CROWN FIRE BEHAVIOR IN CONIFER FORESTS: A PRE-CONFERENCE WORKSHOP

Introduction

International Association of Wildland Fire 4th Fire Behavior and Fuels Conference

February 18, 2013 – Raleigh, NC

The goal of this workshop is provide participants with a summary of the results emanating from the Joint Fire Science Program sponsored project "Crown Fire Behavior Characteristics and Prediction in Conifer Forests: A State of Knowledge Synthesis" (JFSP 09-S-03-1) that began in October 2009.

Workshop Objectives

The current state-of-knowledge with respect to crown fire initiation and propagation in relation to fuel complex characteristics and surface weather conditions will be described with time for questions and discussion. Workshop participants will also have the opportunity to share their experiences and observations regarding crown fires, including thoughts on future research needs and knowledge gaps.

In October 2009, a 3-year project supported by the Joint Fire Science Program was initiated that aims to synthesize the currently available information on crown fire behavior in conifer forests (e.g., the onset of crowning, type of crown fire and the associated spread rate and fireline intensity).

9-month extension requested in July 2012

Project Team Members

Marty Alexander, University of Alberta, Dept. of Renewable Resources, Edmonton, Alberta

Miguel Cruz, CSIRO Ecosystem Sciences and Climate Adaptation Flagship, Canberra, Australia

Nicole Vaillant, USDA Forest Service, Western Wildland Environmental Threat Assessment Center, Prineville, Oregon

Dave Peterson, USDA Forest Service, Pacific Wildland Fire Sciences Laboratory, Seattle, Washington

A critical synthesis on crown fire behavior must rest upon as solid a foundation of knowledge as is possible at this time.

A sufficient body of scientific, peer-reviewed and technical literature of a practical nature does in fact presently exist to be able undertake a synthesis on crown fire behavior.

In addition to summarizing the existing scientific and technical literature on crown fires, project members are also seeking assistance from individuals in the form of field observations of crown fires and related experiences as well as still pictures and video footage.

Getting the word out

A Synthesis on Crown Fires in Conifer Forests is Underway

Martin E. Alexander

The Joint Fire Science Program (JFSP) has elected to support a project aimed at synthesizing the currently available information on the characteristics and prediction of crown fire behavior in conifer forests (Alexander and others 2010). This would include such facets of crown fire behavior as the onset of crowning and the type of crown fire (passive, active, independent) and the associated spread rate and fireline intensity in relation to the wildland fire environment (i.e., fuels, weather, and topography).

While the focus is on North American forests, the synthesis is intended to be global in nature and is intended for multiple audiences ranging from the general public to college students, fire and land managers, university professors, and other researchers.

In addition to summarizing the existing scientific and technical literature on the subject, project members are also actively seeking assistance from individuals in the form of field observations of crown fires and related experiences as well as still pictures and video footage.

We are interested in hearing from you, the wildland fire community, as to your opinions on the subject of crown fires and any specific questions, research needs, or knowledge gaps that you would like to see addressed or discussed in this crown fire synthesis project. Feel free to contact any project team member.

Fayette Lake Fire burning in lodgepole pine at about 9,000 feet (3,000 m) elevation near the Continental Divide on the Jim Bridger Wilderness, Bridger-Teton National Forest, WY. Photo: Richard Claypole, Forest Service, Klamath National Forest, Happy Camp Ranger District, CA, 1988.

To learn more about JFSP Project 09-S-03-1 and ensuing developments, visit the crown fire synthesis project Web site at <http://www.fs.fed.us/wwetac/projects/alexander.html>.

Reference

Alexander, M.E.; Cruz, M.G.; Vaillant, N.M.; Peterson, D.L. 2010. Towards a crown fire synthesis: what would you like to know and what might you be able to contribute? In: Proceedings of 3rd Fire Behavior and Fuels Conference, 25–29 October 2010, Spokane, WA. Birmingham, AL: International Association of Wildland Fire. CD-ROM.

Dr. Marty Alexander is an adjunct professor of wildland fire science and management in the Department of Renewable Resources and Alberta School of Forest Science and Management at the University of Alberta in Edmonton, Alberta, Canada.

JFSP Crown Fire Synthesis Project Team Members

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Dr. Miguel G. Cruz, Research Scientist, CSIRO Ecosystem Sciences and Climate Adaptation Flagship—Bushfire Dynamics and Applications, Canberra, Australian Capital Territory, Australia (miguel.cruz@csiro.au).

Dr. Nicole M. Vaillant, Fire Ecologist, Forest Service, Pacific Northwest Research Station, Western Wildland Environmental Threat Assessment Center, Sparks, NV (nvaillant@fs.fed.us).

Dr. David L. Peterson, Biological Scientist, Forest Service, Pacific Northwest Research Station, Wildland Fire Sciences Laboratory, Seattle, WA (peterson@fs.fed.us).

Proceedings of 3rd Fire Behavior and Fuels Conference, October 25-29, 2010, Spokane, Washington, USA
Published by the International Association of Wildland Fire, Birmingham, Alabama, USA

Towards a crown fire synthesis:
what would you like to know and what might you be able to contribute?

Martin E. Alexander[A,E], Miguel G. Cruz[B], Nicole M. Vaillant[C], and David L. Peterson[D]

[A]University of Alberta, Department of Renewable Resources and Alberta School of Forest Science and Management, Edmonton, AB, T6G 2H1, Canada.
[B]CSIRO Ecosystem Sciences and CSIRO Climate Adaptation Flagship - Bushfire Dynamics and Applications, GPO Box 284, Canberra, ACT 2601, Australia.
[C]USDA Forest Service, Pacific Northwest Station, Western Wildland Environmental Threat Assessment Center, 1200 Franklin Way, Sparks, NV, 89431, USA.
[D]USDA Forest Service, Pacific Northwest Station, Pacific Wildland Fire Sciences Laboratory, 400 N 34th Street, Suite 201, Seattle, WA, 98103, USA.
[E]Corresponding author. Email: mea2@telus.net

...am associated with the Joint Fire Science Program (JFSP) ...wn Fire Behavior Characteristics and Prediction in Conifer ...esis" are actively seeking help and input from members of ...orm of photo documentation of crown fires and suggestions ...itten product

...havior, crown fire initiation, crown fire propagation, crown

...am (JFSP) elected to support a project to undertake a state ...ct of crown fire behavior characteristics and prediction in ...ted to be completed by October 2012. The purpose of this ...ckground information on the project and at the same time ...l fire community for their input and assistance.

...l is on synthesizing the currently available information on ...er forests (e.g. onset of crowning, type of crown fire and ...ntensity) in relation to the wildland fire environment (i.e. ...rmation on crown fire behavior is available from several ...ding the seminal articles by Van Wagner (1977, 1993) on ... 1989) on fire behavior in immature and mature jack pine ...*f Forest Research* as well as the special issue on the ...Experiment (Butler *et al.* 2004*a*, 2004*b*; Stocks *et al.* 2004; ...ecently developed and tested models for predicting passive ...l (Cruz *et al.* 2005; Alexander and Cruz 2006). Additional ...avior can be found in *Forest Science* (Cruz et al. 2004), *International Journal of Wildland Fire* (Cruz *et al.* 2003*c*, 2006*a*, 2006*b*; Cruz and Alexander 2010), *Forestry Chronicle* (Cruz *et al.* 2003*b*), and *Australian Forestry* (Cruz *et al.* 2008).

CROWN FIRES IN CONIFER FORESTS OF THE WORLD: Do you have something to contribute or would like to know about something?

M.G. Cruz, M.E. Alexander, N.M. Vaillant & D.L. Peterson

In October 2009, a 3-year project supported by the Joint Fire Science Program was initiated that aims to synthesize the currently available information on crown fire behavior in conifer forests.

While the focus is on the coniferous forests of the United States and adjacent areas of Canada, the synthesis is intended to be global in nature and is intended for multiple audiences ranging from the general public to college students to fire and land managers to university professors and other researchers.

Information from all regions of the world would be appreciated, including Mexico, South Africa, Australasia, Europe, Central and South America, Europe and Asia.

In addition to summarizing the existing scientific and technical literature on crown fires, project members are also seeking assistance from individuals in the form of field observations of crown fires and related experiences as well as still pictures and video footage in both natural forest stands and industrial plantations.

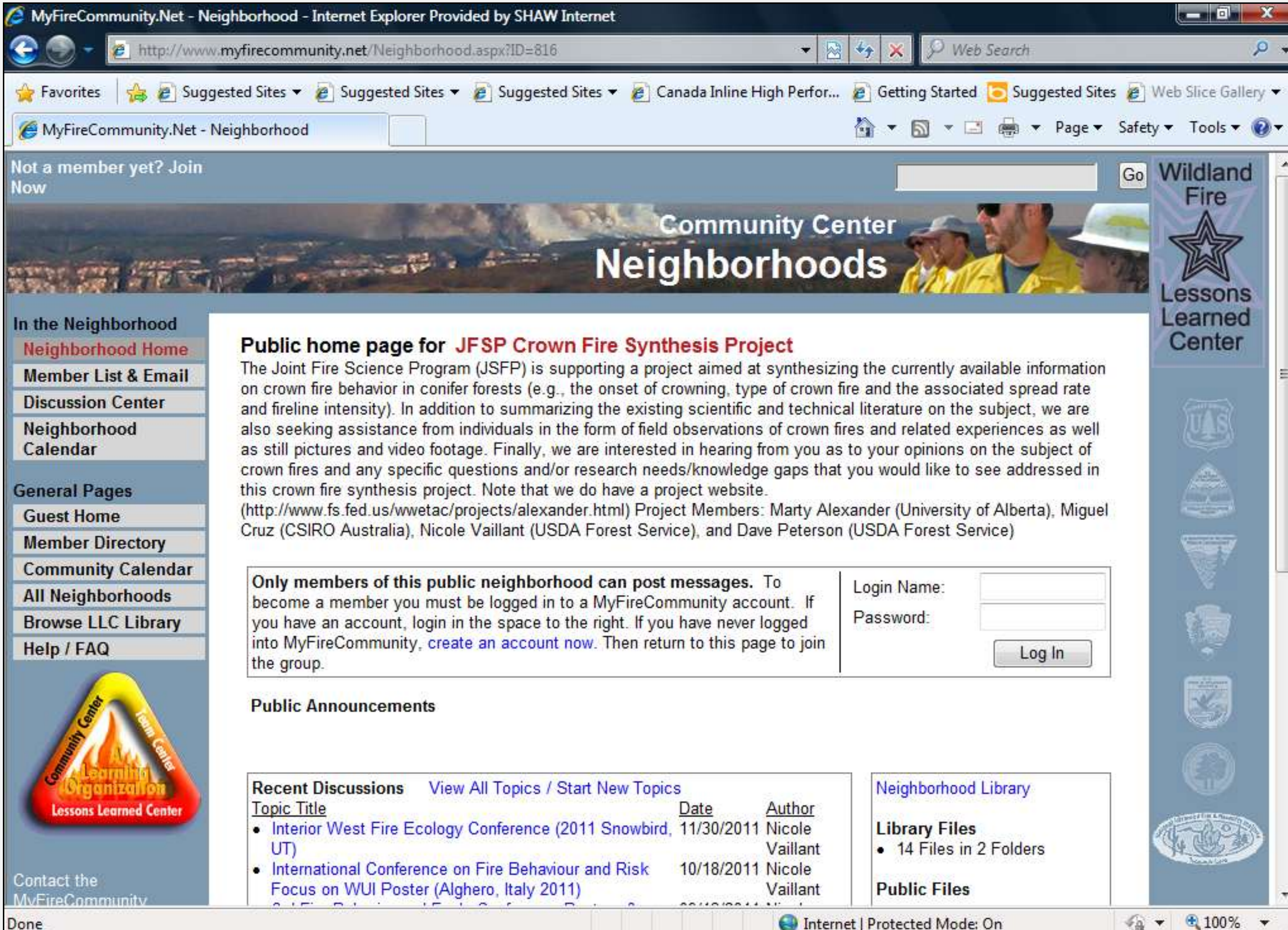
Finally, we are interested in hearing from you – the "end user" – as to your opinions on the subject of crown fires and any specific questions and/or research needs/knowledge gaps that you would like to see addressed in this crown fire synthesis project.

To keep up to date on the crown fire synthesis project periodically visit our website:

http://www.fs.fed.us/wwetac/projects/alexander.html

miguel.cruz@csiro.au

Over 6,000 invitations sent out to join the *Neighborhood*

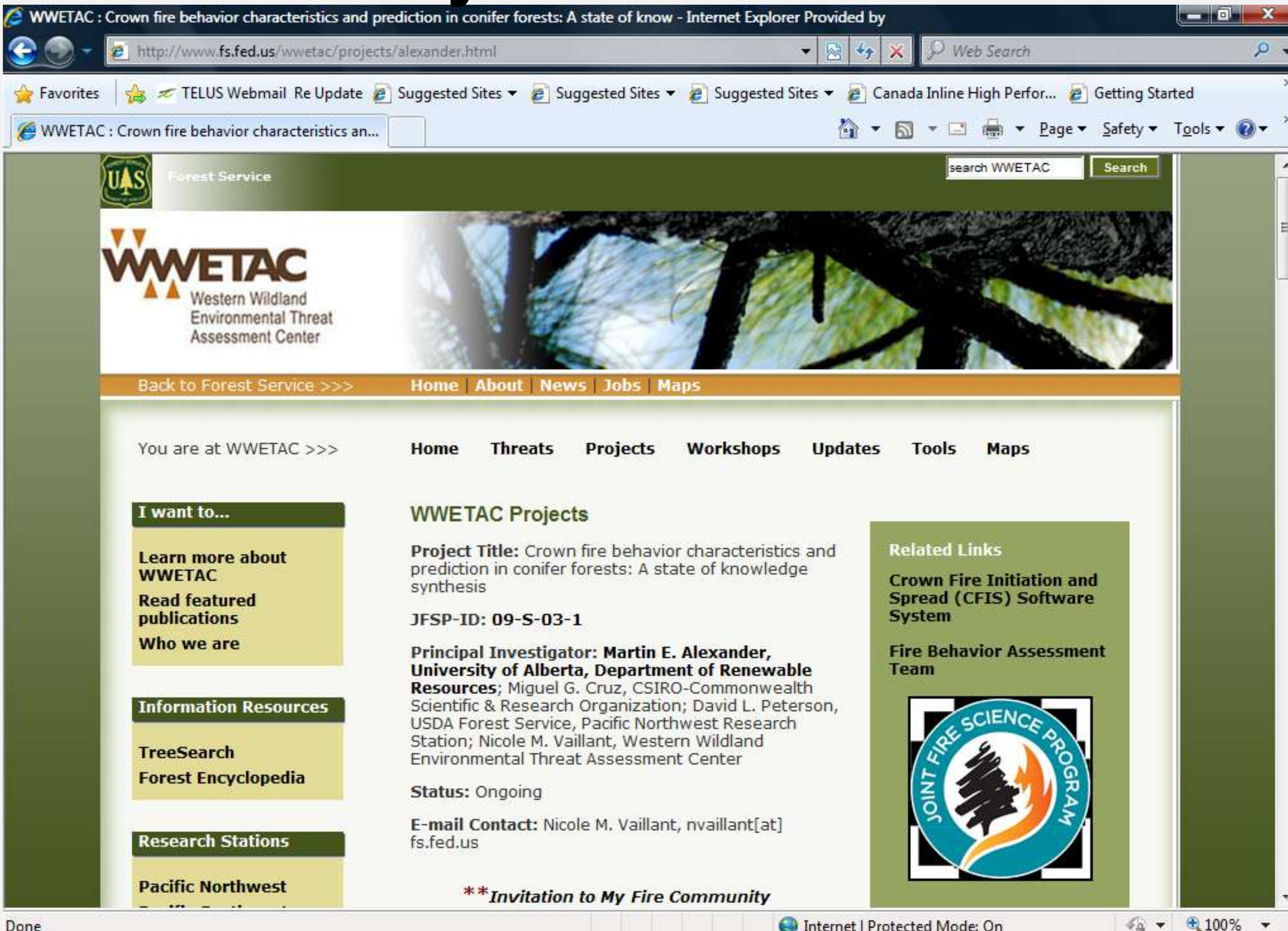


Throughout the process there has been liaison and dialogue with:

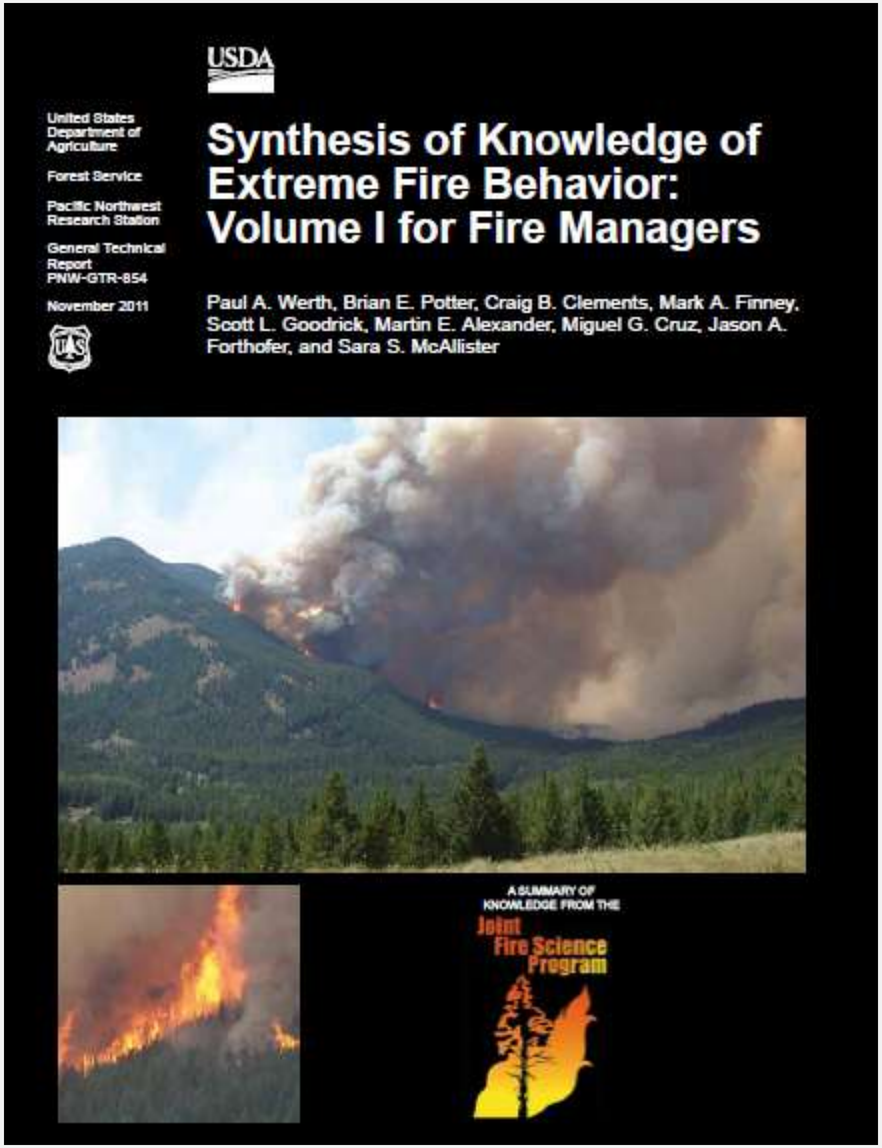
Fire Behavior Sub-Committee

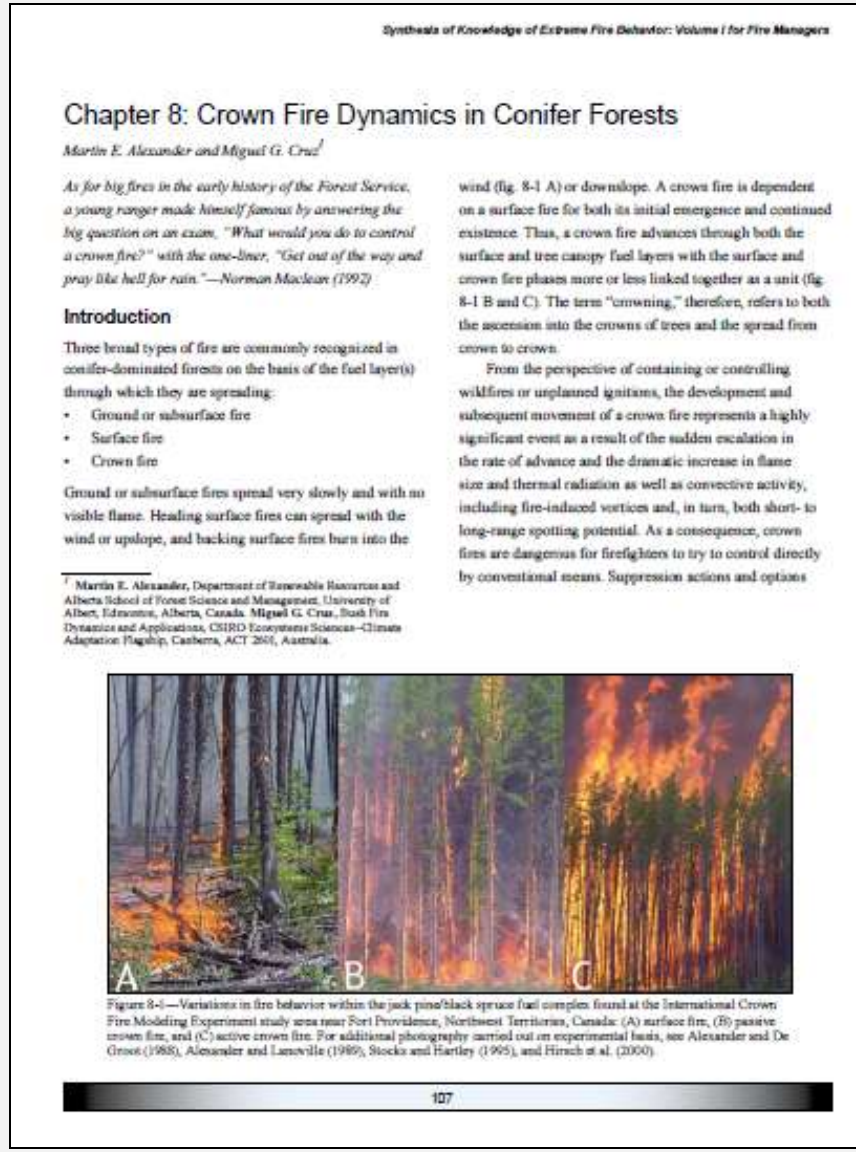
Conference calls and a in person meeting.
Progress reports and provided documents.
E-mails. Reviews by FBSC members.

Project Website



Results to Date





Synthesis of Knowledge of Extreme Fire Behavior: Volume I for Fire Managers

Chapter 8: Crown Fire Dynamics in Conifer Forests

Martin E. Alexander and Miguel G. Cruz[1]

As for big fires in the early history of the Forest Service, a young ranger made himself famous by answering the big question on an exam, "What would you do to control a crown fire?" with the one-liner, "Get out of the way and pray like hell for rain."—Norman Maclean (1992)

Introduction

Three broad types of fire are commonly recognized in conifer-dominated forests on the basis of the fuel layer(s) through which they are spreading:

- Ground or subsurface fire
- Surface fire
- Crown fire

Ground or subsurface fires spread very slowly and with no visible flame. Heading surface fires can spread with the wind or upslope, and backing surface fires burn into the wind (fig. 8-1 A) or downslope. A crown fire is dependent on a surface fire for both its initial emergence and continued existence. Thus, a crown fire advances through both the surface and tree canopy fuel layers with the surface and crown fire phases more or less linked together as a unit (fig. 8-1 B and C). The term "crowning," therefore, refers to both the ascension into the crowns of trees and the spread from crown to crown.

From the perspective of containing or controlling wildfires or unplanned ignitions, the development and subsequent movement of a crown fire represents a highly significant event as a result of the sudden escalation in the rate of advance and the dramatic increase in flame size and thermal radiation as well as convective activity, including fire-induced vortices and, in turn, both short- to long-range spotting potential. As a consequence, crown fires are dangerous for firefighters to try to control directly by conventional means. Suppression actions and options

[1] **Martin E. Alexander**, Department of Renewable Resources and Alberta School of Forest Science and Management, University of Albert, Edmonton, Alberta, Canada. **Miguel G. Cruz**, Bush Fire Dynamics and Applications, CSIRO Ecosystems Sciences–Climate Adaptation Flagship, Canberra, ACT 2601, Australia.

A B C

Figure 8-1—Variations in fire behavior within the jack pine/black spruce fuel complex found at the International Crown Fire Modeling Experiment study area near Fort Providence, Northwest Territories, Canada: (A) surface fire, (B) passive crown fire, and (C) active crown fire. For additional photography carried out on experimental basis, see Alexander and De Groot (1988), Alexander and Lanoville (1989), Stocks and Hartley (1995), and Hirsch et al. (2000).

107

The chapter on crown fires for Volume II -- Fire Behavior Specialists, Researchers and Meteorologists has been completed and reviewed, and is currently undergoing editorial review

Peer-Reviewed Journal Articles

CSIRO PUBLISHING
International Journal of Wildland Fire **2012**, *21*, 168–179
http://dx.doi.org/10.1071/WF10066
Research Note

Evaluating regression model estimates of canopy fuel stratum characteristics in four crown fire-prone fuel types in western North America

Miguel G. Cruz[A,C] *and Martin E. Alexander*[B]

[A]Bushfire Dynamics and Applications, Climate Adaptation Flagship – CSIRO Ecosystem Sciences, GPO Box 1700, Canberra, ACT 2601, Australia.
[B]University of Alberta, Department of Renewable Resources and Alberta School of Forest Science and Management, Edmonton, AB, T6G 2H1, Canada.
[C]Corresponding author. Email: miguel.cruz@csiro.au

CSIRO PUBLISHING
Review

Interdependencies between flame length and fireline intensity in predicting crown fire initiation and crown scorch height

Martin E. Alexander and Miguel G. Cruz

Graphical aids for visualizing Byram's fireline intensity in relation to flame length and crown scorch height

by Martin E. Alexander and Miguel G. Cruz

Martin E. Alexander   Miguel G. Cruz

Flame Length–Fireline Intensity Relationships

Introduction

Forest Ecology and Management
ELSEVIER
Review

Fuels and fire behavior dynamics in bark beetle-attacked forests in Western North America and implications for fire management

Michael J. Jenkins, Wesley G. Page, Elizabeth G. Hebertson, Martin E. Alexander

ARTICLE INFO   ABSTRACT

Contents

Modelling the effects of surface and crown fire behaviour on serotinous cone opening in jack pine and lodgepole pine forests

M. E. Alexander and M. G. Cruz

Peer-Reviewed Journal Articles

CSIRO PUBLISHING
International Journal of Wildland Fire 2012, 21, 709–721
http://dx.doi.org/10.1071/WF11153

Modelling the effects of surface and crown fire behaviour on serotinous cone opening in jack pine and lodgepole pine forests

M. E. Alexander[A,C] and M. G. Cruz[B]

CSIRO PUBLISHING
International Journal of Wildland Fire
http://dx.doi.org/10.1071/WF12008
Review

Assessing the effect of foliar moisture on the spread rate of crown fires

Martin E. Alexander[A] and Miguel G. Cruz[B,C]

[A]University of Alberta, Department of Renewable Resources and Alberta School of Forest Science and Management, Edmonton, AB, T6G 2H1, Canada.
[B]Bushfire Dynamics and Applications Team, CSIRO Ecosystem Sciences and Climate Adaptation Flagship, GPO Box 1700, Canberra, ACT 2601, Australia.
[C]Corresponding author. Email: miguel.cruz@csiro.au

Received 12 January 2012, accepted 6 October 2012, published online 23 November 2012

CSIRO PUBLISHING
International Journal of Wildland Fire 2012, 21, 609–627
http://dx.doi.org/10.1071/WF11020

A mathematical model for predicting the maximum potential spotting distance from a crown fire

Frank A. Albini[A,F], Martin E. Alexander[B,C,E] and Miguel G. Cruz[D]

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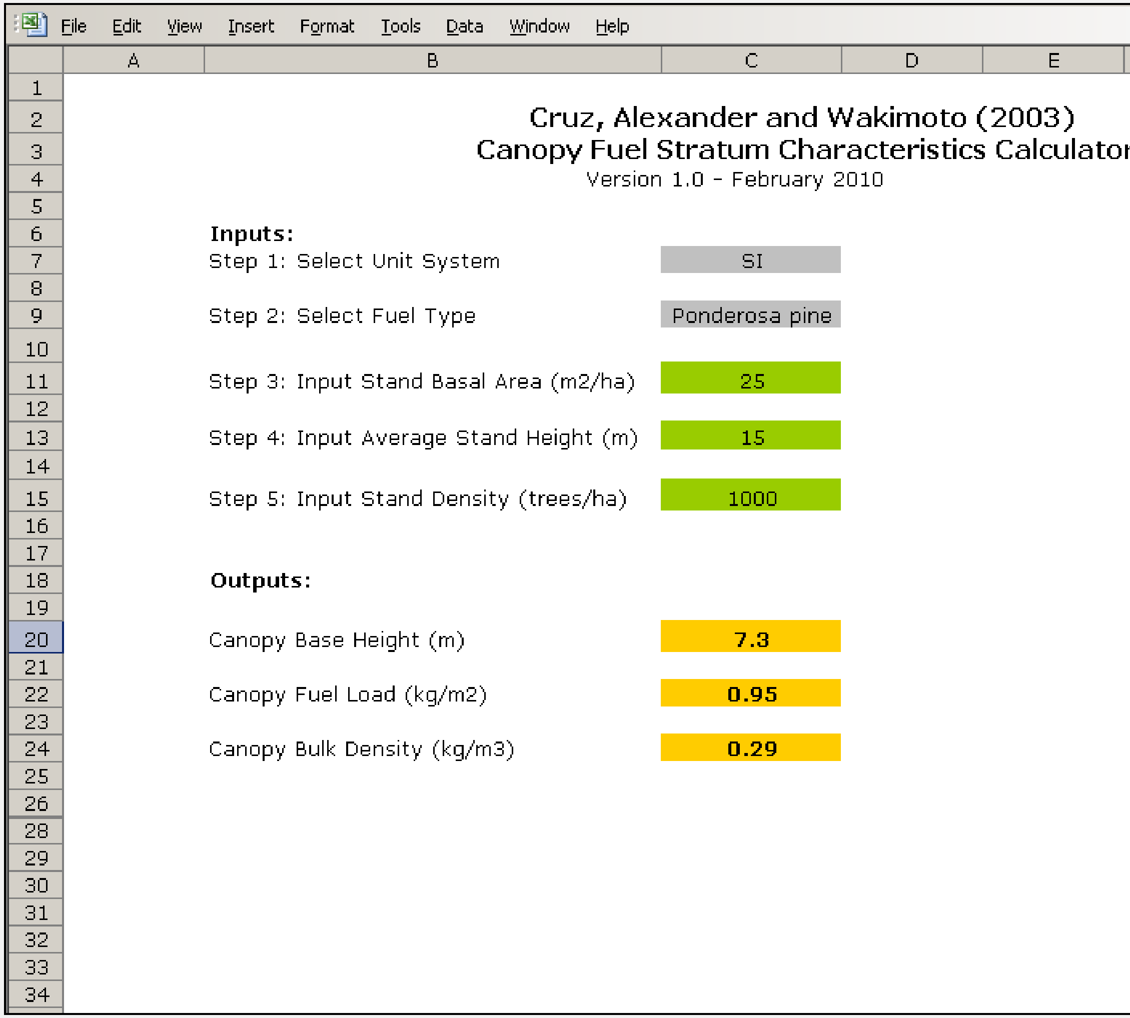
Software



CSIRO PUBLISHING

www.publish.csiro.au/journals/ijwf

International Journal of Wildland Fire, 2003, **12**, 39–50

Assessing canopy fuel stratum characteristics in crown fire prone fuel types of western North America

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[B] Canadian Forest Service, Northern Forestry Centre 5320-122 Street Edmonton, Alberta T6H 3S5, Canada. Telephone: +1 780 435 7346; fax: +1 780 435 7359; email: malexand@nrcan.gc.ca

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Abstract. Application of crown fire behavior models in fire management decision-making have been limited by the difficulty of quantitatively describing fuel complexes, specifically characteristics of the canopy fuel stratum. To estimate canopy fuel stratum characteristics of four broad fuel types found in the western United States and adjacent areas of Canada, namely Douglas-fir, ponderosa pine, mixed conifer, and lodgepole pine forest stands, data from the USDA Forest Service's Forest Inventory and Analysis (FIA) database were analysed and linked with tree-level foliage dry weight equations. Models to predict canopy base height (CBH), canopy fuel load (CFL) and canopy bulk density (CBD) were developed through linear regression analysis and using common stand descriptors (e.g. stand density, basal area, stand height) as explanatory variables. The models developed were fuel type specific and coefficients of determination ranged from 0.90 to 0.95 for CFL, between 0.84 and 0.92 for CBD and from 0.64 to 0.88 for CBH. Although not formally evaluated, the models seem to give a reasonable characterization of the canopy fuel stratum for use in fire management applications.

Additional keywords: canopy base height; canopy bulk density; canopy fuel load; crown fire behavior; crown fuel dynamics.

Introduction

The growing complexity of deterministic fire behavior models implemented in fire management decision support systems requires that descriptions of fuel complex characteristics should be as accurate as possible given the existing resource and knowledge constraints. Until recently in the U.S. fuel complex characterization has been limited to surface fuel beds (e.g. Brown and See 1981; Brown and Bevins 1986) due to the restricted applicability of fire behavior models such as the BEHAVE system (Burgan and Rothermel 1984; Andrews 1986) to this fuel stratum. The development of fire behavior models and systems designed to predict crown fire behavior (Albini 1979, 1996; Van Wagner 1977, 1989; Forestry Canada Fire Danger Group 1992; Call and Albini 1997; Alexander 1998; Finney 1998; Scott and Reinhardt 2001) point out the need to describe the canopy fuel stratum. Based on an analysis of existing fire behavior models and physical reasoning, it is possible to isolate the relevant canopy fuel stratum characteristics that determine crown fire behavior. The canopy structural properties of a stand (e.g. cover, depth, shape, leaf area and leaf distribution) influence understory micrometeorology, and therefore influence certain factors of the fire environment such as subcanopy wind flow (Meyers and Paw U 1987; Amiro 1990) and seasonal and diurnal fuel moisture dynamics (Rothermel *et al.* 1986).

Since canopy fuels are the main fuel layer supporting crown fire spread, canopy structure largely determines combustion requirements and outputs, and consequently important fire behavior descriptors such as rate of fire spread and fire intensity (Byram 1959). With Finney's (1998) implementation of Van Wagner's (1977) crown fire initiation and spread models into the FARSITE fire growth simulator, information on CBD and CBH have become essential for fire management planning (Keane *et al.* 1998), although no method of easily quantifying these parameters is directly available to fire managers. Such information is needed for other crown fire potential assessment schemes (Alexander 1988; Graham *et al.* 1999; Keyes and O'Hara 2002).

Fuel complex characteristics commonly accepted as controlling crown fire spread are CFL, canopy fuel bulk density and CBH. When describing aerial fuels the term crown and canopy have often been used interchangeably without formal

10.1071/WF02024 1049-8001/03/010039

JFSP Advanced Search Results Detail - Internet Explorer Provided by SHAW Internet

http://www.firescience.gov/JFSP_advanced_search_results_detail.cfm?jdbid=%24%26Z%27%3BV%

Favorites | TELUS Webmail | Re Update | Suggested Sites | Suggested Sites | Suggested Sites | Canada Inline High Perfor... | Getting Started

JFSP Advanced Search Results Detail

FIRESCIENCE.GOV

Research Supporting Sound Decisions

Search firescience.gov

Project Search | Research Results Search

Print

Advanced Search Results Detail

JFSP Website

Project ID: 09-S-03-1

Year: 2010

Date Started: 10/01/2009

Ending Date: 06/30/2013

Title: Crown Fire Behavior Characteristics and Prediction in Conifer Forests: A State of Knowledge Synthesis

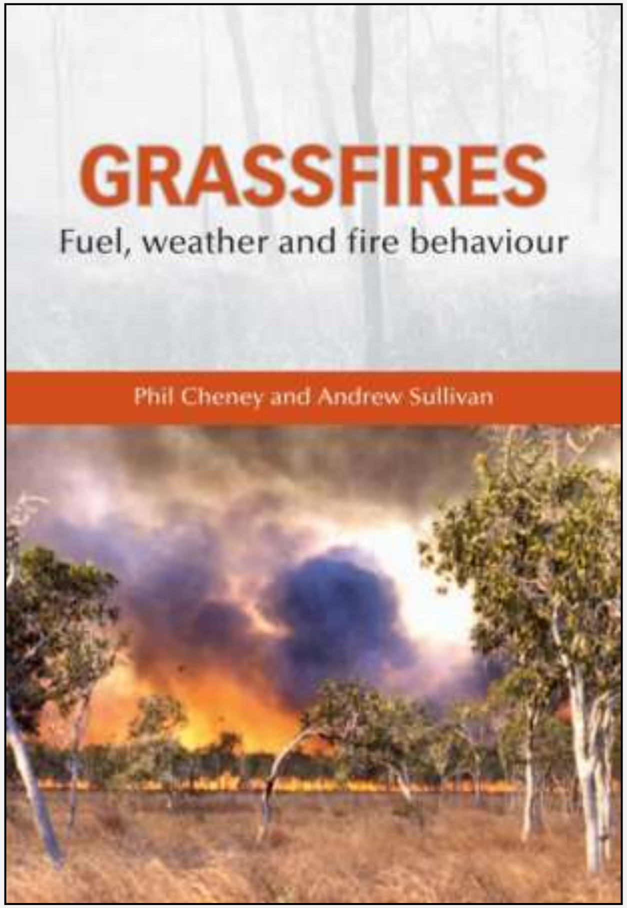
Project Proposal Abstract: The focus of the proposed project will be on synthesizing the available information on crown fire behavior related to conifer forests (e.g., the onset of crowning, type of crown fire and the associated spread rate and fireline intensity, convection column development, spotting, fire-induced vortices). A critical synthesis on crown fire behavior must rest upon as solid a foundation of knowledge as is possible at this time. A sufficient body of scientific, peer-reviewed literature of a practical nature to undertake a synthesis on crown fire behavior presently exists. The literature includes articles published in the Canadian Journal of Forest Research, International Journal of Wildland Fire, Forest Science, Forestry Chronicle, and Australian Forestry. Many of the specific target articles can currently be viewed on the Firehouse website. Input and operational experiences from fire and land managers will also

Planned Products

Final End Products

❑ Book pattern after Australian “Grassfires”

- Text to be completed July 2013.
- Publication of book not likely until early 2013-4.



