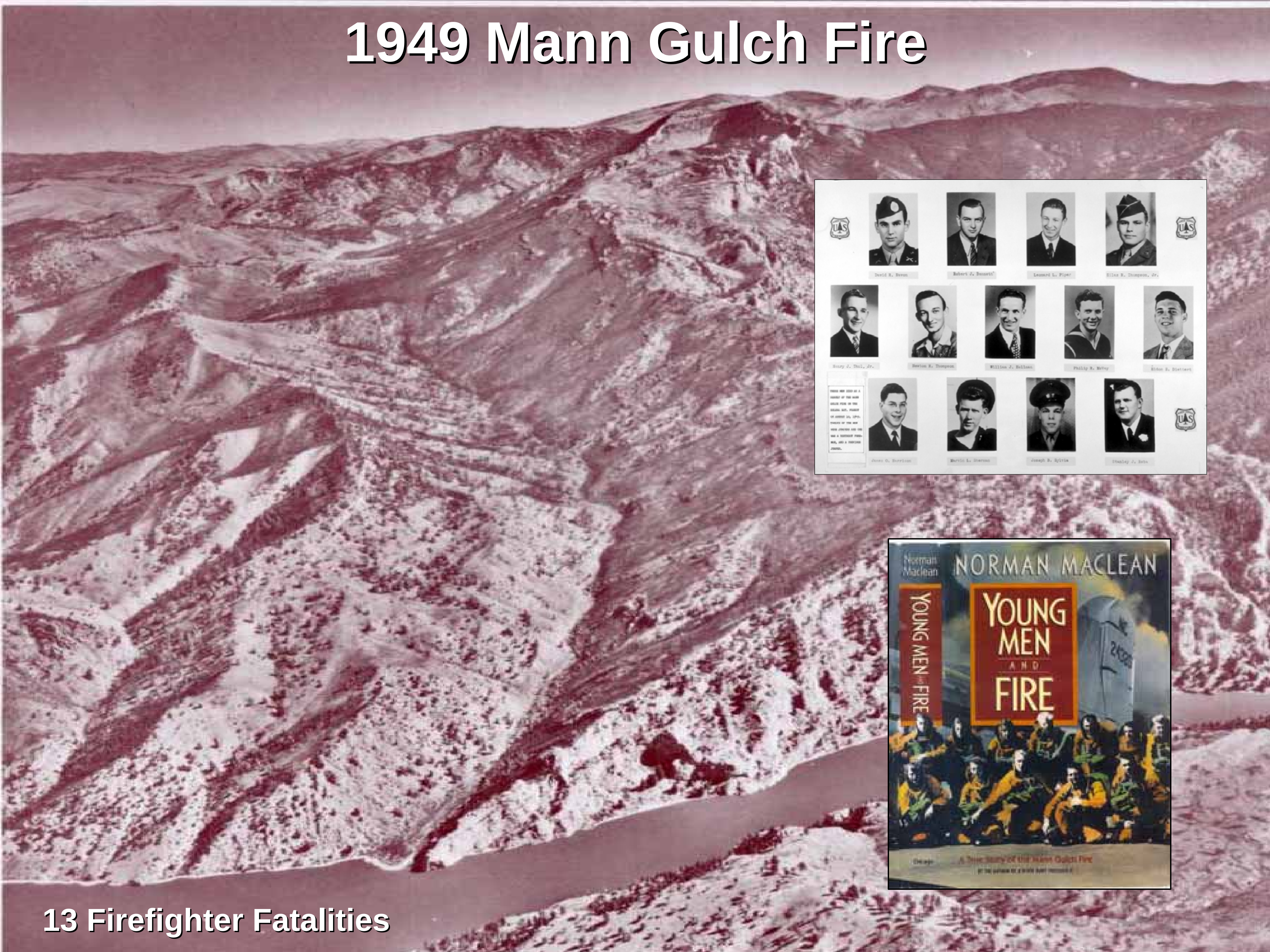
- Common cause of escapes on prescribed fires

WATCH OUT! SITUATION #16



GETTING FREQUENT SPOT FIRES ACROSS LINE

1949 Mann Gulch Fire



13 Firefighter Fatalities

Goal of Wildland Fire Behavior Research

Provide simple, timely answers to the following types of questions:

• What will be the head fire rate of spread? What will be the area, perimeter length, and forward spread distance after 1 hour, 2 hours, 3 hours, and so on?

• Will it be a high-intensity or low-intensity fire? Will it be a crown fire or a surface fire? How difficult will it be to control and extinguish? Will mechanical equipment and/or air tankers be required, or can it be handled safely by a suppression crew? Will the mop-up efforts require more time than normal?

• Is there a possibility of it “blowing up”? Is so, will it produce a towering convection column or have a wind-driven smoke plume? What will be the spotting potential – short- or long-range? Are fire whirls and/or other types of wildland fire vortexes likely to develop? If so, when and where?

Conceptual Model of Scientifically-based Forest Fire Management

(adapted from Burrows 1994)

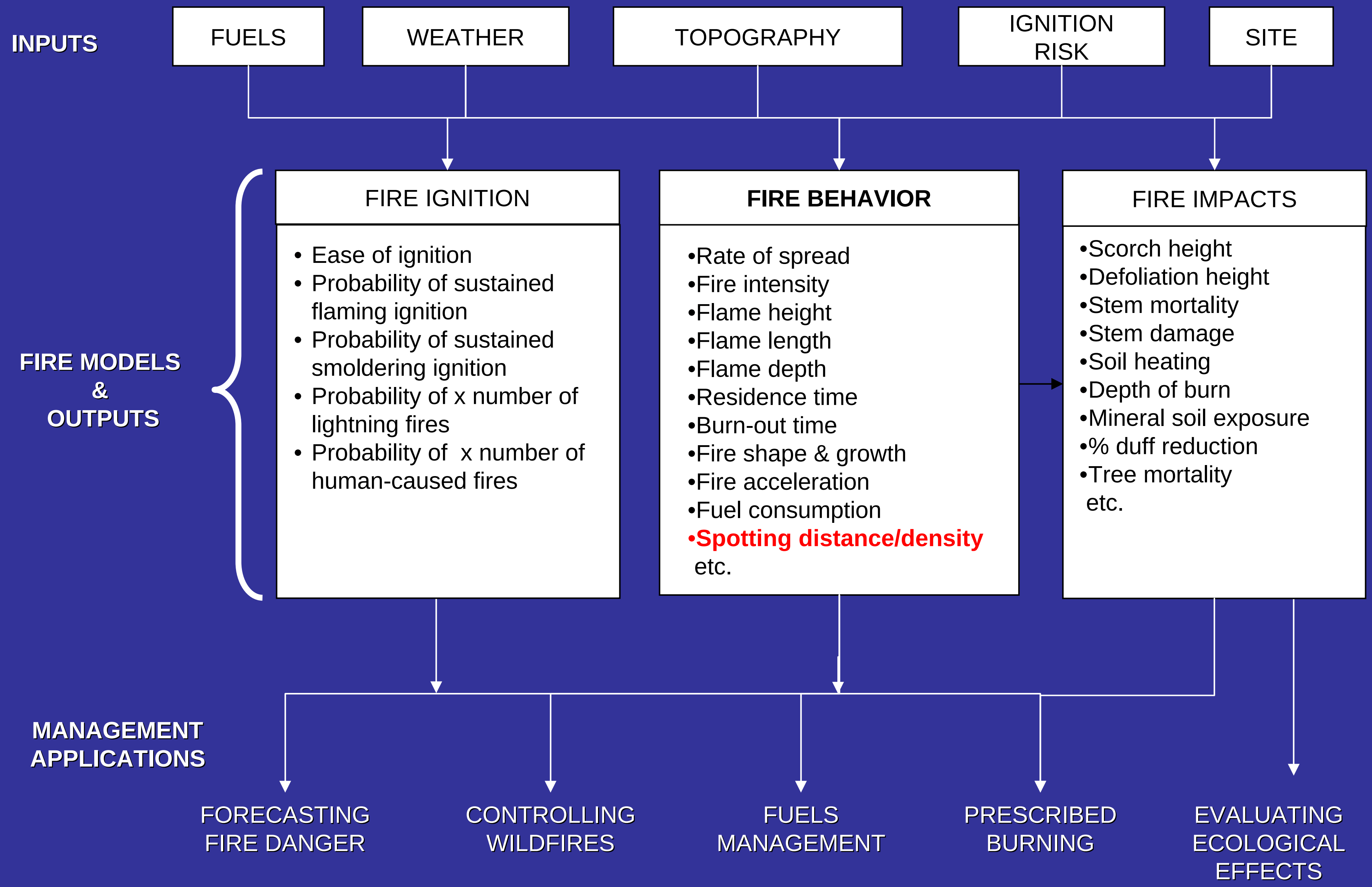


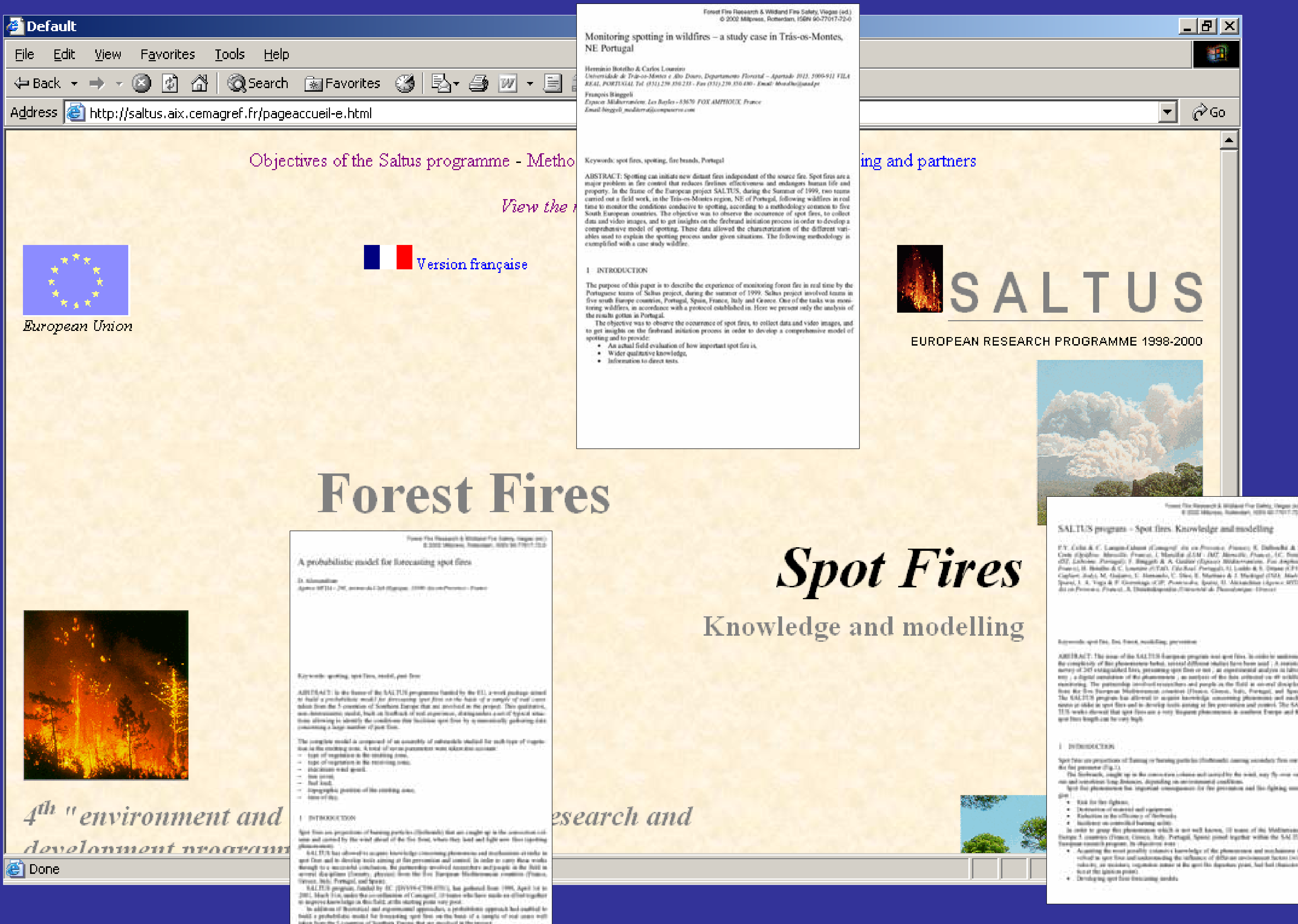
Fig 3. Crown fire progression beneath the canopy in plot 3 recorded over 2.5 min on June 28, 2000. The rate of spread is about 20–30 m·min^{-1} (0.35–0.5 m·s^{-1}). (A) 15:08:26, spot fire starts from ember rain about 10 m ahead of the flame front. (B) 15:08:40, vapor release from bark on tree boles at about 6 m ahead of the flame front. (C) 15:08:48, ignition of forest floor patches and tree boles about 3–4 m ahead of the flame front. (D) 15:08:52, arrival of continuous flame front. (E) 15:09:02, flaming below canopy. (F) 15:10:57, residual flaming of forest floor, downed woody debris, and tree boles.

The in-fire video footage taken during the International Crown Fire Modelling Experiment (ICFME) vividly showed the significance of saturated, short-range spotting to the fire spread process.

Short-range spotting (i.e., up ~200 m) is very common in high intensity fires

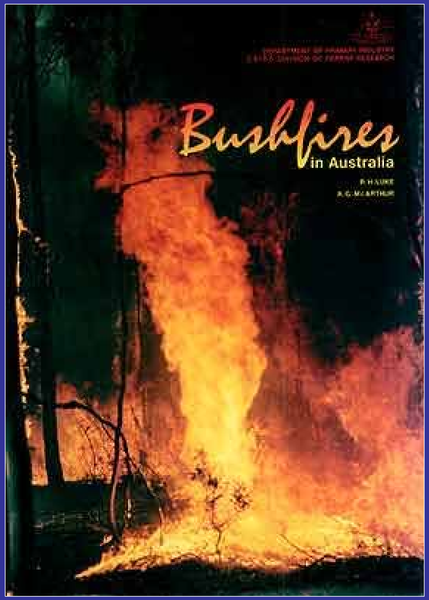
Medium-range spotting (i.e., between ~200 m - 2 km) is less common

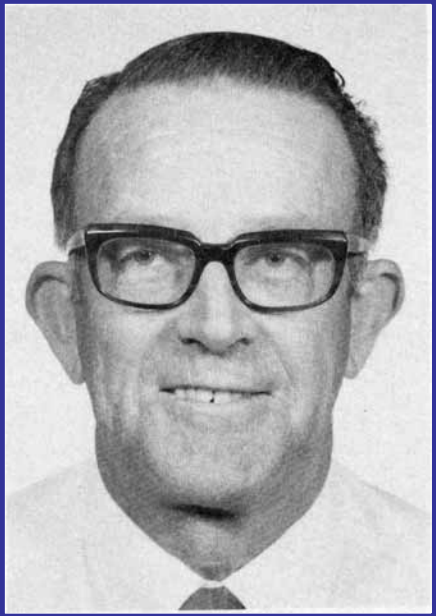
European Research Project on Spotting (1999-2000)



Long-range Spotting Records

On the fires near Gippsland, Victoria in March 1965 "... one well authenticated spot fire started 18 miles [29 km] ahead of the main fire. This is certainly an Australian record." -- A.G. McArthur (1968. The fire control problem and fire research in Australia. Proc. 6th World Forestry Congress.)





Victoria, Australia – February 2009

A New Record??? 21 miles or 34 kilometres?

Three Types of Horizontal Vortices Observed in Wildland Mass and Crown Fires

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(Manuscript received 25 October 1986, in final form 4 May 1987)

ABSTRACT

Observation shows that three types of horizontal vortices may form during intense wildland fires. Two of these vortices are longitudinal relative to the ambient wind and the third is transverse. One of the longitudinal types, a vortex pair, occurs with extreme heat and low to moderate wind speeds. It may be a somewhat common structure on the flanks of intense crown fires when burning is concentrated along the fire's perimeter. The second longitudinal type, a single vortex, occurs with high winds and can dominate the entire fire. The third type, the transverse vortex, occurs on the upstream side of the convection column during intense burning and relatively low winds. These vortices are important because they contribute to fire spread and are a threat to fire fighter safety.

This paper documents field observations of the vortices and supplies supportive meteorological and fuel data. The discussion includes applicable laboratory and conceptual studies in fluid flow and heat transfer that may apply to vortex formation.