Final End Products (cont.)

- Special issue of *Fire Management Today that will summarize the content of the book.*

Looking at late 2013 for publication.

The Icebreaker

Crown Fire Behavior in Conifer Forests
8:00 am – 3:00 pm
Instructors: *Marty Alexander, University of Alberta, Miguel Cruz, CSIRO Australia, Nicole Vaillant, USFS, PNW Research Station*
The current state-of-knowledge with respect to crown fire initiation and propagation in relation to fuel complex characteristics and surface weather conditions will be described with time for questions and discussion. Workshop participants will also have the opportunity to share their experiences and observations regarding crown fires, including thoughts on future research needs and knowledge gaps. **Participants will be asked to submit a color photo of a crown fire to be projected during the workshop and be prepared to orally provide a short description of the image.** The instructors will elicit input on fuels and fire behavior characteristics that are unique to the southern United States in regards to crown fire behavior in conifer forests.

CROWN FIRE BEHAVIOR IN CONIFER FORESTS: A PRE-CONFERENCE WORKSHOP

Workshop Icebreaker

International Association of Wildland Fire 4th Fire Behavior and Fuels Conference

February 18, 2013 – Raleigh, NC

Brad Reed

Little Salmon Fire 2003 cresting the Ridge.

Note the wind sock in left foreground.

Column interaction of same fire

Grant Pearce

Berwick Forest Fire, NZ, Feb. 1995

Jim Prevette

Pains Bay

Jim Reardon

Soil Heating Associated with Crown Fires in NWT

Nothing received....

Sara McAllister

NWT fine vs. coarse fuel - VIDEO

Sara McAllister

Salt Fire - VIDEO

Steven Miller

Benton Fire

Steven Miller

District dozer waiting for spots

Steven Miller

Scrub burning hot

Steven Miller

Crown fire in scrub, Buck Lake

Steven Miller

Scrub burn at Buck Lake - VIDEO

Wesley Page

David Finn

My topical submission is regarding the transition process for surface to crown fire in open bole pine stands.

The current Canadian Forest Fire Danger Rating System uses the formula:

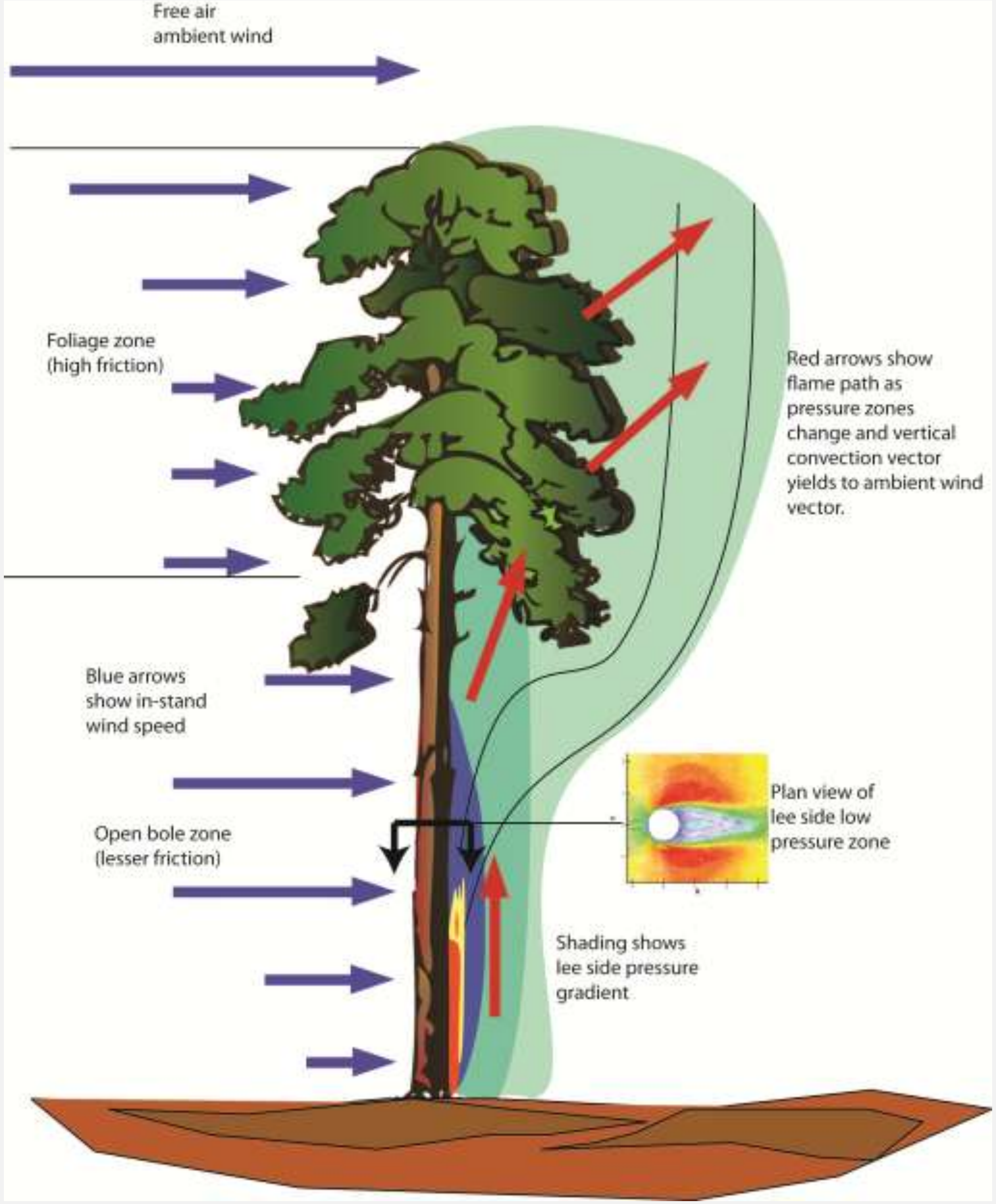
$$CSI=(0.001 \times CBH^{1.5} \times (460+25.9 \times FMC))^{1.5}$$

where CSI = Critical Surface Intensity in kW/m, CBH=Crown Base Height in meters, FMC=Foliar Moisture Content in %(gravimetric).

CSI is the threshold heat output level where surface fire intensity creates enough open air convective energy to cause ignition in the overstory canopy.

My observation in the field is that there is an entirely different mechanism that carries fire into the canopy, and that is the focused convection present in lee-side vorticity. My photos show this phenomenon and my drawing shows my hypotheses of what is happening. Other factors to consider are bark flake ease of ignition, bark flake fuel loading, tree and canopy shape, and in-stand wind conditions.

David Finn


Free air
ambient wind
Foliage zone
(high friction)
Red arrows show
flame path as
pressure zones
change and vertical
convection vector
yields to ambient wind
vector.
Blue arrows
show in-stand
wind speed
Open bole zone
(lesser friction)
Plan view of
lee side low
pressure zone
Shading shows
lee side pressure
gradient

David Finn

David Finn

LaWen Hollingsworth

Morris Johnson

Wallow Fire – Fuel Treatments

CROWN FIRE BEHAVIOR IN CONIFER FORESTS: A PRE-CONFERENCE WORKSHOP

General Background Information on Crown Fires

International Association of Wildland Fire 4th Fire Behavior and Fuels Conference

February 18, 2013 – Raleigh, NC

Why are crown fires significant

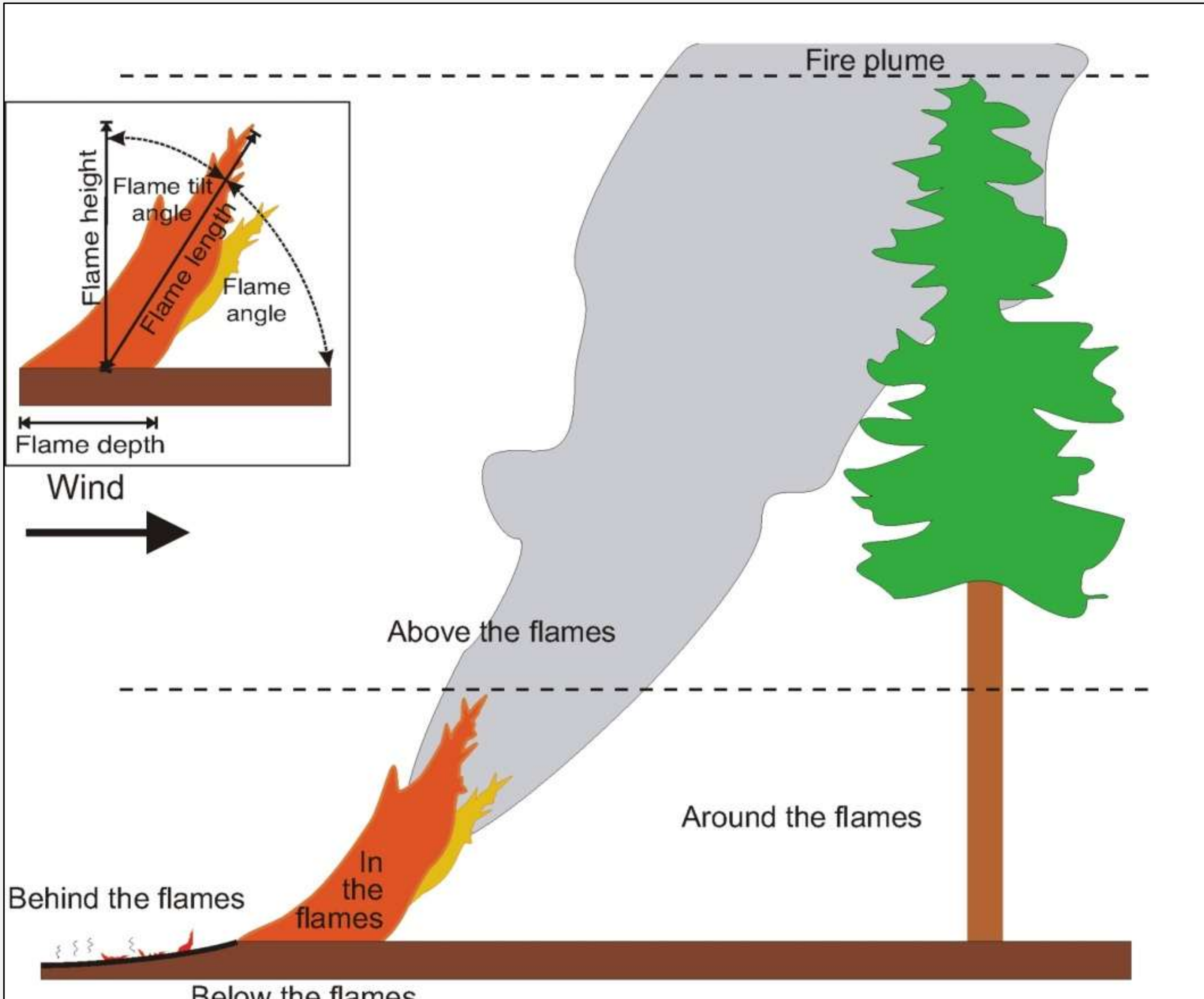
Suppression Expenditures

Community Protection

Resource Damages & Impacts

Firefighter Safety

Use of Fire



Fire plume
Flame height
Flame tilt angle
Flame length
Flame angle
Flame depth
Wind
Above the flames
Around the flames
In the flames
Behind the flames
Below the flames

Basic Features of a Forest of Wildland Fire:

It spreads but it also …

consumes
or
"eats" fuel
and …

it produces
heat energy
and light in
…

… a visible
flaming
combustion
reaction.

Basic descriptor of a spreading heat source:

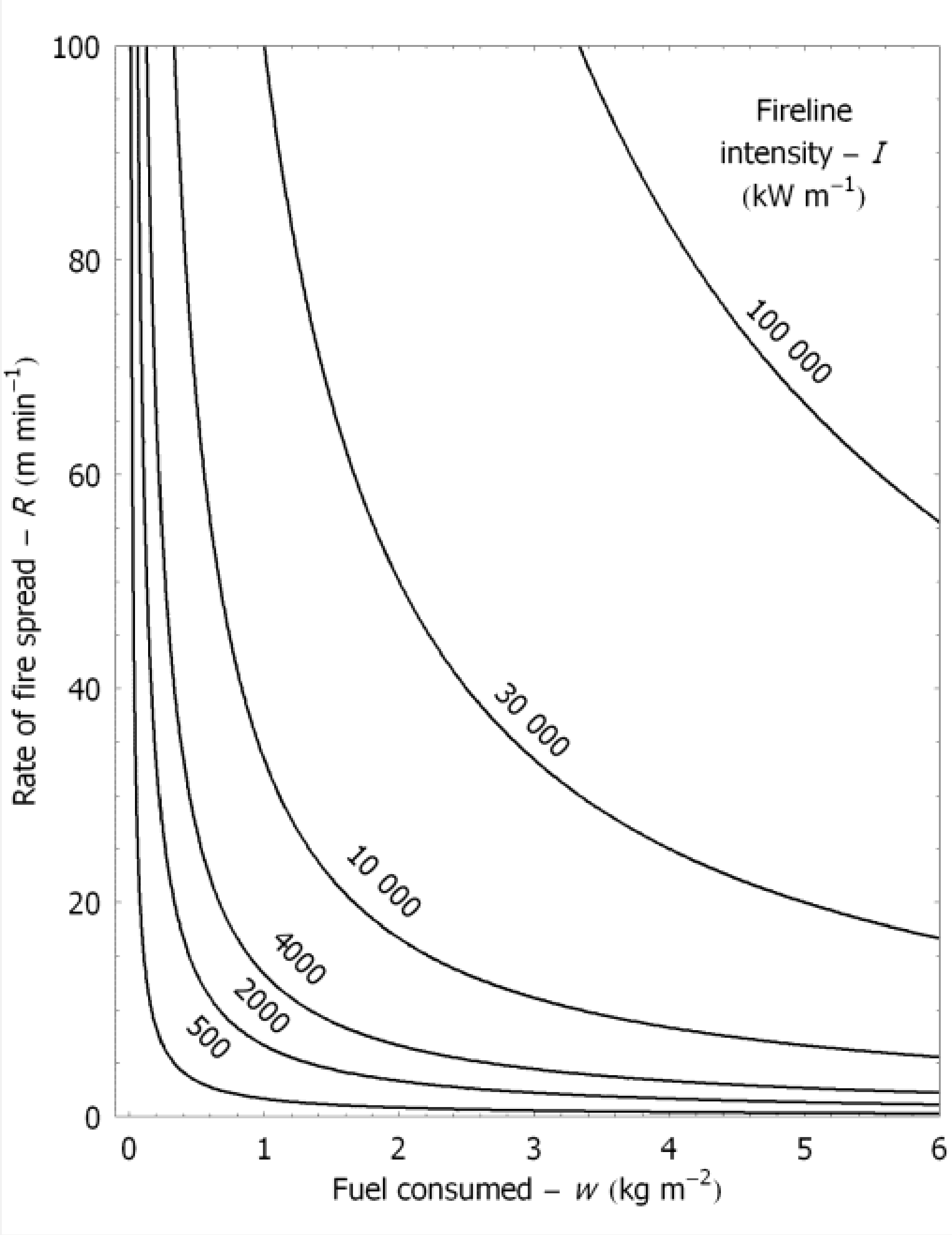
$$I = H \cdot w \cdot r$$

I – Byram's (1959) fireline intensity (kW/m)

H – Net low heat of combustion (~18 000 kJ/kg)

w – Fuel consumed in active flaming front (kg/m^2)

r – Linear rate of fire spread (m/sec)



Fire behavior characteristics chart

Onset of crowning:

- 5-10 m min^{-1}
- >4000 kW m^{-1}

Continuous active crowning:

- 15-30 m min^{-1}
- >10 000 kW

Flame front residence time -- t_r (sec)

$$t_r = D/r$$

D = Flame depth (m)

r = Rate of fire spread (m/sec)

What is a “crown fire”?

A “crown fire” is defined as:

A fire that advances through the crown fuel layer, usually in conjunction with the surface fire. Crowning can be classified according to the degree of dependence on the surface fire phase.

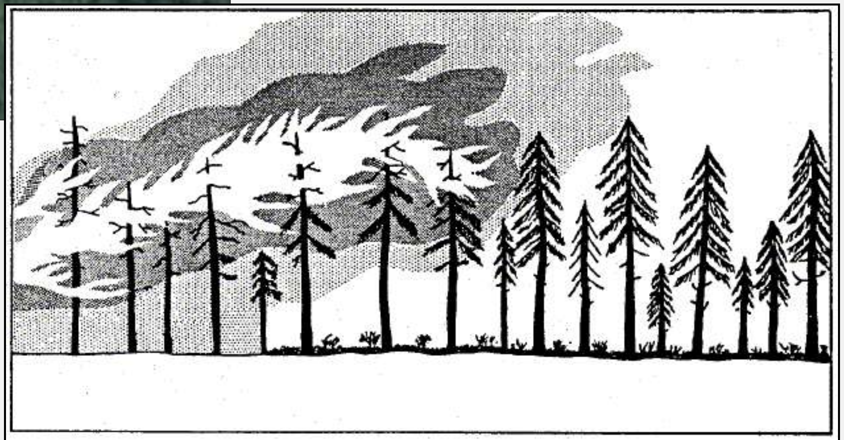
What is “crowning”?

“Crowning” is defined as:

A fire ascending into the crowns of trees and spreading from crown to crown.

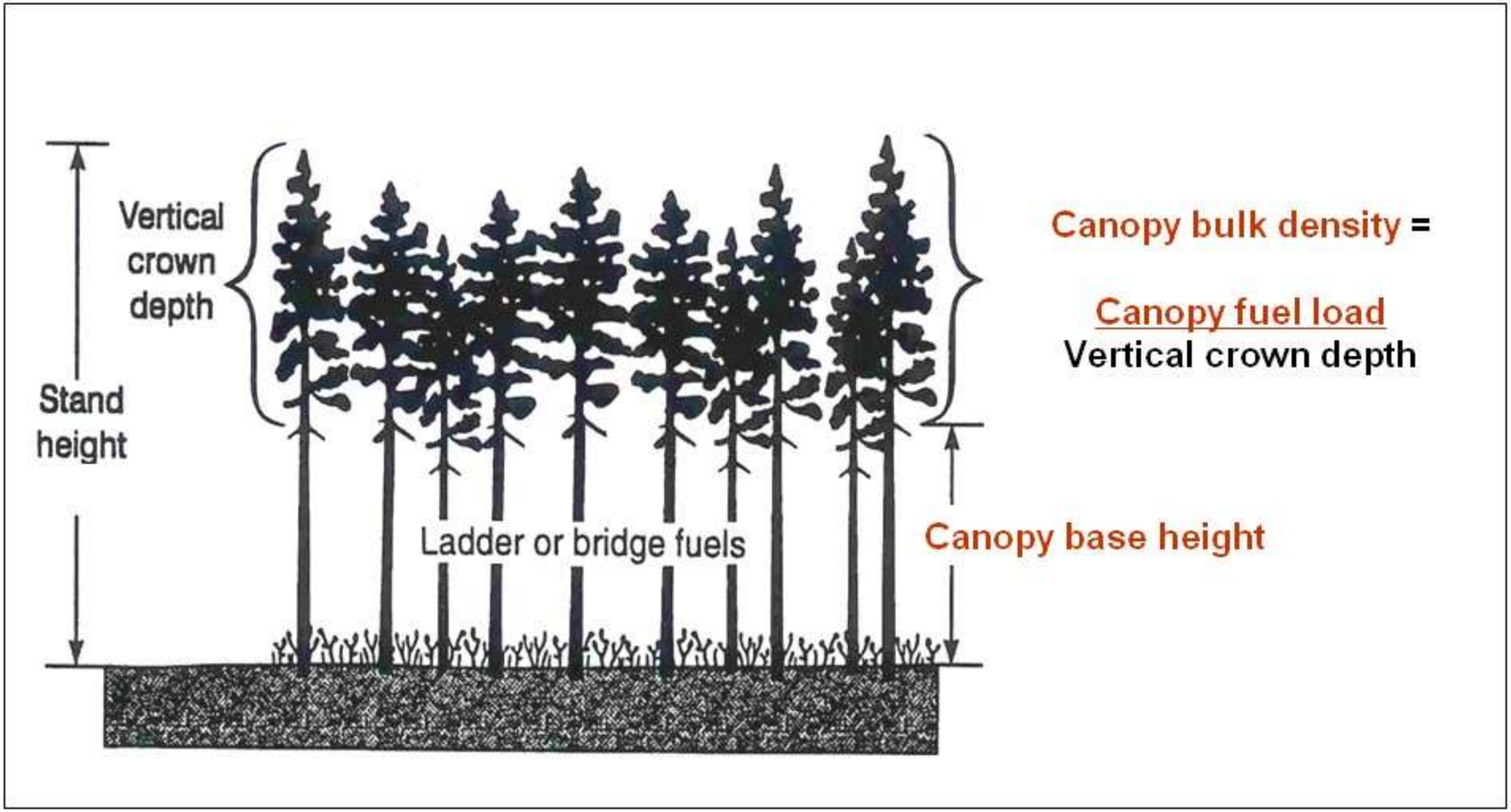
from Merrill and Alexander (1987) – Glossary of Forest Fire Management Terms

What types of crown fires are there?



See Van Wagner (1977) Conditions for the start and spread of crown fire. *CJFR*

Canopy Fuel Stratum and Stand Characteristics



Available Crown Fuel Load: needle foliage, lichens, small dead and live (a proportion) twigs < 1 cm in diameter

Ladder or bridge fuels: bark flakes, lichens, needle drape, boles branches (live & dead), understory conifers, tall shrubs

Type of Crown Fire:

Passive or Dependent

Passive Crown Fires can occur under two broad situations:

- Canopy base height and canopy bulk density are considered optimum but fuel moisture and wind conditions are not quite severe enough to induce full-fledged crowning

- Canopy base height and canopy bulk density are, respectively, above and below the thresholds generally considered necessary for crowning so that even under severe burning conditions full-fledged crowning is not possible, although vigorous, high-intensity fire behavior can occur.

Type of Crown Fire:
Active, Running or Continuous

Active Crown Fires are most likely to occur in forests that have:

- Ground and surface fuels that permit development of a substantial surface fire
- A moderately high canopy or crown base height
- A fairly continuous crown layer of moderate to high bulk density and low to normal foliar moisture content

Type of Crown Fire:

Independent

"The crown phase will ... No longer depend in any way on the surface phase and can run ahead on its own."
– Van Wagner (1977)

Adapted from Brown and Davis (1973)

"In other words, the spread of crown fire independent of any surface fire is essentially ruled out as a stable phenomenon on level terrain. …" – Van Wagner (1993)

Understanding Crown Fire Behavior from Experimental Fire and Wildfire Observations

Red Pine Plantation, Petawawa, Ontario




Lodgepole Pine Stand, central British Columbia

Mature Jack Pine Stand,
Northeastern Ontario

Mature Jack Pine Stand,
Northeastern Alberta

Immature Jack Pine Stand, Northeastern Ontario

Spruce-budworm Killed Balsam Fir Stand, Northeastern Ontario

Spruce-Lichen Woodland Stand, Northwest Territories

Lowland Black Spruce Stand, North-central Alberta

International Crown Fire Modelling Experiment (ICFME), Northwest Territories

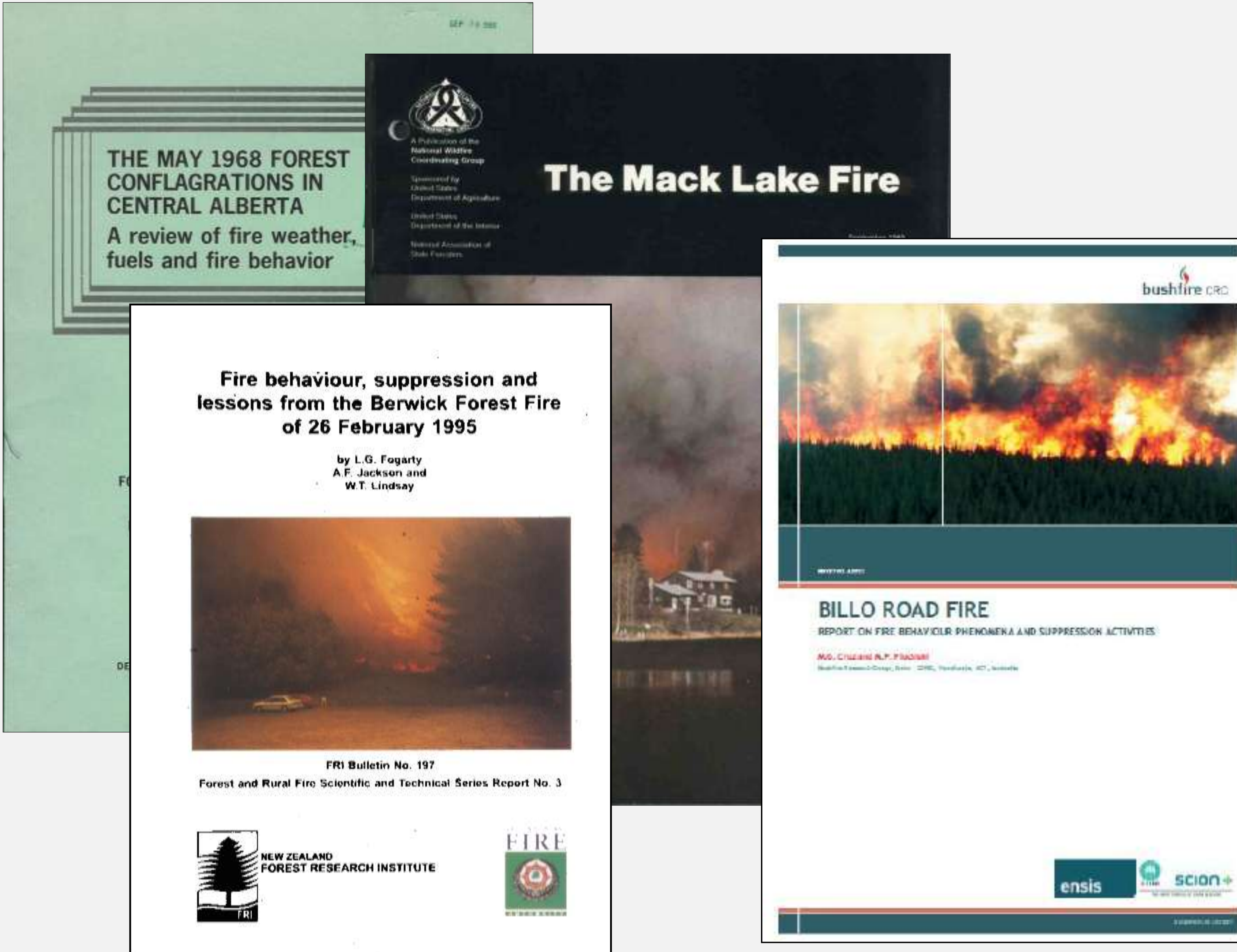

Wildfire
Observations

General Value of Case Studies

"Time and time again case histories have proven their value as training aids and as sources of research data."

Chandler (1976)

Craig C. Chandler
USFS Fire Research Director

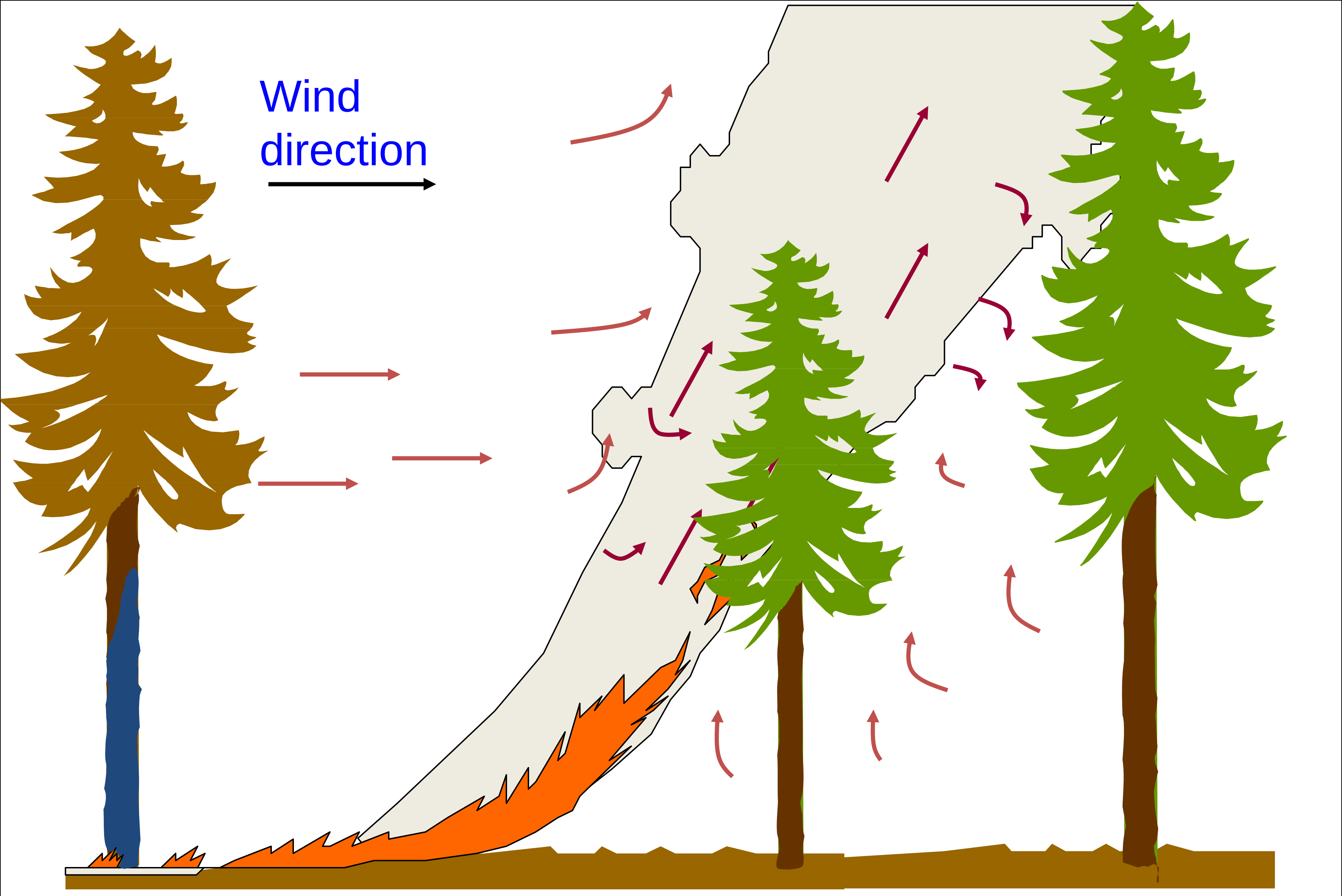

THE MAY 1968 FOREST CONFLAGRATIONS IN CENTRAL ALBERTA
A review of fire weather, fuels and fire behavior
The Mack Lake Fire
A Publication of the National Wildfire Coordinating Group
Fire behaviour, suppression and lessons from the Berwick Forest Fire of 26 February 1995
by L.G. Fogarty
A.F. Jackson and
W.T. Lindsay
FRI Bulletin No. 197
Forest and Rural Fire Scientific and Technical Series Report No. 3
NEW ZEALAND
FOREST RESEARCH INSTITUTE
FRI
FIRE
bushfire CRC
BILLO ROAD FIRE
REPORT ON FIRE BEHAVIOUR PHENOMENA AND SUPPRESSION ACTIVITIES
ensis
scion

CROWN FIRE BEHAVIOR IN CONIFER FORESTS: A PRE-CONFERENCE WORKSHOP

Crown Fire Initiation and Sustained Propagation

International Association of Wildland Fire 4th Fire Behavior and Fuels Conference

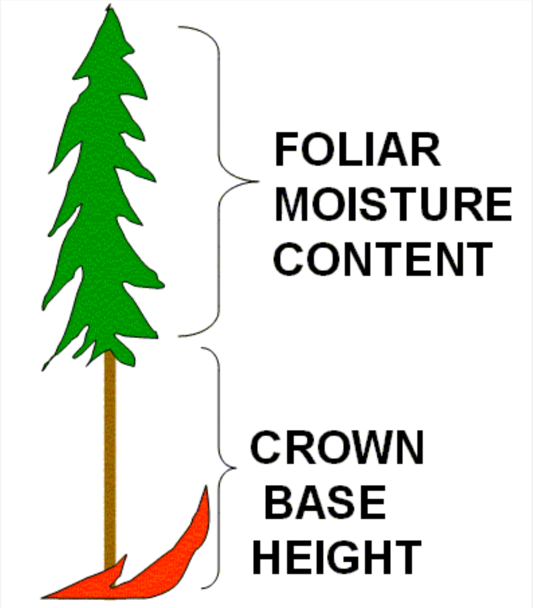
February 18, 2013 – Raleigh, NC



Cross section of a wind-driven surface fire

Van Wagner’s (1977) Crown Fire Initiation Model

Vertical fire spread into the overstory canopy will occur when the surface fire intensity (I_s) attains the critical value I_o as determined by z and m.



$I_s < I_o$:
Surface Fire

$I_s \sim I_o$: Surface Fire - Crown Fire Transition

$I_s > I_o$:
Crown Fire

Van Wagner's (1977) Theory on Initiation of Crowning: Starting with two basic equations

Temperature rise (ΔT) at height z over a line heat source, I (after Thomas 1963)

$$\Delta T \propto I^{2/3}/z$$

Heat of ignition (h – kJ/kg) in relation to foliar moisture content (m - %) (from Van Wagner 1968)

$$h = 460 + 25.9 \cdot M$$

Replacing $\Delta T/h_o$ with an empirical quantity C yields:

$$I_o = (C \cdot z \cdot h)^{3/2}$$

where I_o is the critical surface intensity (kW/m) needed to initiate crowning and C is a criterion for initial crown combustion

Van Wagner's (1977) Criterion for Initial Crown Combustion

***"The quantity C is best regarded as an empirical constant of complex dimensions whose value is to be found from field observations."* – Van Wagner (1977)**

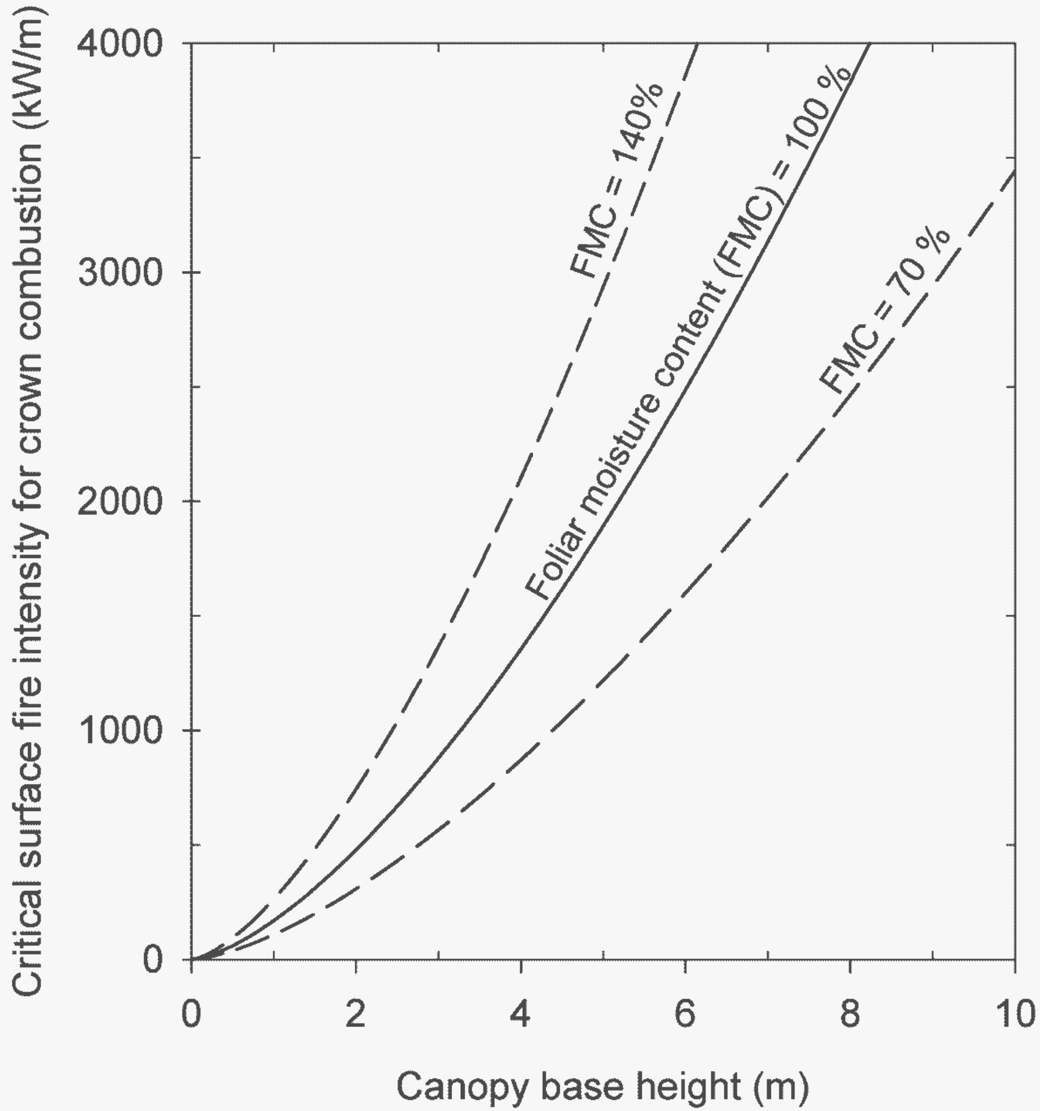
A value of 0.010 was derived for ***C*** from an experimental fire in a red pine plantation (z = 6 m and m = 100%) exhibiting an intensity of ~ 2500 kW/m just prior to crowning as follows:

$$C = I_o^{3/2}/(z \cdot h)$$

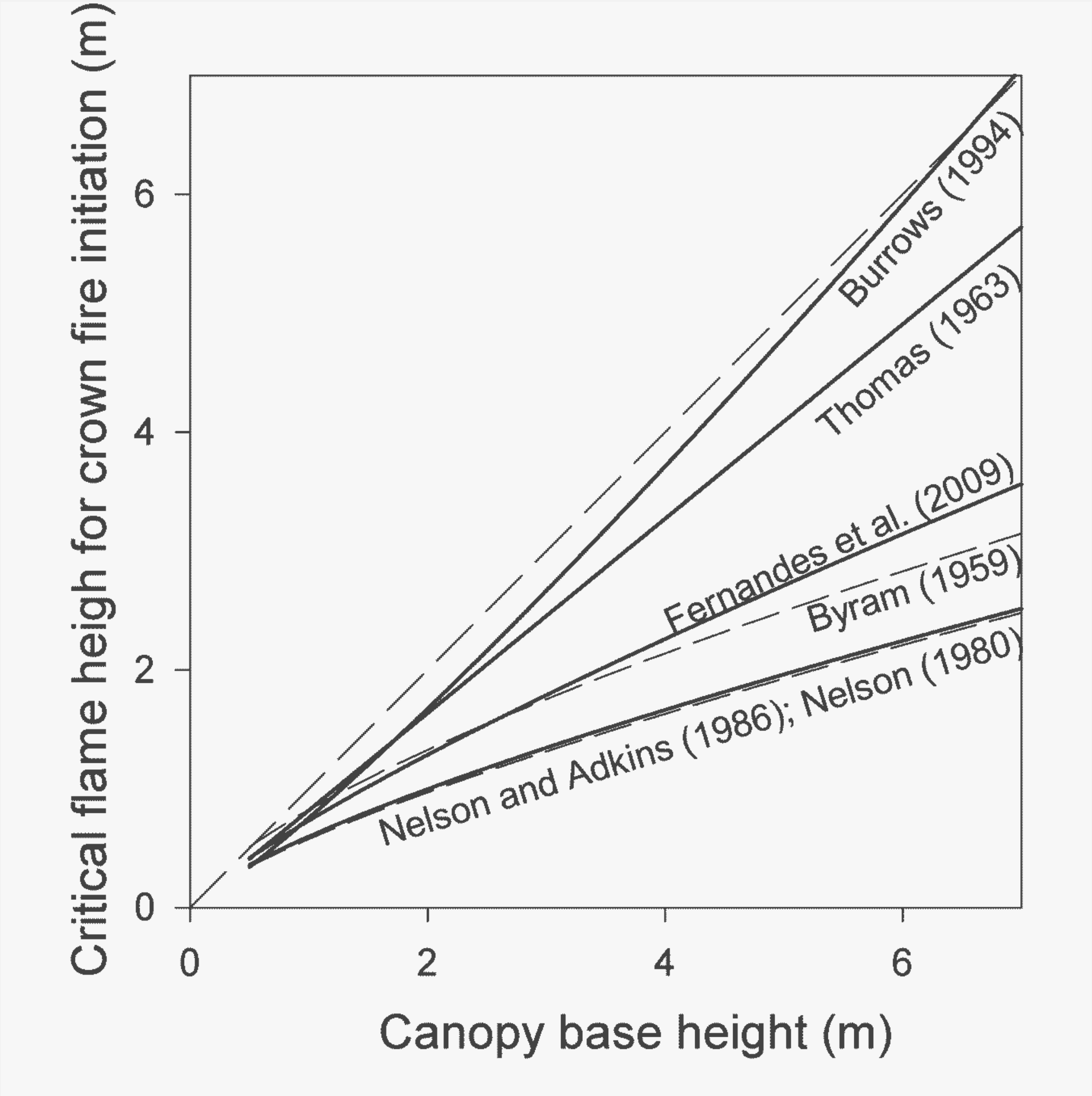
$$C = 2500^{3/2}/(6 \cdot (460 + 26 \cdot 100))$$

$$C = 0.010$$

Van Wagner's (1977) Crown Fire Initiation Model



Van Wagner's (1977) Crown Fire Initiation Model



Van Wagner's (1977) Crown Fire Initiation Model: Strengths and Weaknesses

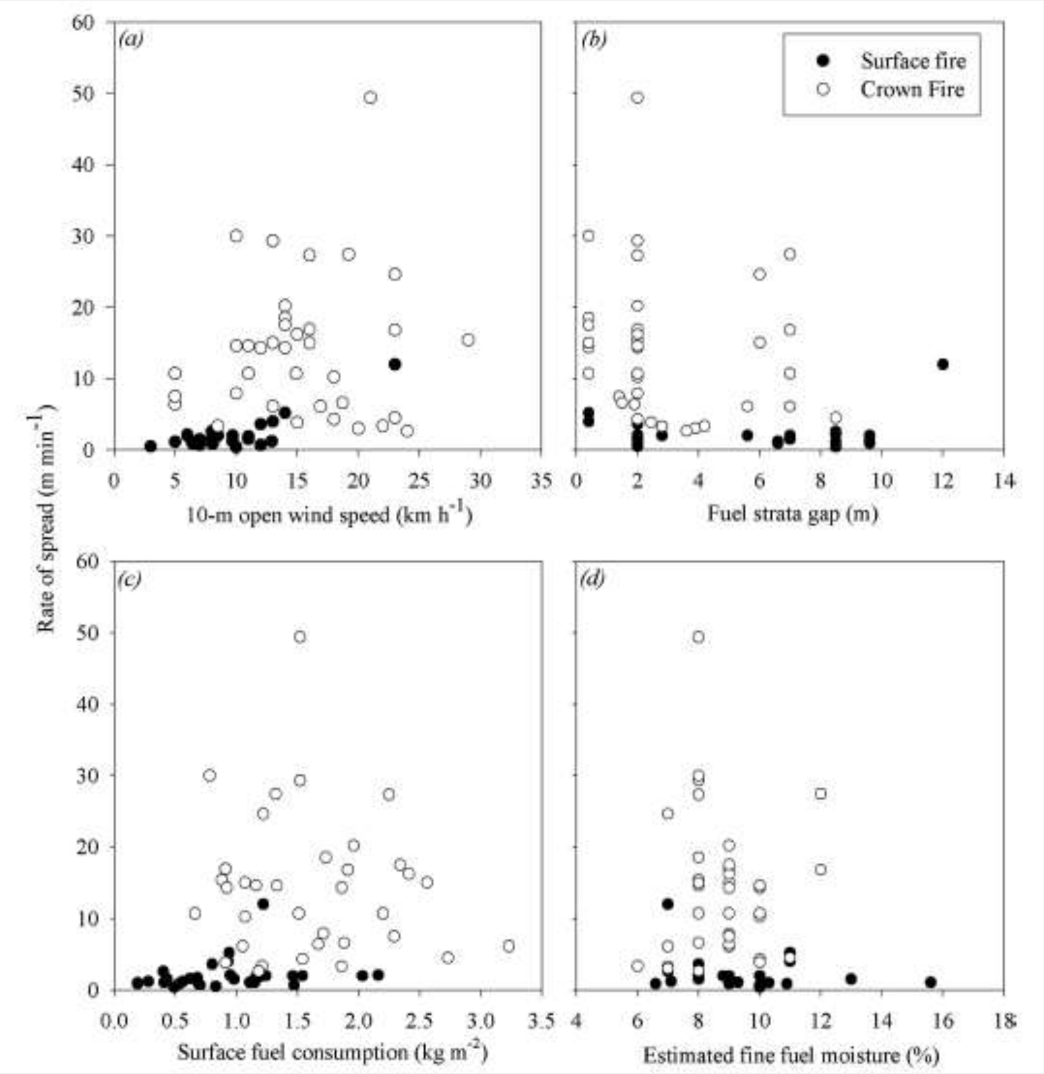
Simplicity:

Only two crown fuel properties (***z*** and ***m***) and an estimate of potential surface fire intensity required as inputs

Limitations:

• Truth of the matter is, that separate ***C*** values are required for distinctly different fuel complexes – furthermore, currently used value (0.010) is essentially based on a single observation.
• Doesn't allow for variable duration of heating (presently the flame front residence time is a constant 50 sec) – thus, quite possible for two surface fires to have the same intensity but significantly different residence times (e.g., grass vs. conifer needle forest floor).
• Surface burning conditions (i.e., temp, RH, plus in-stand wind and thus fire plume angle) a constant rather than a variable.

Cruz, Alexander and Wakimoto (2004) Crown Fire Occurrence Probability Model



- Comprehensive review of the literature
- Number of variables examined
- Data available for 34 surface fires & 37 crown fires (principally Canadian but a few fires from Portugal and Australia)

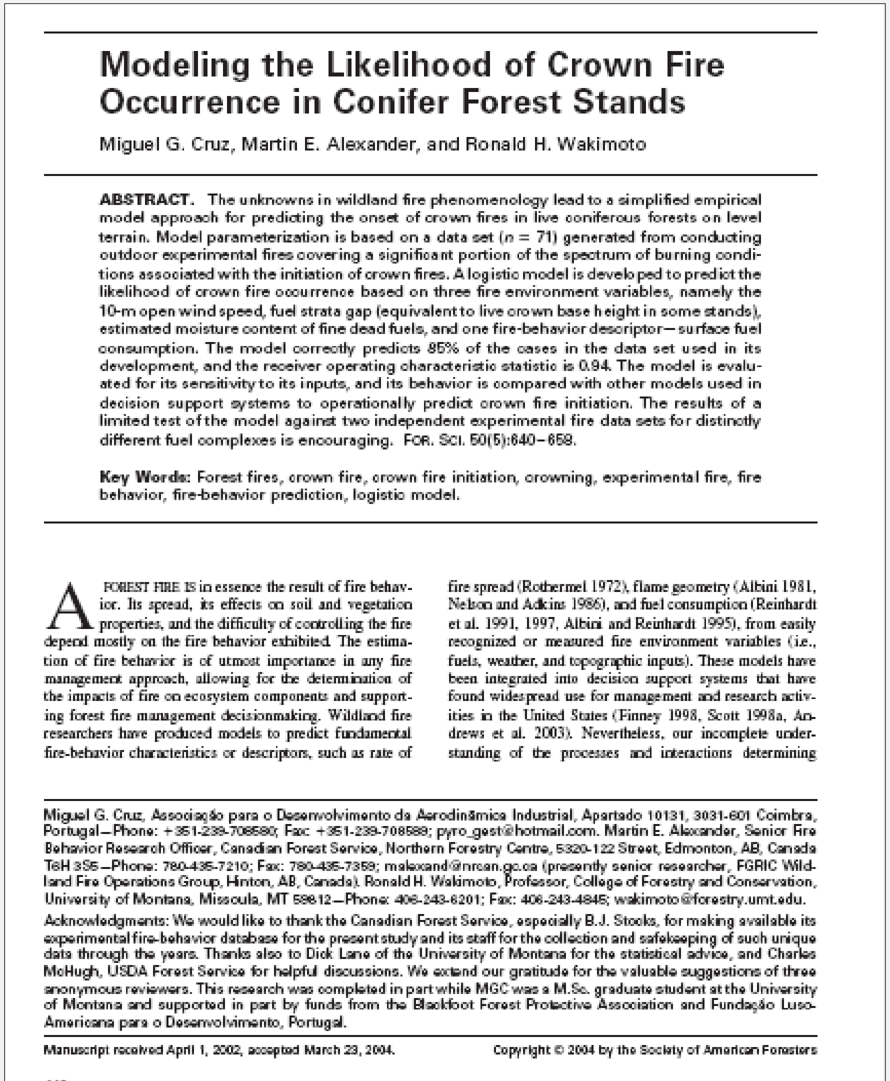
Red pine plantation, Ontario

Lodgepole pine stand, BC

Immature Jack Pine Stand, Northeastern, ON

Spruce-Lichen Woodland Stand, NWT

Cruz, Alexander and Wakimoto (2004) Crown Fire Occurrence Probability Model



Modeling the Likelihood of Crown Fire Occurrence in Conifer Forest Stands

Miguel G. Cruz, Martin E. Alexander, and Ronald H. Wakimoto

ABSTRACT. The unknowns in wildland fire phenomenology lead to a simplified empirical model approach for predicting the onset of crown fires in live coniferous forests on level terrain. Model parameterization is based on a data set ($n = 71$) generated from conducting outdoor experimental fires covering a significant portion of the spectrum of burning conditions associated with the initiation of crown fires. A logistic model is developed to predict the likelihood of crown fire occurrence based on three fire environment variables, namely the 10-m open wind speed, fuel strata gap (equivalent to live crown base height in some stands), estimated moisture content of fine dead fuels, and one fire-behavior descriptor—surface fuel consumption. The model correctly predicts 85% of the cases in the data set used in its development, and the receiver operating characteristic statistic is 0.94. The model is evaluated for its sensitivity to its inputs, and its behavior is compared with other models used in decision support systems to operationally predict crown fire initiation. The results of a limited test of the model against two independent experimental fire data sets for distinctly different fuel complexes is encouraging. For. Sci. 50(5):640–658.

Key Words: Forest fires, crown fire, crown fire initiation, crowning, experimental fire, fire behavior, fire-behavior prediction, logistic model.

A FOREST FIRE IS in essence the result of fire behavior. Its spread, its effects on soil and vegetation properties, and the difficulty of controlling the fire depend mostly on the fire behavior exhibited. The estimation of fire behavior is of utmost importance in any fire management approach, allowing for the determination of the impacts of fire on ecosystem components and supporting forest fire management decisionmaking. Wildland fire researchers have produced models to predict fundamental fire-behavior characteristics or descriptors, such as rate of fire spread (Rothermel 1972), flame geometry (Albini 1981, Nelson and Adkins 1986), and fuel consumption (Reinhardt et al. 1991, 1997, Albini and Reinhardt 1995), from easily recognized or measured fire environment variables (i.e., fuels, weather, and topographic inputs). These models have been integrated into decision support systems that have found widespread use for management and research activities in the United States (Finney 1998, Scott 1998a, Andrews et al. 2003). Nevertheless, our incomplete understanding of the processes and interactions determining

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Acknowledgments: We would like to thank the Canadian Forest Service, especially B.J. Stocks, for making available its experimental fire-behavior database for the present study and its staff for the collection and safekeeping of such unique data through the years. Thanks also to Dick Lane of the University of Montana for the statistical advice, and Charles McHugh, USDA Forest Service for helpful discussions. We extend our gratitude for the valuable suggestions of three anonymous reviewers. This research was completed in part while MGC was a M.Sc. graduate student at the University of Montana and supported in part by funds from the Blackfoot Forest Protective Association and Fundação Luso-Americana para o Desenvolvimento, Portugal.

Manuscript received April 1, 2002, accepted March 23, 2004.

October 2004 – *Forest Science*

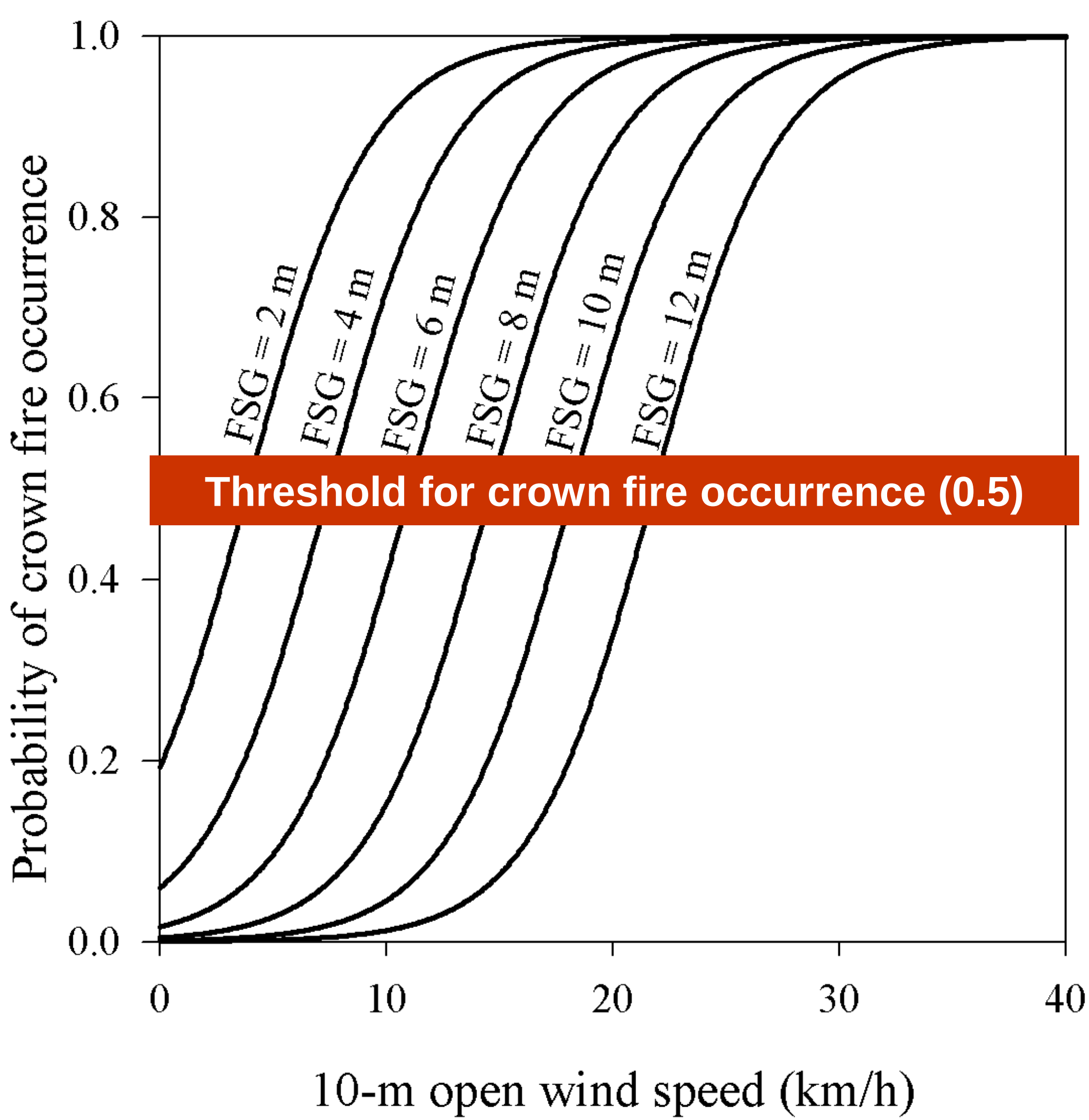
Logistic regression model requires three environmental inputs:

- 10-m open wind speed (***U_{10}***);
- Canopy base height (CBH) or fuel strata gap (***FSG***);
- Estimated fine fuel moisture (***EFFM***); and one fire behavior description:

- Surface fuel consumption (***SFC***) class (<1, 1-2, >2 kg/m^2)

Threshold for Crown Fire Occurrence judged to be 50% Probability.

Cruz, Alexander and Wakimoto (2004) Crown Fire Occurrence Probability Model

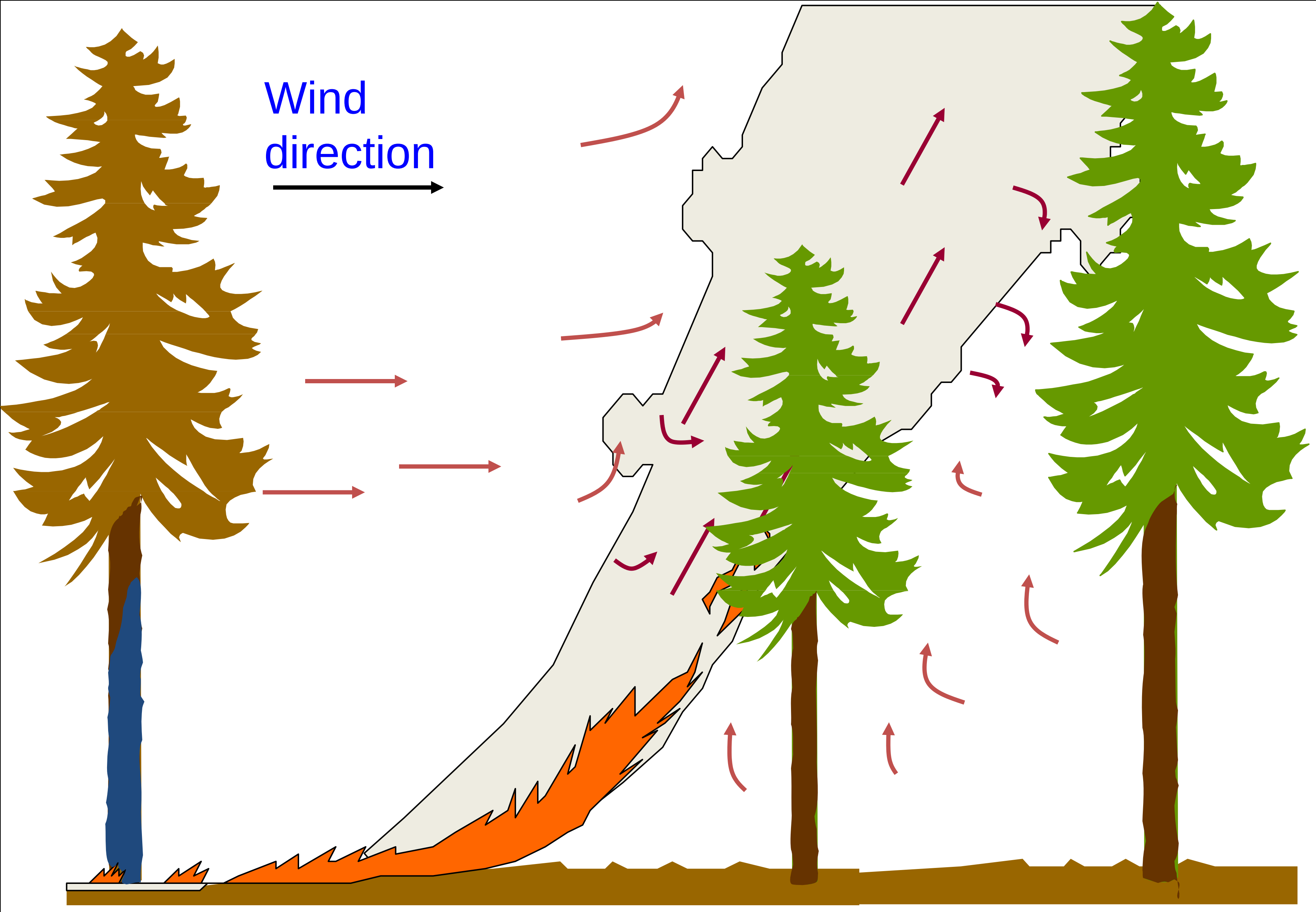


Effect of 10-m Open Wind Speed (*U_{10}*) under variable Fuel Strata Gap (*FSG*)

Assume:

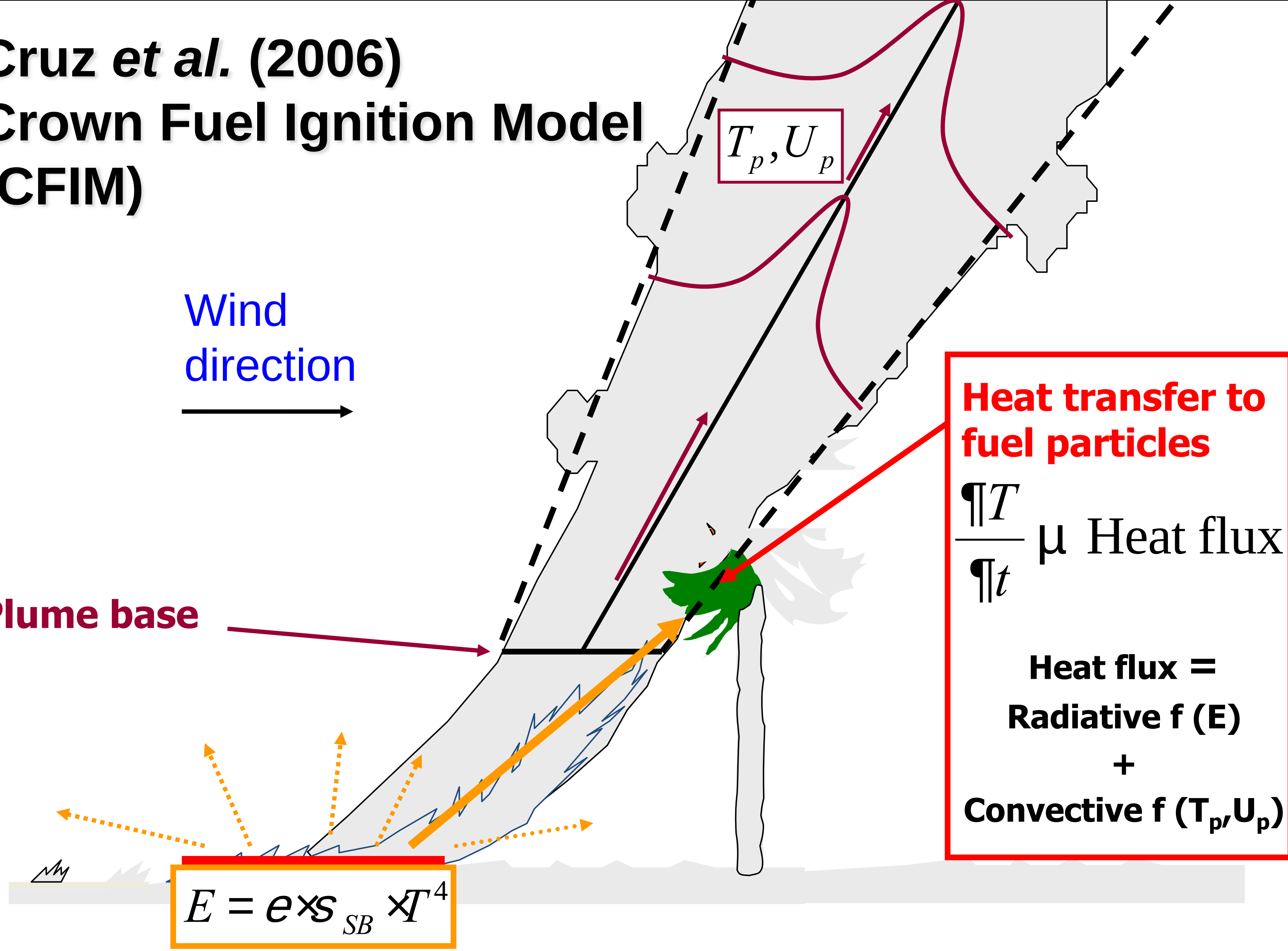
EFFM = 6%

SFC = 1-2 kg/m^2

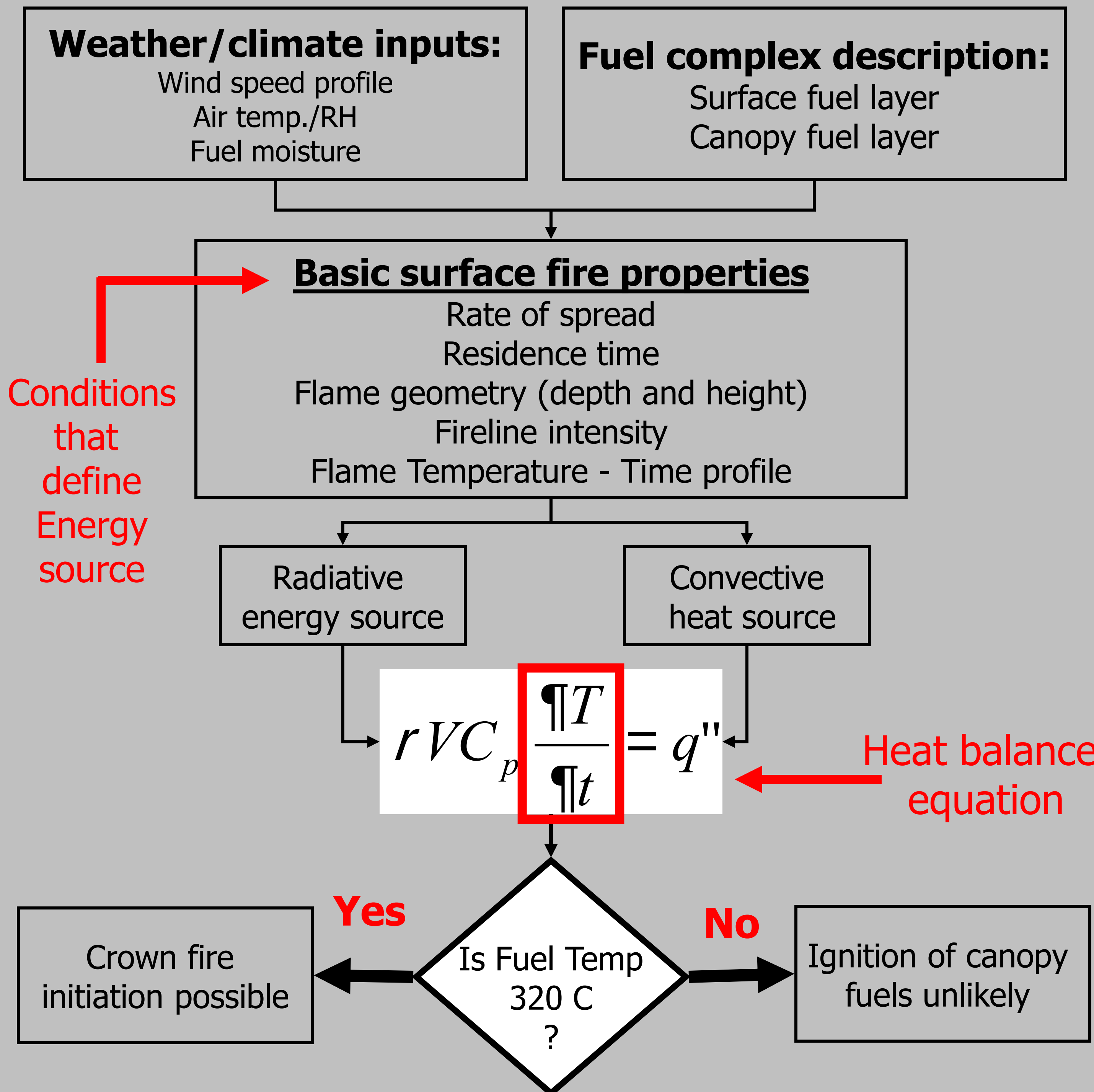


Cross section of a wind-driven surface fire

Cruz *et al.* (2006)
Crown Fuel Ignition Model (CFIM)



Cruz *et al.* (2006) Crown Fuel Ignition Model (CFIM)



Cruz *et al.* (2006)
Crown Fuel Ignition Model (CFIM):

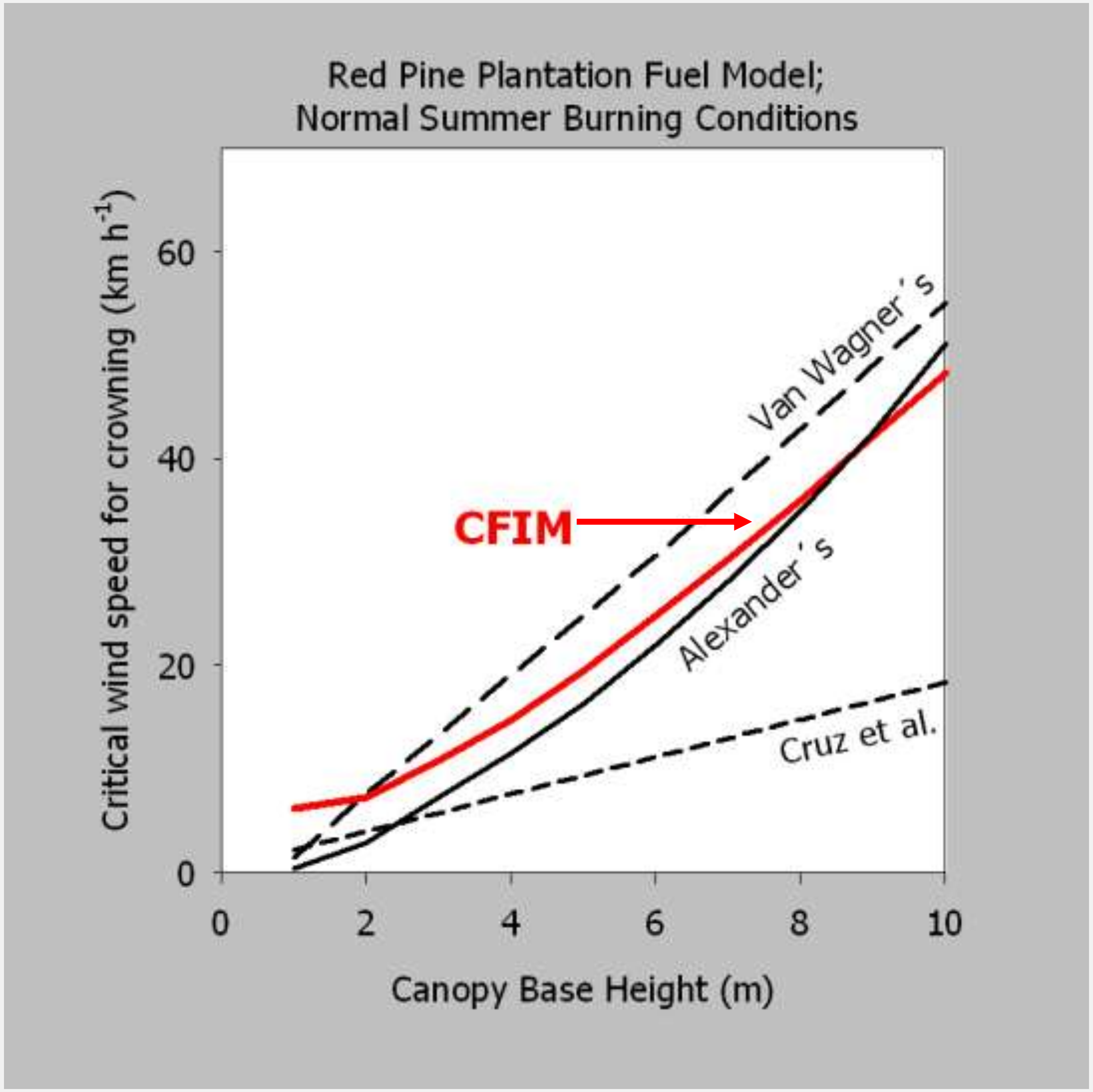
Evaluation Protocol

• Sensitivity analysis of input parameters

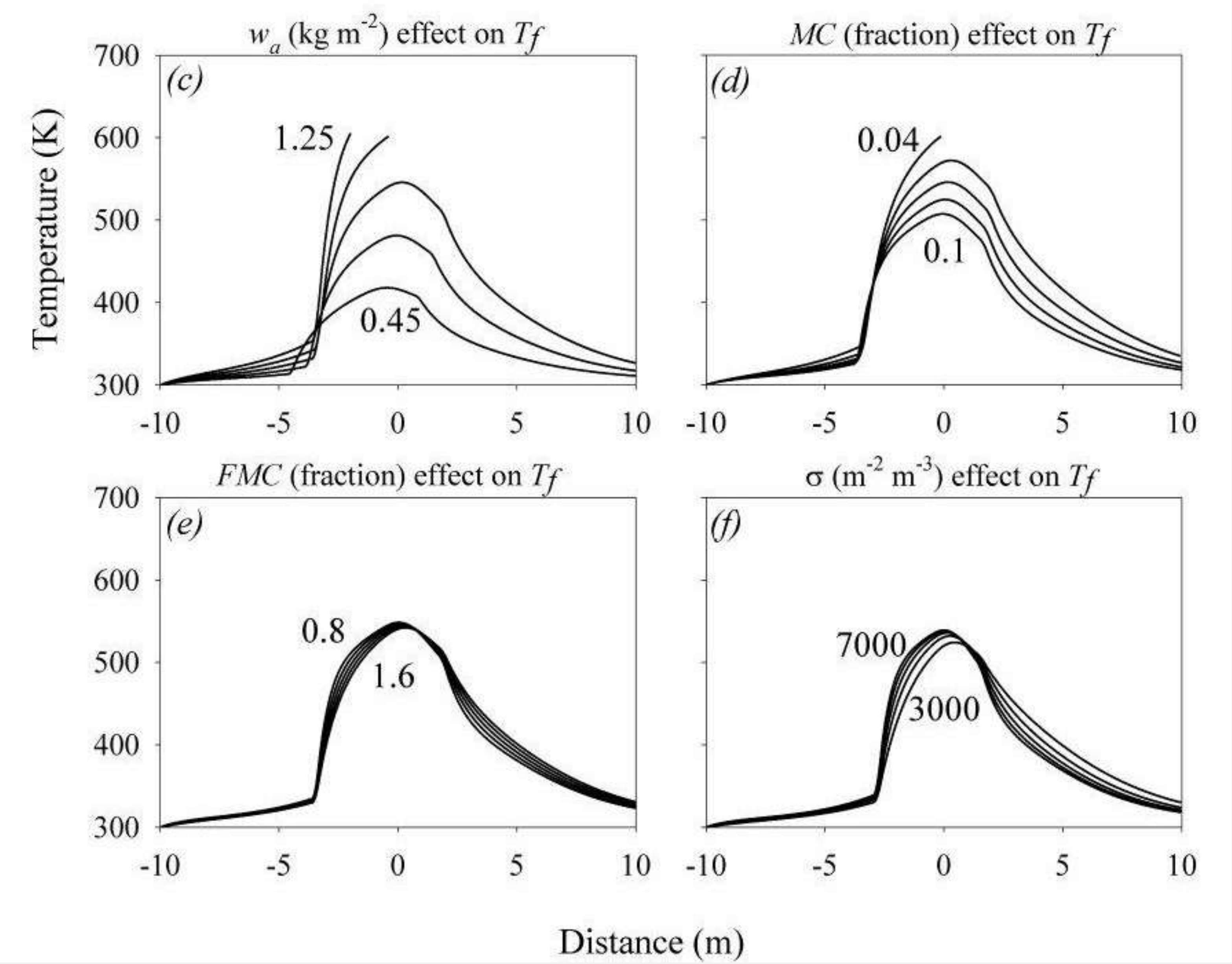
• Comparison against other models (Van Wagner 1977; Alexander 1998; Cruz, Alexander and Wakimoto 2004)

• Experimental fires (correctly predicted 14 of the 15 fires)

CFIM evaluation: critical wind speed for crowning under variable canopy base height.