1. Introduction

The occurrence of vertical vortices in wildland fires has been well documented as well as mathematically modeled and duplicated in laboratory experiments (e.g., Byram and Martin, 1970; Church et al., 1980; Emori and Saito, 1982). Conversely, the subject of horizontal vortices in wildland fires is relatively unexplored, even though the occurrence of bent over smoke plumes splitting sideways into two counterrotational regions was described and modeled relatively early, by Turner (1960) and Scorer (1968). Applications of these findings were mostly confined to the field of air pollution, especially smokestack emissions. Initial results from the investigation of horizontal vortices in mass and crown fires[1] were restricted to a few papers concentrating on observation (i.e., Schaefer, 1957; Church et al., 1980), and a two-part paper presenting computer simulations by Luti (1980, 1981).

More recently, Haines and Smith (1983) and Smith et al. (1986) conducted wind tunnel simulations of horizontal vortices applicable to wildland fires. These experiments showed that when air flowed parallel to a heated metal ribbon that simulated the flank of a crown fire, a thin, buoyant plume capped with a vortex pair developed above the ribbon along its length. Nonuniform heating and a subsequent temperature gradient, transverse to the mainstream flow, produced the vortex pair, perhaps through interaction with the boundary layer.

These results suggested that longitudinal vortex pairs may be a somewhat common structure on the flanks of intense crown fires when burning is concentrated along the fire's perimeter. Because these vortices can generate large-scale secondary flows capable of transporting firebrands, they are an important consideration in fire fighter safety. The safety factor is of concern because suppression forces find it difficult, if not impossible, to attack the head of a major crown fire. Consequently, suppression forces tend to concentrate their efforts on the fire's flanks, controlling lateral spread.

In addition to the longitudinal vortex pair, two other distinct types of horizontal vortices have been observed in crown and mass fires, one longitudinal, the other transverse. The longitudinal vortex has been reported only once in the literature (Schaefer, 1957), occurring with intense burning and high winds.

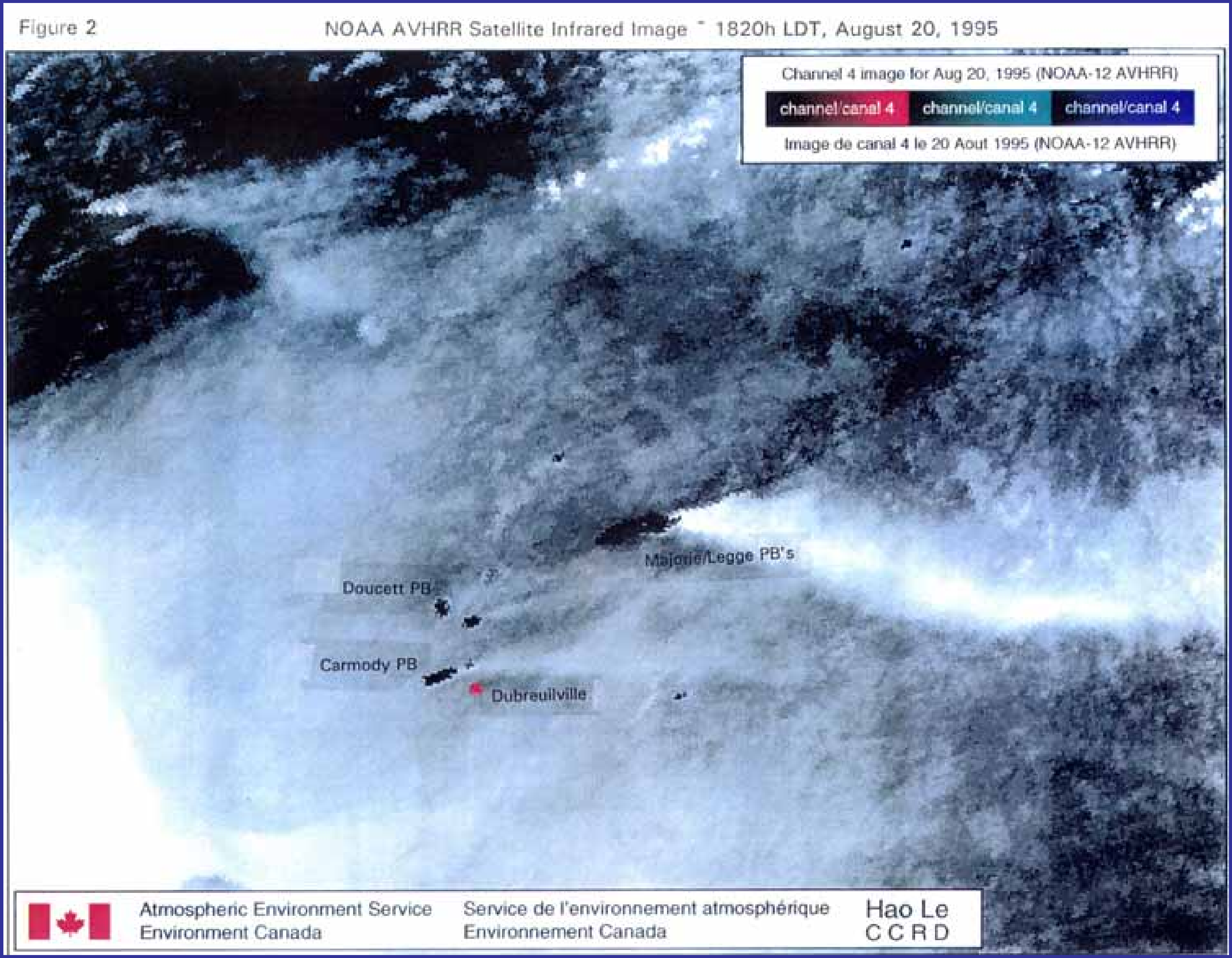
The transverse horizontal vortex consists of a series of rapidly moving vortices that give the appearance of "climbing" the upstream side of the convection column. As with the vortex pair, the transverse type seems to occur during low ambient wind speeds and intense

[1] Crown fires advance from top to top of trees or shrubs. Although they may appear independent of surface fires, they are usually linked with them. Crown fires are most often a phenomenon of conifer forests but also occur in other cover types, principally chaparral and eucalyptus forests. The term *mass fire* characterizes those fires displaying extreme behavior when large amounts of fuels burn simultaneously over a wide area.

Haines and Smith (1987) report that the 1976 New Miner Fire in central Wisconsin, burning in jack pine stands, produced spot fires up to 4 km.

Spot fire distance of ~5 km reported during 2003 fire season in British Columbia

Brian Stocks (CFS ON) speculated on a possible spot fire distance of ~7 km resulting from a prescribed fire escape in August 1995

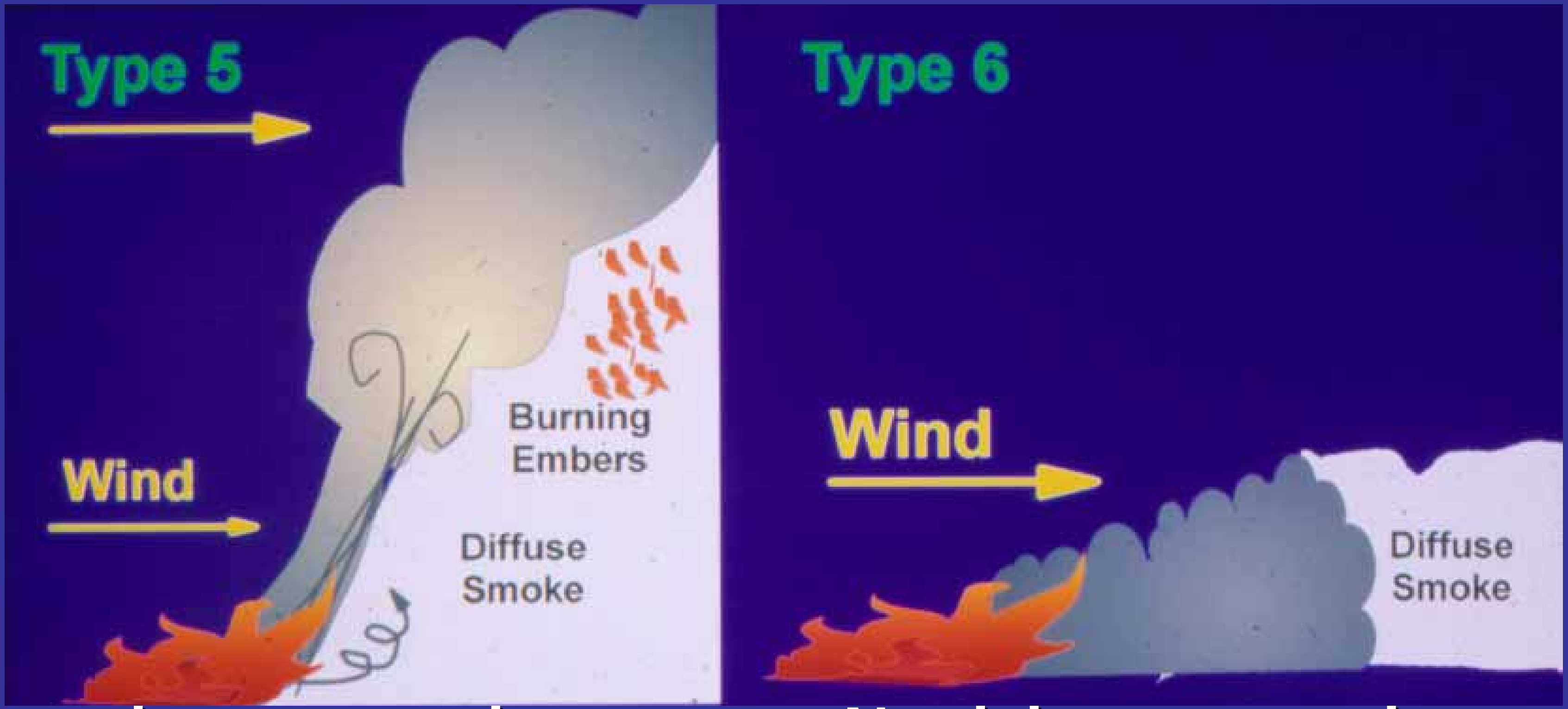


The prediction of spot fire behavior from a mathematical modelling standpoint is a difficult problem because of the large number of factors involved.

Consider for example:

- **Probability of production of firebrands**
- **Wind speeds**
- **Fire intensity**
- **Number of firebrands**
- **Type of firebrands**
- **Fuelbed type is receptive to ignition**
- **Probability of ignition**
- **Weather and fuel conditions favorable for fire spread**

Smoke Pattern/Convection Column Types (Kerr et al. 1971)



- Learning convection column with moderate surface winds that strengthen with height.
- Rapid, erratic spread with both short- and long-distance spotting

- No rising convection column under strong surface winds.
- Very rapid spread driven by combined fire and wind energy; frequent close-in spotting.

The prediction of spot fires involves two separate issues:

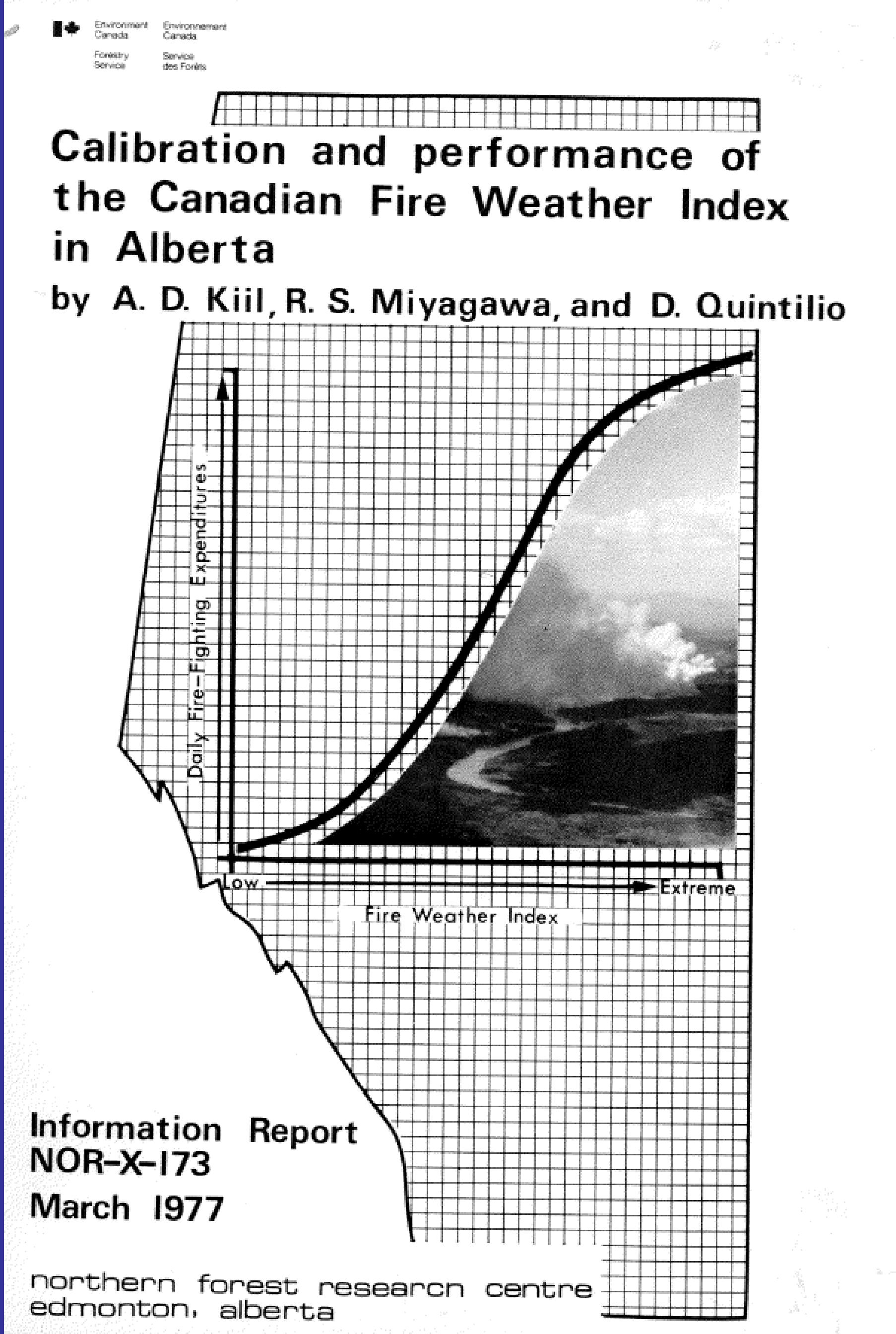
Spotting Distance
(i.e., transport of the firebrand)

Probability of Ignition
(i.e., by the firebrand)

Prediction or estimation could be accomplished by **past experience**, from **case studies** or **other means of empirical data collection** and/or models.

"Behavior records including rate of spread where made during 33 days of observation on 10 large fires in Oregon and Washington. With one possible exception, most of the spread resulted from wind-carried embers that started spot fires ahead of the main fire. As fuels become drier, volume of fuel greater, or wind stronger, rate of spread by spotting increased. Spot fires ¼-mile **[0.4 kilometres]** *ahead of the main fire were common and in a few cases spot fires suddenly appeared as far as two miles* **[3.2 kilometres]** *ahead of any other visible fire."*

from Annual Report – 1951
Pacific Northwest
Forest and Range Experiment Station
USDA Forest Service


Environment Canada Environnement Canada
Forestry Service Service des Forêts

Calibration and performance of the Canadian Fire Weather Index in Alberta

by A. D. Kiil, R. S. Miyagawa, and D. Quintilio

Information Report
NOR-X-173
March 1977

northern forest research centre
edmonton, alberta

Kiil et al. (1977) reported spotting distances up to about 1.9 km on the 2600 fires that occurred in Alberta between 1965-1969. They found that the average maximum spotting distance was 300 m and occurred when winds exceed 40 km/h.

Bunting and Wright (1974. *Journal of Forestry*)
Texas Prescribed Fires

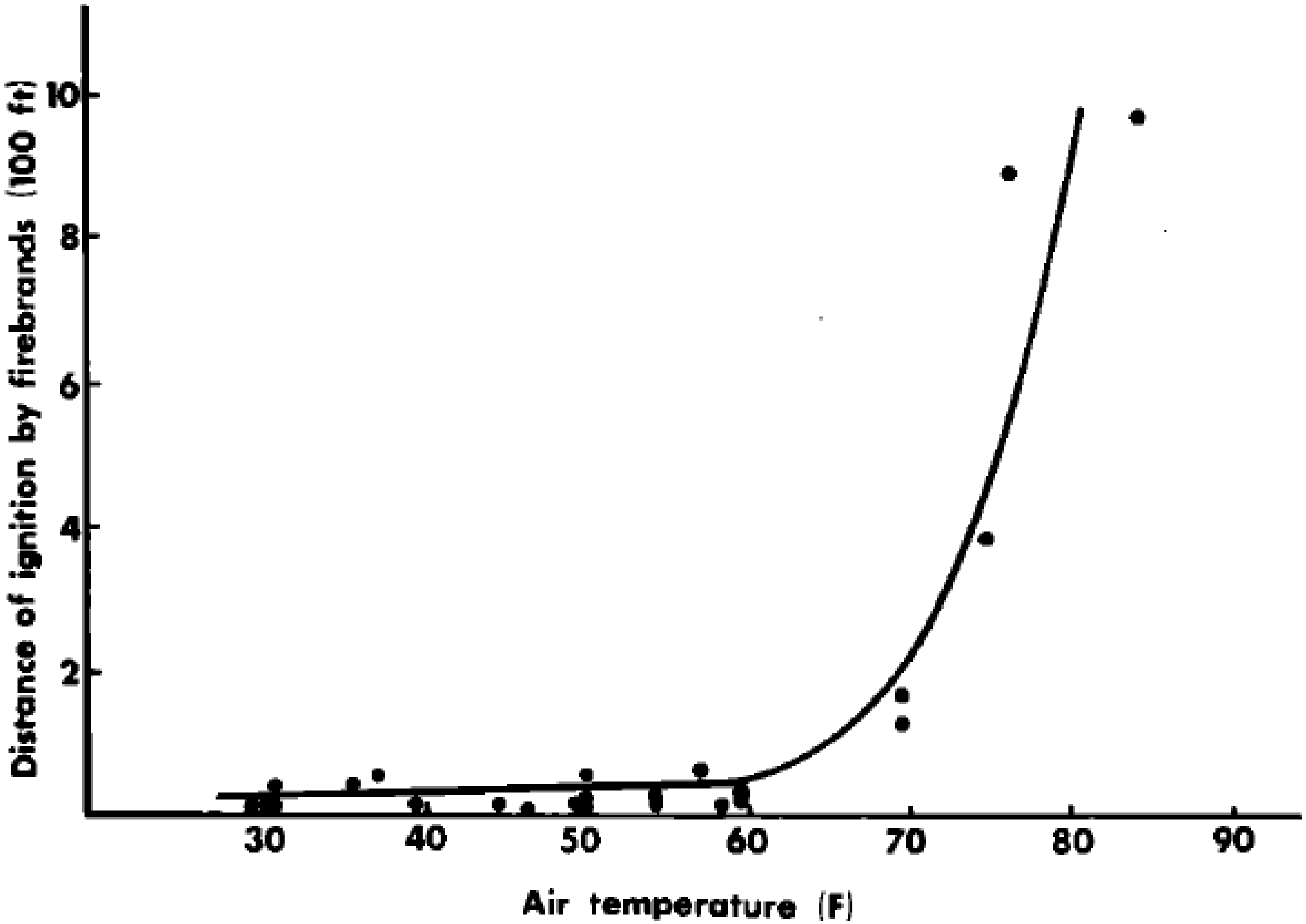
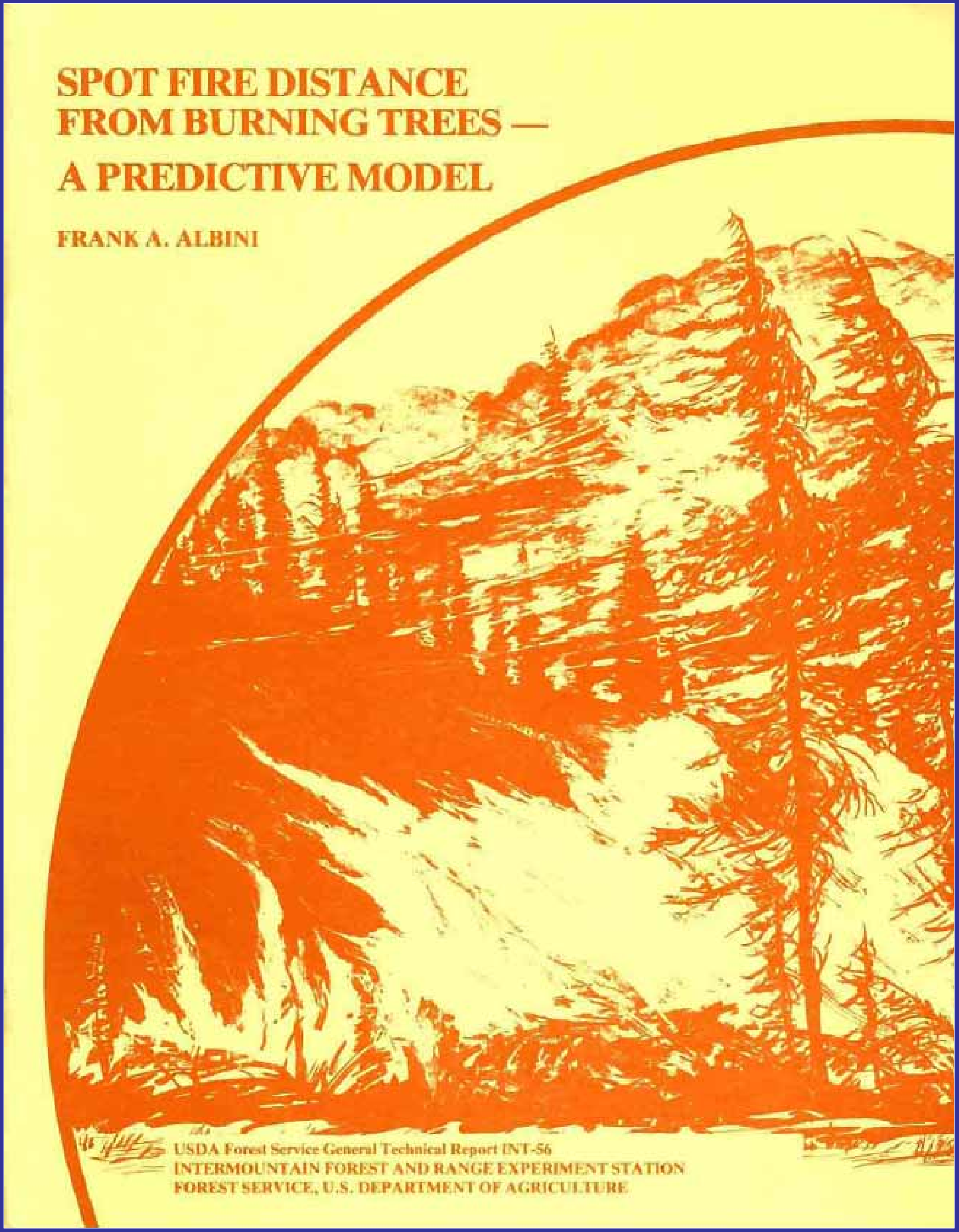


Figure 1. The maximum distance of spot fires from prescribed fires in relation to air temperature. Spot fires within 60 feet of the main fire could have been caused by flaming or nonflaming firebrands.

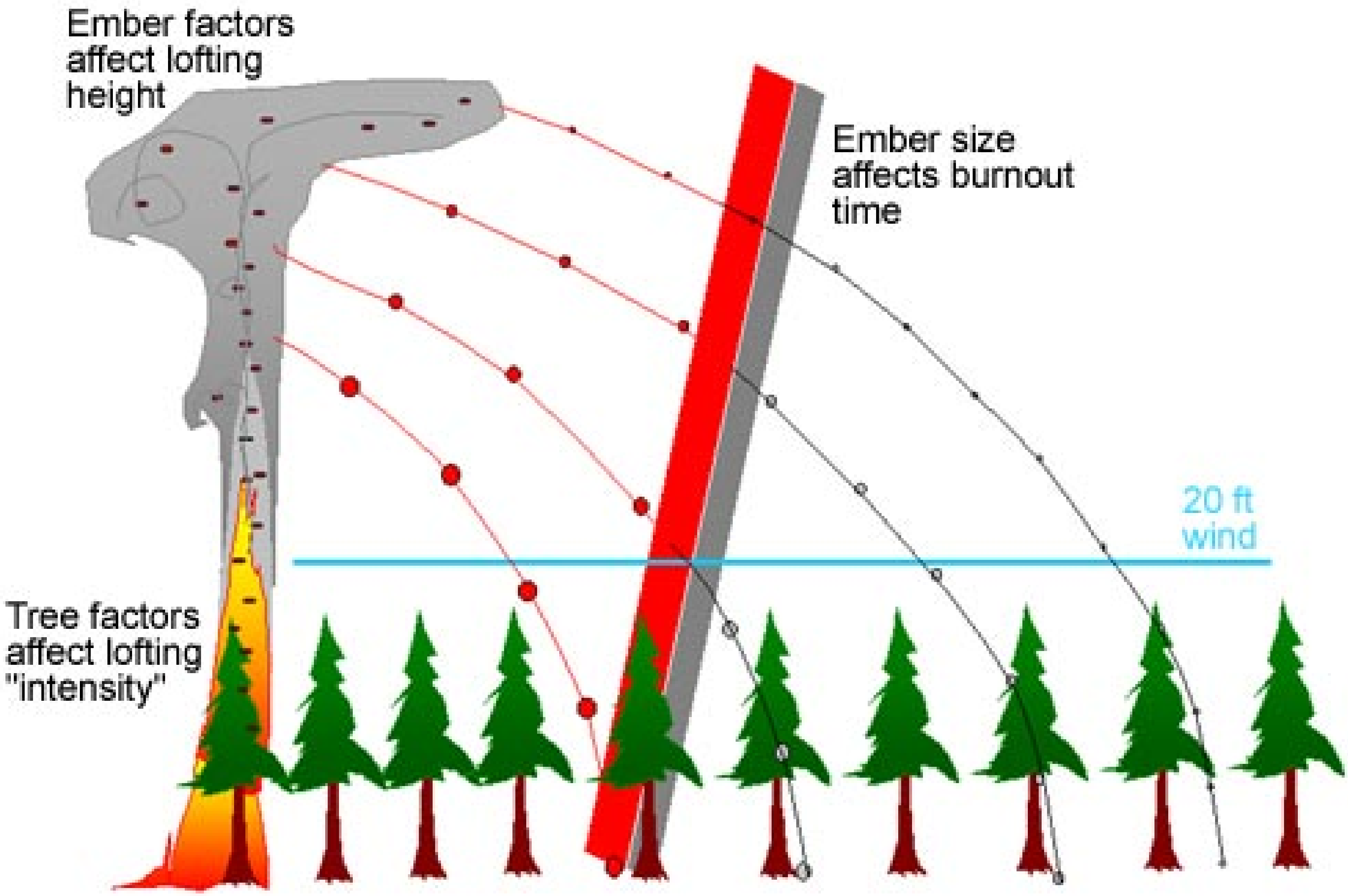
SPOT
FIRE
TRANSPORT

We certainly don’t know enough about all the factors affecting spotting to estimate how many spot fires might occur under certain conditions.

The distance a firebrand might be thrown is considered to be a function of the height a firebrand is injected into the convection column as dictated by the power of the fire and then in turn on the ambient wind speed.



Frank Albini initially developed a model for predicting the maximum spot fire distance from burning trees in 1979.

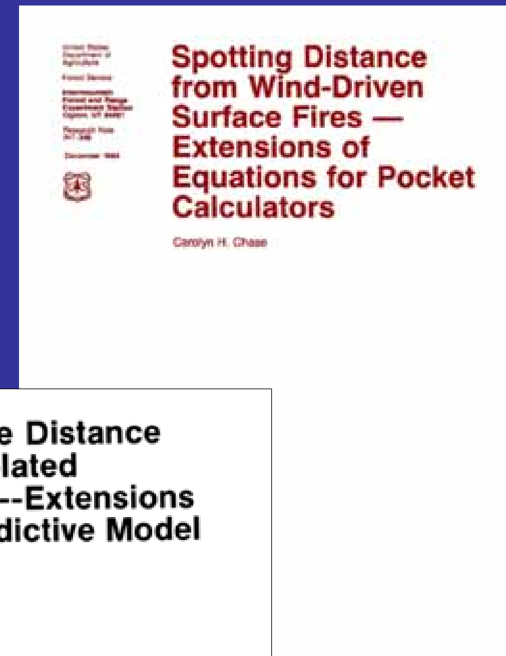


Factors Affecting Spotting

In the 1980s, Albini subsequently extended the general model form to burning piles (e.g., windrows) and wind-driven surface fires in open fuel types (e.g., grass, slash, shrublands) as well as simplified terrain situations.

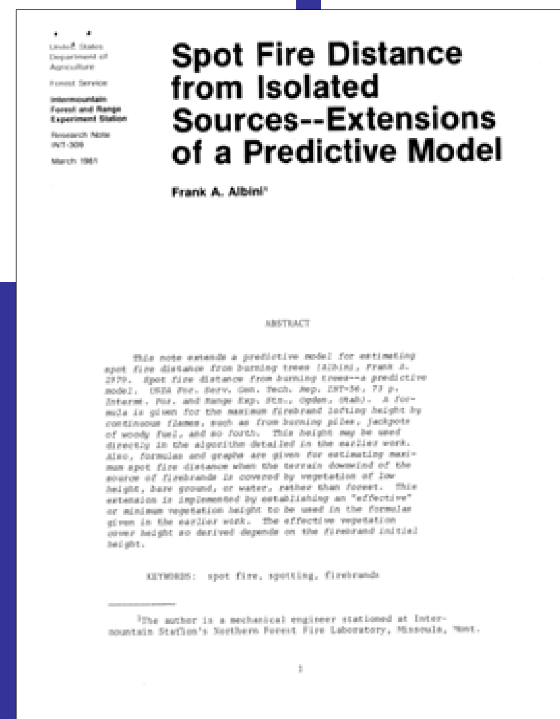
Potential Spotting Distance from Wind-Driven Surface Fires

Frank A. Albini



Spotting Distance from Wind-Driven Surface Fires — Extensions of Equations for Pocket Calculators

Carolyn H. Chase



Spot Fire Distance from Isolated Sources--Extensions of a Predictive Model

Frank A. Albini[1]

ABSTRACT

This note extends a predictive model for estimating spot fire distance from burning trees (Albini, Frank A. 1979. Spot fire distance from burning trees--a predictive model. USDA For. Serv. Gen. Tech. Rep. INT-56, 73 p. Intermt. For. and Range Exp. Stn., Ogden, Utah). A formula is given for the maximum firebrand lofting height by continuous flames, such as from burning piles, jackpots of woody fuel, and so forth. This height may be used directly in the algorithm detailed in the earlier work. Also, formulas and graphs are given for estimating maximum spot fire distance when the terrain downwind of the source of firebrands is covered by vegetation of low height, bare ground, or water, rather than forest. This extension is implemented by establishing an "effective" or minimum vegetation height to be used in the formulas given in the earlier work. The effective vegetation cover height so derived depends on the firebrand initial height.

KEYWORDS: spot fire, spotting, firebrands

[1]The author is a mechanical engineer stationed at Intermountain Station's Northern Forest Fire Laboratory, Missoula, Mont.

1

The Albini <u>maximum</u> spotting distance models do not include:

1. **The likelihood of firebrand material.**
2. **Availability of optimum firebrand material.**
3. **The probability of spot fire ignition.**
4. **The number of spot fires.**

All of these models are primarily designed for conditions of intermediate fire severity (i.e., perhaps up to 1-3 km).

The Albini models are not applicable to firewhirls.