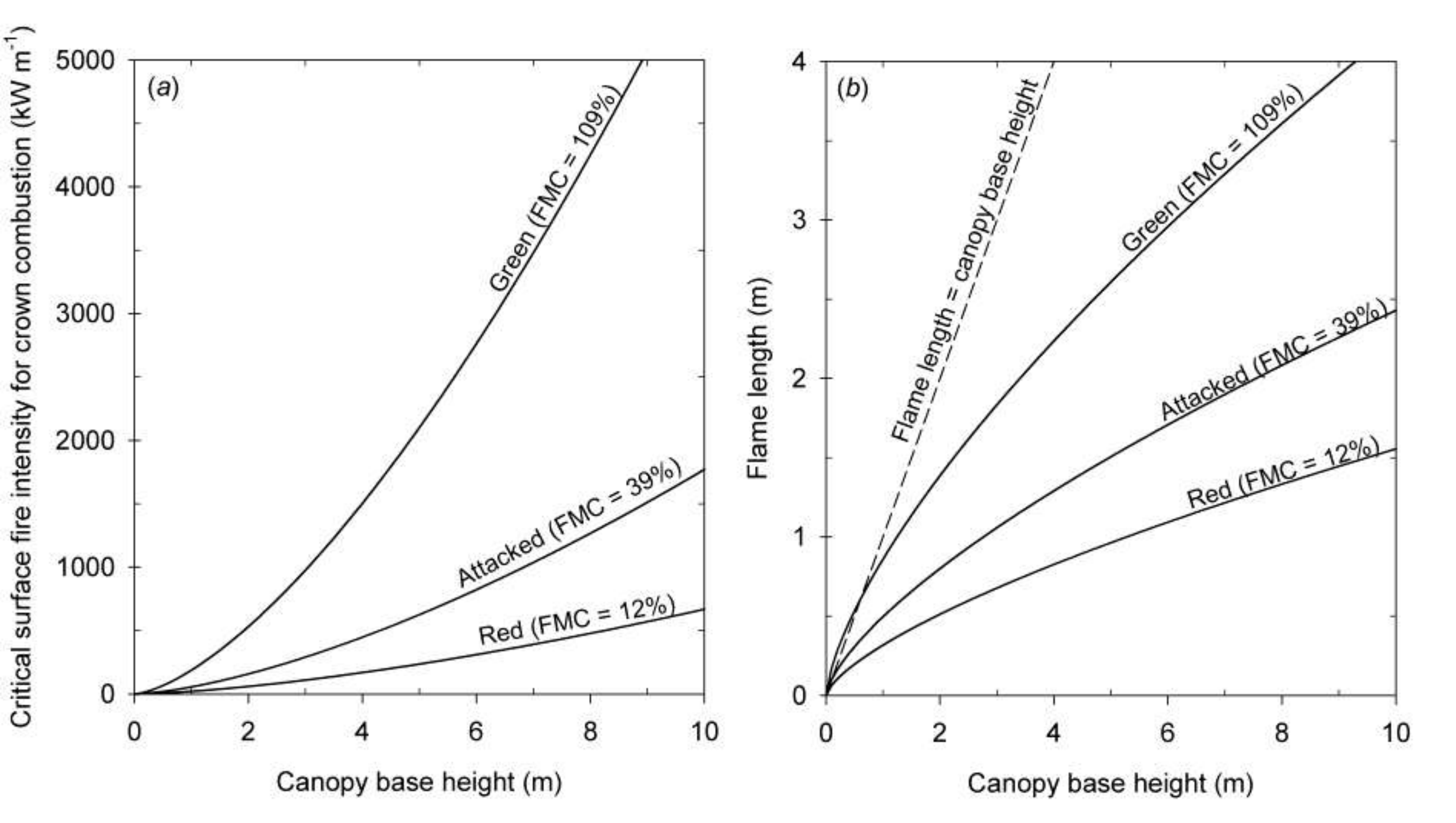
CFIM evaluation: sensitivity analysis



Ignition of dead crown fuels

Photo from Martin Simard

Ignition of dead crown fuels – application of Van Wagner crown fire initiation model



From Jenkins, Page, Hebertson and Alexander, 2012 FEM

Crown Fire Propagation

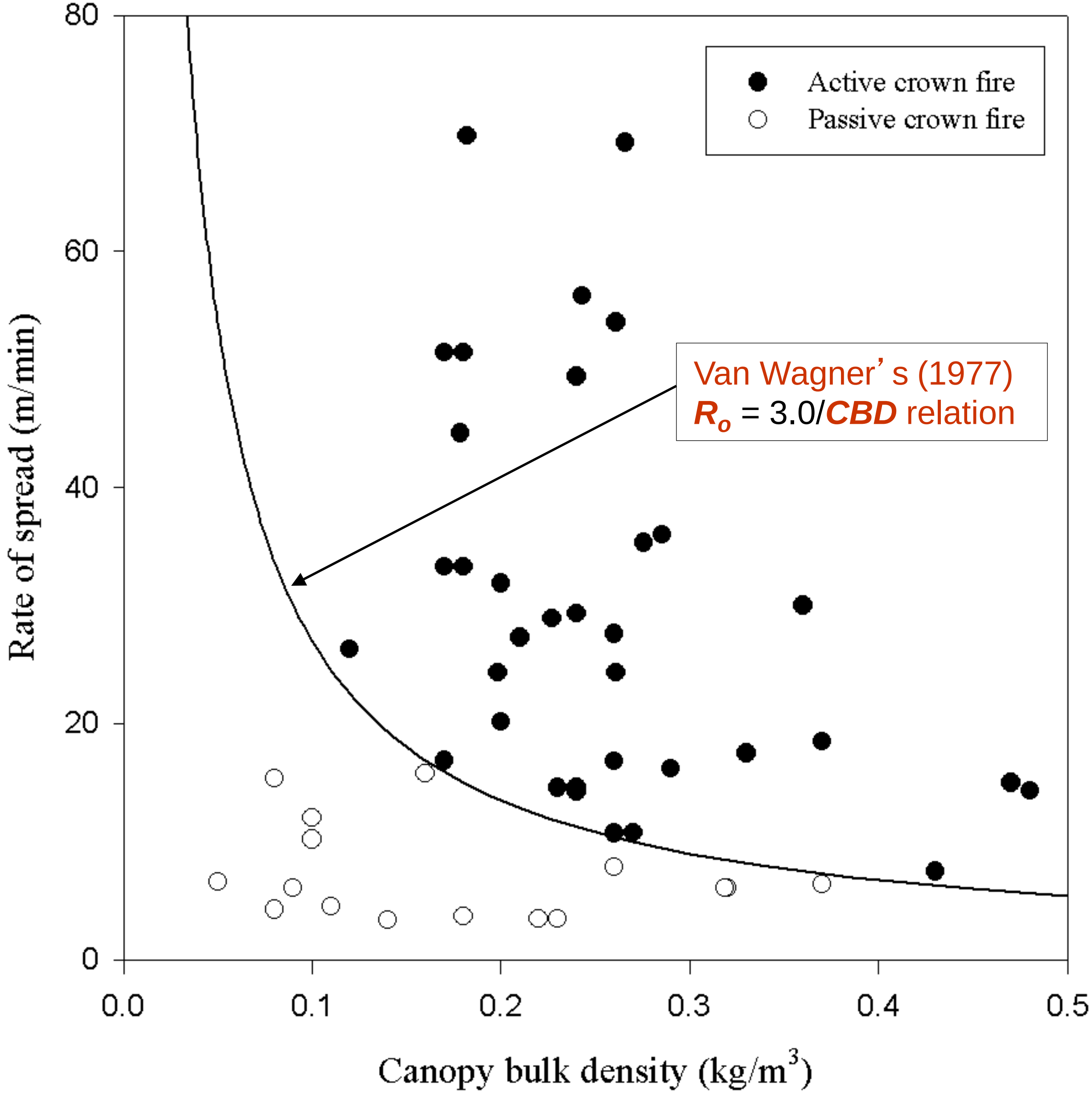
Van Wagner's (1977) Criteria for Solid Crown Flame

Based on rearranging a simple heat balance equation (cf. Thomas *et al.* 1964) for fire spread in wildland fuel the following relation was proposed:

$$R_o = S_o / CBD$$

Where R_o is the critical minimum spread (m/min) in order to sustain a continuous flame front within the crown fuel layer, S_o is the critical mass flow rate for solid crown flame (kg/m^2-min), and CBD is the canopy bulk density (kg/m^3).

S_o is regarded as an empirical constant to be derived from field observations. Best available estimate (3.0) based on experimental fires in red pine plantations.



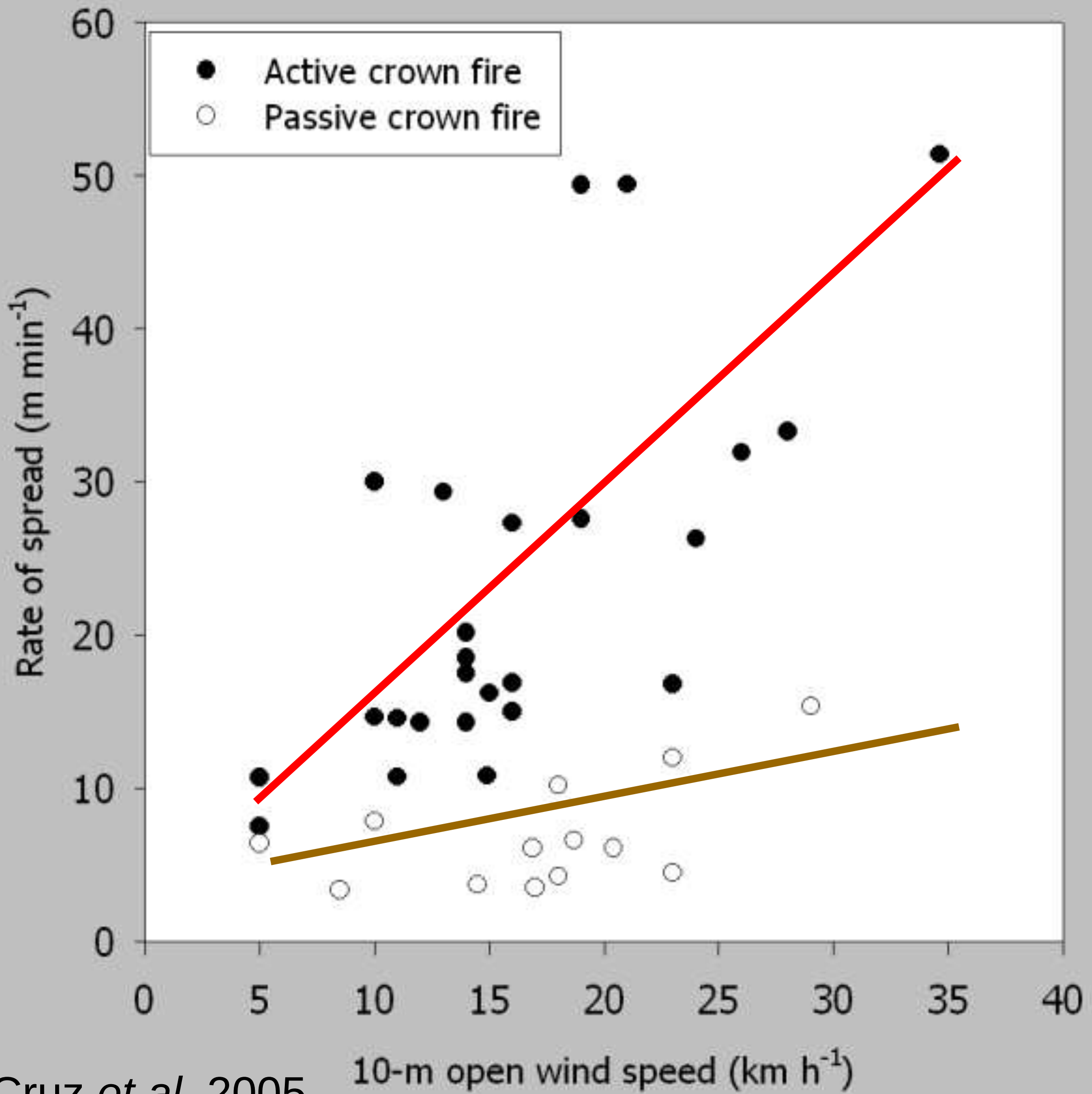
from Cruz, Alexander and Wakimoto (2005)

Experimental crown fires used in the development of the Canadian FBP System plotted.

Points of note:

- No passive crown fires with ***CBD*** < 0.05 kg/m^3
- No active crown fires with ***CBD*** < 0.11 kg/m^3

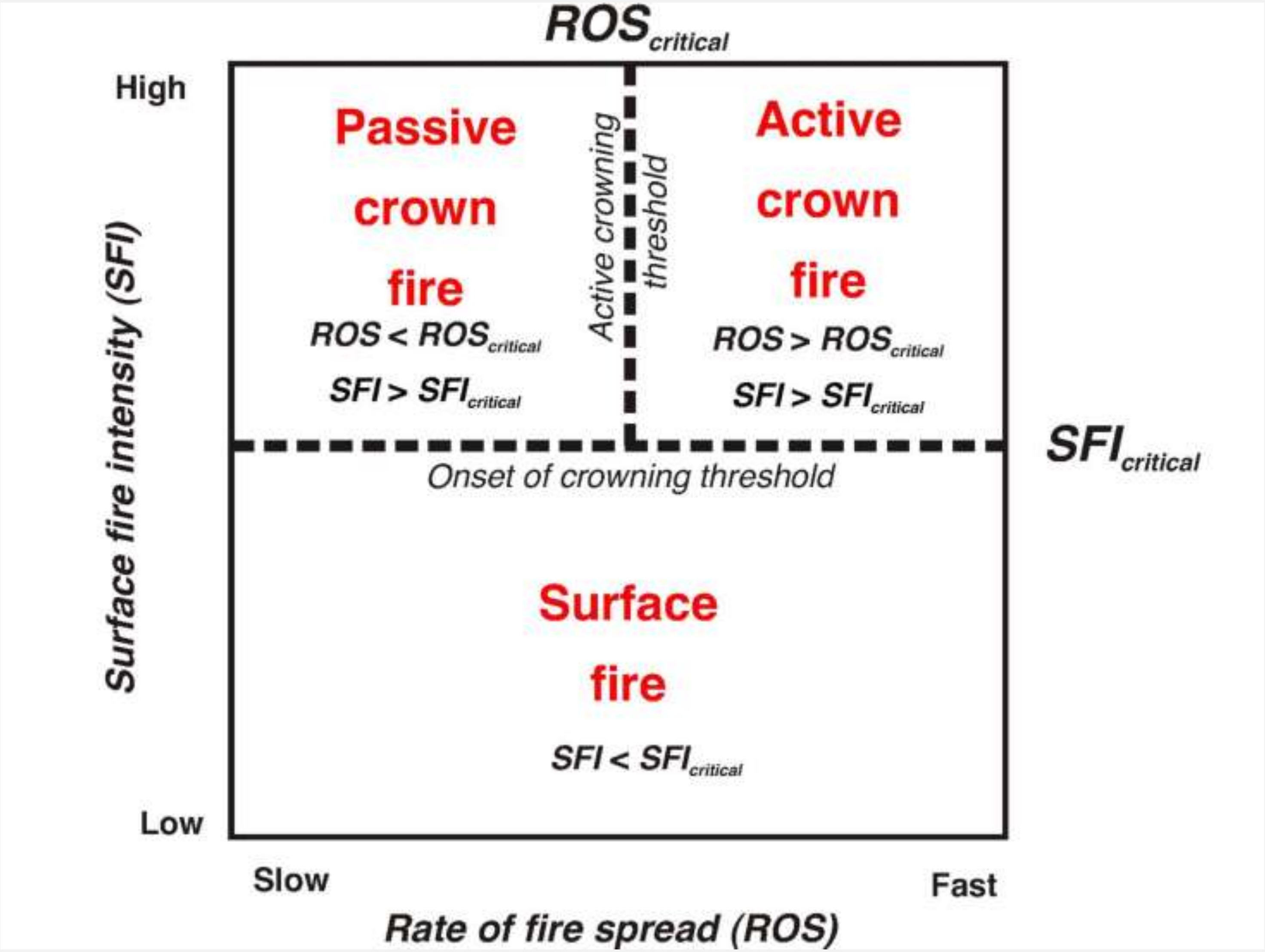
Crown fire rate of spread vs wind speed per spread regime



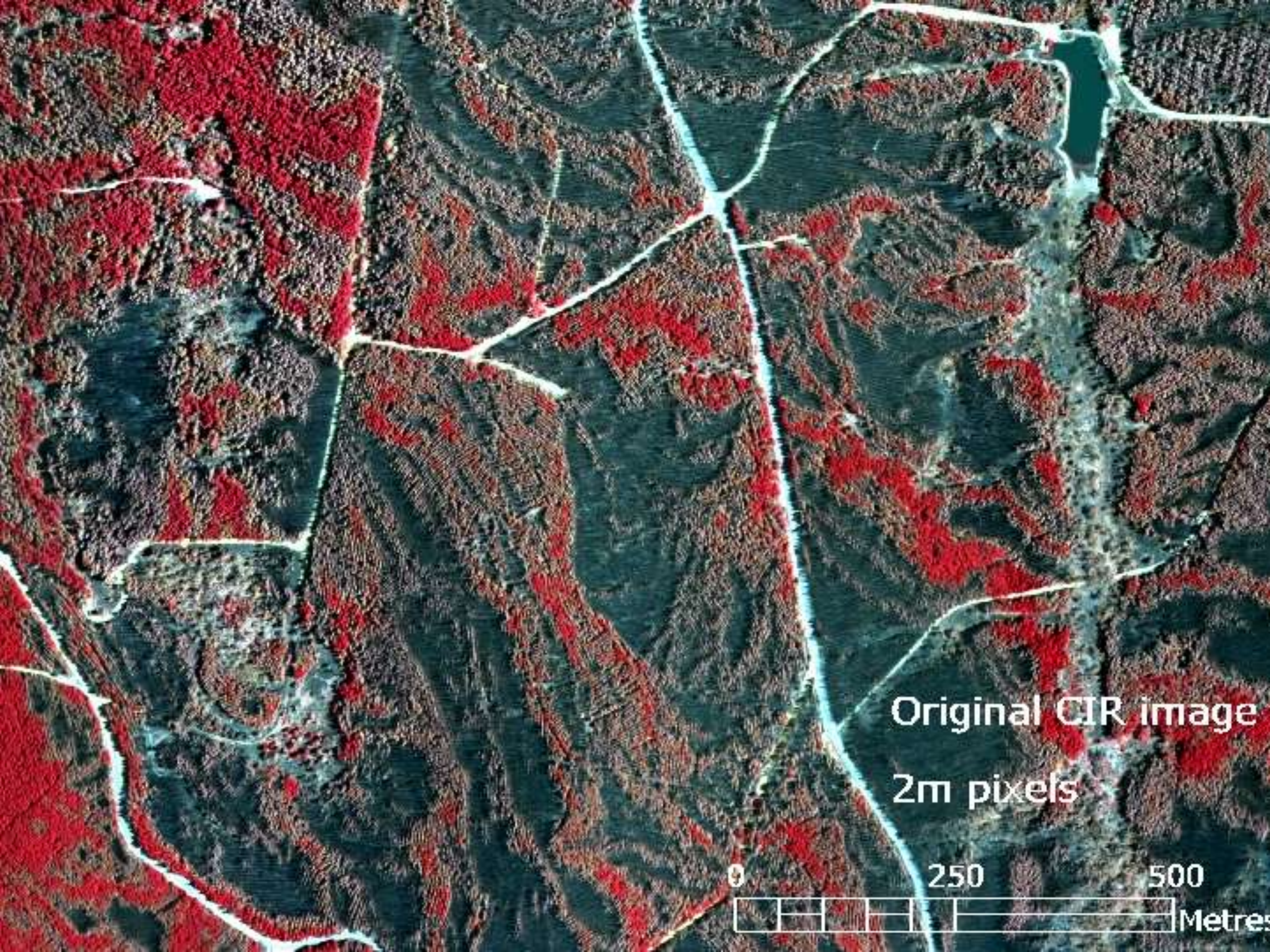
Cruz *et al*. 2005

Alexander et al. (1991) found in the Porter Lake Project that Van Wagner’s (1977) R_o relation worked reasonably well in a fuel type that you would consider as discontinuous or non-uniform from a crown fuel layer perspective, at least as the stand level.

Linking crown fire initiation and propagation theories

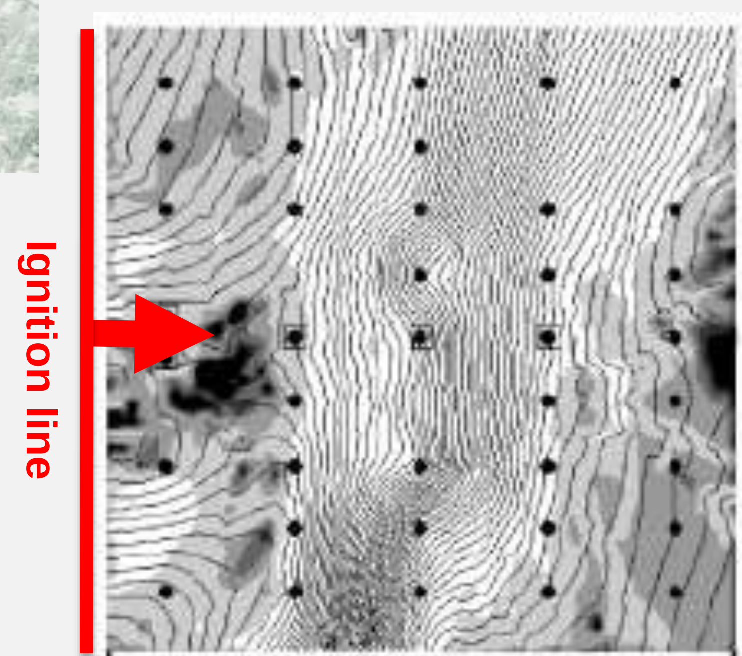


Intermittent crown fire propagation

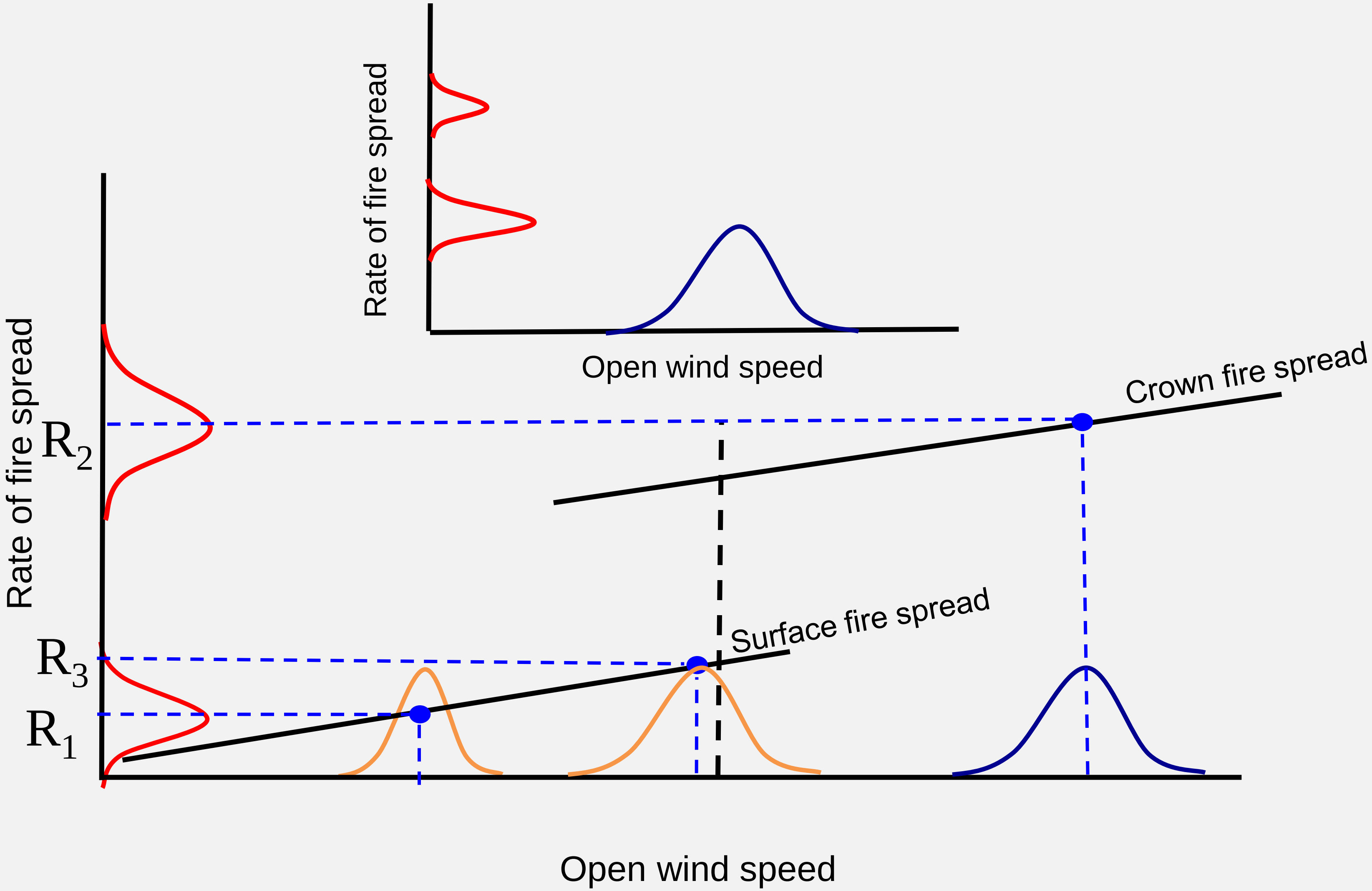

Original CIR image
2m pixels
0
250
500
Metres

Onset of crowning: effect on fire spread
ICFME Plot 8; Taylor *et al*. 2004; Stocks *et al*. 2004)

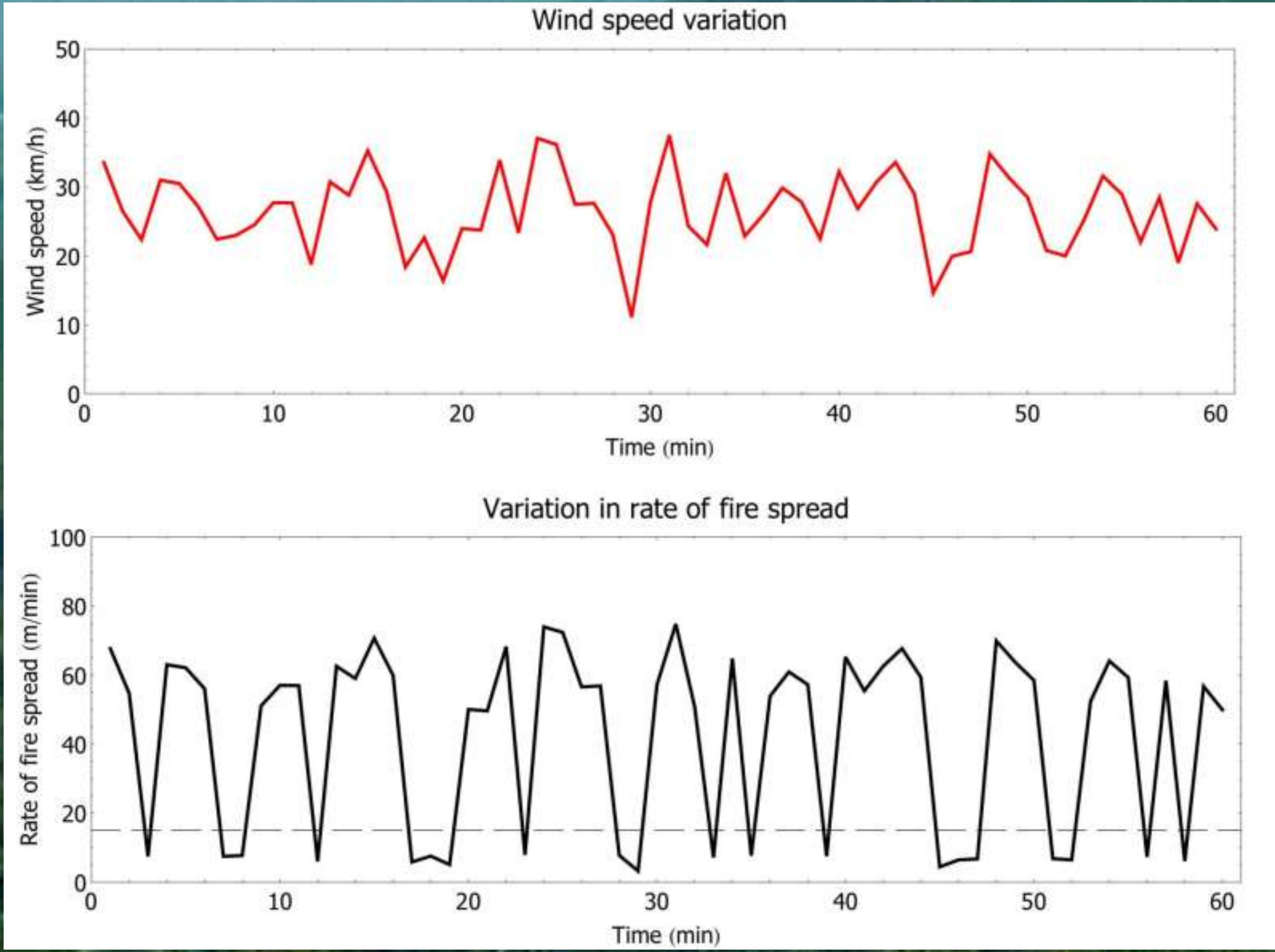
Phase	U10 (km/h)	ROS (m/min)
1 **(C)**	11.0	24.3
2 **(S)**	8.3	5.6
3 **(C)**	14.3	54.0



Intermittent crown fire propagation



Intermittent crown fire propagation



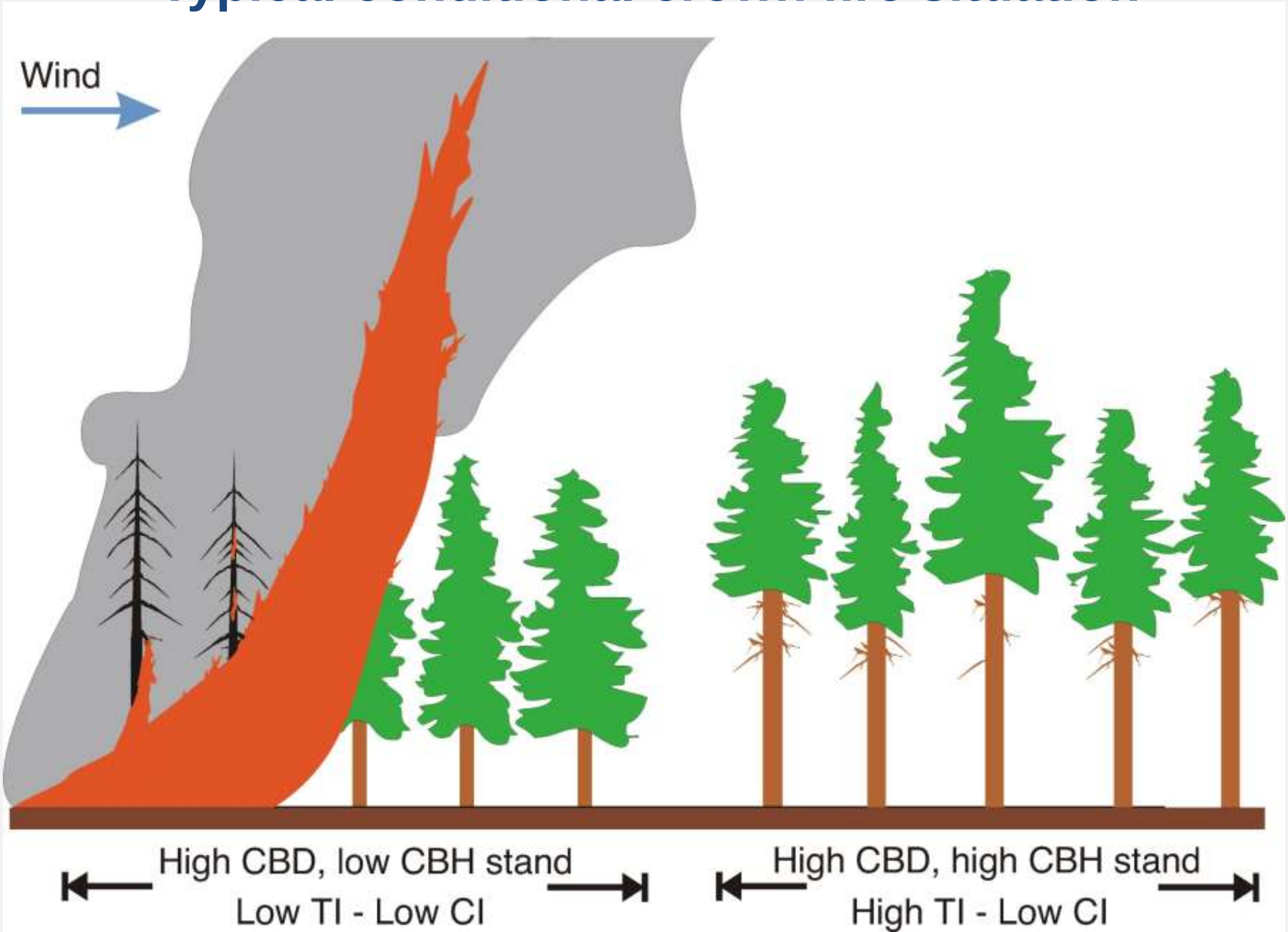
Conditional Crown Fire

A conditional crown fire represents a situation where conditions exist to support an active crown fire but would not result in the initiation of a crown fire (Scott and Reinhardt 2001).

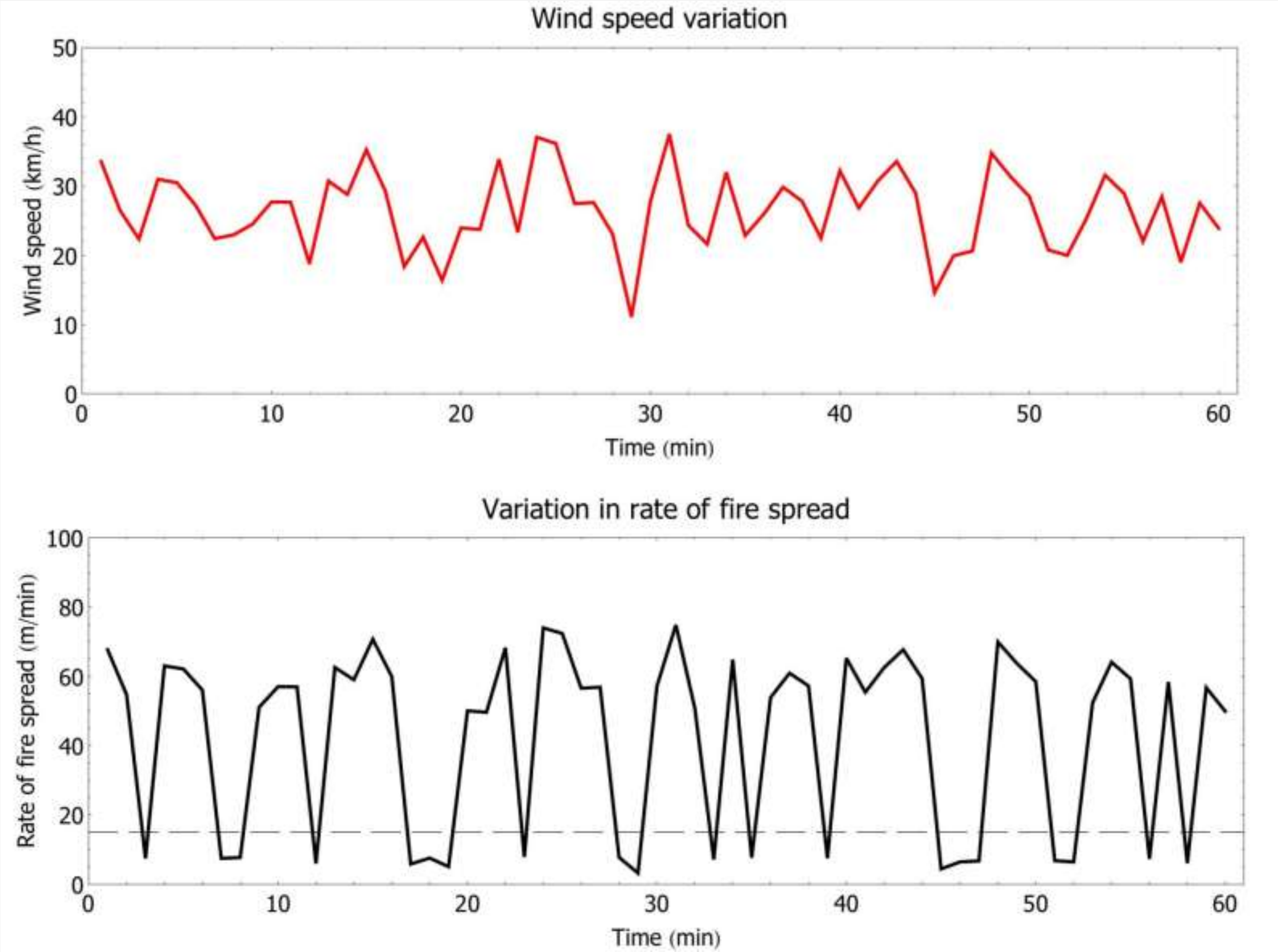
- Relatively high CBH and CBD.
- More extreme conditions (of wind and fuel moisture) are required to initiate crown fire than to maintain active crown fire.