There has been limited documented evaluation of these models

The following is from Rothermel (1983):

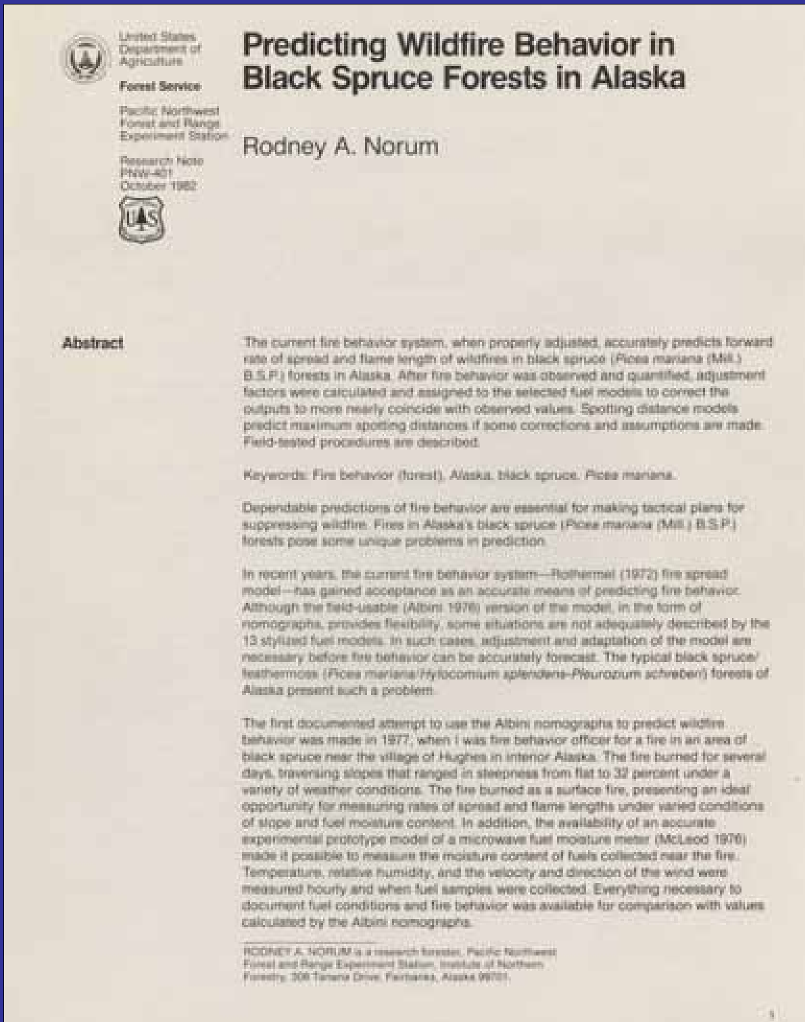
On the Lily Lake Fire (Bear River Ranger District, Wasatch National Forest), frequent intermediate-range spotting from torching lodgepole pine afforded two opportunities to test the spotting model in its new form for the TI–59 calculator (letter by Frank Albini on file at the Northern Forest Fire Laboratory).

Test results for spotting distance (miles):

Case	Model high estimate	Model low estimate	Midrange of model estimate	Reconstruction of actual spotting distance
1	1.32	0.97	1.04	0.76
2	.91	.40	.64	.75

"But they never underpredict".

A Testimonial



United States Department of Agriculture

Forest Service

Pacific Northwest Forest and Range Experiment Station

Research Note PNW-401 October 1982

Predicting Wildfire Behavior in Black Spruce Forests in Alaska

Rodney A. Norum

Abstract

The current fire behavior system, when properly adjusted, accurately predicts forward rate of spread and flame length of wildfires in black spruce (*Picea mariana* (Mill.) B.S.P.) forests in Alaska. After fire behavior was observed and quantified, adjustment factors were calculated and assigned to the selected fuel models to correct the outputs to more nearly coincide with observed values. Spotting distance models predict maximum spotting distances if some corrections and assumptions are made. Field-tested procedures are described.

Keywords: Fire behavior (forest), Alaska, black spruce, *Picea mariana*.

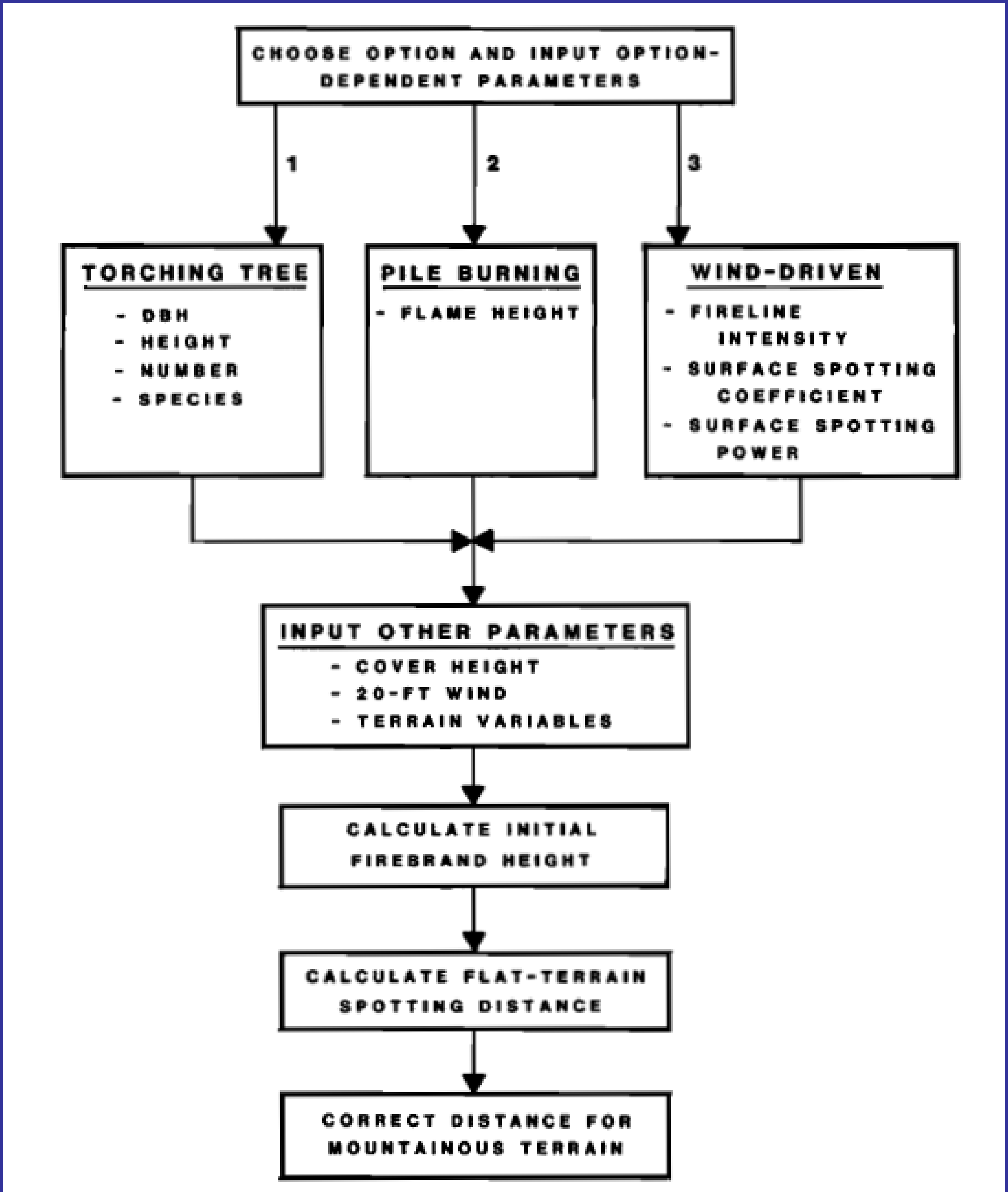
Dependable predictions of fire behavior are essential for making tactical plans for suppressing wildfire. Fires in Alaska's black spruce (*Picea mariana* (Mill.) B.S.P.) forests pose some unique problems in prediction.

In recent years, the current fire behavior system—Rothermel (1972) fire spread model—has gained acceptance as an accurate means of predicting fire behavior. Although the field-usable (Albini 1976) version of the model, in the form of nomographs, provides flexibility, some situations are not adequately described by the 13 stylized fuel models. In such cases, adjustment and adaptation of the model are necessary before fire behavior can be accurately forecast. The typical black spruce/feathermoss (*Picea mariana/Hylocomium splendens–Pleurozium schreberi*) forests of Alaska present such a problem.

The first documented attempt to use the Albini nomographs to predict wildfire behavior was made in 1977, when I was fire behavior officer for a fire in an area of black spruce near the village of Hughes in interior Alaska. The fire burned for several days, traversing slopes that ranged in steepness from flat to 32 percent under a variety of weather conditions. The fire burned as a surface fire, presenting an ideal opportunity for measuring rates of spread and flame lengths under varied conditions of slope and fuel moisture content. In addition, the availability of an accurate experimental prototype model of a microwave fuel moisture meter (McLeod 1976) made it possible to measure the moisture content of fuels collected near the fire. Temperature, relative humidity, and the velocity and direction of the wind were measured hourly and when fuel samples were collected. Everything necessary to document fuel conditions and fire behavior was available for comparison with values calculated by the Albini nomographs.

RODNEY A. NORUM is a research forester, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, 308 Tanana Drive, Fairbanks, Alaska 99701.

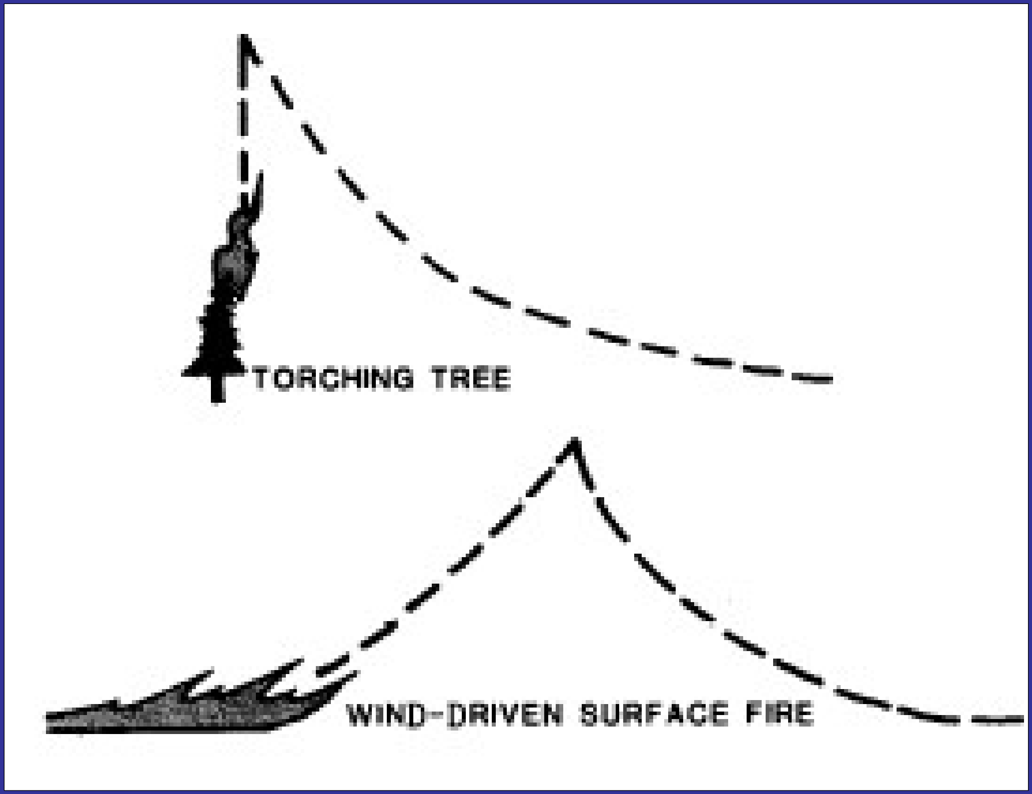
"Although substantiating data are scanty and will likely remain so, I have successfully predicted spot fire distances using Albini's (1979) procedure. I have monitored weather conditions and observed spot fire distances on many occasions during 1977 and the years since. A suitable value for the number of trees [6] burning simultaneously was found by using observed and measured conditions ..."



Albini Maximum Spotting Distance Models

3 Firebrand Sources:

- Torching tree(s)
- Pile Burning
- Wind-driven Surface Fires



A firebrand from a single torching tree or a burning pile is lifted straight up and then carried by the prevailing wind.

This is compared to a firebrand from a wind-driven surface fire, which is carried some distance downwind from the fire-front where the thermal originated before it is carried by the prevailing wind.

Common to all 3 Firebrand Sources

Mean Cover Height

- Range: 0-91 m
- If forest is open, divide by 2, otherwise retain full height
- Vegetation over which the firebrand is travelling

6.1-m Open Wind Speed

- Range: 0-159 km/h
- Decrease 10-m Open Wind by 15% to approximate 6.1-m (20 ft) Open Wind as per Lawson and Armitage (2008).

Ridge/Valley Elevational Difference

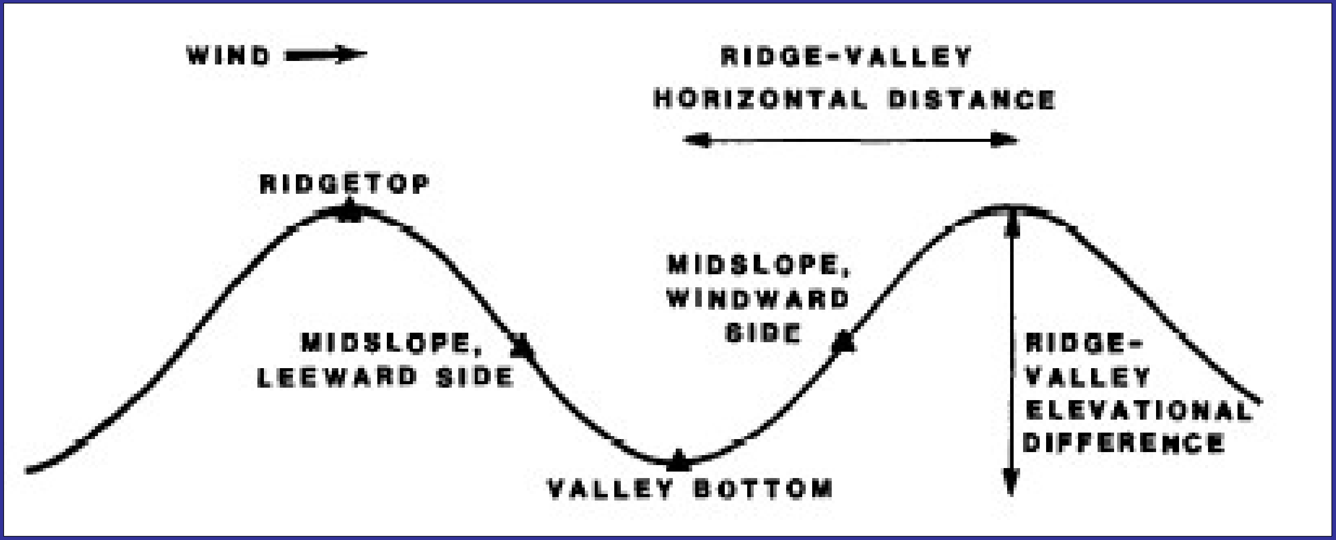
Range: 0-1219 m

Ridge/Valley Horizontal Distance

Range: 0-6 km

Spotting Distance Source Location

(1) Midslope, Windward Side (2) Valley Bottom
(3) Midslope, Leeward Side (4) Ridgetop



For Torching Trees

Species

- Engelmann Spruce
- Douglas-fir & Subalpine Fir
- Hemlock
- Ponderosa Pine & Lodgepole Pine
- White Pine
- Balsam Fir & Grand Fir
- Slash Pine & Longleaf Pine
- Pond Pine & Shortleaf Pine
- Loblolly Pine

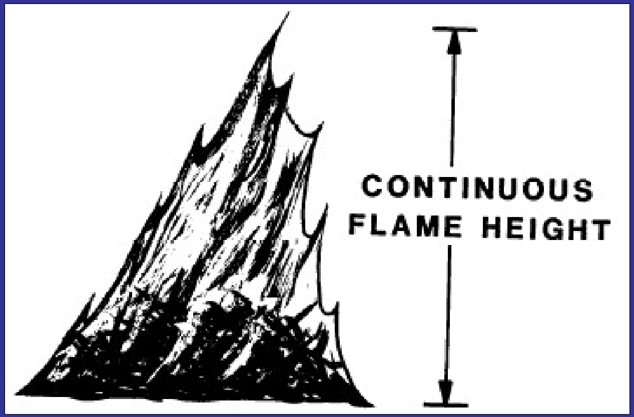
Diameter-at-Breast Height or DBH (range: 13-102 cm)

Tree Height (range: 3-91 m)

Number of Trees Torching (range: 1-30)

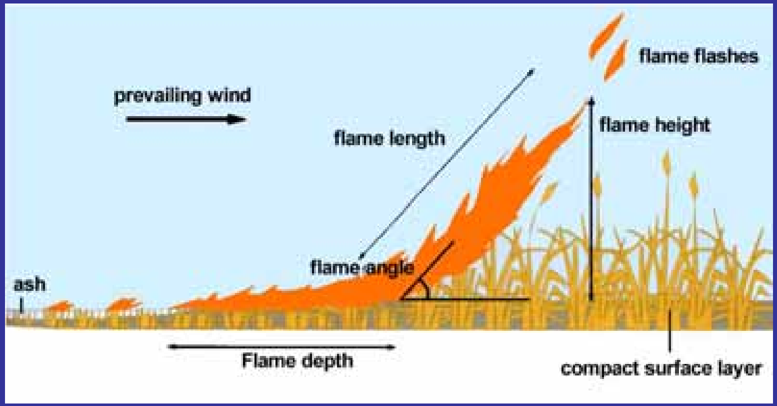
For Burning Piles

Continuous Flame Height
Range: 0.3 - 30 m



For Wind-driven Surface Fires

Flame Length
Range: 0.1 - 30 m



Albini Spotting Model for Active Crown Fires

(applicable to level terrain only)

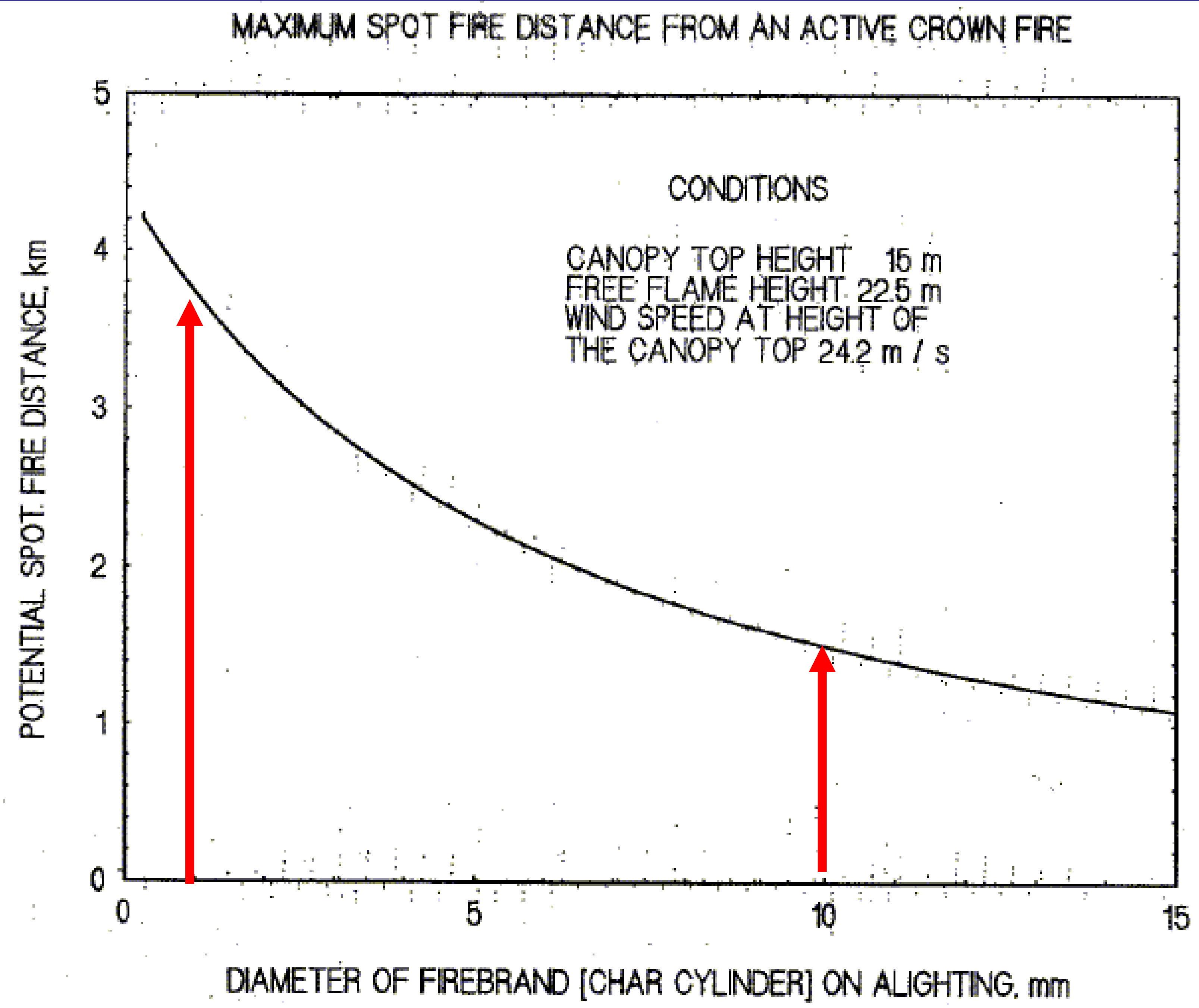
Developed under contract in 1998 based on financial support from several Canadian fire management agencies (coordinator: M.E. Alexander). Effort currently underway to publish in a scientific journal.

Inputs:

- **Average Crown Top Height of Forest Cover**
- **Average Height of Flame Above Canopy Top (observed/estimated or inferred from Fire Intensity)**
- **Mean Wind Speed at Canopy Top or at Some Height in the " Open" (e.g., 10-m open wind) in which case the Measured Height is entered**
- **Minimum Diameter of Char Cylinder Firebrand Reaching the Surface or Size Upon Alighting**
- **Maximum Firebrand Diameter Alighting Diameter**

Maximum Firebrand Diameter Alighting Diameter

A firebrand of 10 mm in diameter upon reaching the surface "… should be expected to start spot fires promptly upon alighting" and that firebrands as small as 1 mm in diameter "… often will not start spot fires [immediately], but they may initiate smouldering combustion in the duff or litter (fermentation layer) on the forest floor, to emerge as flaming fire starts after a considerable delay." -- Frank Albini (1999. Unpublished contract report)


MAXIMUM SPOT FIRE DISTANCE FROM AN ACTIVE CROWN FIRE
CONDITIONS
CANOPY TOP HEIGHT 15 m
FREE FLAME HEIGHT 22.5 m
WIND SPEED AT HEIGHT OF
THE CANOPY TOP 24.2 m / s
POTENTIAL SPOT FIRE DISTANCE, km
0
1
2
3
4
5
0
5
10
15
DIAMETER OF FIREBRAND [CHAR CYLINDER] ON ALIGHTING, mm

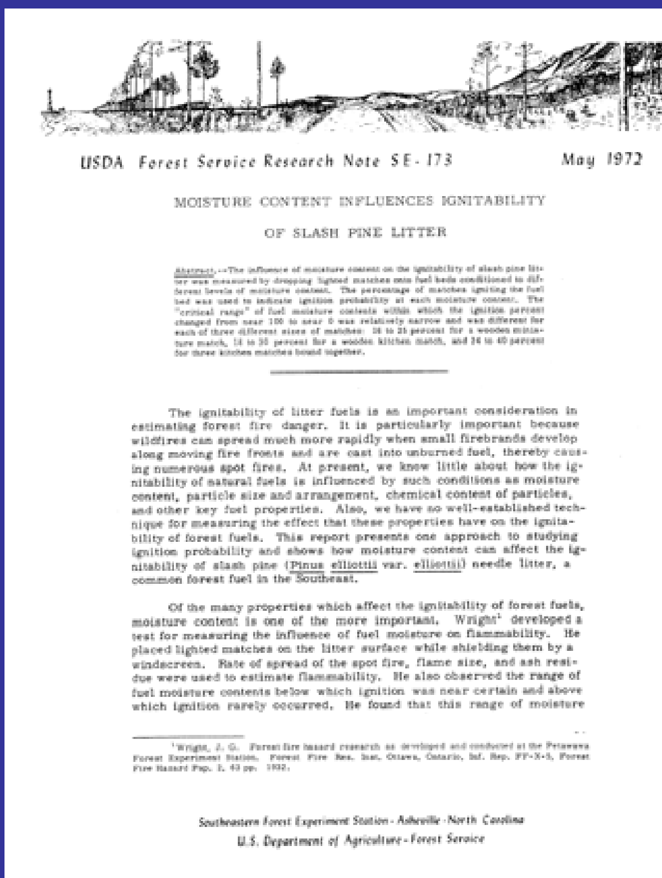
PROBABILTIY
OF
IGNITION

Sole U.S. probability of ignition guideline

Table IV-4.— Probability of ignition (Percent)

Shading	Dry bulb temp	Fine dead fuel moisture (percent) 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Percent	°*F*																
0–10	110 +	100	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10
	100–109	100	90	80	70	60	60	50	40	40	30	30	20	20	20	10	10
	90– 99	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	80– 89	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	70– 79	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	60– 69	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	50– 59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40– 49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30– 39	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
10–50	110 +	100	100	80	70	60	60	50	40	40	30	30	20	20	20	20	10
	100–109	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	90– 99	100	90	80	70	60	50	40	40	30	30	30	20	20	20	10	10
	80– 89	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	70– 79	100	80	70	60	50	50	40	40	30	30	20	20	20	10	10	10
	60– 69	90	80	70	60	50	50	40	30	30	20	20	20	20	10	10	10
	50– 59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40– 49	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	30– 39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
60–90	110 +	100	90	80	70	60	50	50	40	40	30	30	20	20	20	10	10
	100–109	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	90– 99	100	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10
	80– 89	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	70– 79	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	60– 69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50– 59	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	40– 49	90	70	60	50	50	40	30	30	30	20	20	20	10	10	10	10
	30– 39	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
100	110 +	100	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10
	100–109	100	90	80	70	60	50	40	40	30	30	20	20	20	20	10	10
	90– 99	100	80	70	60	60	50	40	40	30	30	20	20	20	10	10	10
	80– 89	90	80	70	60	50	50	40	30	30	30	20	20	20	10	10	10
	70– 79	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	60– 69	90	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10
	50– 59	90	70	60	60	50	40	40	30	30	20	20	20	10	10	10	10
	40– 49	80	70	60	50	50	40	30	30	20	20	20	10	10	10	10	10
	30– 39	80	70	60	50	40	40	30	30	20	20	20	10	10	10	10	10

Probability of Spot Fire Ignition Laboratory Study by Blackmarr (1972) at the Southern Forest Fire Laboratory, Macon, Georgia



USDA Forest Service Research Note SE-173 May 1972

MOISTURE CONTENT INFLUENCES IGNITABILITY

OF SLASH PINE LITTER

Abstract.--The influence of moisture content on the ignitability of slash pine litter was measured by dropping lighted matches onto fuel beds conditioned to different levels of moisture content. The percentage of matches igniting the fuel bed was used to indicate ignition probability at each moisture content. The "critical range" of fuel moisture contents within which the ignition percent changed from near 100 to near 0 was relatively narrow and was different for each of three different sizes of matches: 16 to 25 percent for a wooden miniature match, 14 to 30 percent for a wooden kitchen match, and 24 to 40 percent for three kitchen matches bound together.

The ignitability of litter fuels is an important consideration in estimating forest fire danger. It is particularly important because wildfires can spread much more rapidly when small firebrands develop along moving fire fronts and are cast into unburned fuel, thereby causing numerous spot fires. At present, we know little about how the ignitability of natural fuels is influenced by such conditions as moisture content, particle size and arrangement, chemical content of particles, and other key fuel properties. Also, we have no well-established technique for measuring the effect that these properties have on the ignitability of forest fuels. This report presents one approach to studying ignition probability and shows how moisture content can affect the ignitability of slash pine (Pinus elliottii var. elliottii) needle litter, a common forest fuel in the Southeast.

Of the many properties which affect the ignitability of forest fuels, moisture content is one of the more important. Wright[1] developed a test for measuring the influence of fuel moisture on flammability. He placed lighted matches on the litter surface while shielding them by a windscreen. Rate of spread of the spot fire, flame size, and ash residue were used to estimate flammability. He also observed the range of fuel moisture contents below which ignition was near certain and above which ignition rarely occurred. He found that this range of moisture

[1] Wright, J. G. Forest fire hazard research as developed and conducted at the Petawawa Forest Experiment Station. Forest Fire Res. Inst. Ottawa, Ontario, Inf. Rep. FF-X-5, Forest Fire Hazard Pap. 2. 40 pp. 1932.

Southeastern Forest Experiment Station - Asheville - North Carolina
U.S. Department of Agriculture - Forest Service

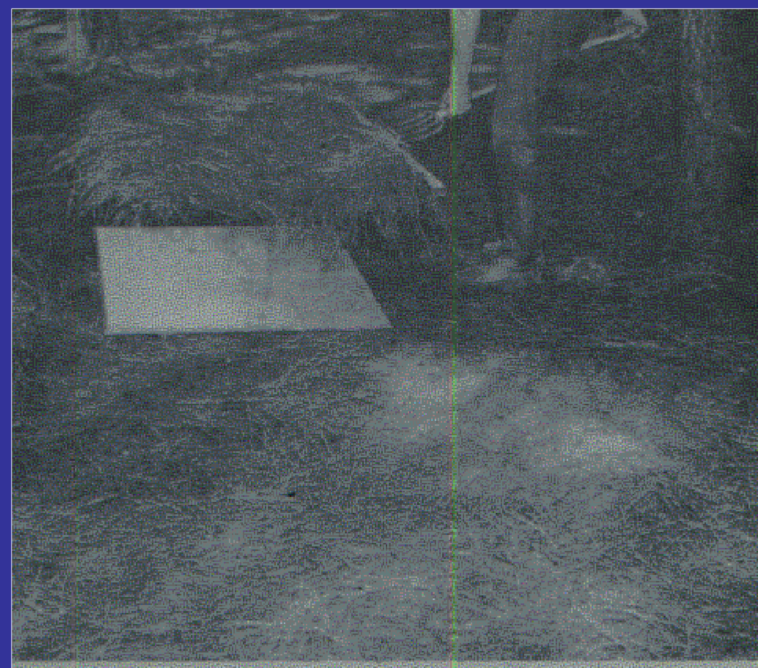
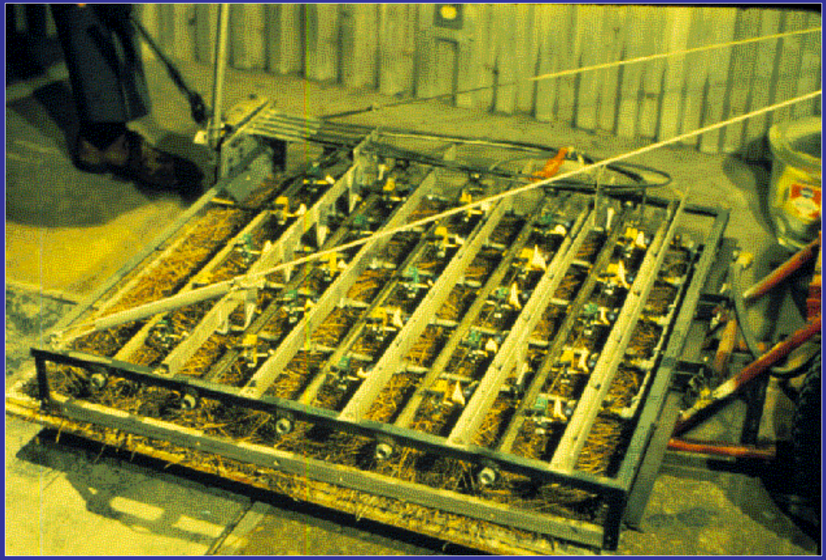
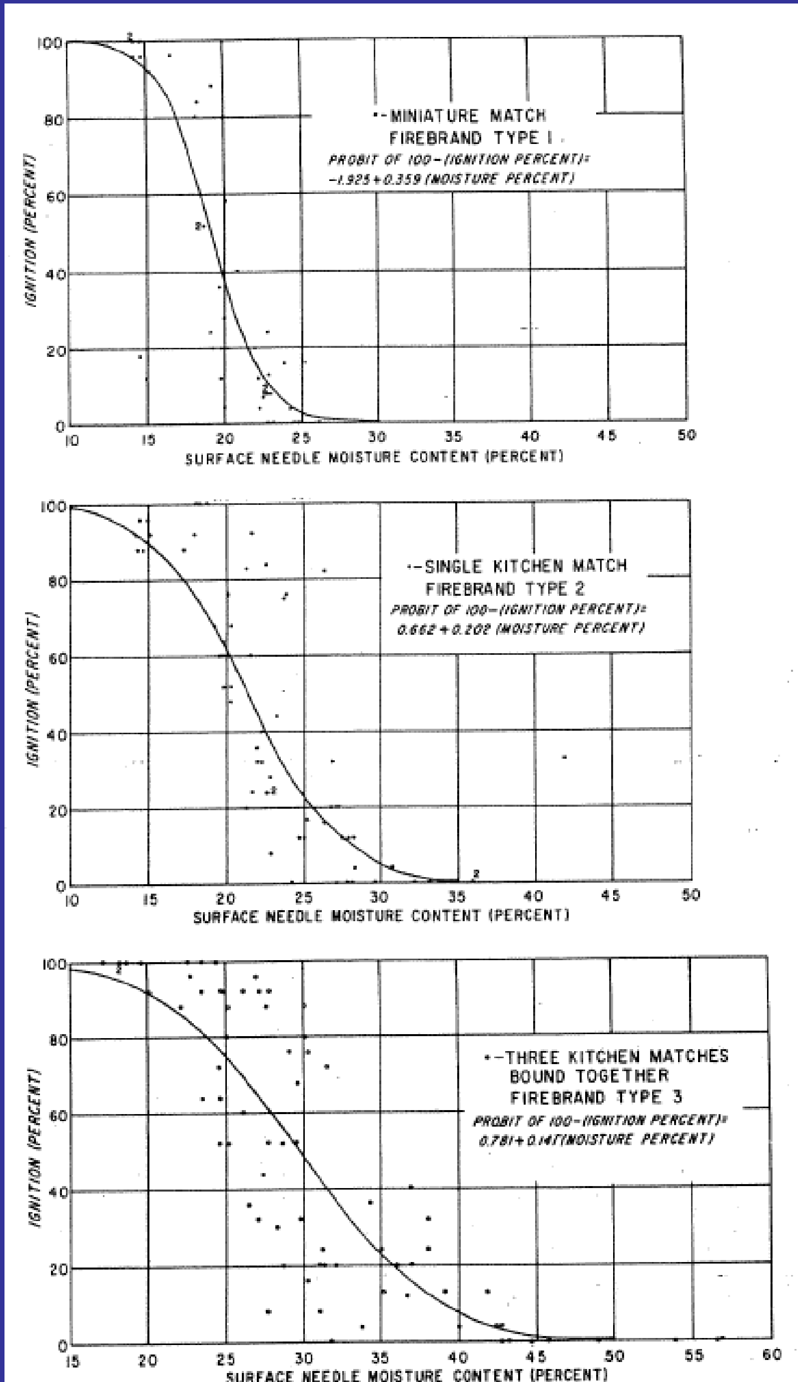


Figure 2.--Natural fuel beds were collected from a slash pine plantation by removing the entire litter layer from a 36- by 36-inch area and placing it on an aluminum screen.