Fire Type		Active crown fire?	
		No	Yes
Transition to crown fire?	No	Surface Fire	Conditional Crown Fire
	Yes	Passive Crown Fire	Active Crown Fire

Typical conditional crown fire situation



Effect of transient wind speed in simulated crown fire spread rate



CROWN FIRE BEHAVIOR IN CONIFER FORESTS: A PRE-CONFERENCE WORKSHOP

Crown Fire Characteristics

International Association of Wildland Fire 4th Fire Behavior and Fuels Conference

February 18, 2013 – Raleigh, NC

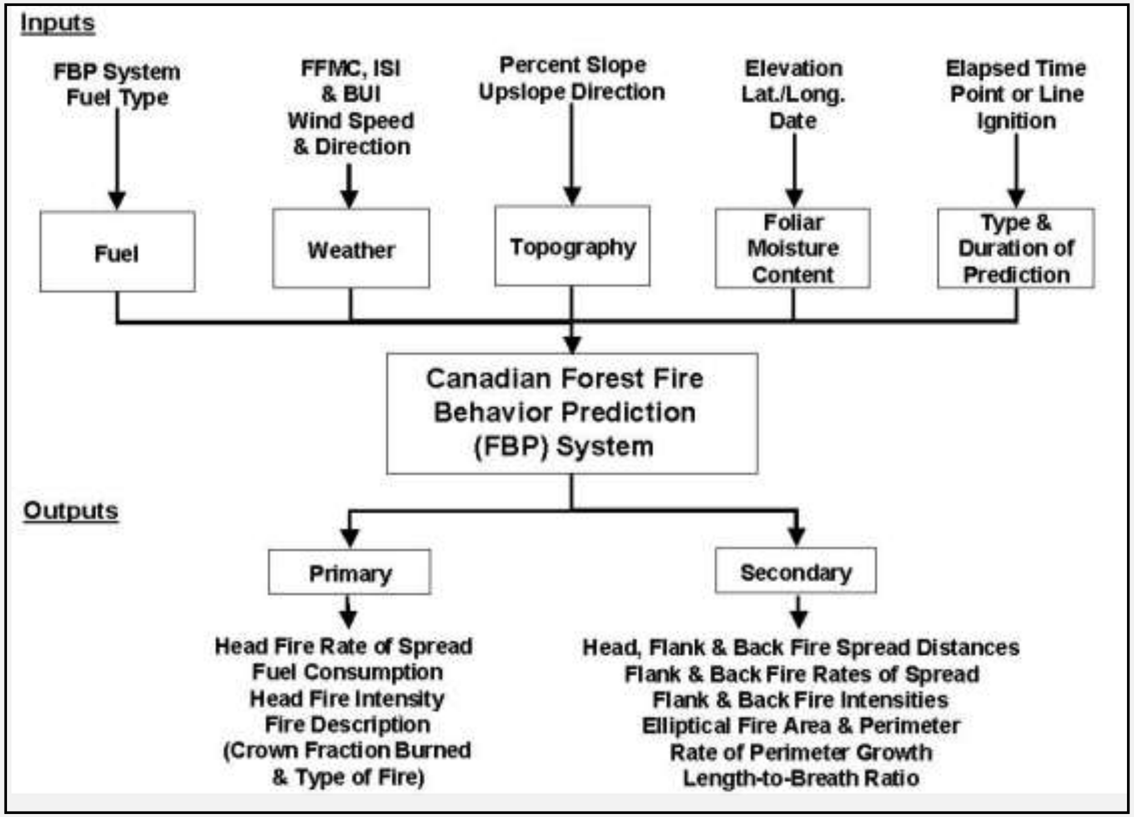
Crown Fire Rate of Spread

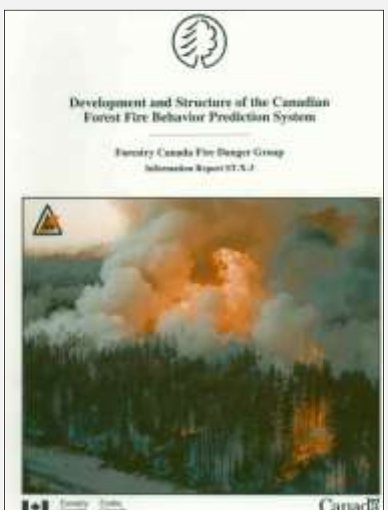
Canadian FBP System

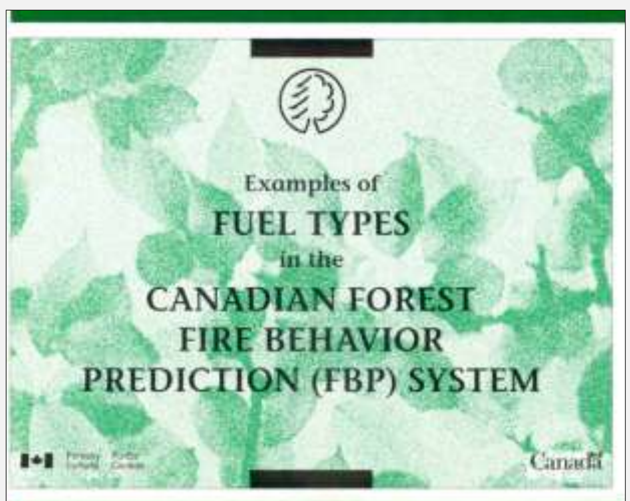
• Interim edition in 1984

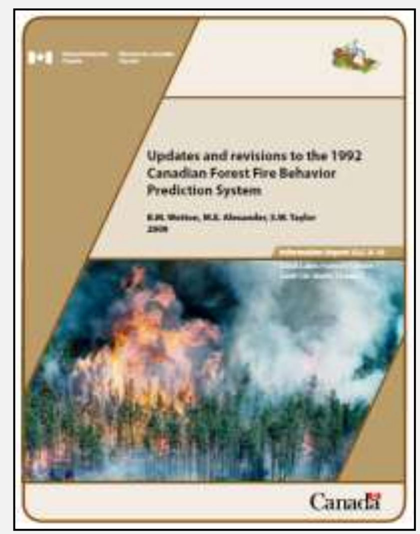
• First complete edition in 1992

• Update in 1997

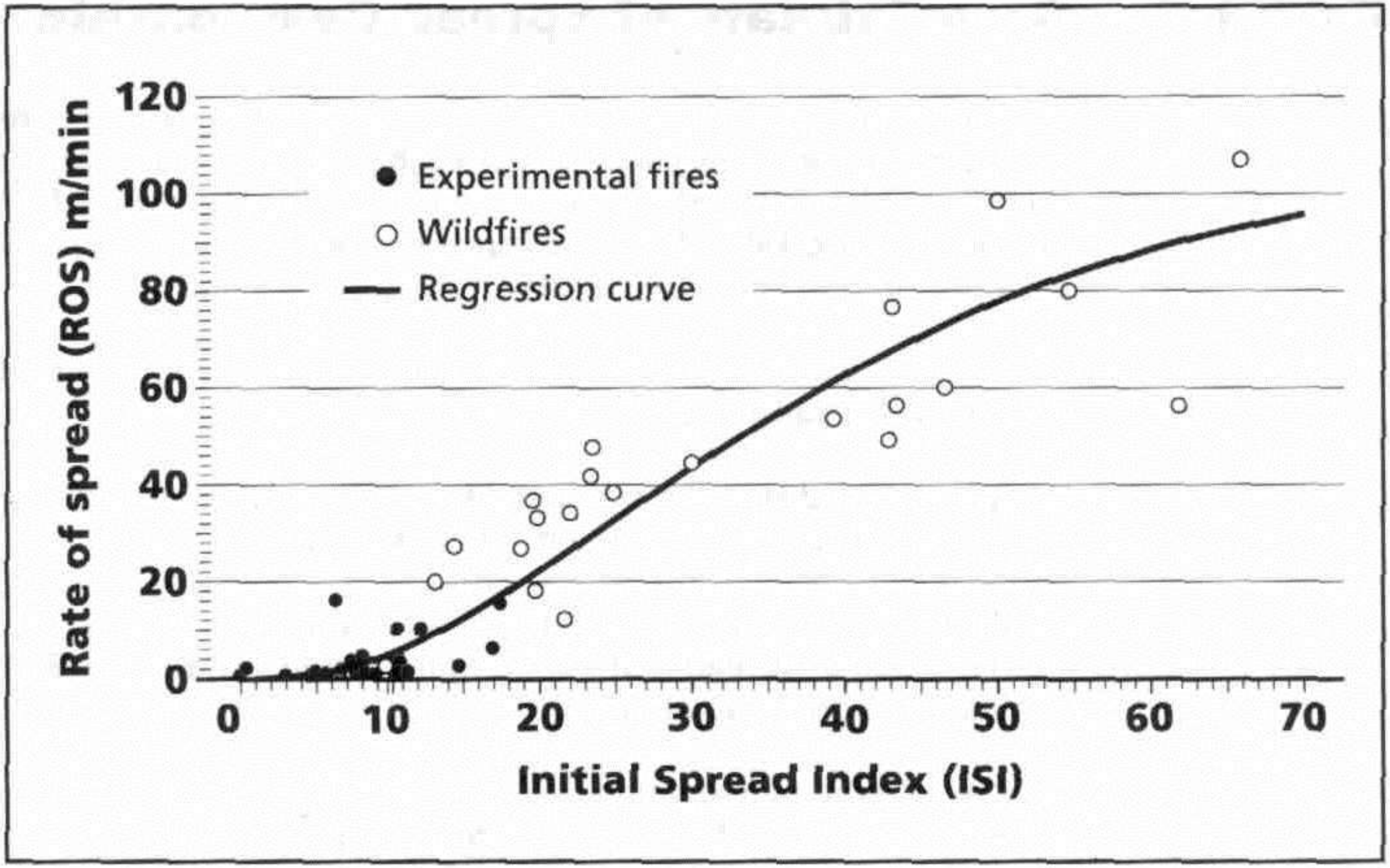






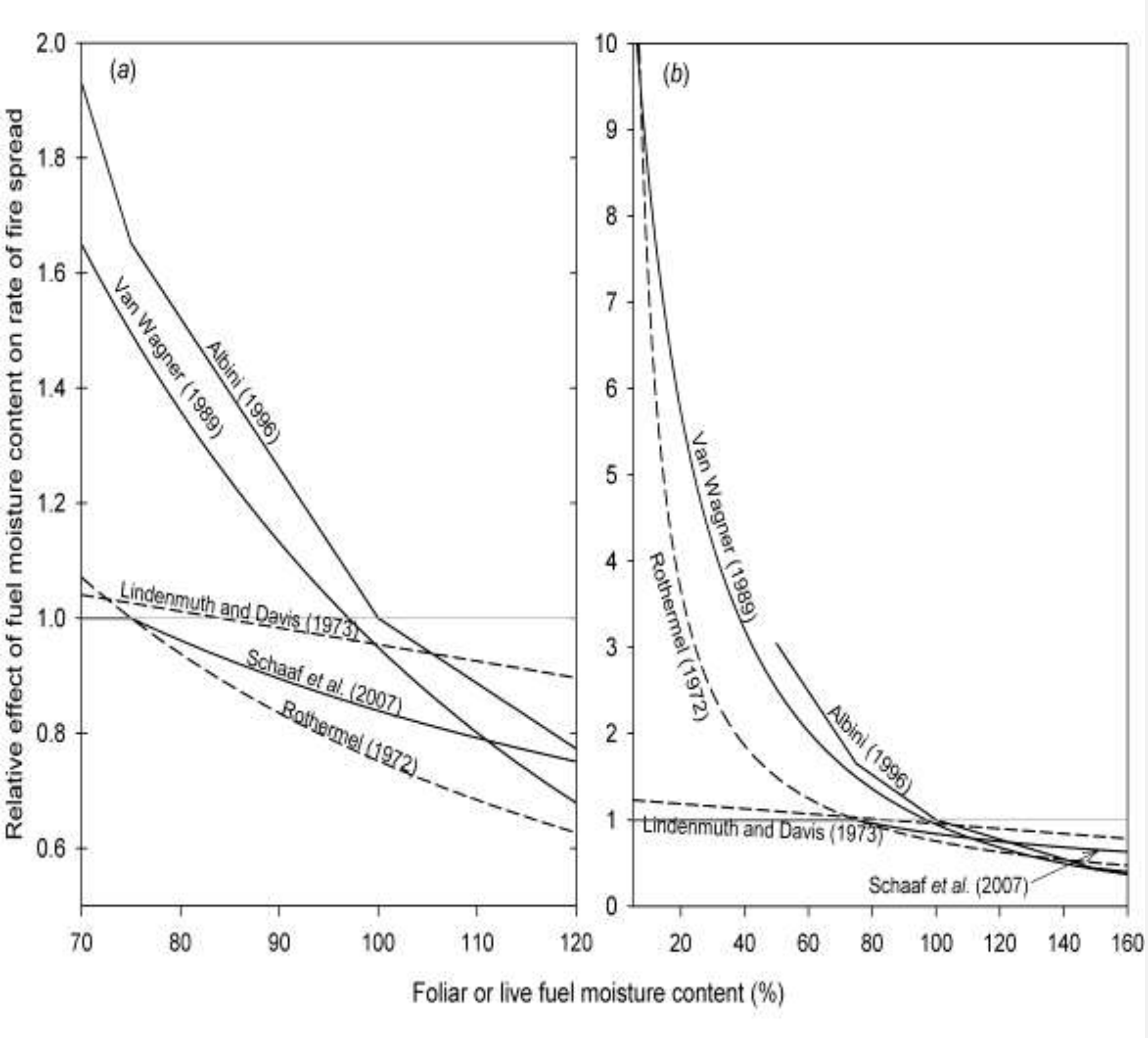


Canadian FBP System:
Surface & Crown Rate of Spread
(Natural Forest Stands)



Mature Jack or Lodgepole Pine (C-3) Fuel Type

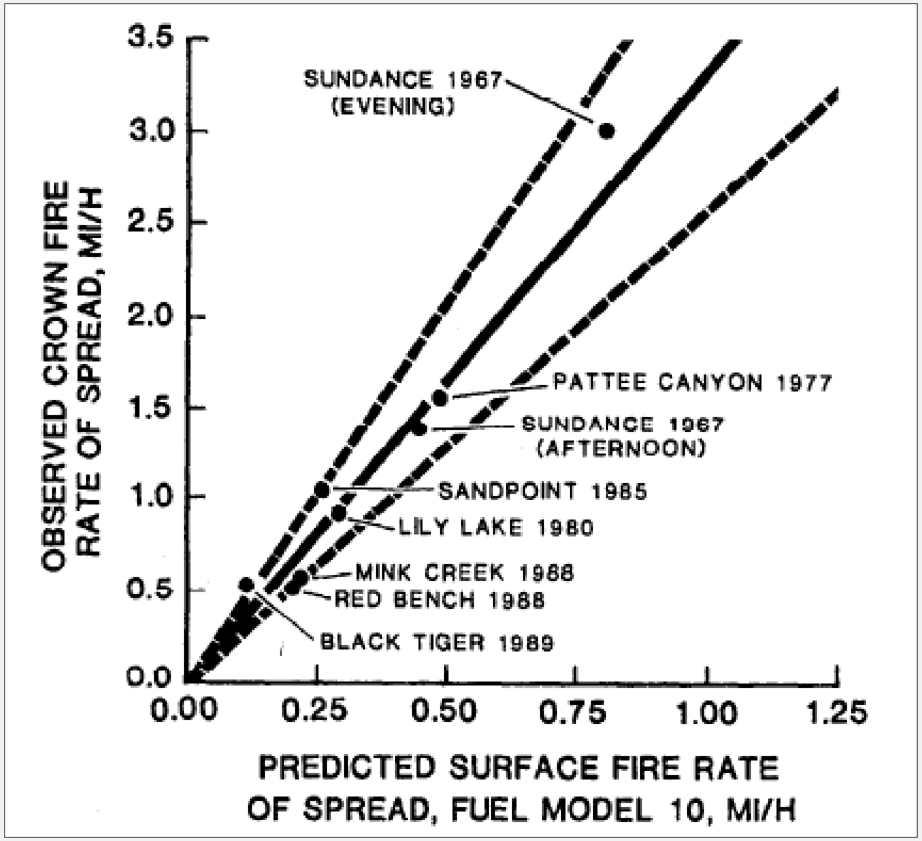
Assessing the effect of foliar moisture on the spread rate of crown fires



Assessing the effect of foliar moisture on the spread rate of crown fires.

Reference	Dominant species and principal location	No. of fires	Range in LFM (%)	Range in ROS (m min^{-1})	Correlation coefficient (*p*-value)
Thomas (1970)	*Calluna vulgaris* (GB)	12	10 - 60	1.1 - 18	--[A]
Lindenmuth and Davis (1973)	*Quercus turbinella* (Arizona, US)	32	71 - 142	up to 14	0.08 (>0.05) [B]
Van Wilgen *et al.* (1985)	*Leucadendron laureolum* (South Africa)	14	58 - 147	2.4 - 53	-0.30 (0.29)
Marsden-Smedley and Catchpole (1995)	*Gymnoschoenus sphaerocephalus* (Tasmania, AU)	68	23 - 132	0.6 - 55	0.06 (0.69)
McCaw *et al.* (1995)	*Eucalyptus tetragona* (Western Australia, AU)	9	68 - 90	7.7 - 40.5	-0.17 (0.66)
Catchpole *et al.* (1998)	Heath and mallee (NZ and AU)	133	--[C]	0.6 - 60.0	-- [D] (>0.05) [B]
Fernandes *et al.* (2000)	*Erica umbellata*, *Chamaespartium tridentatum* (PT)	44	66 - 112	0.7 - 14.1	0.26 (>0.05)[B]
Fernandes (2001)	*Ulex* sp., *Erica* sp., *Chamaespartium tridentatum* (PT)	29	72 - 113	0.7 - 20.0	-- [D] (>0.05)[B]
Bilgili and Saglam (2003)	*Quercus coccifera*, *Arbutus andrachnea* (TR)	25	28 - 51	0.8 - 6.6	0.36 (0.075)
Saglam *et al.* (2007)	*Quercus coccifera* (TR)	17	69 - 109	0.6 - 8.4	-0.42 (0.09)
Saglam *et al.* (2008)	*Arbutus andrachnea*, *Pistacia lentiscus* (TR)	18	60 - 164	0.4 -7.4	0.36 (0.138)
Davies *et al.* (2009)	*Calluna vulgaris*, *Vaccinium myrtillus* (GB)	26	55 - 97	0.5 - 12.6	--[E]
Cruz *et al.* (2010)	*Eucalyptus calicogona*, *E. diversifolia* (South Australia, AU)	28	51 - 93	1.2 - 55	0.17 (0.39)

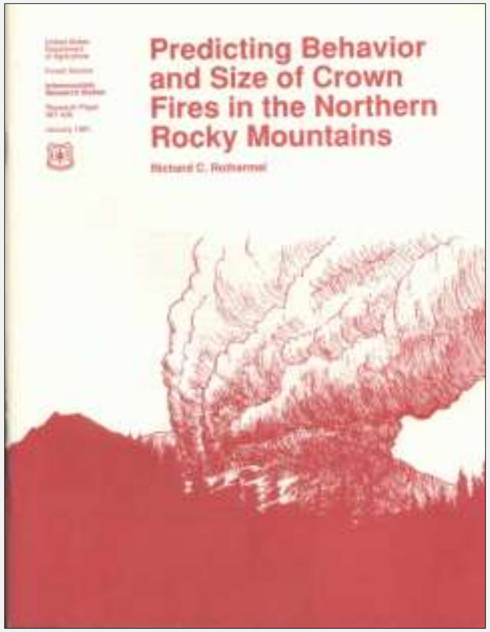
Rothermel (1991) Rate of Spread "Model" for Wind-driven Crown Fires



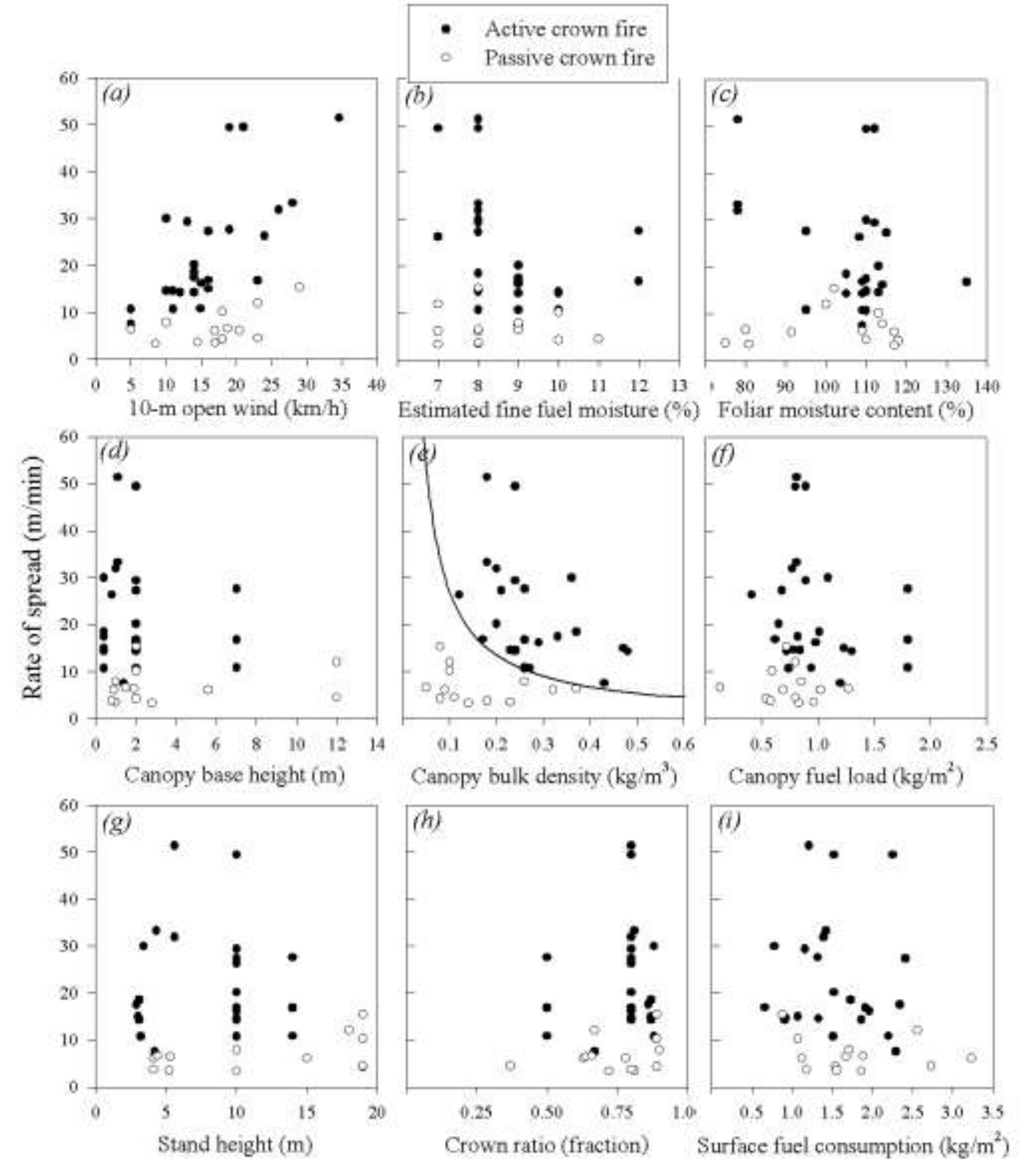
A statistical correlation between the predicted surface fire rate of spread for Fuel Model 10 (wind reduction factor 0.4) and 8 western U.S. wildfire observations

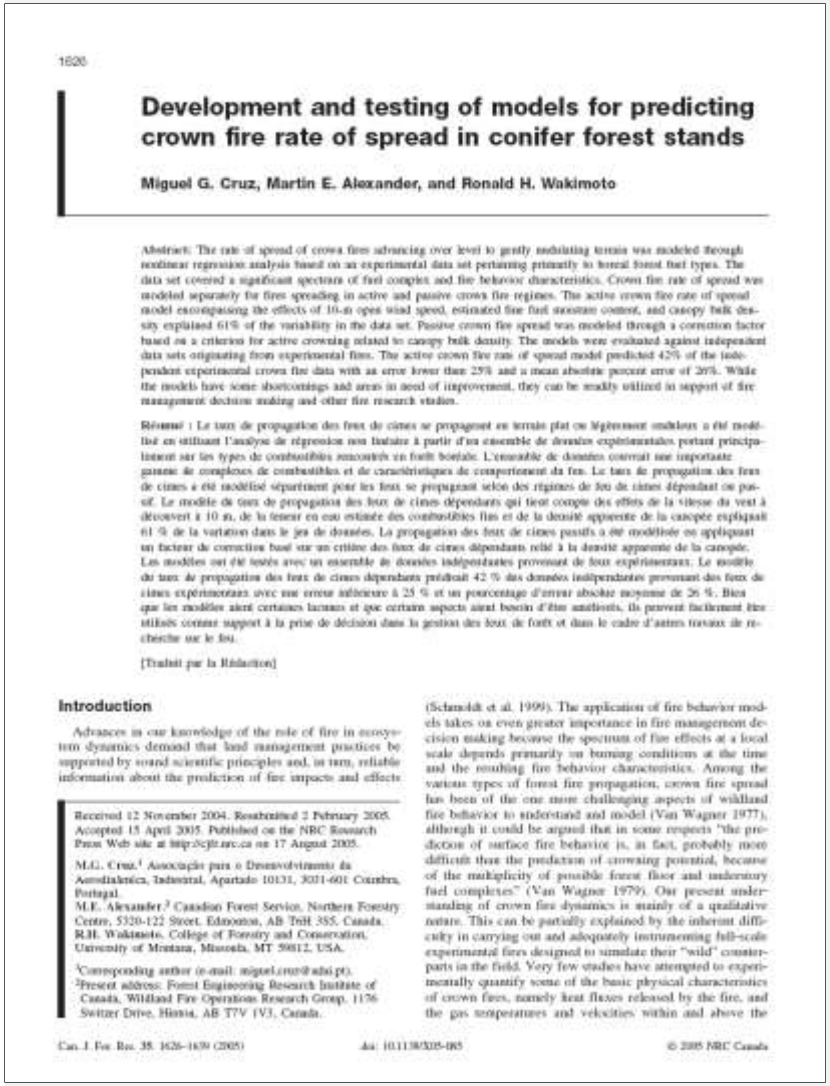
Ave. Crown Fire ROS = 3.34 x Surface Fire ROS

Max. Crown Fire ROS = 1.7 x Ave. Crown Fire ROS



Cruz, Alexander and Wakimoto (2005)
Crown Fire Rate of Spread Models





Development and testing of models for predicting crown fire rate of spread in conifer forest stands

Miguel G. Cruz, Martin E. Alexander, and Ronald H. Wakimoto

Abstract: The rate of spread of crown fires advancing over level to gently undulating terrain was modeled through nonlinear regression analysis based on an experimental data set pertaining primarily to boreal forest fuel types. The data set covered a significant spectrum of fuel complex and fire behavior characteristics. Crown fire rate of spread was modeled separately for fires spreading in active and passive crown fire regimes. The active crown fire rate of spread model encompassing the effects of 10-m open wind speed, estimated fine fuel moisture content, and canopy bulk density explained 61% of the variability in the data set. Passive crown fire spread was modeled through a correction factor based on a criterion for active crowning related to canopy bulk density. The models were evaluated against independent data sets originating from experimental fires. The active crown fire rate of spread model predicted 42% of the independent experimental crown fire data with an error lower than 25% and a mean absolute percent error of 26%. While the models have some shortcomings and areas in need of improvement, they can be readily utilized in support of fire management decision making and other fire research studies.

Résumé : Le taux de propagation des feux de cimes se propageant en terrain plat ou légèrement onduleux a été modélisé en utilisant l'analyse de régression non linéaire à partir d'un ensemble de données expérimentales portant principalement sur les types de combustibles rencontrés en forêt boréale. L'ensemble de données couvrait une importante gamme de complexes de combustibles et de caractéristiques de comportement du feu. Le taux de propagation des feux de cimes a été modélisé séparément pour les feux se propageant selon des régimes de feu de cimes dépendant ou passif. Le modèle du taux de propagation des feux de cimes dépendants qui tient compte des effets de la vitesse du vent à découvert à 10 m, de la teneur en eau estimée des combustibles fins et de la densité apparente de la canopée expliquait 61 % de la variation dans le jeu de données. La propagation des feux de cimes passifs a été modélisée en appliquant un facteur de correction basé sur un critère des feux de cimes dépendants relié à la densité apparente de la canopée. Les modèles ont été testés avec un ensemble de données indépendantes provenant de feux expérimentaux. Le modèle du taux de propagation des feux de cimes dépendants prédisait 42 % des données indépendantes provenant des feux de cimes expérimentaux avec une erreur inférieure à 25 % et un pourcentage d'erreur absolue moyenne de 26 %. Bien que les modèles aient certaines lacunes et que certains aspects aient besoin d'être améliorés, ils peuvent facilement être utilisés comme support à la prise de décision dans la gestion des feux de forêt et dans le cadre d'autres travaux de recherche sur le feu.

[Traduit par la Rédaction]

Introduction

Advances in our knowledge of the role of fire in ecosystem dynamics demand that land management practices be supported by sound scientific principles and, in turn, reliable information about the prediction of fire impacts and effects (Schmoldt et al. 1999). The application of fire behavior models takes on even greater importance in fire management decision making because the spectrum of fire effects at a local scale depends primarily on burning conditions at the time and the resulting fire behavior characteristics. Among the various types of forest fire propagation, crown fire spread has been of the one more challenging aspects of wildland fire behavior to understand and model (Van Wagner 1977), although it could be argued that in some respects "the prediction of surface fire behavior is, in fact, probably more difficult than the prediction of crowning potential, because of the multiplicity of possible forest floor and understory fuel complexes" (Van Wagner 1979). Our present understanding of crown fire dynamics is mainly of a qualitative nature. This can be partially explained by the inherent difficulty in carrying out and adequately instrumenting full-scale experimental fires designed to simulate their "wild" counterparts in the field. Very few studies have attempted to experimentally quantify some of the basic physical characteristics of crown fires, namely heat fluxes released by the fire, and the gas temperatures and velocities within and above the

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Cruz, Alexander and Wakimoto (2005)

Crown Fire Rate of Spread Models: The Equations

***Active Crown Fires*: *CAC* $\geq$ 1.0**

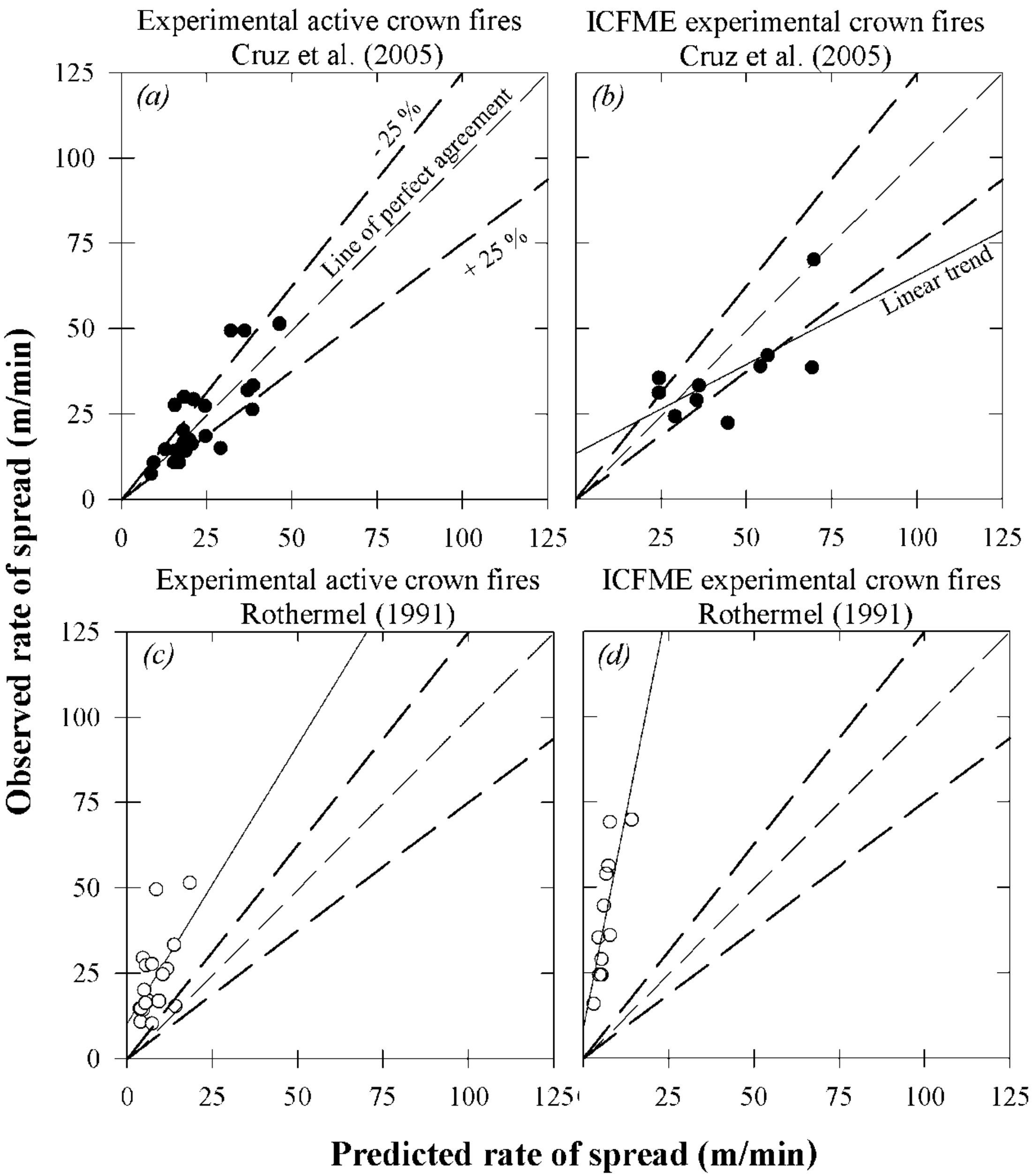
$$CROS_A = 11.02 \cdot (U_{10})^{0.9} \cdot CBD^{0.19} \cdot exp(-0.17 \cdot EFFM)$$

***Passive Crown Fires*: CAC < 1.0**

$$CROS_P = CROS_A \, . \, exp(-CAC)$$

where ***CAC*** is the criterion for active crowning dimensionless), ***CBD*** is the canopy bulk density (kg/m^3), U_{10} is the 10-m open wind speed km/h), ***EFFM*** is the estimated fine fuel moisture (%), $CROS_A$ is the active crown fire rate of spread (m/min), and $CROS_P$ is the passive crown fire rate of spread (m/min).

Model Evaluation – experimental data



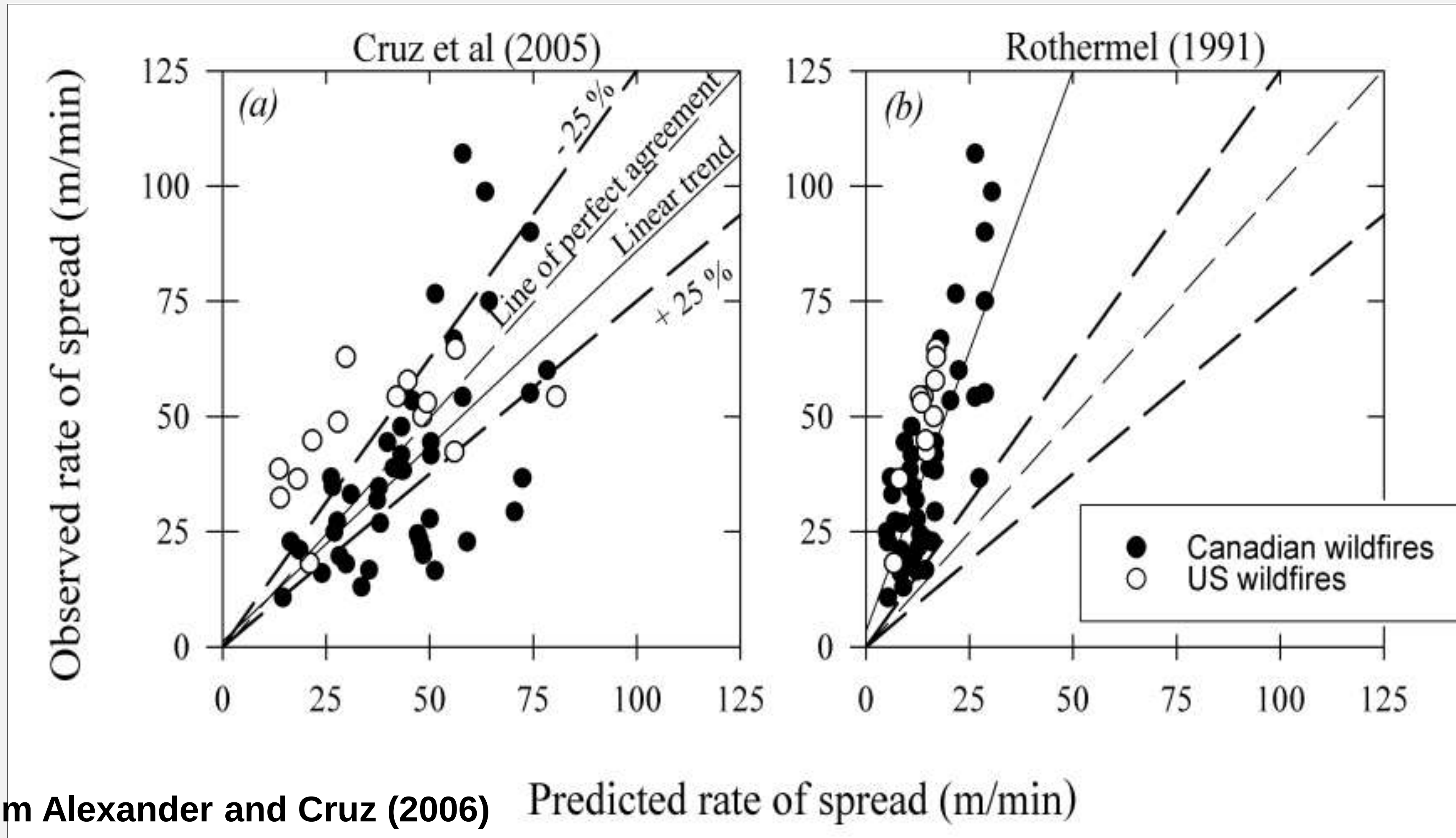
Crown Fire Rate of Spread Models: Evaluation Against Experimental Active Crown Fires

Rothermel (1991) under-predicts by a factor of 2-5 and shows little sensitivity to burning conditions.

Cruz, Alexander and Wakimoto (2005)

Model Evaluation – wildfire data

The Cruz, Alexander and Wakimoto (2005) model outputs have been compared to 57 wildfire observations (43 Canadian & 14 U.S.) obtained from case studies. The results have been quite favourable.



From Alexander and Cruz (2006)

Crown fire potential in FCCS (Schaaf *et al*. 2007; CJFR)

A conceptual framework for ranking crown fire potential in wildland fuelbeds[1]

Mark D. Schaaf, David V. Sandberg, Maarten D. Schreuder, and Cynthia L. Riccardi

Abstract: This paper presents a conceptual framework for ranking the crown fire potential of wildland fuelbeds with forest canopies. This approach extends the work by Van Wagner and Rothermel, and introduces several new physical concepts to the modeling of crown fire behaviour derived from the reformulated Rothermel surface fire modeling concepts proposed by Sandberg et al. (this issue). This framework forms the basis for calculating the crown fire potentials of Fuel Characteristic Classification System (FCCS) fuelbeds (Ottmar et al., this issue). Two new crown fire potentials are proposed (*i*) the torching potential (TP) and (*ii*) the active crown potential (AP). A systematic comparison of TP and AP against field observations and Crown Fire Initiation and Spread (CFIS) model outputs produced encouraging results, suggesting that the FCCS framework might be a useful tool for fire managers to consider when ranking the potential for crown fires or evaluating the relative behaviour of crown fires in forest canopies.

Résumé : Cet article présente un cadre conceptuel pour classer le potentiel de feu de cimes des couches de combustibles en milieu naturel où il y a des canopées forestières. Cette approche pousse plus loin les travaux de Van Wagner et de Rothermel et introduit plusieurs concepts physiques nouveaux dans la modélisation du comportement des feux de cimes dérivés des concepts reformulés de Rothermel pour la modélisation des feux de surface proposés par Sandburg et al. (ce numéro). Ce cadre forme la base pour calculer les potentiels de feu de cimes des couches de combustibles du système de classification des caractéristiques des combustibles (SCCC) (Ottmar et al., ce numéro). Deux nouvelles possibilités de feux de cimes sont proposées : (*i*) la possibilité de flambée en chandelle et (*ii*) la possibilité de feu de cime dépendant. Une comparaison systématique de ces deux types de feux de cimes avec des observations sur le terrain et les prévisions du modèle de l'École canadienne d'enquêtes sur les incendies a donné des résultats encourageants. Ces résultats indiquent que le cadre du SCCC pourrait s'avérer un outil utile que les responsables de la gestion des incendies devraient considérer pour classer le potentiel de feu de cimes ou pour évaluer le comportement relatif des feux de cimes dans les canopées forestières.

[Traduit par la Rédaction]

Introduction

The Fuel Characteristic Classification System (FCCS; Ottmar et al. 2007) offers the capacity to describe the physical characteristics of any wildland fuelbed no matter how complex, and the capacity to compare one fuelbed with another. FCCS enables the user to assess the absolute and relative effects of fuelbed differences due to natural events, fuel management practices, or the passage of time. The differences can be expressed as native physical differences, such as changes in loadings and arrangements of fuelbed components, or as changes in the potential fire behaviour and effects, such as fire behaviour or fuel consumption (Sandberg et al. 2007*b*). Comparing the potential for crown fire initiation and spread among the various FCCS fuelbeds is problematic because there is no broadly applicable and physics-based crown fire model available that accounts for these fuelbed differences. FCCS does not require specific prediction of crown fire behaviour across the full range of fire environments, but does require a relative ranking of crown fire potential over the full range of wildland fuelbed characteristics.

The past 40 years or so of fire research and observations have produced a significant body of literature on crown fires. Van Wagner's (1964, 1968) papers on experimental crown fires in red pine (*Pinus resinosa* Ait.) plantations may be considered the start of the modern era of crown fire research. Subsequent studies ranged from observations of the characteristics of intense, rapidly moving wildfires, to descriptions of fire types (e.g., Van Wagner 1977, Rothermel 1991), to a heuristic key for rating crown fire potential (e.g., Fahnestock 1970), to the development of various mathematical models for predicting crown fire behaviour (e.g., Kilgore and Sando 1975; Scott and Reinhardt 2001; Van Wagner 1977, 1989, 1993). The identification of dependent crown fire thresholds by Scott and Reinhardt (2001) based on stylized fuelbeds and Rothermel's (1972)

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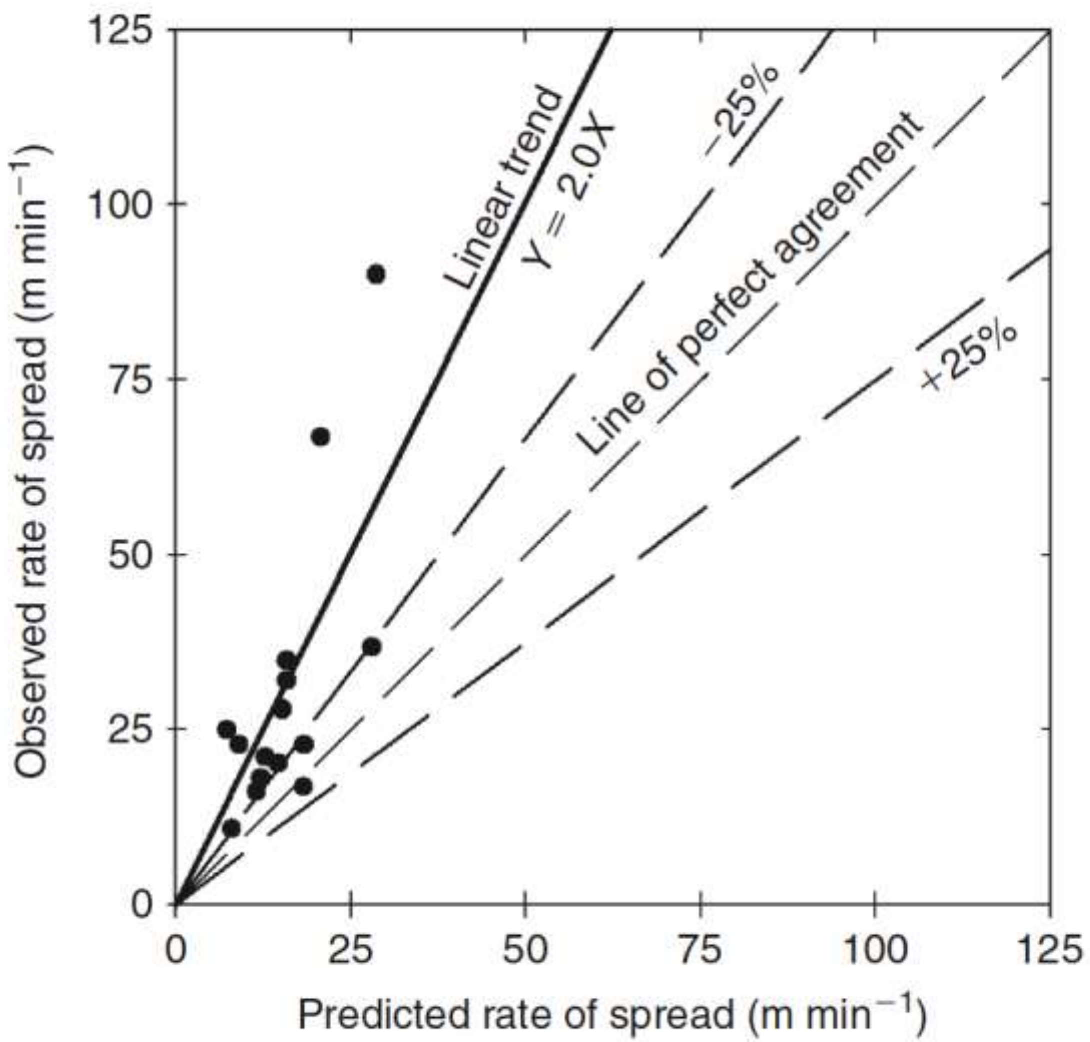
Reparameterization of Rothermel (1972) and (1991) models with updated linkages;

Aimed to describe crown fire potential with Fuel Characteristics Classification System.

Outputs are:
- Torching potential (TP)
- Active crowning potential (AP)
- Crown fire rate of spread

Schaaf et al. (2007) model: Comparison Against Experimental Crown Fires (black spruce –feather moss fuel complex)



Model output showed **under-prediction trend**.

Need further evaluation against other fuel types.

A radiation-driven model for crown fire spread[1]

B.W. Butler, M.A. Finney, P.L. Andrews, and F.A. Albini

Abstract: A numerical model for the prediction of the spread rate and intensity of forest crown fires has been developed. The model is the culmination of over 20 years of previously reported fire modeling research and experiments; however, it is only recently that it has been formulated in a closed form that permits a priori prediction of crown fire spread rates. This study presents a brief review of the development and structure of the model followed by a discussion of recent modifications made to formulate a fully predictive model. The model is based on the assumption that radiant energy transfer dominates energy exchange between the fire and unignited fuel with provisions for convective cooling of the fuels ahead of the fire front. Model predictions are compared against measured spread rates of selected experimental fires conducted during the International Crown Fire Modelling Experiment. Results of the comparison indicate that the closed form of the model accurately predicts the relative response of fire spread rate to fuel and environment variables but overpredicts the magnitude of fire spread rates.

Résumé : Les auteurs ont développé un modèle numérique pour prédire le taux de propagation et l'intensité des feux de cimes. Le modèle est l'aboutissement d'expérimentations et de recherches sur la modélisation du feu rapportées depuis plus de 20 ans. Cependant, ce n'est que récemment qu'une formulation dans une forme analytique a permis la prédiction a priori du taux de propagation d'un feu de cimes. Cet article présente une brève revue du développement et de la structure du modèle suivie d'une discussion des modifications récentes qui ont été apportées pour formuler un modèle entièrement prédictif. Le modèle est basé sur l'hypothèse voulant que le transfert d'énergie de rayonnement domine les échanges d'énergie entre le feu et les combustibles non enflammés en tenant compte du refroidissement des combustibles par convection à l'avant du front. Les prédictions du modèle sont comparées aux mesures du taux de propagation de certains feux expérimentaux allumés dans le cadre de L'Expérience internationale de modélisation des feux de cimes. Le résultat des comparaisons indique que la forme analytique du modèle prédit correctement la réaction relative du taux de propagation aux combustibles et aux variables environnementales mais surestime l'ampleur du taux de propagation du feu.

[Traduit par la Rédaction]

Introduction

Fire behaviour models form the foundation of decision support systems (Andrews 1986; Andrews and Queen 2001). Historically, crown fires account for only a small percentage of the total number of wildland fires that occur each fire season. However, it is this small number of fires burning with relatively high intensities that result in the majority of acreage burned (Pyne et al. 1996). Methods and models for predicting the onset and spread of crown fire have been used extensively by fire and land managers to minimize risk to life and property, project the growth of ongoing fires, plan for prescribed fires, and examine trade-offs in vegetation treatment options. Limitations exist in currently available models (Deeming et al. 1977; Van Wagner 1977; Xanthopoulos 1990; Rothermel 1991; Forest Canada Fire Danger Group 1992; Canadian Forestry Service 1997; Alexander 1998; Cruz et al. 2002, 2003). Such models are useful, relatively fast to compute, but also inherently limited in their range of applicability. Models based on physical principles, on the other hand, have the potential to accurately predict the parameters of interest over a broader range of input variables than empirically based models. Physics-based models can also provide the basic information needed for proper description of physical processes (i.e., fluid flow, heat transfer, and chemical kinetics). But physics-based models also include inherent weaknesses; they imply that the developer has an adequate understanding of the underlying physical relations sufficient to achieve the desired objectives, that the underlying physics can be represented mathematically in a manner that permits numerical solution while retaining adequate realism, that the informational needs of the mathematics can be met by the user, and that the predicted variables are in a form to be useful by the practitioner. Improved models are needed for increased accuracy in fire behaviour prediction, fire danger rating calcu-

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[1]This article is one of a selection of papers published in this Special Issue on The International Crown Fire Modelling Experiment (ICFME) in Canada's Northwest Territories: Advancing the Science of Fire Behaviour.
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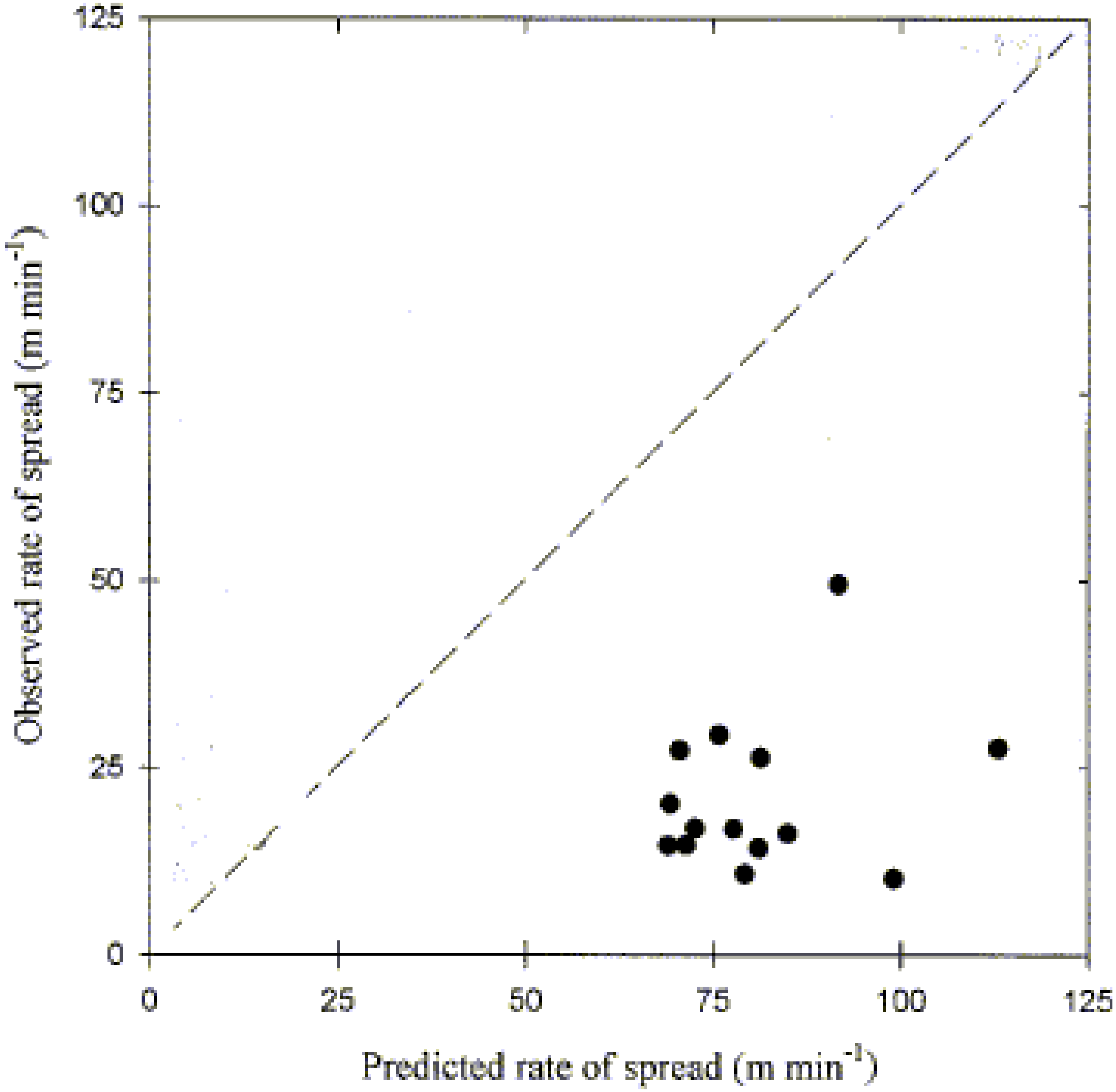
Canadian Journal of Forest Research
July 2004

In the mid to late 90s Dr. Frank Albini was supported by the Canadian Forest Service and USDA Forest Service to develop a new physically-based rate of spread model for crown fires. The testing and calibration of this model was largely the impetus for ICFME.

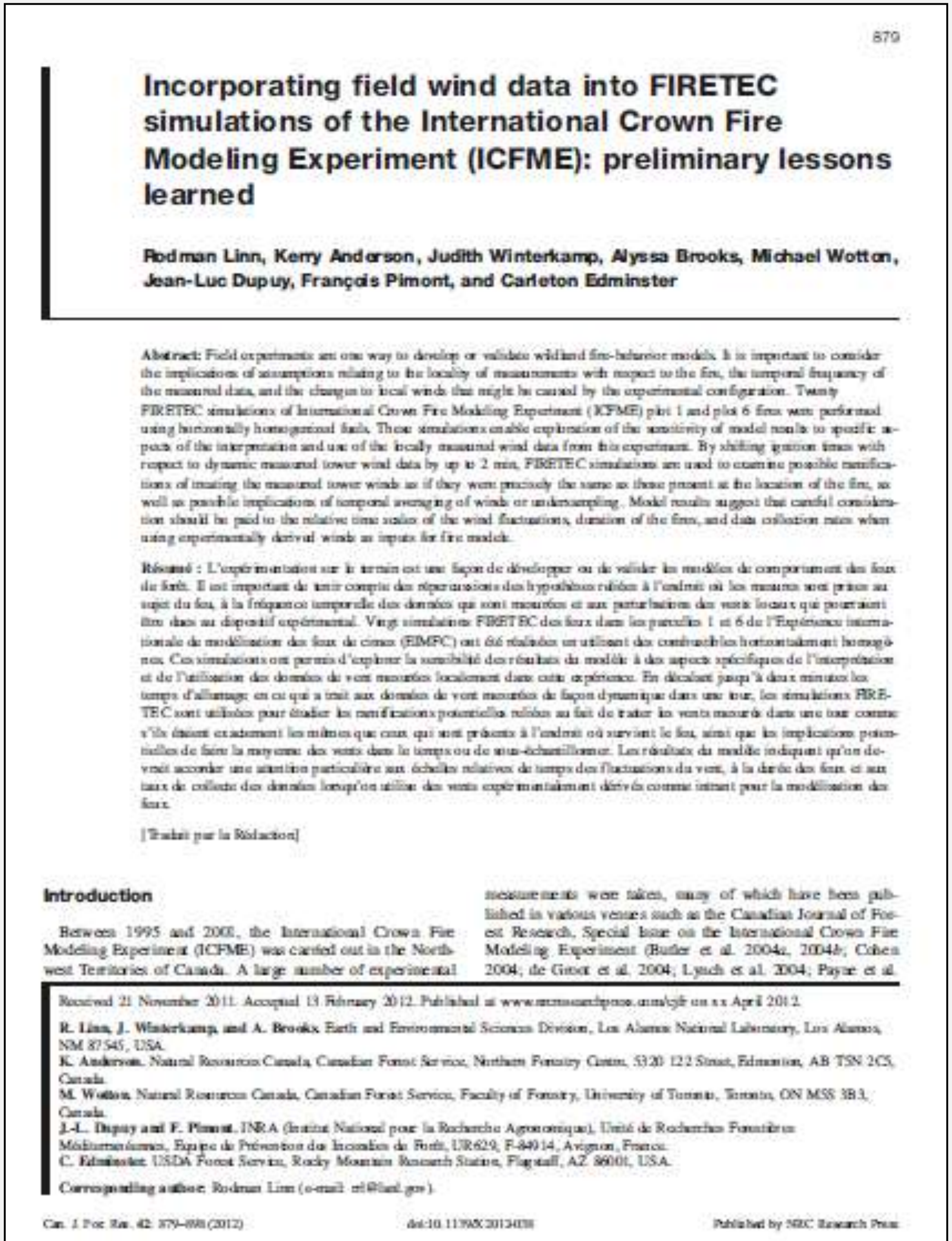
Dr. Frank Albini
ICFME 1997

Albini Physically-based Crown Fire Rate of Spread Model: Comparison Against Other Experimental Crown Fires



This included experimental active crown fires in immature jack pine, red pine plantation, and black spruce-lichen woodland.

Model output showed large **over-predictions**.



Incorporating field wind data into FIRETEC simulations of the International Crown Fire Modeling Experiment (ICFME): preliminary lessons learned

Rodman Linn, Kerry Anderson, Judith Winterkamp, Alyssa Brooks, Michael Wotton, Jean-Luc Dupuy, François Pimont, and Carleton Edminster

Abstract: Field experiments are one way to develop or validate wildland fire-behavior models. It is important to consider the implications of assumptions relating to the locality of measurements with respect to the fire, the temporal frequency of the measured data, and the changes to local winds that might be caused by the experimental configuration. Twenty FIRETEC simulations of International Crown Fire Modeling Experiment (ICFME) plot 1 and plot 6 fires were performed using horizontally homogeneous fuels. These simulations enable exploration of the sensitivity of model results to specific aspects of the interpretation and use of the locally measured wind data from this experiment. By shifting ignition times with respect to dynamic measured tower wind data by up to 2 min, FIRETEC simulations are used to examine possible ramifications of treating the measured tower winds as if they were precisely the same as those present at the location of the fire, as well as possible implications of temporal averaging of winds or undersampling. Model results suggest that careful consideration should be paid to the relative time scales of the wind fluctuations, duration of the fires, and data collection rates when using experimentally derived winds as inputs for fire models.

Résumé : L'expérimentation sur le terrain est une façon de développer ou de valider les modèles de comportement des feux de forêt. Il est important de tenir compte des répercussions des hypothèses reliées à l'endroit où les mesures sont prises au sujet du feu, à la fréquence temporelle des données qui sont mesurées et aux perturbations des vents locaux qui pourraient être dues au dispositif expérimental. Vingt simulations FIRETEC des feux dans les parcelles 1 et 6 de l'Expérience internationale de modélisation des feux de cimes (EIMFC) ont été réalisées en utilisant des combustibles horizontalement homogènes. Ces simulations ont permis d'explorer la sensibilité des résultats du modèle à des aspects spécifiques de l'interprétation et de l'utilisation des données de vent mesurées localement dans cette expérience. En décalant jusqu'à deux minutes les temps d'allumage en ce qui a trait aux données de vent mesurées de façon dynamique dans une tour, les simulations FIRETEC sont utilisées pour étudier les ramifications potentielles reliées au fait de traiter les vents mesurés dans une tour comme s'ils étaient exactement les mêmes que ceux qui sont présents à l'endroit où survient le feu, ainsi que les implications potentielles de faire la moyenne des vents dans le temps ou de sous-échantillonner. Les résultats du modèle indiquent qu'on devrait accorder une attention particulière aux échelles relatives de temps des fluctuations du vent, à la durée des feux et aux taux de collecte des données lorsqu'on utilise des vents expérimentalement dérivés comme intrant pour la modélisation des feux.

[Traduit par la Rédaction]

Introduction

Between 1995 and 2001, the International Crown Fire Modeling Experiment (ICFME) was carried out in the Northwest Territories of Canada. A large number of experimental measurements were taken, many of which have been published in various venues such as the Canadian Journal of Forest Research, Special Issue on the International Crown Fire Modeling Experiment (Butler et al. 2004*a*, 2004*b*; Cohen 2004; de Groot et al. 2004; Lynch et al. 2004; Payne et al.

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Linn et al. (2012) compared FIRETEC rate of fire spread predictions with observed values for two of the 10 ICFME experimental crown fires.

The FIRETEC rate of spread predictions were in close agreement with the observed spread rates.

Crown Fire Intensity and Flame Size

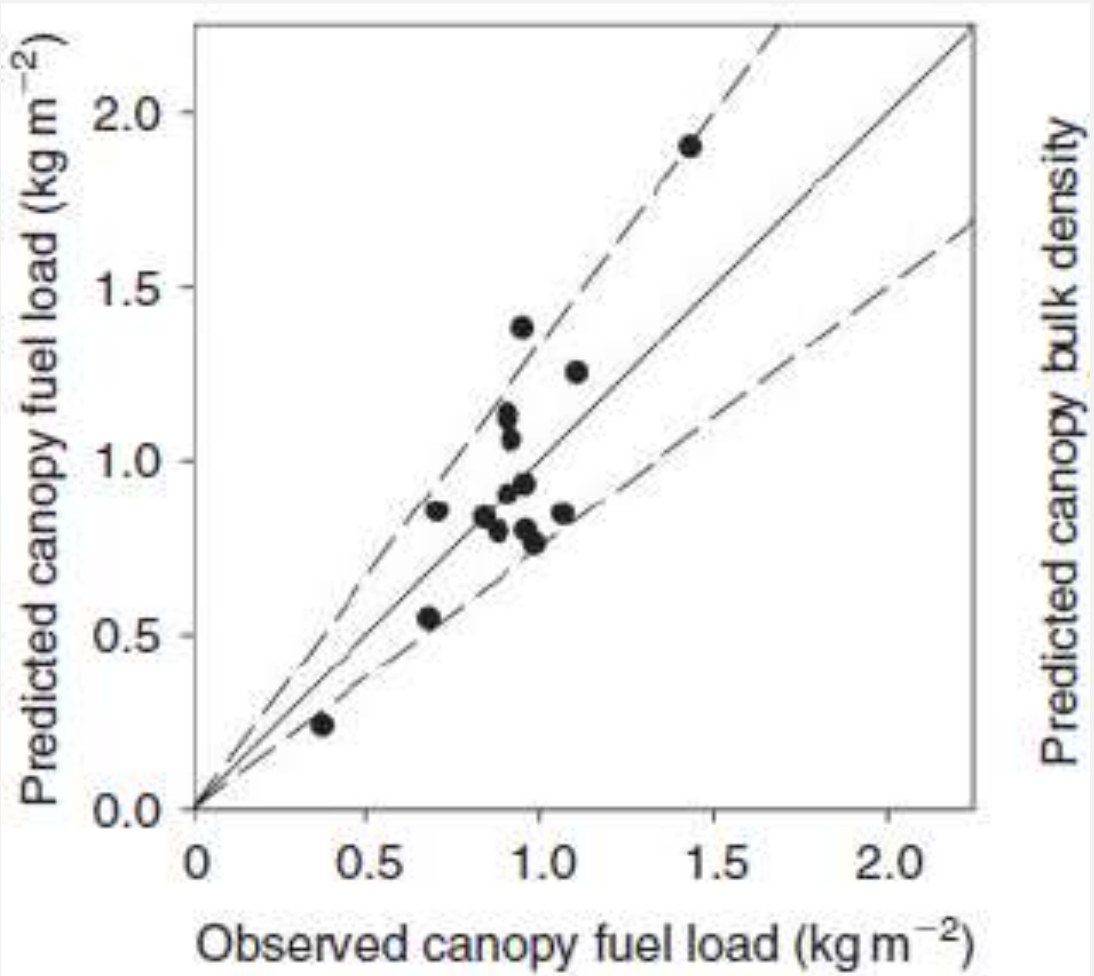
Crown Fire Intensity

The $\boldsymbol{W}$ in $I = \boldsymbol{H} \cdot \boldsymbol{W} \cdot \boldsymbol{R}$ includes an estimate of crown fuel consumption (***CFC***) that generally takes the following form:

$$\boldsymbol{CFC} = \boldsymbol{CFL} \cdot \boldsymbol{CFB}$$

where ***CFL*** = available crown fuel load.

Evaluating regression model estimates of canopy fuel stratum characteristics in four crown fire-prone fuel types in western North America.



Observed vs. expected CFL for 16 PP stands in the Black Hills, SD

Evaluation of the Cruz et al. 2003 regression equations to predict CBH, CBD & CFL from stand characteristics

Comparison to original data treated and independent PP data set

Summary on Crown Fuel Consumption for the 10 Primary ICFME Fires Based on Post-burn Crown Weight Sampling

(from Stocks, Alexander, Wotton *et al.* 2004)

Needles – 100%

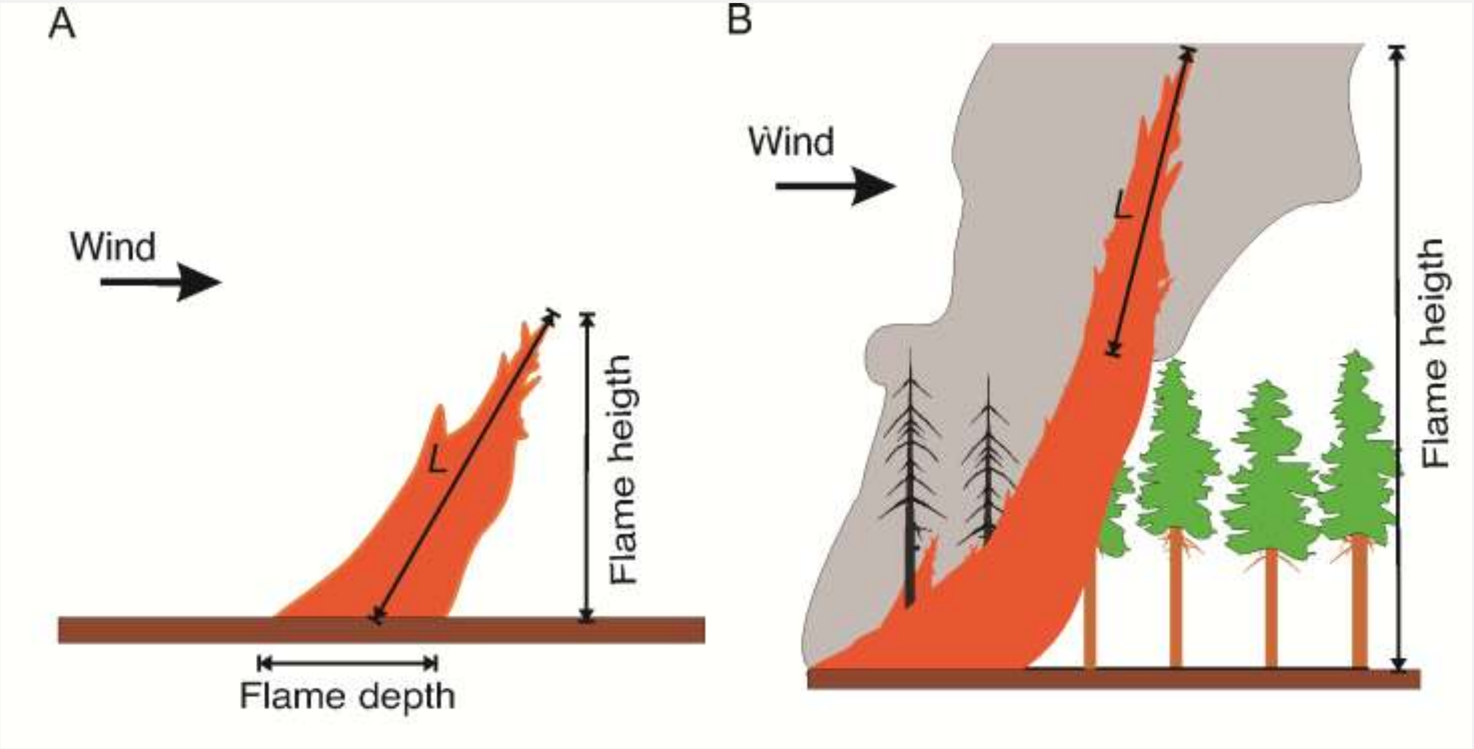
< 0.5 cm roundwood (overstory & understory – 86%

0.5-1.0 cm roundwood (overstory) – 70%

0.5-1.0 cm roundwood (understory) – 80%

1.0-3.0 cm (overstory) – 42%

Surface vs. Crown Fire Flame Lengths



Byram (1959) indicated that his fire intensity-flame length equation would under-predict the flame length for "… *high intensity crown fires because much of the fuel is a considerable distance above the ground*."

He suggested, on the basis of personal visual estimates, that "… *this can be corrected for by adding one-half of the mean canopy height* …" to the flame length value obtained by his equation. Thus, the equation for crown fire flame lengths (***L_c***) taking into account stand height (***SH***) becomes :

$$L_c = 0.0775 \cdot (I)^{0.46} + (SH/2)$$

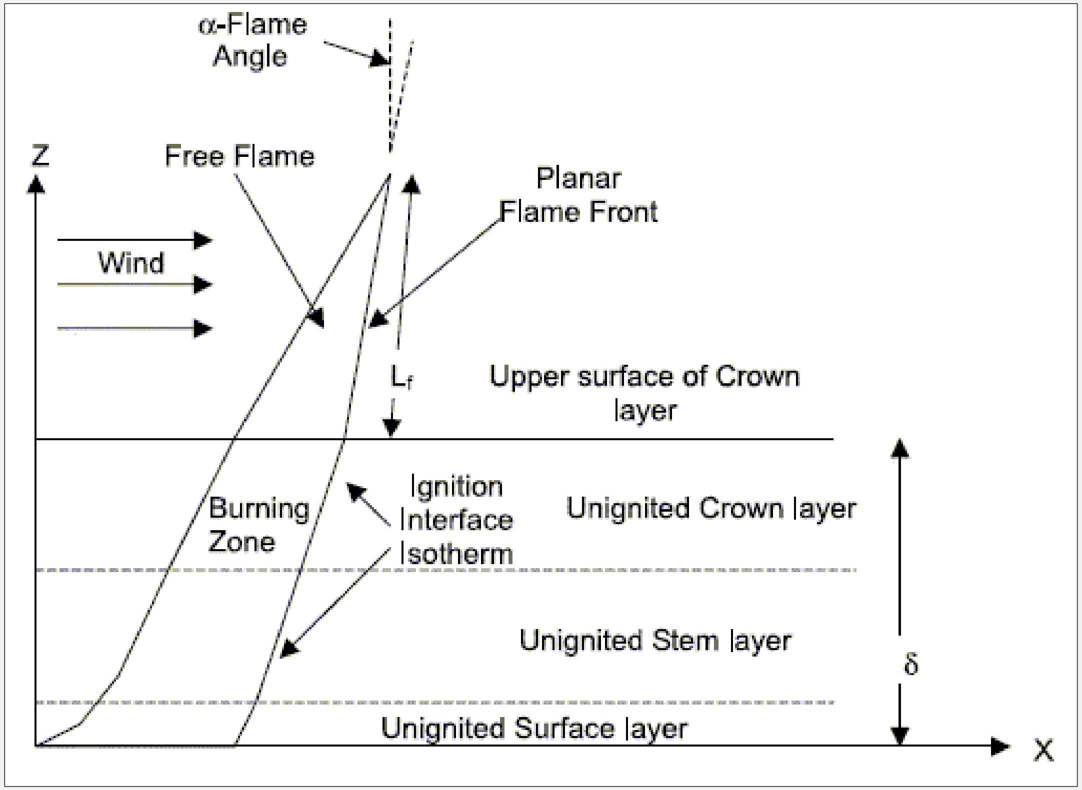
Rothermel (1991) suggested using Thomas' (1963) relation to estimate the flame lengths of crown fires from fire intensity:

$$L_c = 0.0266 \cdot (I)^{2/3}$$

More recently Butler *et al.* (2004) proposed the following relation for calculating the flame lengths of crown fires from fire intensity:

$$L_f = 0.0175 \cdot (I)^{2/3}$$

Where L_f is the flame length measured from the upper surface of the fuel array.



None of these methods seem to work consistently well based on comparisons against experimental crown fires undertaken in Canada. Take, for example, the following experimental crown fires in red pine plantations (***SH*** = 15 m) documented by Van Wagner (1977).