Slash pine needle litter fuelbeds

Blackmarr (1972) Ignition Probability Study





Single miniature match
50% P_{ig} – 19% MC

Single kitchen match
50% P_{ig} – 22% MC

3 kitchen matches
50% P_{ig} – 30% MC

Blackmarr (1972) study illustrates not only the importance of moisture content on ignition probability but the significance of firebrand size.

CFS 2-minute Test Fire Program – 1930-1961

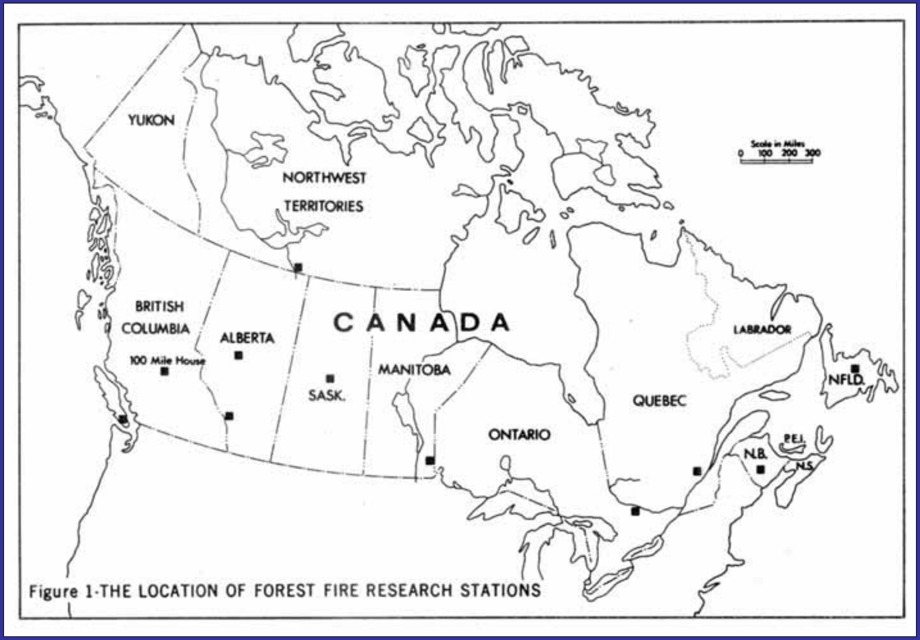


Figure 1-THE LOCATION OF FOREST FIRE RESEARCH STATIONS

CFS 2-min test fire study near Prince George, BC carried out in the mid to late 60s

Probability of Sustained Flaming Ignition

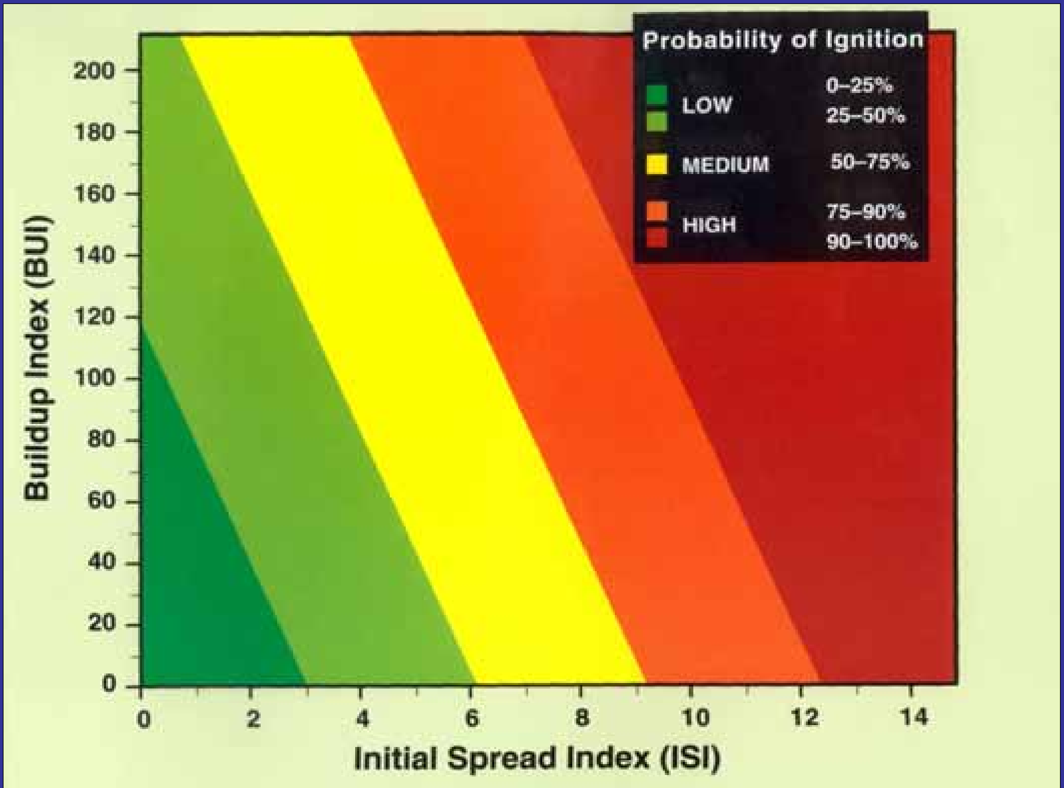


Table S1.2

"Moist" lodgepole pine forest type - probability of sustained igniton (%) and ignition class.

	Buildup Index (BUI)							
ISI	0–20	21–30	31–40	41–60	61–80	81–120	121–160	161–200
0.5	13	15	16	18	21	26	33	41
1	15	17	19	21	24	29	37	46
1.5	18	20	21	24	27	33	41	50
2	20	23	24	27	31	37	45	54
2.5	23	26	28	31	34	41	50	59
3	27	29	31	34	38	45	54	63
4	34	37	39	43	47	54	62	70
5	42	46	48	51	56	62	70	77
6	51	54	57	60	64	70	77	83
7	60	63	65	68	72	77	83	87
8	68	70	72	75	78	82	87	91
9	75	77	79	81	84	87	91	93
10	81	83	84	86	88	90	93	95
11	86	87	88	90	91	93	95	96
12	89	91	91	92	94	95	96	97
13	92	93	94	94	95	96	97	98
14	94	95	95	96	97	97	98	99
15	96	96	97	97	98	98	99	99
18	99	99	99	99	99	99	100	100

Ignition Class	Probability %
LOW	0-49
MEDIUM	50-75
HIGH	76-100

Lawson and Dalrymple (1996)

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Modelling the probability of sustained flaming: predictive value of fire weather index components compared with observations of site weather and fuel moisture conditions

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Abstract. We investigated the likelihood that short-duration sustained flaming would develop in forest ground fuels that had direct contact with a small and short-lived flame source. Data from 1027 small-scale experimental test fires conducted in field trials at six sites in British Columbia and the North-West Territories between 1958 and 1961 were used to develop logistic regression models for ten fuel categories that represent unique combinations of forest cover, ground fuel type, and in some cases, season. Separate models were developed using two subsets of independent variables: (1) weather variables and fuel moisture measurements taken at the site of the test fire; and (2) Canadian Fire Weather Index (FWI) system components calculated from weather observations recorded at a nearby station. Results indicated that models developed with FWI system components were as effective as models developed with site variables at predicting the probability of short-duration sustained flaming in most fuel categories. FWI system components were not useful for predicting sustained flaming in spring grass fuels and had limited usefulness for modelling the probability of sustained flaming in aspen leaf ground fuels during summer conditions. For all other fuel categories, FWI system components were highly effective substitutes for site variables for modelling the probability of sustained flaming.

Additional keywords: Canada, fire behaviour, fire danger, fire hazard, logistic regression, probability of ignition.

Introduction

The conditions under which sustained flaming develops in forest ground fuels exposed to an ignition source are both varied and complex. Sustained flaming can be considered the outcome of a successful fire ignition and encompasses three factors identified by Anderson (1970) as determinants of flammability: ignitability, sustainability and combustibility. Ignitability refers to the ease of ignition. Combustibility is the post-ignition rate of burning, and sustainability refers to how well the fuel continues to burn, or combustion stability. Forest fuel receptivity to ignition will depend on the type of fuel exposed to the ignition source, the fuel moisture content, the characteristics of the ignition source, and the influence of micro-site variables such as air flow, wind (Brown and Davis 1973) and fuel shading (Lin 1999). Fuel-specific assessments of the likelihood of sustained flaming are important for understanding the mechanisms that lead to the initiation and spread of forest fires and for predicting forest susceptibility to fire in a given geographical location and time period, which is important for both research and operational fire management applications.

Daily, hourly, and instantaneous fluctuations in fire susceptibility can result from changes in weather variables that influence fire behaviour and fuel moisture content. Seasonal variations are associated with long-term weather trends and phenological changes in vegetation. Fire danger rating systems, like the Canadian Fire Weather Index (FWI) system (Van Wagner 1987), were developed to provide daily and hourly ratings of fire susceptibility. Calculated for individual weather stations from a set of weather observations, the FWI system provides nationally consistent and readily available ratings of fire susceptibility. Although fuel moisture codes of the FWI system were developed to be representative of fuels in a mature, closed canopy jack pine (*Pinus banksiana* Lamb.) or lodgepole pine (*Pinus contorta* Dougl.) stand, in practice FWI system components are not regarded as fuel-specific indicators. FWI system components are considered generalisations of fuel moisture and fire susceptibility applicable to a wide variety of stands and are based on fundamental relationships between weather variables, fuel moisture conditions, and observed fire behaviour.

Statistical models have been used to investigate these fundamental relationships using either historical data of observed wildfire events or experimental fires ignited in laboratory or field settings. Models based on historical data have been used to describe landscape level relationships among weather variables, fuel or vegetation characteristics, and patterns of observed fire events (e.g. Wotton and Martell 2005; Krawchuk *et al.* 2006). Socioeconomic variables and fire management activities have also been combined with ecological variables to model variability in fire events across large areas (e.g. Mercer and Prestemon 2005). Effectiveness of fire danger rating indices at predicting

 10.1071/WF06072 1049-8001/07/020161

Latest analysis of 2-min test fire data and models for predicting the probability of sustained flaming combustion

Weir (2004. *Fire Management Today*)
Oklahoma Prescribed Fires

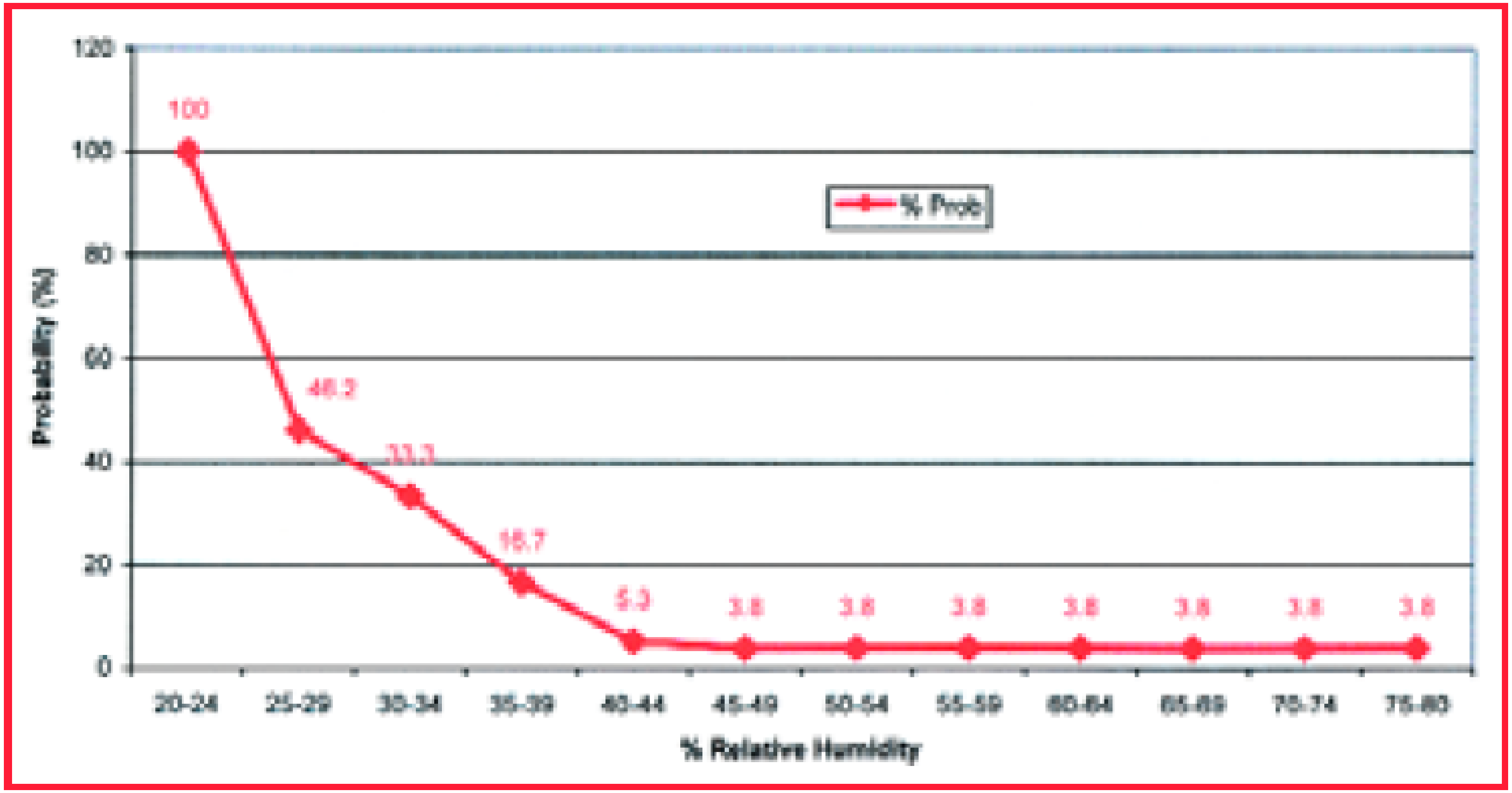


Figure 2—*The probability of spot fires as a function of relative humidity, based on 99 prescribed fires conducted across Oklahoma from 1996 to 2002.*

Suggestions & Closing Remarks

Spotting Workshop held in Edmonton in 2004 to discuss spotting considerations in *Prometheus*

foothills
MODEL FOREST
research growing into practice

Chisholm/Dogrib Fire Research Initiative
Quicknote 6

November 2004 By: M.E. Alexander, C. Tymstra & K.W. Frederick

Incorporating breaching and spotting considerations into *PROMETHEUS* – the Canadian wildland fire growth model

PROMETHEUS is a spatially explicit deterministic model that simulates fire growth based on fuel type information, fire weather and fire danger data, and topographic characteristics. This is accomplished largely by utilizing the two major modules of the Canadian Forest Fire Danger Rating System, namely the Canadian Forest Fire Weather Index (FWI) System and the Canadian Forest Fire Behaviour Prediction (FBP) System. The wildland fire environments to which *PROMETHEUS* is applied include both natural (e.g., water bodies, rock outcrops, particular fuel types, recent burns) and man-made barriers (e.g., roads, plowed fields, irrigated pastures, planned firebreaks) to fire spread. These discontinuities in the fuel type mosaic are treated as "non fuel" in the model (i.e., unburnable).