		------------- Predicted L_c (m) ---------		
Exp. Fire	**Obs. L_c (m)**	**Byram (1959)**	**Thomas (1963)**	**Butler *et al.* (2004)**
C4	**19.8**	**15.1**	**20.2**	**28.8**
C6	**30.5**	**15.3**	**21.2**	**29.4**

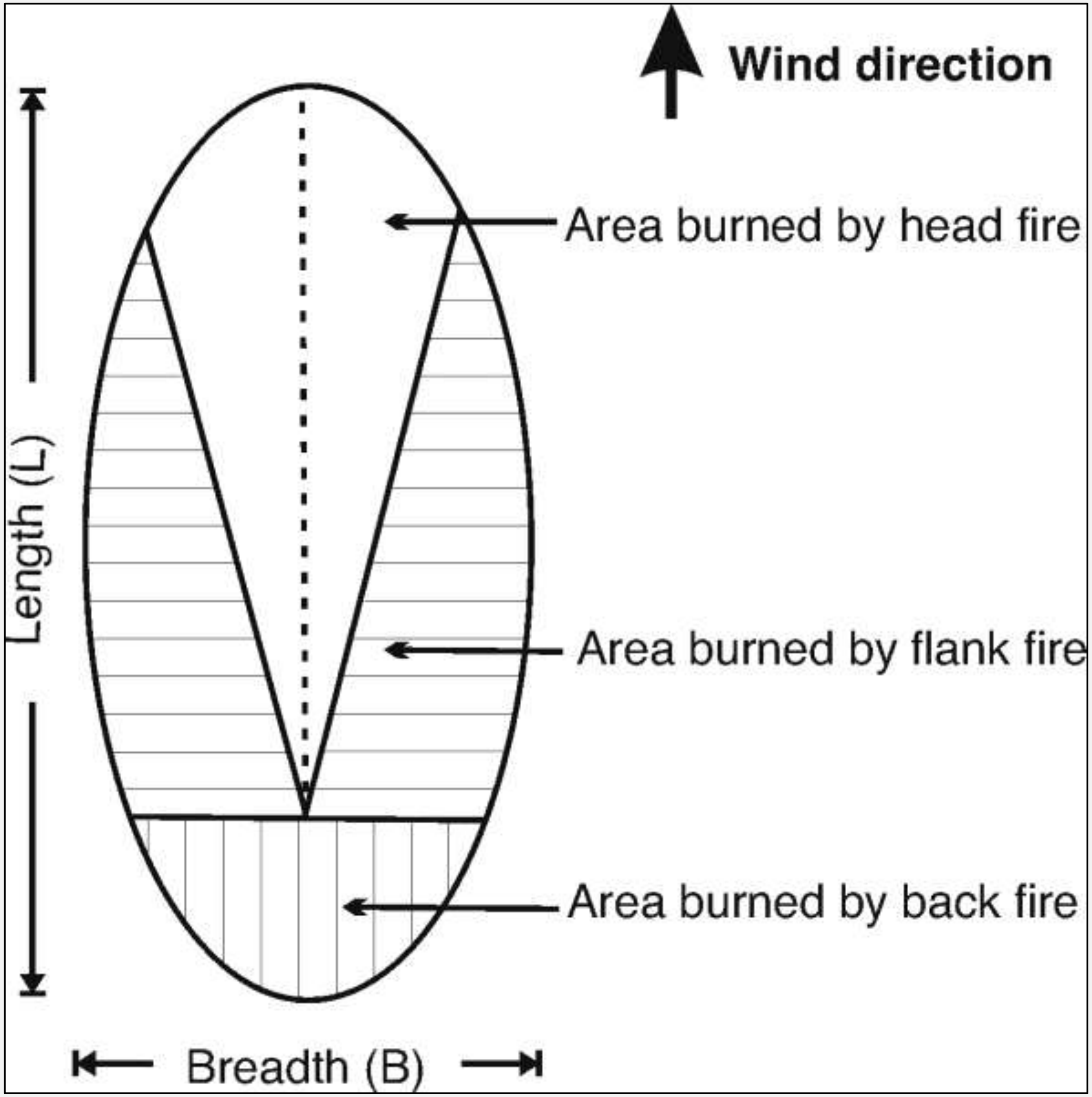
General Observation Based on Experimental Crown Fires:

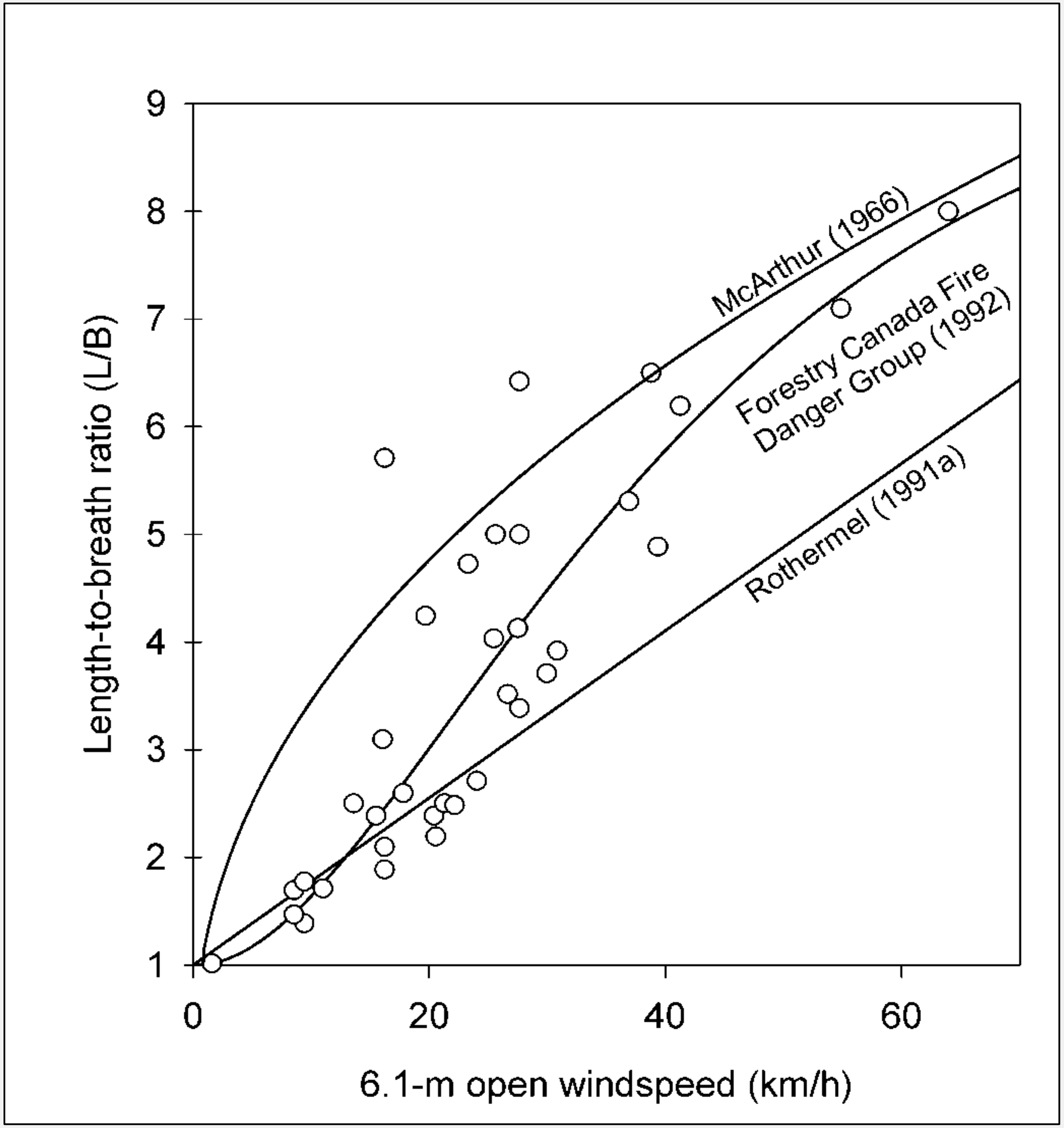
The flame front depth increases as fire intensity increases rather than a corresponding increase in the vertical flame length.

ICFME Plot 9 – Fire Intensity ~93,000 kW/m

Alexander's Simple Rule of Thumb for Crown Fire Flame Heights: 2-3 x Stand Height for Active Crown Fires

Crown Fire Spread Distance and Fire Size


Wind direction
Area burned by head fire
Area burned by flank fire
Area burned by back fire
Length (L)
Breadth (B)



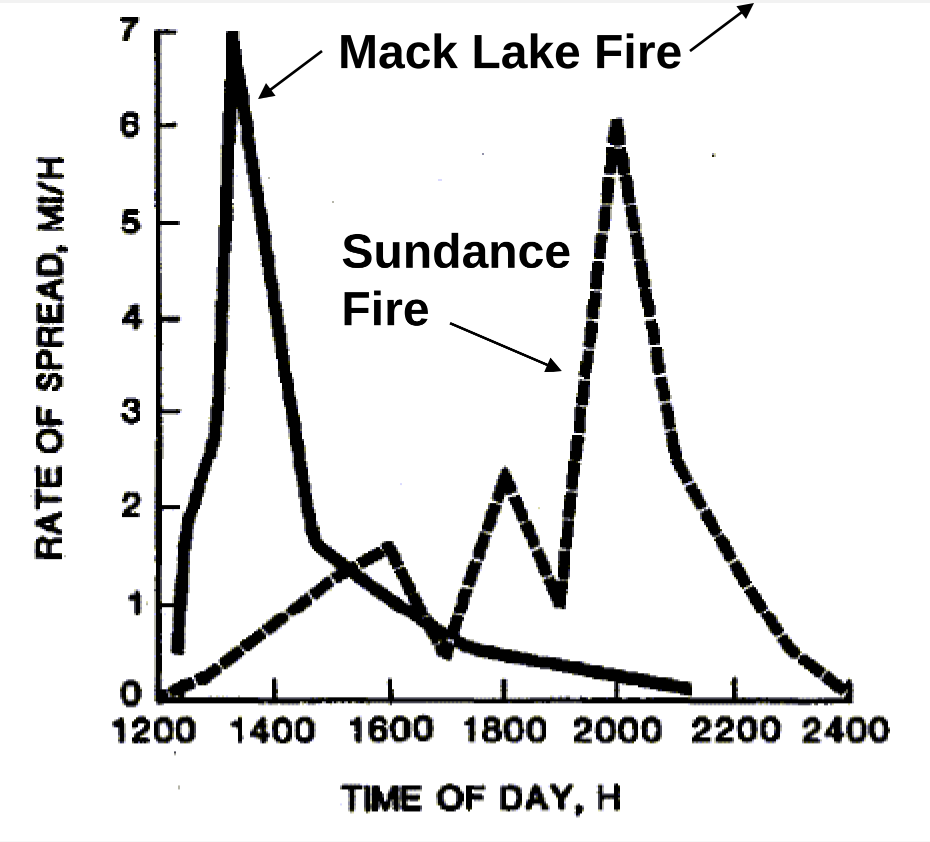
Rothermel (1991) L/B function tends to underpredict above 25 km/h

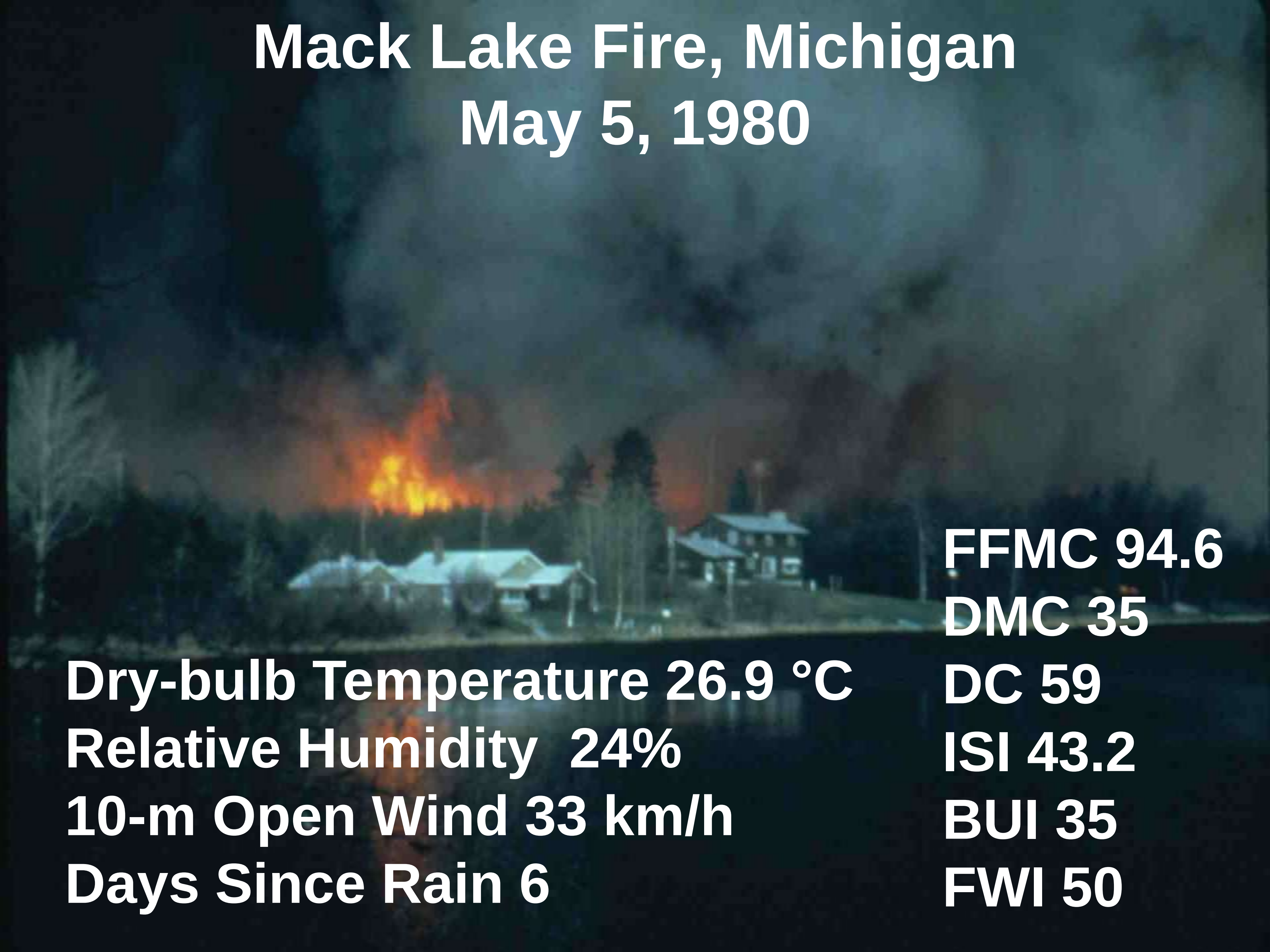
Plume- or Convection-Dominated vs. Wind-driven Crown Fires

In his publication, Rothermel (1991) identified 3 plume-dominated crown fires:

- 1980 Mack Lake Fire, Michigan
- 1985 Butte Fire, Idaho
- 1990 Dude Fire, Arizona

In the case of the Mack Lake Fire, the fire was observed to spread at a rate of 188 m/min (11.3 km/h) over a 20-min period. This was considered as evidence of a plume-dominated crown fire run. I view it simply as a chance observation with no associated wind speeds.




Mack Lake Fire, Michigan
May 5, 1980
Dry-bulb Temperature 26.9 °C
Relative Humidity 24%
10-m Open Wind 33 km/h
Days Since Rain 6
FFMC 94.6
DMC 35
DC 59
ISI 43.2
BUI 35
FWI 50

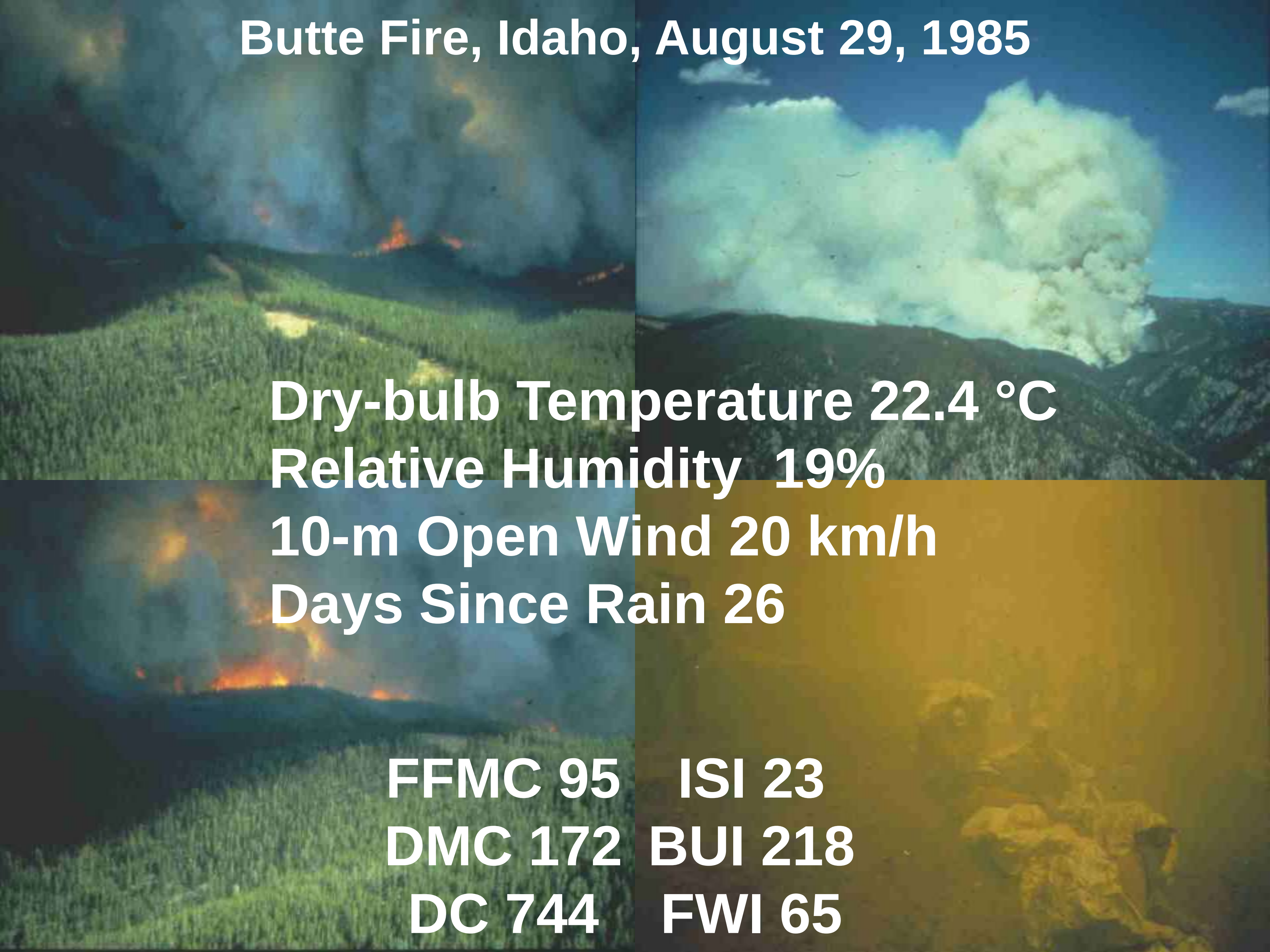
Mack Lake Fire, Michigan May 5, 1980

The following comparisons are based on the major run of the Mack Lake Fire that occurred between 1230 and 1600 hours EDT on May 5, 1980 using FBP System Fuel Type C-4, a 0% Slope and 100% Foliar Moisture Content:

Fire Behavior Characteristic	Predicted	Observed
Head Fire Rate of Spread (m/min)	57	56
Head Fire Intensity (kW/m)	33 660	30 440
Forward Spread Distance (km)	11.5	12.1
Area Burnt (ha)	2534	2743
Fire Perimeter (km)	24.8	20.0

Predicted Type of Fire at the "Head" :

Continuous Crown Fire (100% Crown Fuel Involvement)


Butte Fire, Idaho, August 29, 1985
Dry-bulb Temperature 22.4 °C
Relative Humidity 19%
10-m Open Wind 20 km/h
Days Since Rain 26
FFMC 95 ISI 23
DMC 172 BUI 218
DC 744 FWI 65

Butte Fire, Idaho, August 29, 1985

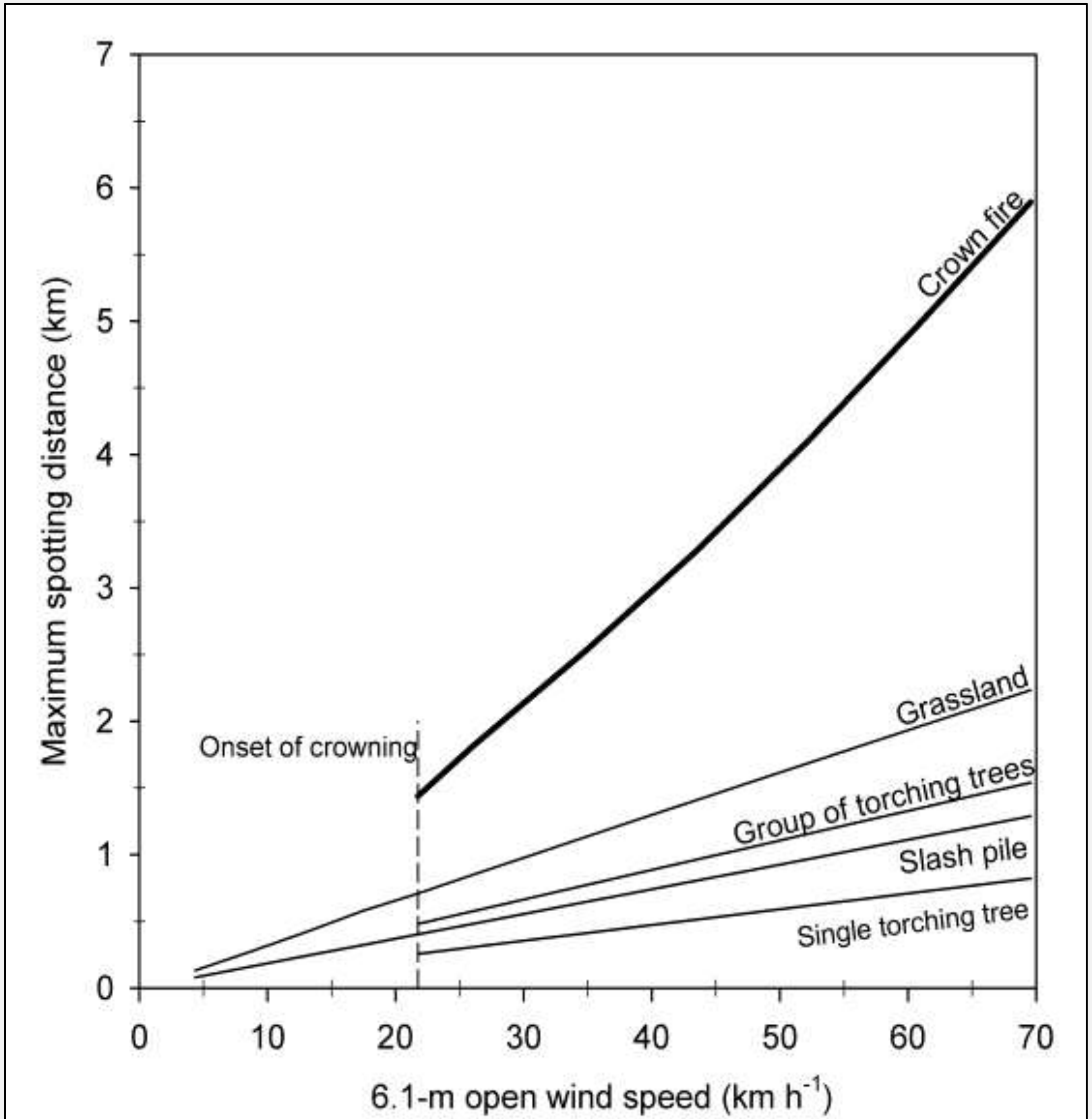
The following comparisons are based on the major run of the Butte Fire that occurred between 1430 and 1610 hours MDT on August 29, 1985 using FBP System Fuel Type C-3, a 9% slope and 105% Foliar Moisture Content:

Fire Behavior Characteristic	Predicted	Observed
Head Fire Rate of Spread (m/min)	22.3	24.7
Head Fire Intensity (kW/m)	43 326	N/A
Forward Spread Distance (m)	2200	2460

Predicted Type of Fire at the "Head" :

Continuous Crown Fire (>99% Crown Fuel Involvement)

Spotting from Active Crown Fires



Maximum spotting distance (km)
7
6
5
4
3
2
1
0
Crown fire
Grassland
Onset of crowning
Group of torching trees
Slash pile
Single torching tree
0
10
20
30
40
50
60
70
6.1-m open wind speed (km h-1)

CROWN FIRE BEHAVIOR IN CONIFER FORESTS: A PRE-CONFERENCE WORKSHOP

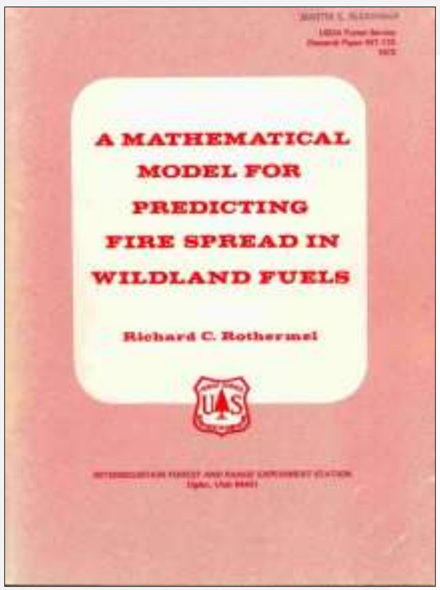
Operational Prediction of Crown Fire Behavior

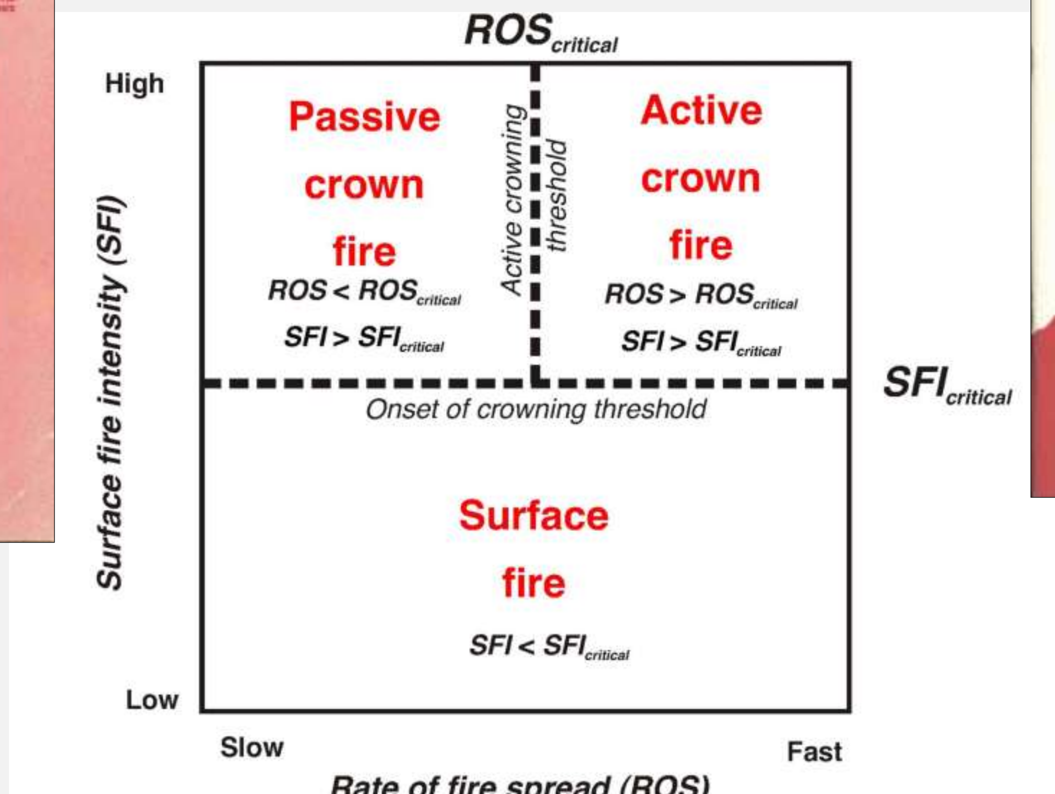
International Association of Wildland Fire 4th Fire Behavior and Fuels Conference

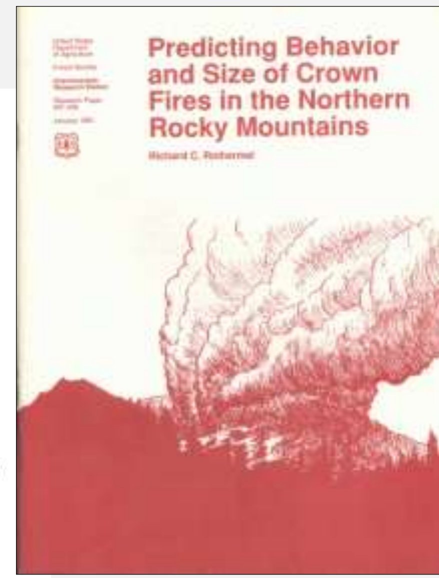
February 18, 2013 – Raleigh, NC

Crown fire behaviour prediction in US fire behaviour prediction systems

Rothermel (1972) → **Van Wagner (1977)** ⇄ **Rothermel (1991)**

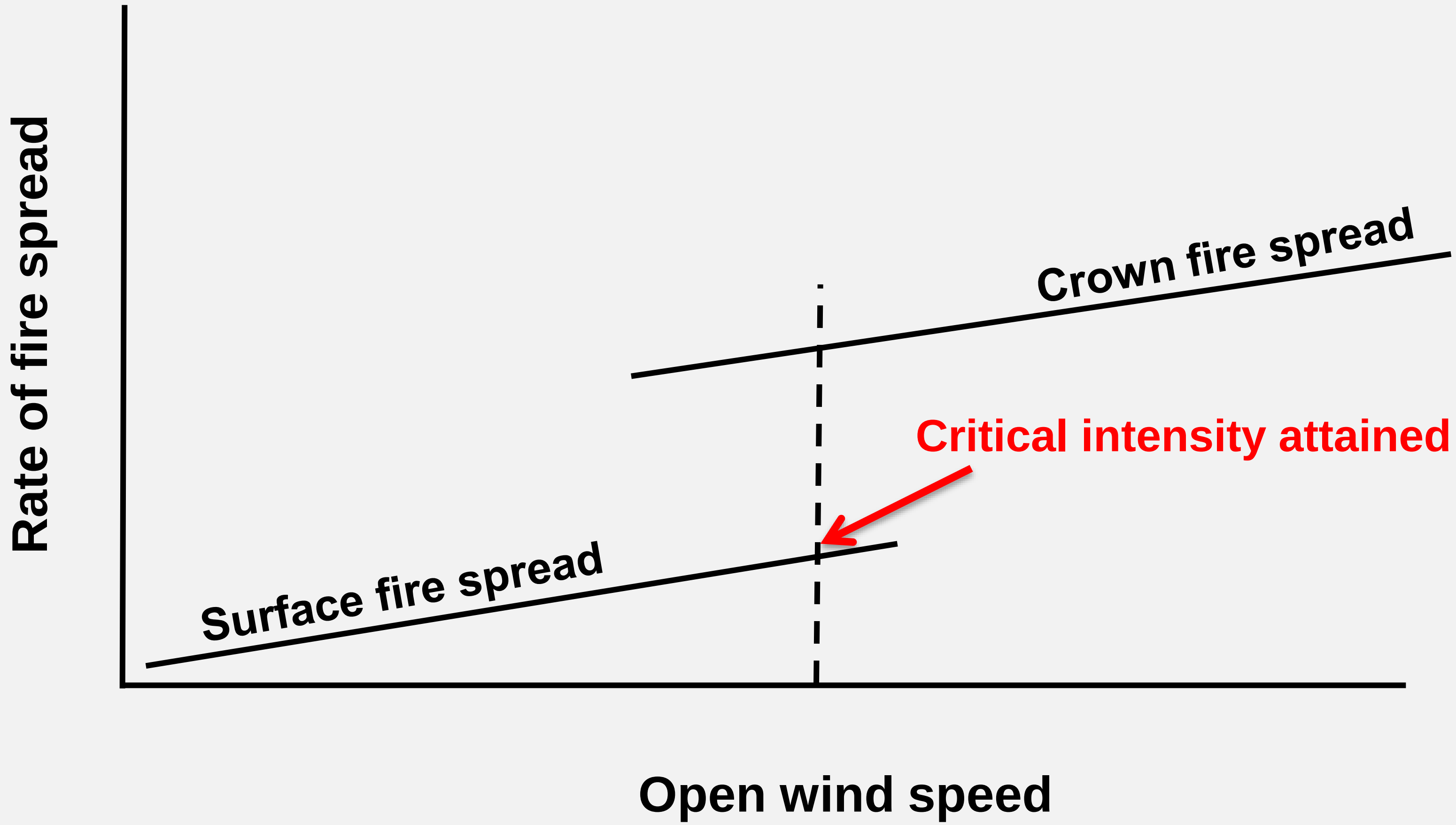




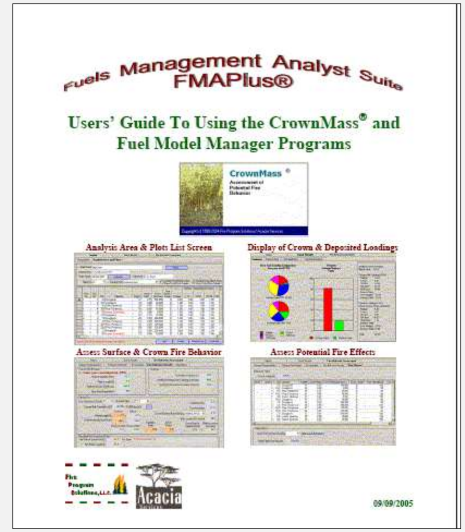


Linking surface and crown fire behaviour models

Rothermel (1972) → Van Wagner (1977) ⇄ Rothermel (1991)

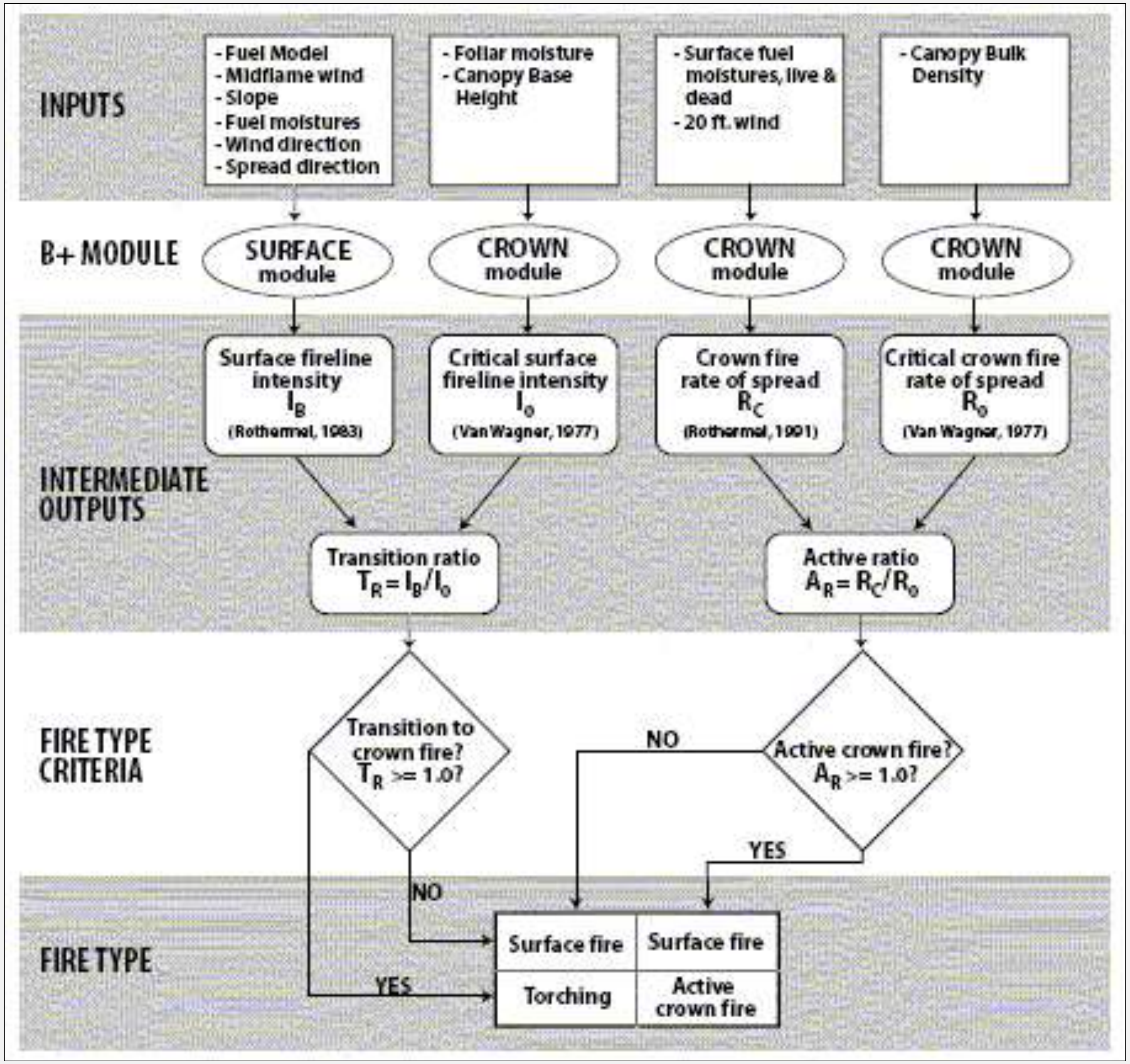


US fire behaviour prediction systems



Crown Fire Logic in *BehavePlus* Version 3.0

(Andrews *et al.* 2005)



Incorporates Van Wagner's (1977) crown fire initiation model and Rothermel's (1991) crown fire rate of spread model but there no transition function for scaling rate of spread between surface fire and active crown fire, although ratios are outputted.