Barriers to fire spread either: (1) stop fire growth; (2) hinder fire growth (i.e., fire spreads laterally around an unburnable patch of ground); or (3) temporarily halt or delay maximum fire growth potential (e.g., the development of new, discrete ignition points across a wide water body as result of "mass transport" need time to reach their equilibrium rate of fire spread). Models like *PROMETHEUS* must be capable of dealing with these barriers to fire spread in order to realistically simulate the growth of free-burning wildland fires. *PROMETHEUS* presently handles the first two cases except for roads and narrow water bodies. The breaching or crossing of a barrier can occur by one, all or any combination of the following mechanisms:

- Spotting (i.e., sparks or embers are carried by the wind and start new fires beyond the zone of direct ignition by the main advancing fire front)
- Thermal radiation, either by pilot (firebrand) or spontaneous ignition
- Direct flame contact by the fire's leading edge
- Fire whirls

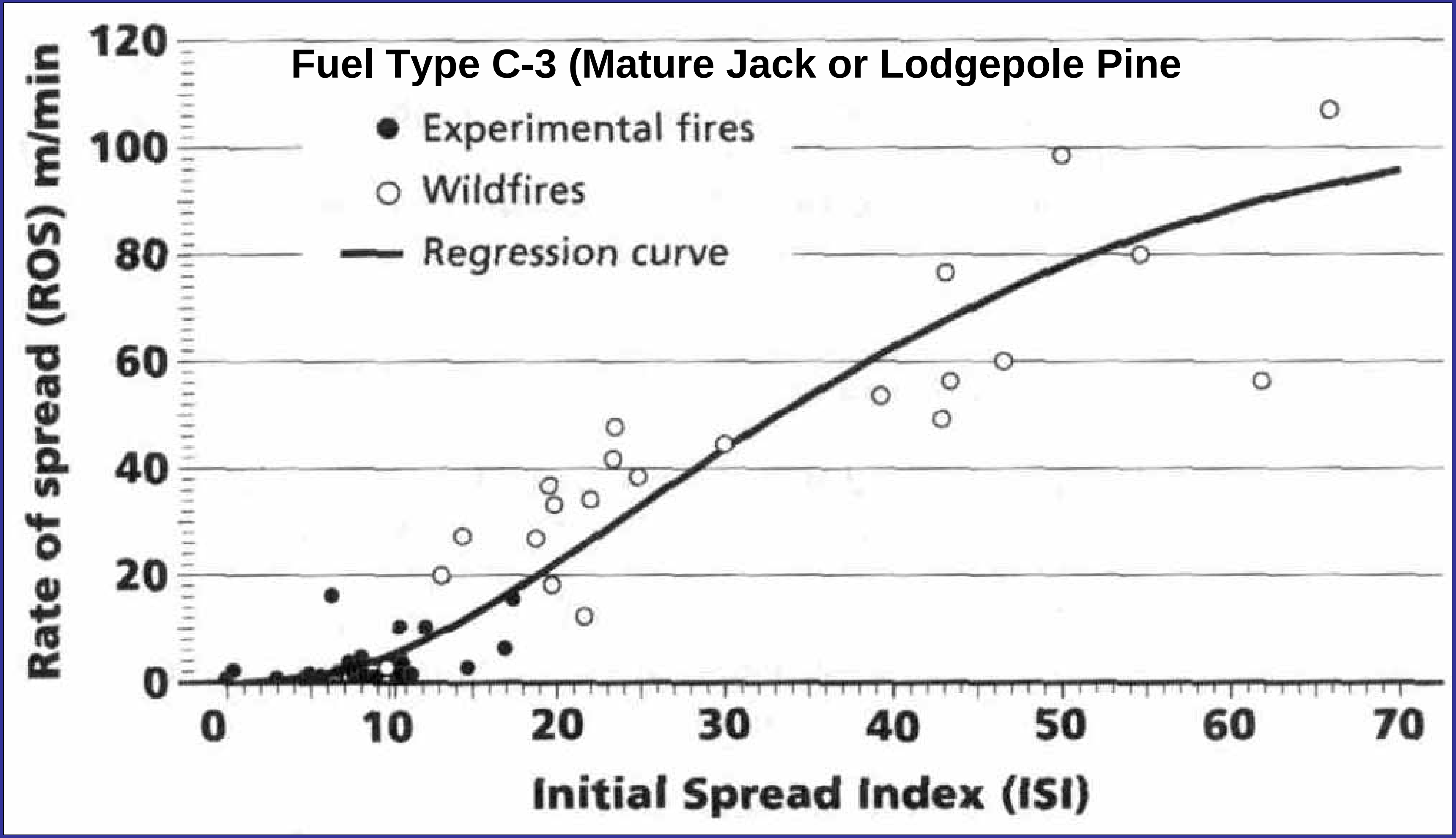
Whether this happens or not depends on a multitude of factors but principally on the barrier or break width, the level of fire behaviour (i.e., fire intensity, flame size), characteristics of the fuel type (i.e., firebrand material), size of the fire, associated burning conditions (e.g., wind velocity, air temperature, relative humidity, fuel dryness), and terrain features. The mathematical prediction of fire whirl development is beyond the current state-of-the-art with respect to wildland fire growth modeling, although a good deal of general qualitative information exists from operational experiences and experimental fire studies. In regards to the other three breaching mechanisms, varying degrees of predictability exist as a result of observations and measurements of wildfires, prescribed fires and experimental fires, and theoretical work.

The effect of spotting on a fire's overall rate of advance is implicitly accounted for in each of the FBP System fuel type rate of spread functions used in *PROMETHEUS* as a result of the empirical nature of their development. What these sub-models do not do is predict spot fire distances or their distribution/density. High-density, short-range spotting (say 0.1-100 m) is a common feature of many free-burning wildland fires, especially during "critically dry" fuel conditions (e.g., once the Fine Fuel Moisture Code (FFMC) component of the FWI System exceeds ~90). In the case of surface fires, significant spotting begins to occur once frontal intensities exceed ~1500-2000 kW/m. Low-density, intermediate- to medium-range spotting (~100-1000 m) such as observed on the Chisholm and Dogrib fires during the 2001 fire season in Alberta is a common occurrence with high-intensity crown fires. Long-range spotting (e.g., 1.0-10 km) occurs much less frequently. In continuous fuels, short- and medium-range spot fires are normally overrun by the main advancing fire front before they are able to developed sufficiently to increase the rate of advance.

The prediction of spot fires in terms of barrier breaching is an inherently difficult problem in part because two distinct phases are involved in the spotting phenomenon, the first being the transport distance of a "live" firebrand downwind of the flaming source and secondly whether the surface fuels are receptive to ignition once a firebrand has landed. Mathematical models have been developed by Dr. Frank A. Albini to predict the maximum distance a firebrand will be transported from four different sources: single or group tree torching, burning piles of woody debris, wind-driven surface fires in open fuel types (e.g., grass, shrubs, slash), and active crown fires. The latter model is deemed applicable only to flat, uniformly forested terrain whereas the other three models have been developed to consider some simplifications of complex terrain. These

For more information on the subject covered in this Quicknote, please contact Dr. Marty Alexander, RPF (Marty.Alexander@gov.ab.ca), Senior Researcher, FERIC Wildland Fire Operations Research Group, at (780) 865-8200 and/or visit the *PROMETHEUS* website (http://www.firegrowthmodel.com/index.cfm).

Spotting is implicitly accounted for the FBP System rate of spread models.



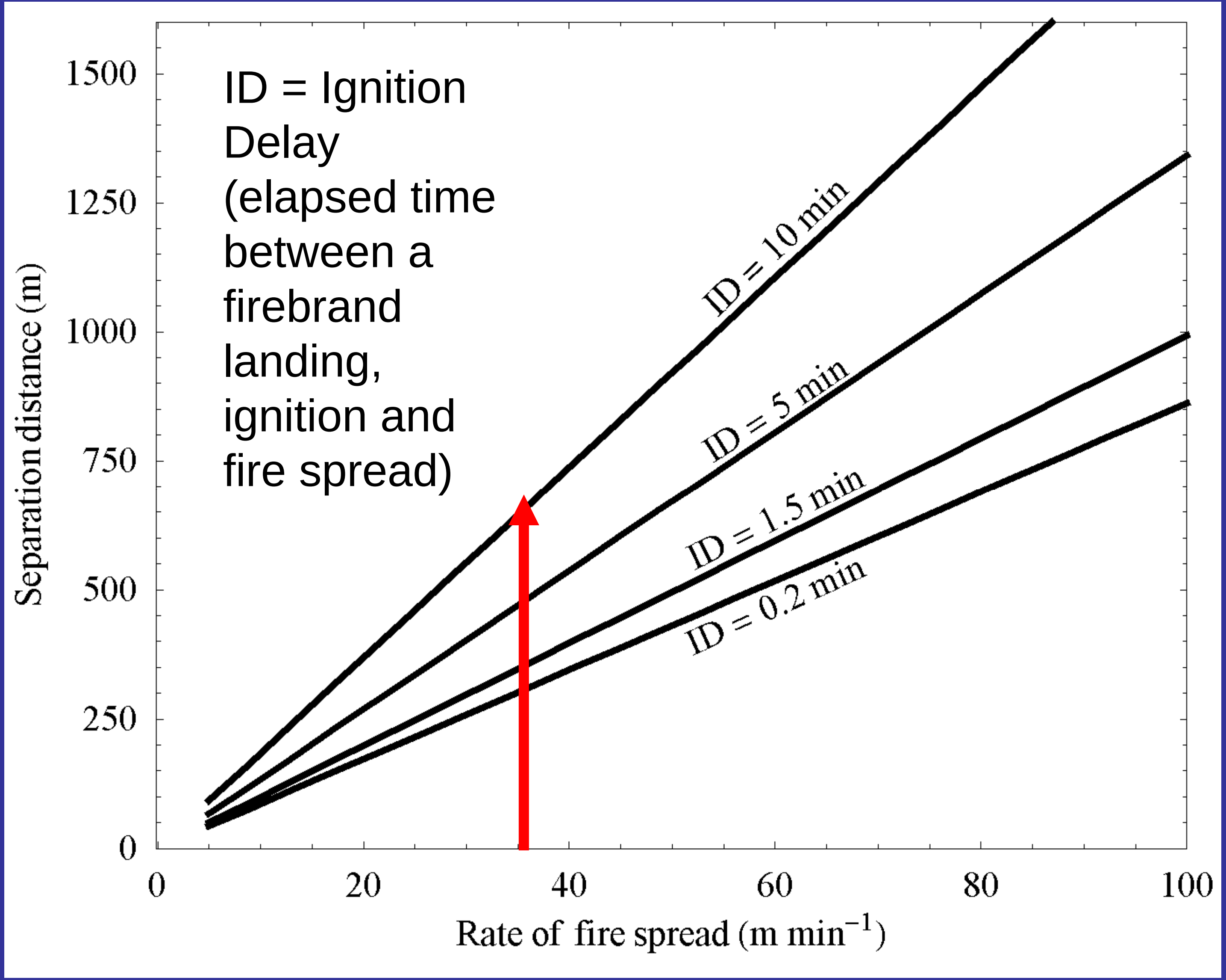
Looking for a spotting effect on fire spread rate is not seen as fruitful.

Most forest or wildland fires start from a point.

Porter Lake Experimental Point Source Fire P2

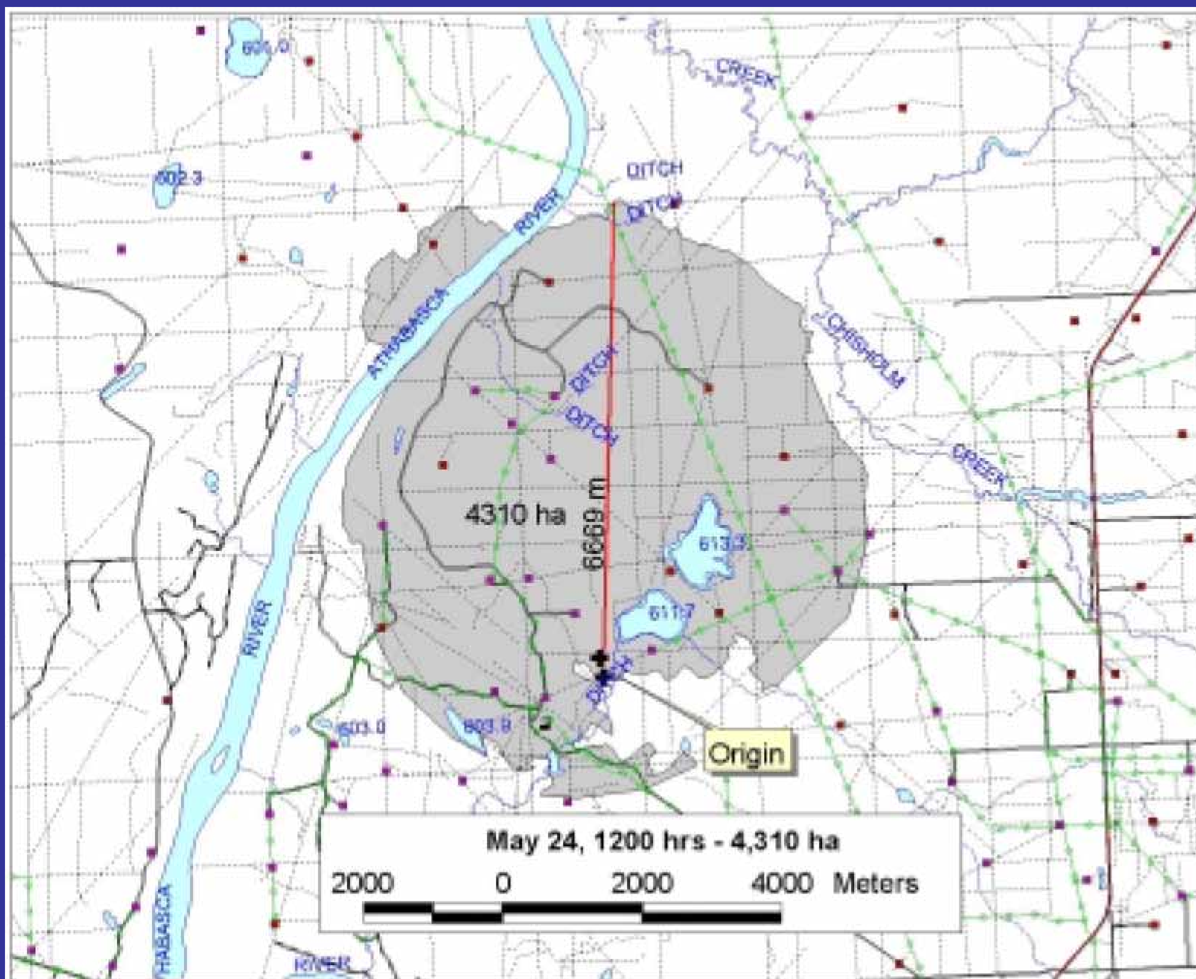
Porter Lake Experimental Point Source Fire P2

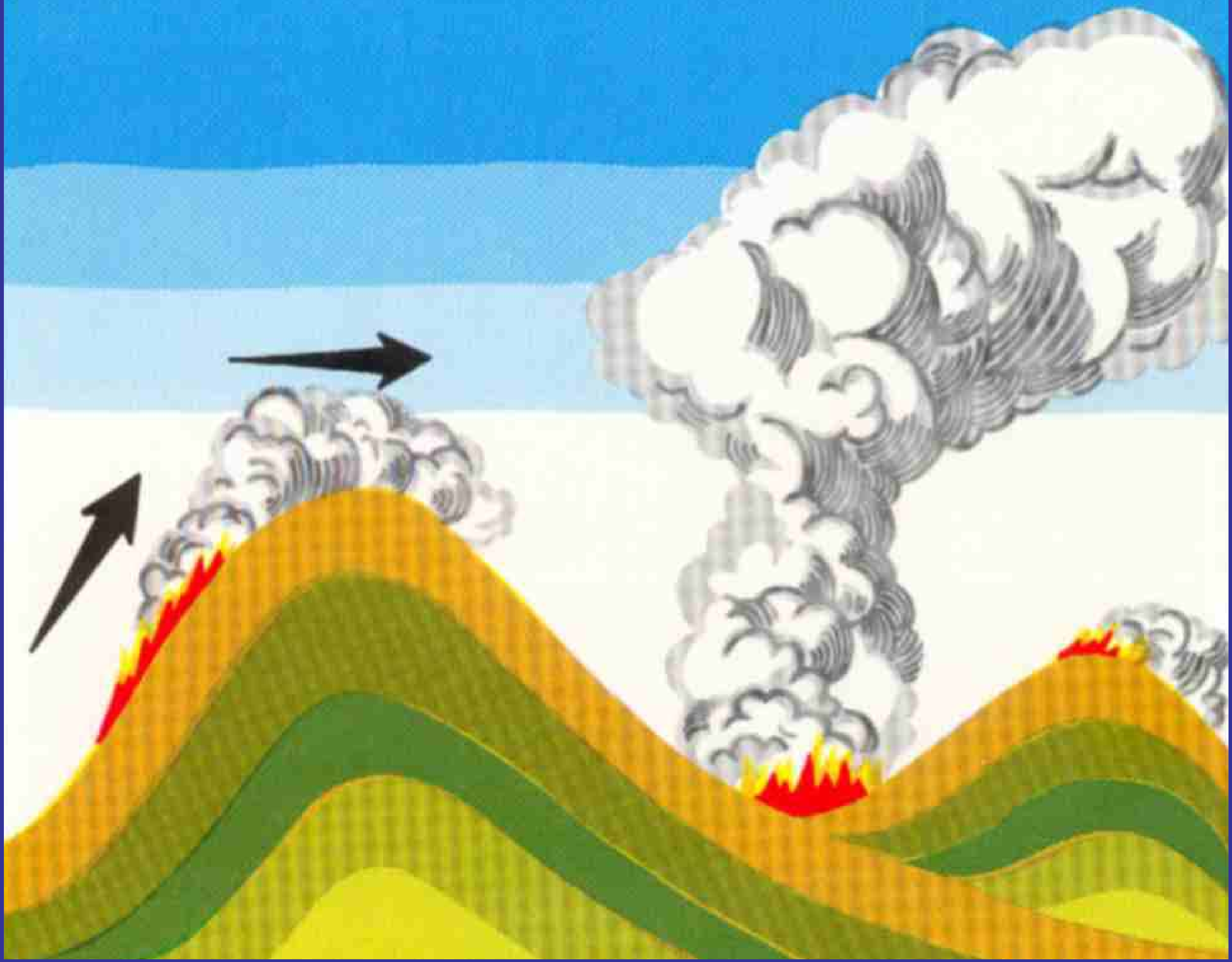
Alexander and Cruz (2006. *Can. J. For. Res.*) Spotting Separation Distance Model



Assuming a nominal spread rate of 35 m/min (2.1 km/h), spotting distances would have to exceed 300-700 m in order to increase the overall rate of advance. In-draft effects are not considered.

Focus in *PROMETHEUS* should be on judging whether spotting can overcome major barriers to fire spread





Strong winds blowing over mountainous topography often cause very complex fire behavior patterns.

Insect and Disease Killed Forest Stands Produce Numerous Spot Fires

Safety Alert for Wildland Firefighters: Fuel Conditions in Spruce-Beetle-Killed Forests of Alaska*

Martin E. Alexander and Joseph C. Stam

The fire environment on Kenai Peninsula and in south-central Alaska has experienced significant changes due to the recent spruce beetle epidemic (Fastabend 2002). Firefighters and fire researchers do not have enough experience with wildland fires that occur in the dead-spruce/cured-grass fuel complexes to appraise potential fire behavior in these fuel types accurately. All firefighters, despite their general experience level, should use caution when approaching fire incidents in beetle-killed areas.

Look Up, Look Down, Look Around—and Look Out!

The Fireline Safety Reference (NWCG 1993) lists "bug kill" as a fuel component indicator of potentially erratic fire behavior. When evaluating and suppressing a wildland fire in spruce-beetle-killed forests in Alaska, the LCES (lookouts, communications, escape routes, safety zones) checklist (Gleason 1991) must address the factors shown below. The factors are based on fuel and stand sampling in spruce-beetle-killed stands, observations of recent wildland fires in similar fuel situations, experimental fires in other, similar insect-affected fuel types (Stocks 1987), and accepted fire behavior principles.

- Spruce beetle-killed forests are usually more flammable than live spruce forests. Therefore, they exhibit characteristics associated with extreme, difficult-to-predict fire behavior.
- The increase in grass fuels following a spruce beetle outbreak will predispose the dead and dying forests to fires that rapidly spread in the spring before greenup. Spread rates and fire intensities are usually greater in beetle-killed areas than in healthy spruce stands.
- Candling, torching, and crown fires are common in spruce-beetle-killed areas, even under seemingly mild burning conditions.
- Prolific fire spotting and the potential for "mass fire" or area ignition are usual in spruce-beetle-killed areas.
  - Dead trees that have blown or fallen down in beetle-killed areas will impede fireline construction and hinder escape to safety zones. The combination of dead grass and large quantities of dead and down timber will severely limit fire shelter deployment opportunities.
  - Falling snags can be expected in spruce-beetle-killed areas during strong winds and along the fire perimeter after passage of an active flame front.

Spruce-beetle-killed forest, Kenai Peninsula, AK, illustrating the dead-tree and cured-grass components of these fuel complexes. Photo: W. Wahrenbrock, Alaska Department of Natural Resources, Division of Forestry, Soldotna, AK, 1998.

Heavy accumulations of dead and down woody surface fuels associated with a Sitka spruce stand killed by the spruce beetle, Kenai Peninsula, AK. Note the individual (W. Wahrenbrock) in the background. Photo: W. Oja, USDA Forest Service, Chugach National Forest, Steward Ranger District, Steward, AK, 2002.

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Gleason, P. 1991. LCES—A key to safety in the wildland fire environment. Fire Management Notes. 52(4): 9.

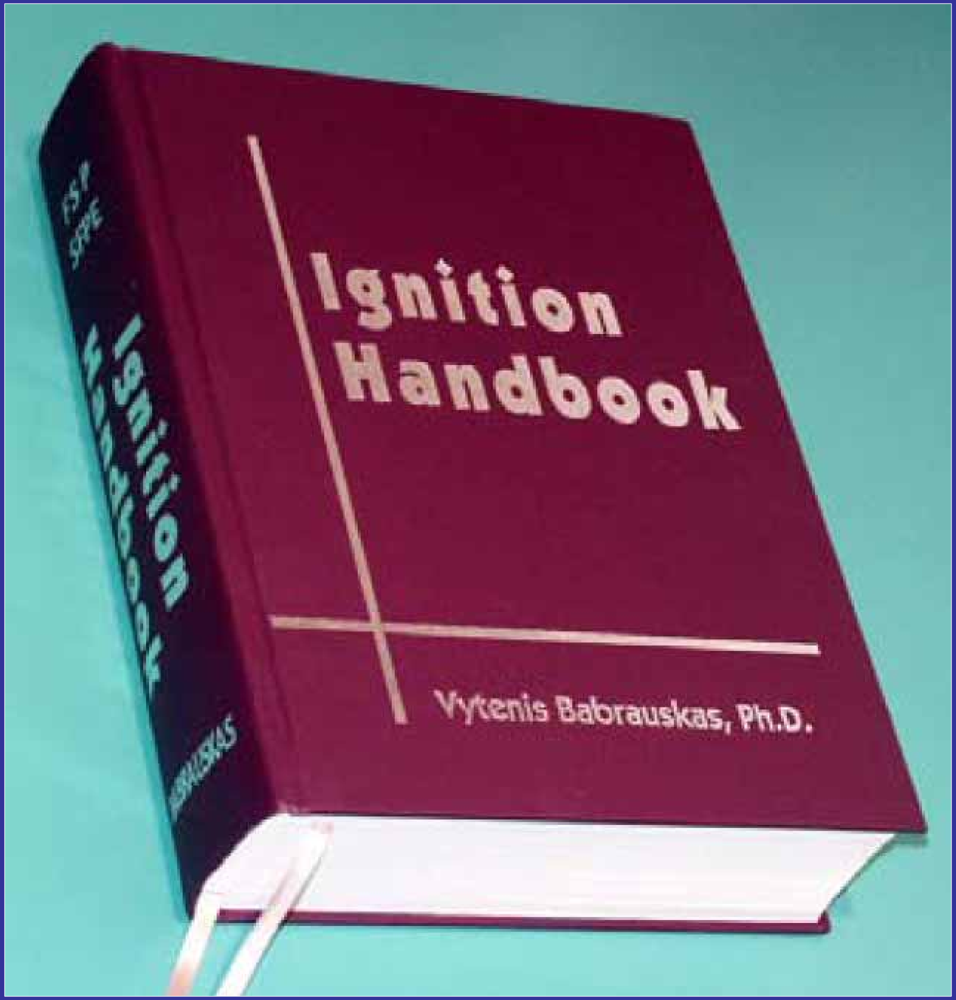
Stocks, B.J. 1987. Fire potential in the spruce budworm-damaged forests of Ontario. Forestry Chronicle. 63: 8–14.

National Wildfire Coordinating Group (NWCG). 1993. Fireline safety reference. NFES 2243. Boise, ID: NWCG.

Marty Alexander is a senior fire behavior research officer, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta, Canada; and Joe Stam is the chief of fire and aviation, Alaska Department of Natural Resources, Division of Forestry, Anchorage, AK.

* This article is based on a wildland fire safety message originally posted on the Alaska Fire Service Website at <http://fire.ak.blm.gov> in May 2001.

Get to know the literature well



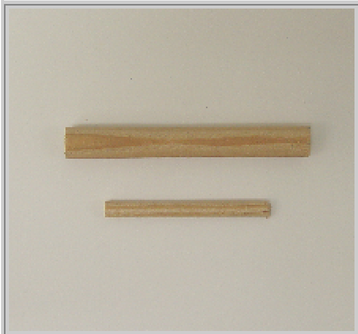
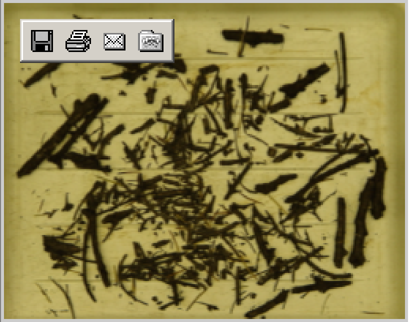
Get up to speed on the latest research on spotting

NIST WUI Overview

Address http://www2.bfrl.nist.gov/userpages/wmell/public.html#Firebrand_Experiments_

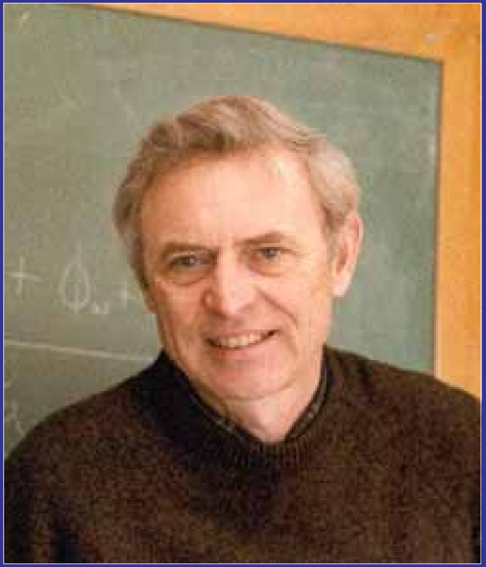
Work at NIST is focused on the ignition of a range of target fuel types (pine needles, cedar shingle crevices, paper, hardwood mulch, cut grasses). Each target fuel is tested at different moisture levels and wind conditions. A number of brand types and brand conditions (flaming versus glowing, single versus multiple brands) were used. Brands that were generated from burning Douglas trees (2.4 m and 5 m tall) are being collected and measured.

Brand shapes used in ignition studies

The brands below were ignited and dropped on target fuels of different moistures and wind enviornments.		
	Disk shaped. This shape has good lofting capabilites and is an approximation of firebrands generated from burning bark and roof shingles. Disk dimensions: diameter = 25 mm; thickness = 8 mm Disk dimensions: diameter = 50 mm; thickness = 6 mm A paper covering disk shaped brands is here..	
	Cylindrical shaped: This shape approximates branches and twigs based on brands collected from burning Douglas firs tree in NIST Large Fire Laboratory (see image at right). Size of Douglas fire dowels at left are: length = 76 mm; diameter = 10 mm length = 51 mm; diameter = 5mm	

Bear in mind the "Fire Behavior Prediction Paradox" (Rothermel 1987) we commonly fall into

- The models and systems aren't accurate enough.
- The models and systems are too complicated.



The resolution of either one of these problems worsens the other.

Presumably, crude but reliable decision aids are needed at the field level.

Be able to match Theory vs. Reality

Typical Spotting Distances

< 50 m: Very common

Up to 200 m: Common

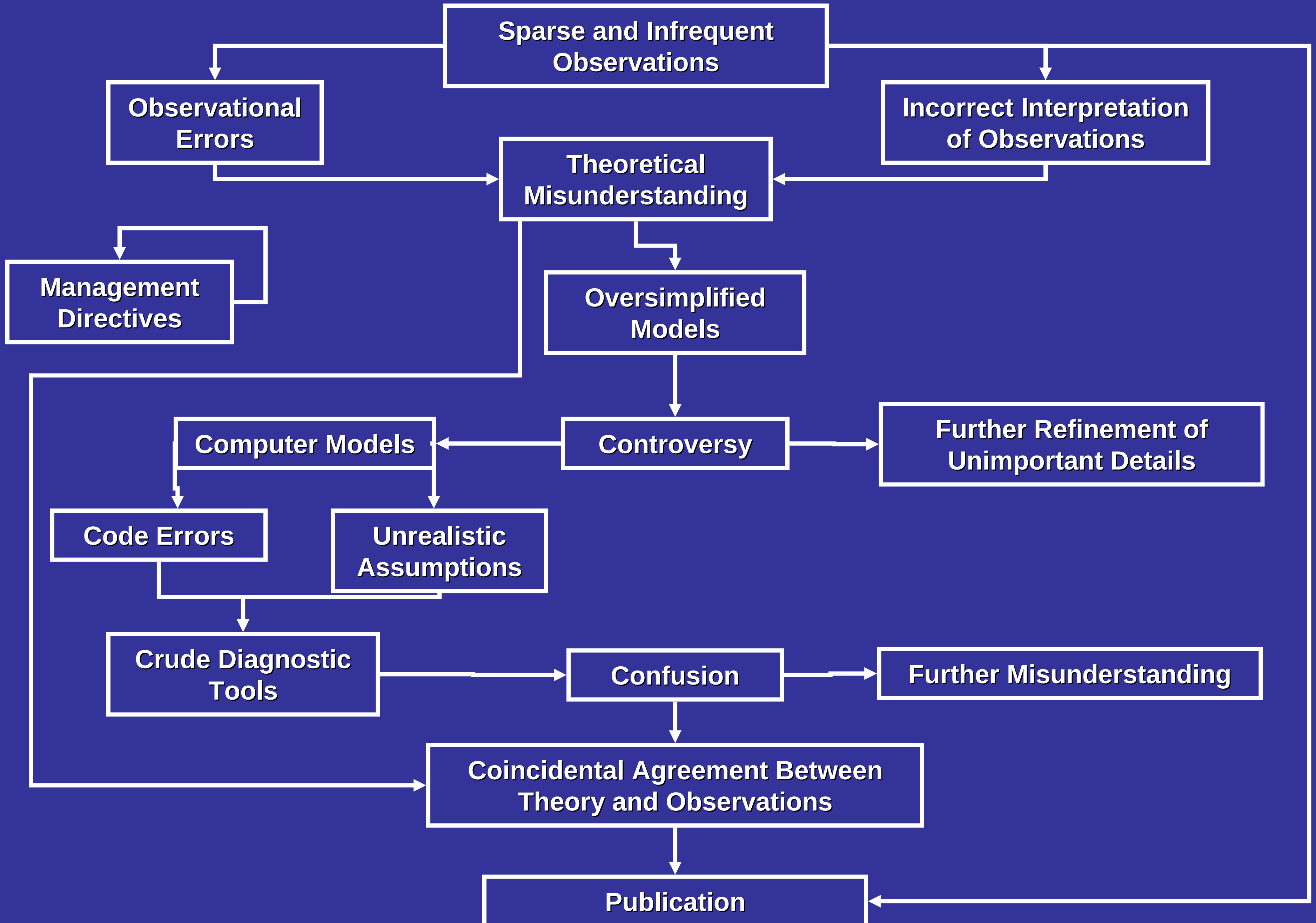
>2.0 km: Uncommon

6-8 km: Rare

Common Ignition Threshold in the Boreal Forest?

Fine Fuel Moisture Code (FFMC) > 90

The Course of Wildland Fire Behavior Prediction Science?



The End – Questions? Comments?