From BehavePlus Training Lesson 13 – Crown Fire (www.fire.org)

Calculation of Fire Intensity per Byram (1959)

$$I = H \cdot W \cdot R$$

Calculation of Byram's Fire Intensity in the context of Rothermel (1972)

$$H \cdot W = H_A$$

$$H_A = I_R \cdot t_r$$

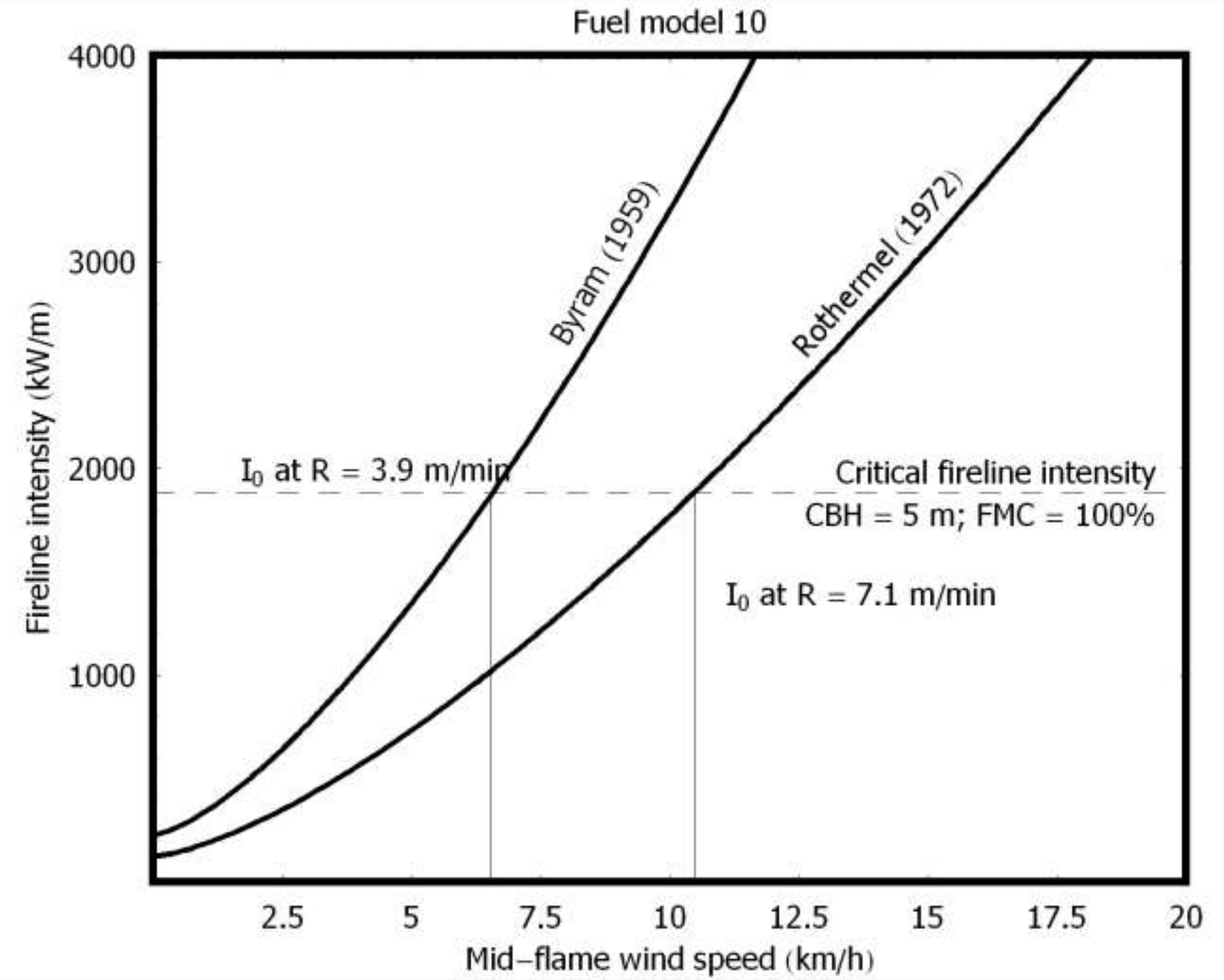
$$I = I_R \cdot t_r \cdot R$$

where H_A is the heat per unit area (kJ/m^2), I_R is the reaction intensity (kW/m^2) as per Rothermel (1972), and t_r is the flame front residence time (sec) as per Anderson (1969) relation based on the characteristic surface-area-to-volume ratio for the fuelbed.

Result:

I values calculated via Rothermel (1972) are up to ~1/2 to 2/3 lower compared to Byram (1959)

Thus, when Van Wagner's (1977) crown fire initiation model is implemented in the context of the various U.S. fire behavior decision support systems, it is grossly underestimating the presumed onset of crowning.



Fuel moistures:

1-hr TL – 7%
10-hr TL – 8%
Woody – 30%

Slope steepness:

Level terrain

Coupling Rothermel's Surface Fire (1972) and Crown Fire (1991) Rate of Spread Models

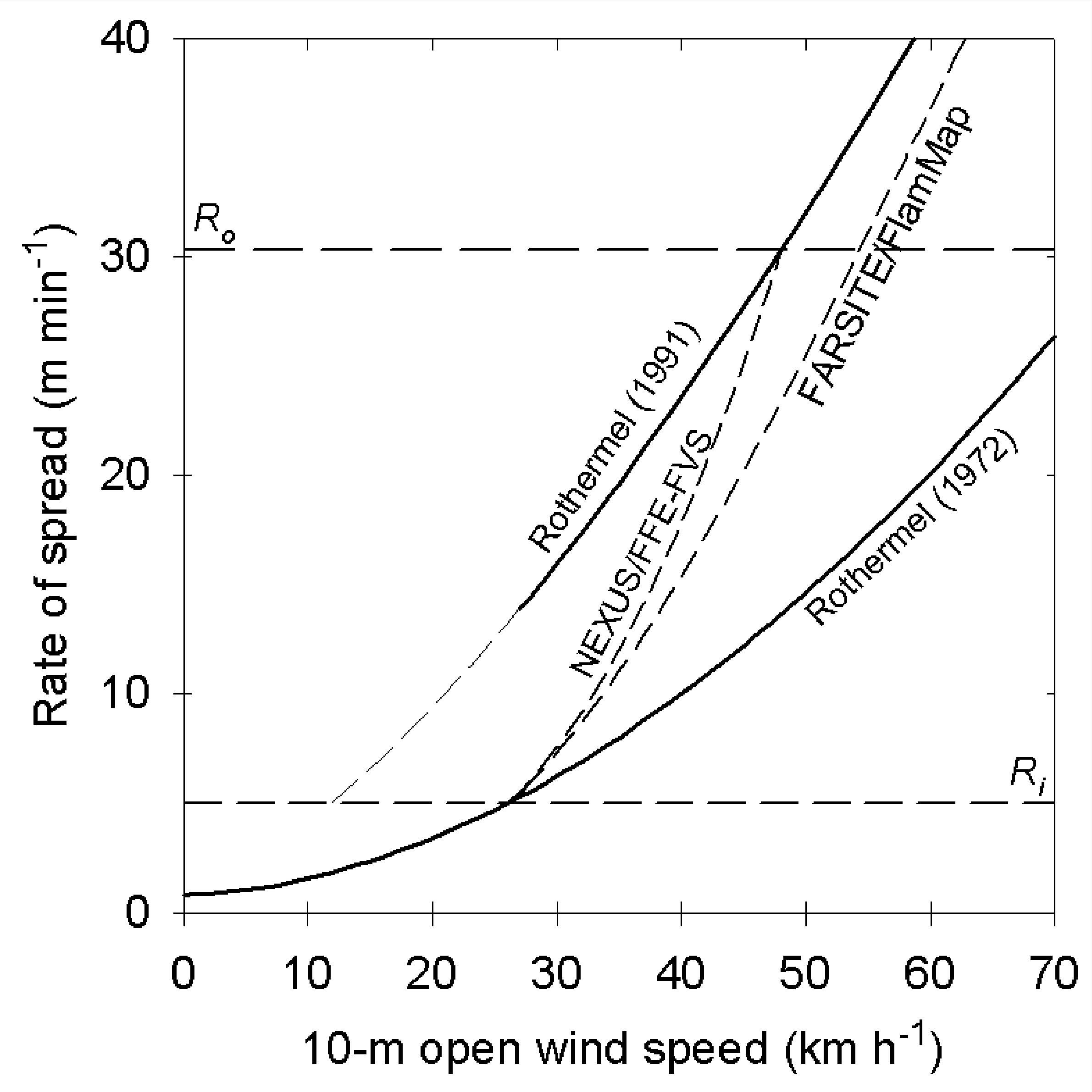
- ***FARSITE*** and ***FlamMap*** uses the Van Wagner (1993) approach (i.e., a unique ***a*** coefficient to calculate ***CFB*** as dictated by the critical surface fire spread rate (based on ***SFC***, ***CBH*** and ***m***) for the onset of crowning and critical minimum spread rate for active crowning (based on ***CBD***).

- ***NEXUS*** (and in turn the ***FFE-FVS***) uses a linear relation between the critical surface fire spread rate (based on ***SFC***, ***CBH*** and ***m***) for the onset of crowning and critical minimum spread rate for active crowning (based on ***CBD***).

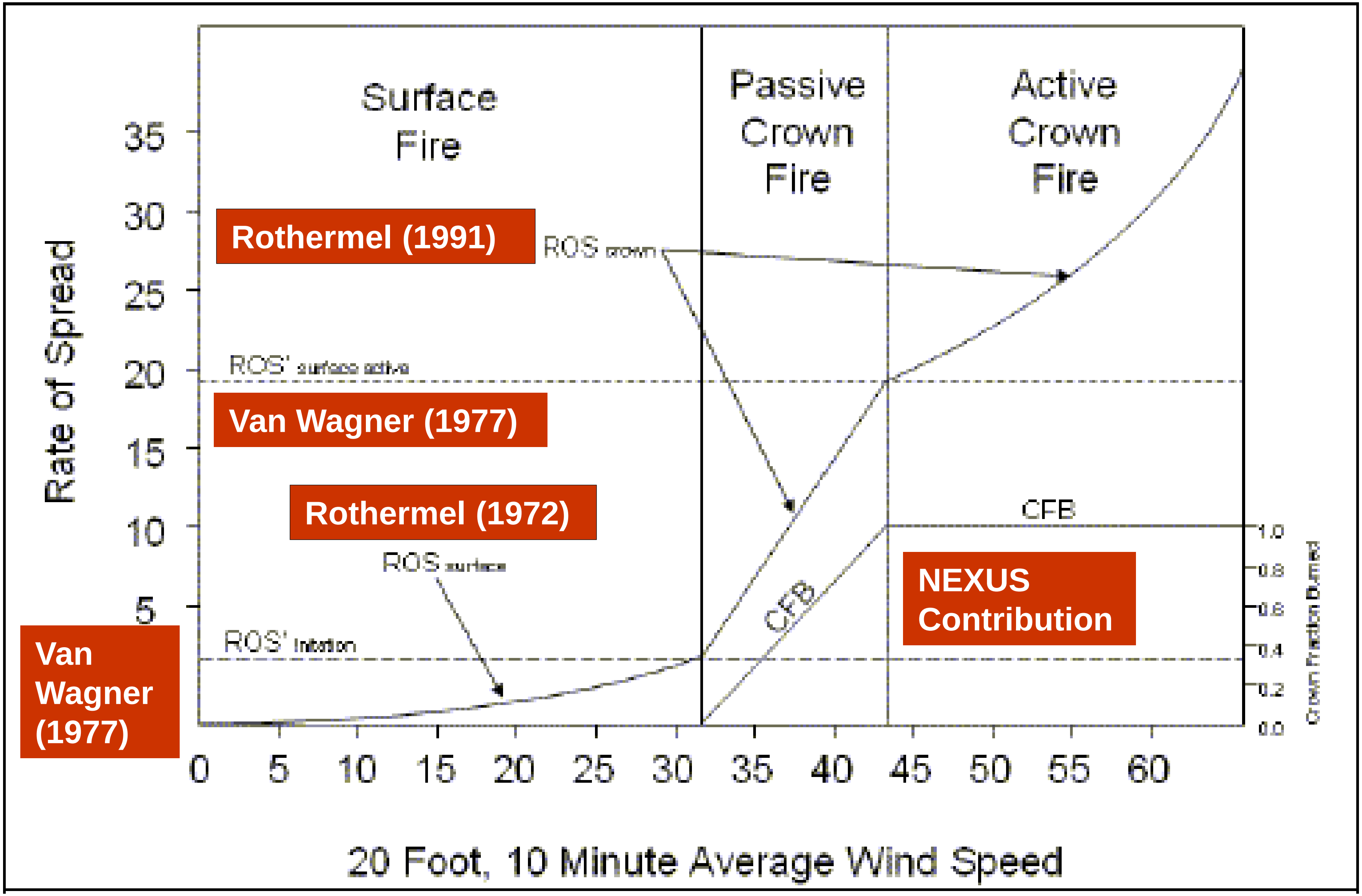
- ***Fuels Management Analyst*** includes both the ***FARSITE***/***FlamMap*** and ***NEXUS***/***FFE-FVS*** methods

For copy of user guide see:
http://www.fireps.com/software/ug_cm3.pdf

Coupling Rothermel's Surface Fire (1972) and Crown Fire (1991) Rate of Spread Models

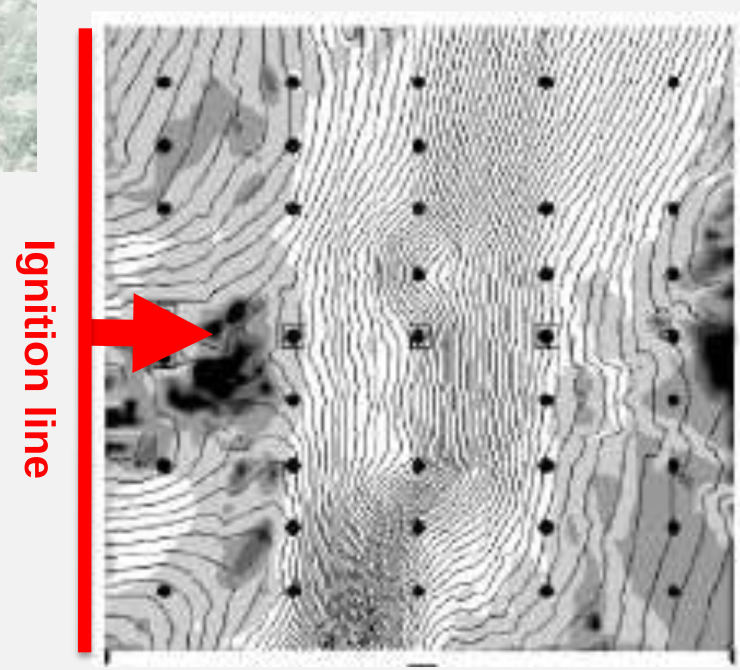


NEXUS Simulation (Scott and Reinhardt 2001)



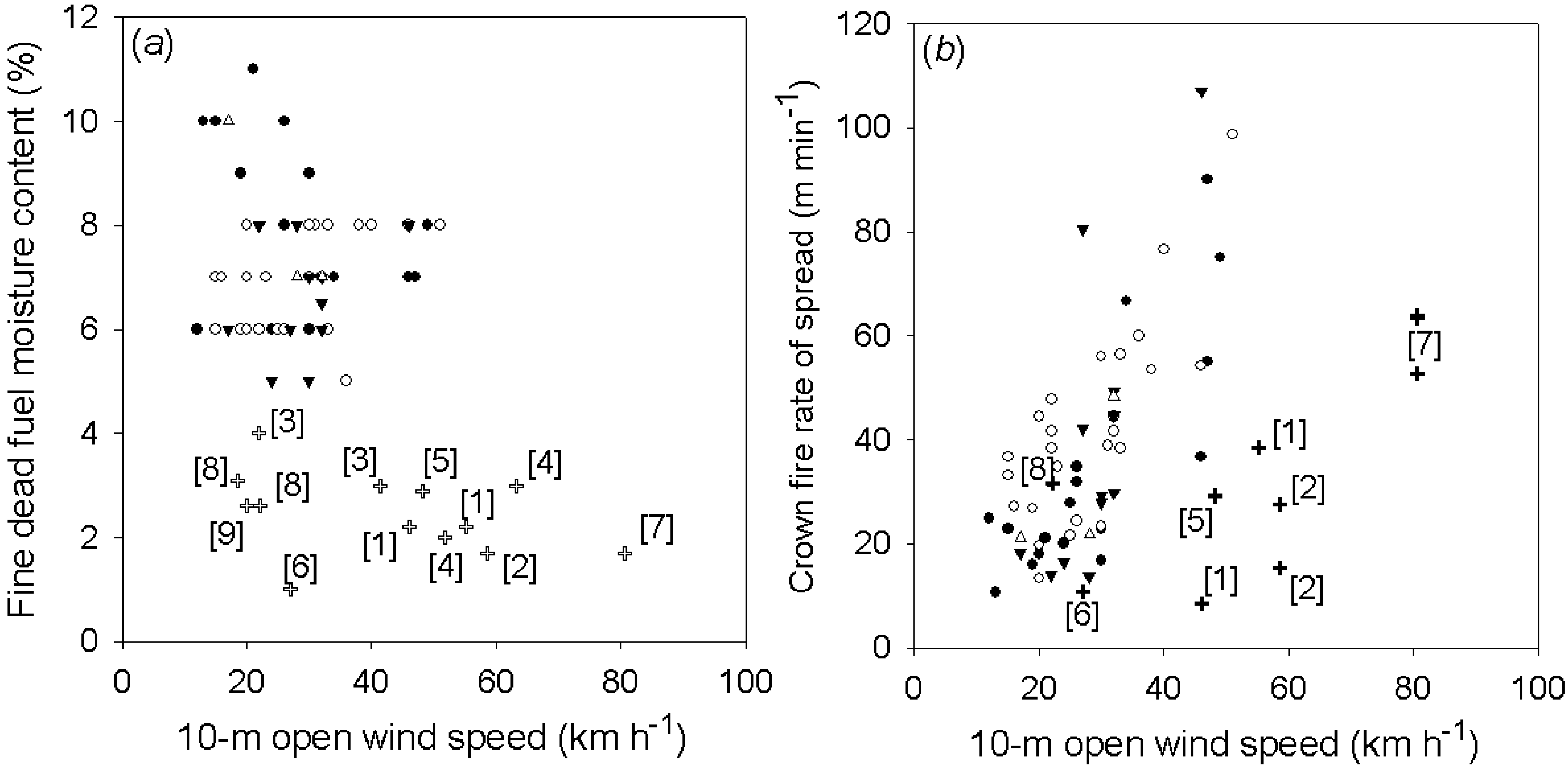
Onset of crowning: effect on fire spread
ICFME Plot 8; Taylor *et al*. 2004; Stocks *et al*. 2004)

Phase	U10 (km/h)	ROS (m/min)
1 **(C)**	11.0	24.3
2 **(S)**	8.3	5.6
3 **(C)**	14.3	54.0

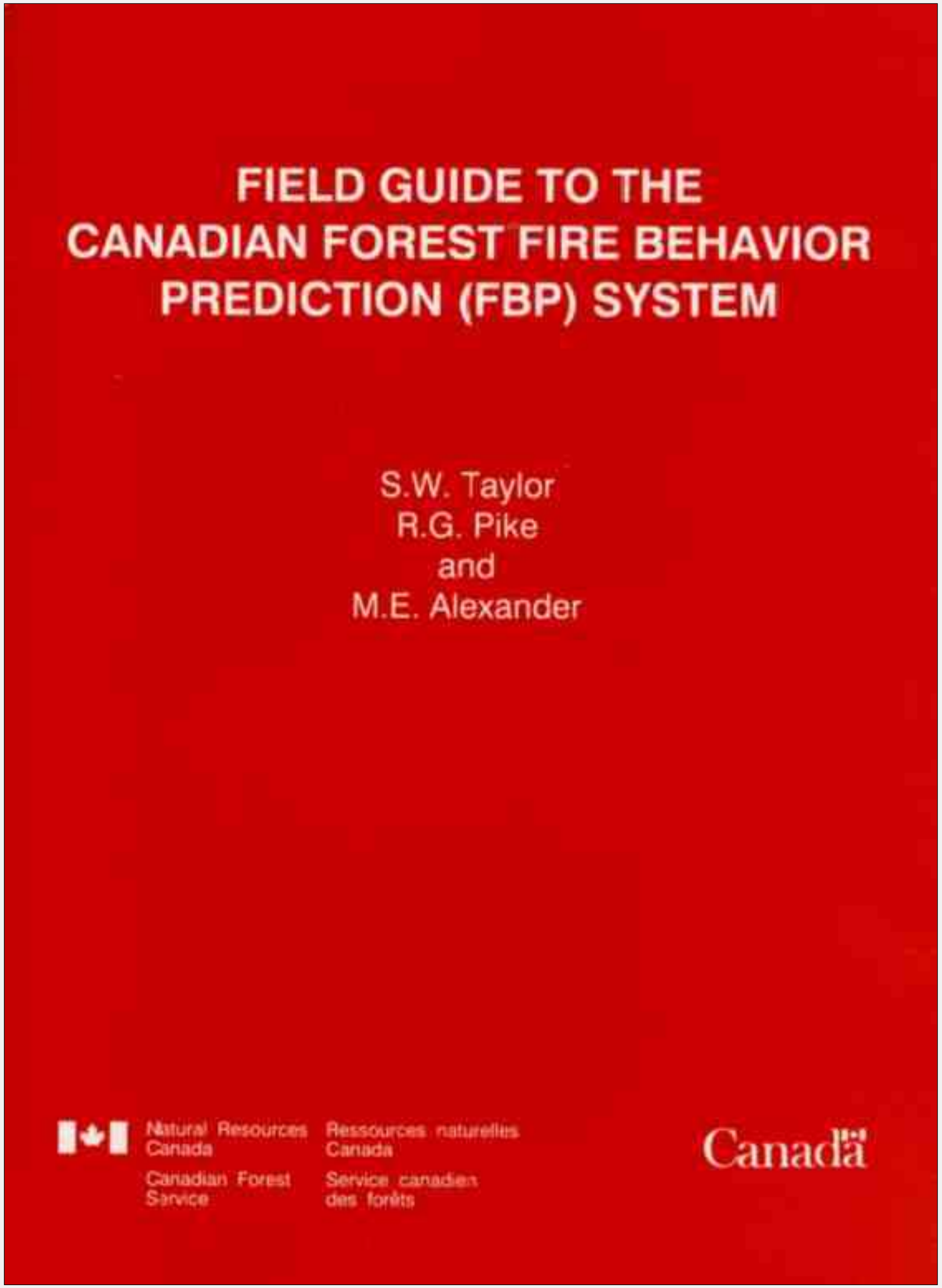


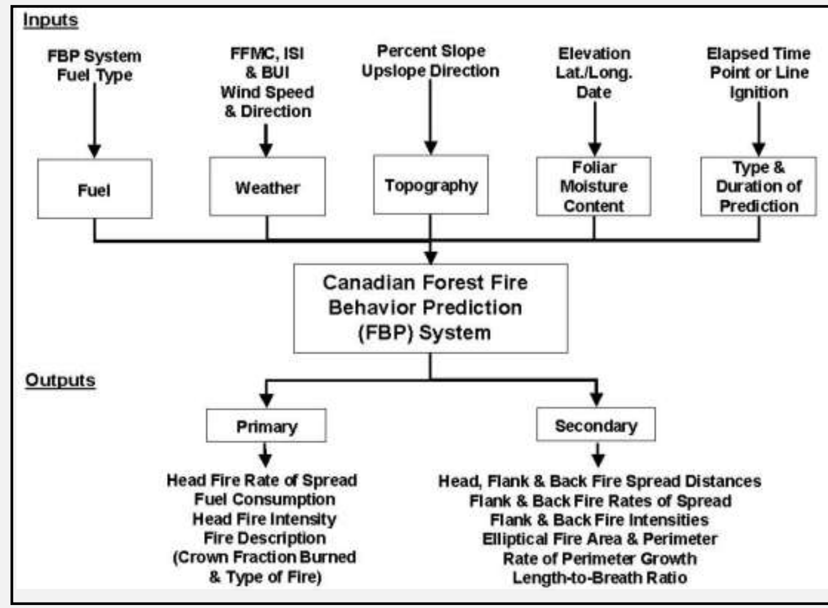
Rothermel's (1991) Crown Fire Rate of Spread Model

- Under prediction bias -



Cruz and Alexander (2010), Crown fire potential: a critique of current approaches and recent simulation studies. *IJWF*


FIELD GUIDE TO THE
CANADIAN FOREST FIRE BEHAVIOR
PREDICTION (FBP) SYSTEM
S.W. Taylor
R.G. Pike
and
M.E. Alexander
Natural Resources Canada
Ressources naturelles Canada
Canadian Forest Service
Service canadien des forêts
Canada


Inputs
FBP System Fuel Type
FFMC, ISI & BUI Wind Speed & Direction
Percent Slope Upslope Direction
Elevation Lat./Long. Date
Elapsed Time Point or Line Ignition
Fuel
Weather
Topography
Foliar Moisture Content
Type & Duration of Prediction
Canadian Forest Fire Behavior Prediction (FBP) System
Outputs
Primary
Secondary
Head Fire Rate of Spread
Fuel Consumption
Head Fire Intensity
Fire Description
(Crown Fraction Burned & Type of Fire)
Head, Flank & Back Fire Spread Distances
Flank & Back Fire Rates of Spread
Flank & Back Fire Intensities
Elliptical Fire Area & Perimeter
Rate of Perimeter Growth
Length-to-Breath Ratio

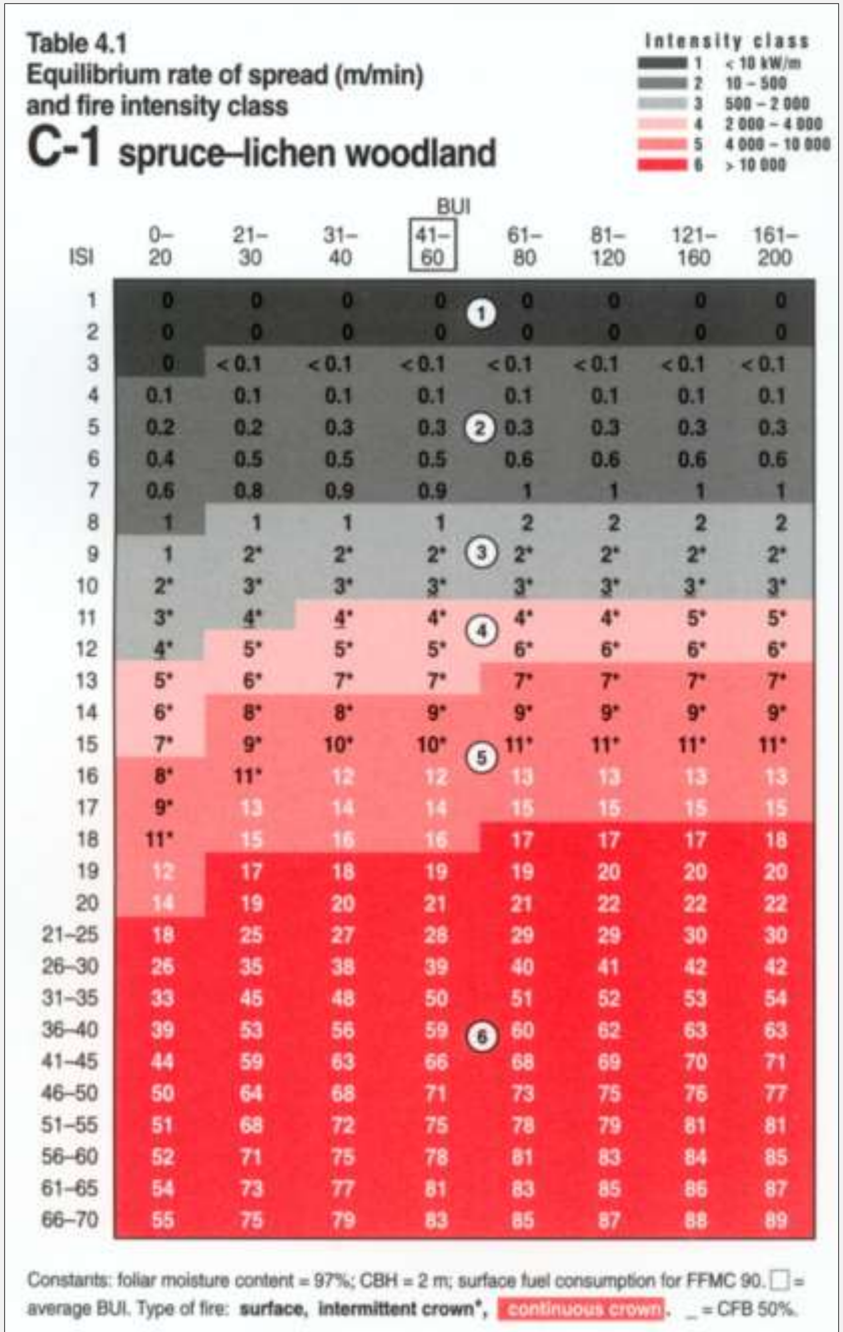


Table 4.1
Equilibrium rate of spread (m/min) and fire intensity class

C-1 spruce–lichen woodland

Intensity class	
1	< 10 kW/m
2	10 – 500
3	500 – 2 000
4	2 000 – 4 000
5	4 000 – 10 000
6	> 10 000

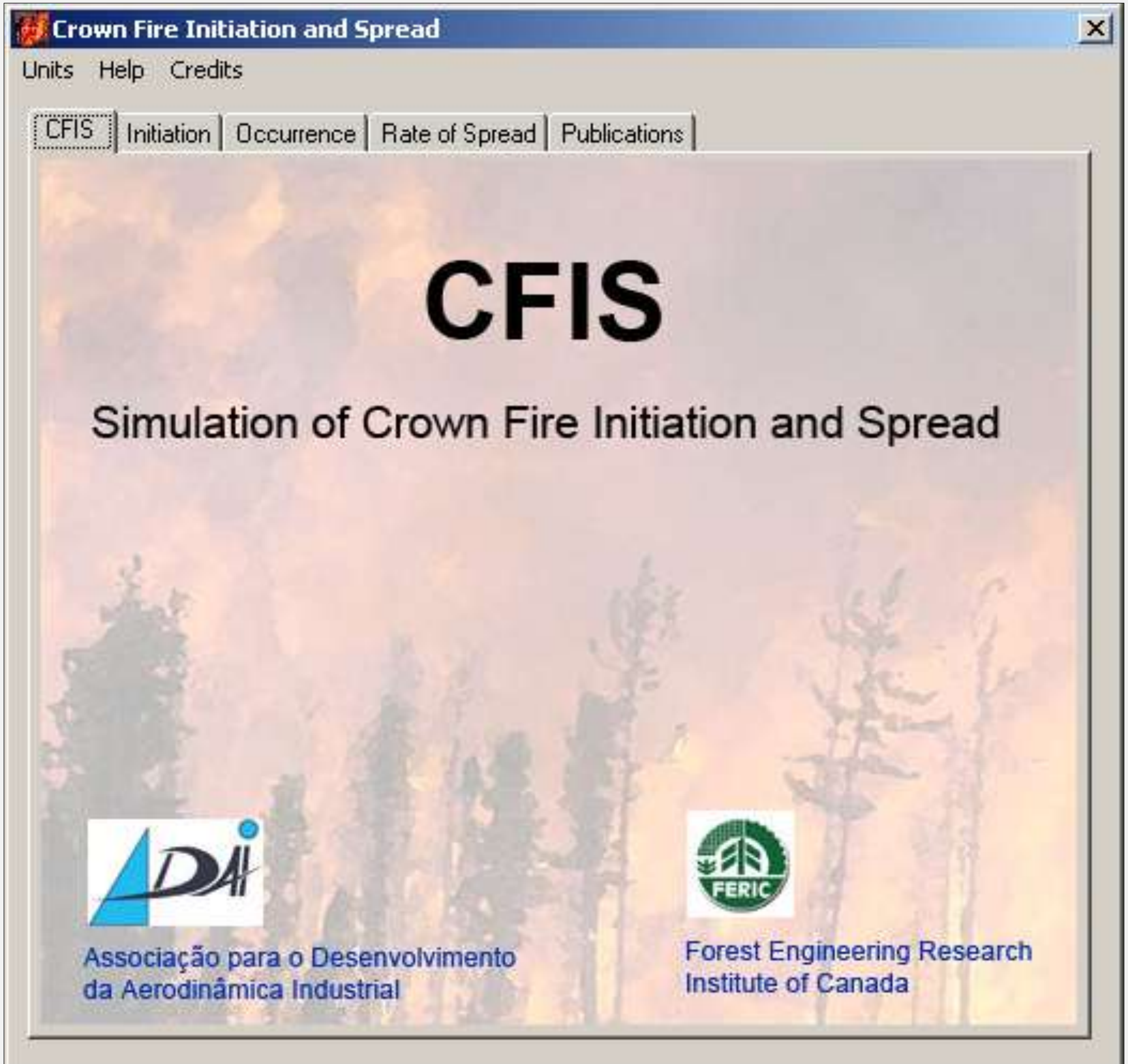
ISI \ BUI	0–20	21–30	31–40	41–60	61–80	81–120	121–160	161–200
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
5	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
6	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.6
7	0.6	0.8	0.9	0.9	1	1	1	1
8	1	1	1	1	2	2	2	2
9	1	2*	2*	2*	2*	2*	2*	2*
10	2*	3*	3*	3*	3*	3*	3*	3*
11	3*	4*	4*	4*	4*	4*	5*	5*
12	4*	5*	5*	5*	6*	6*	6*	6*
13	5*	6*	7*	7*	7*	7*	7*	7*
14	6*	8*	8*	9*	9*	9*	9*	9*
15	7*	9*	10*	10*	11*	11*	11*	11*
16	8*	11*	12	12	13	13	13	13
17	9*	13	14	14	15	15	15	15
18	11*	15	16	16	17	17	17	18
19	12	17	18	19	19	20	20	20
20	14	19	20	21	21	22	22	22
21–25	18	25	27	28	29	29	30	30
26–30	26	35	38	39	40	41	42	42
31–35	33	45	48	50	51	52	53	54
36–40	39	53	56	59	60	62	63	63
41–45	44	59	63	66	68	69	70	71
46–50	50	64	68	71	73	75	76	77
51–55	51	68	72	75	78	79	81	81
56–60	52	71	75	78	81	83	84	85
61–65	54	73	77	81	83	85	86	87
66–70	55	75	79	83	85	87	88	89

Constants: foliar moisture content = 97%; CBH = 2 m; surface fuel consumption for FFMC 90. ☐ = average BUI. Type of fire: **surface**, **intermittent crown***, continuous crown. _ = CFB 50%.

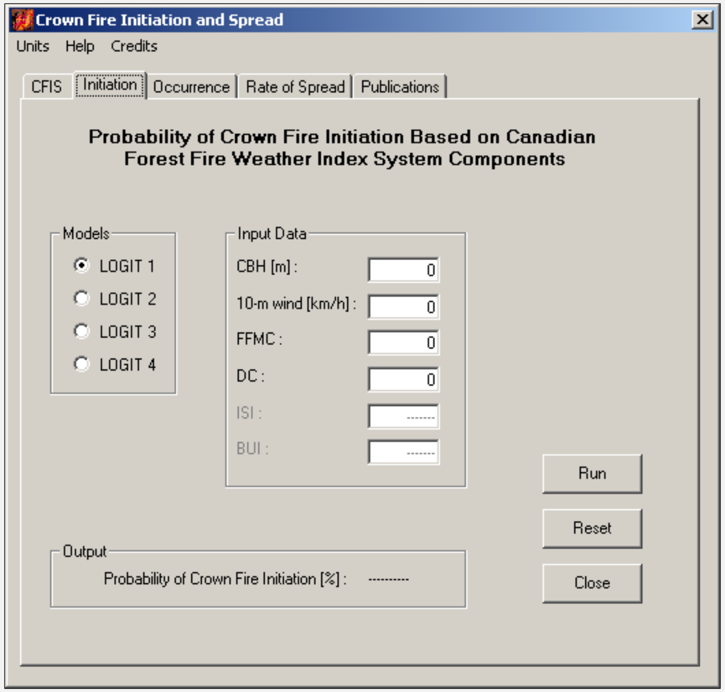
Sample page from FBP System "Red Book"

For a given fuel type, each table provides the following:

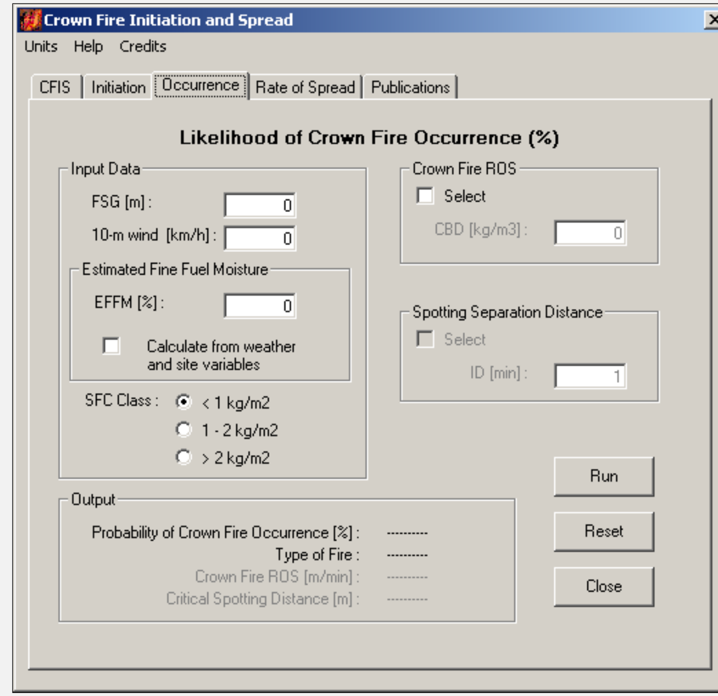
- Head fire rate of spread;
- Type of fire (surface, intermittent crown or continuous crown);
- Intensity class; and
- 50% CFB threshold.



Cruz, Alexander and Wakimoto (2003, 2004, 2005) crown fire behavior models have now been incorporated into a software package.

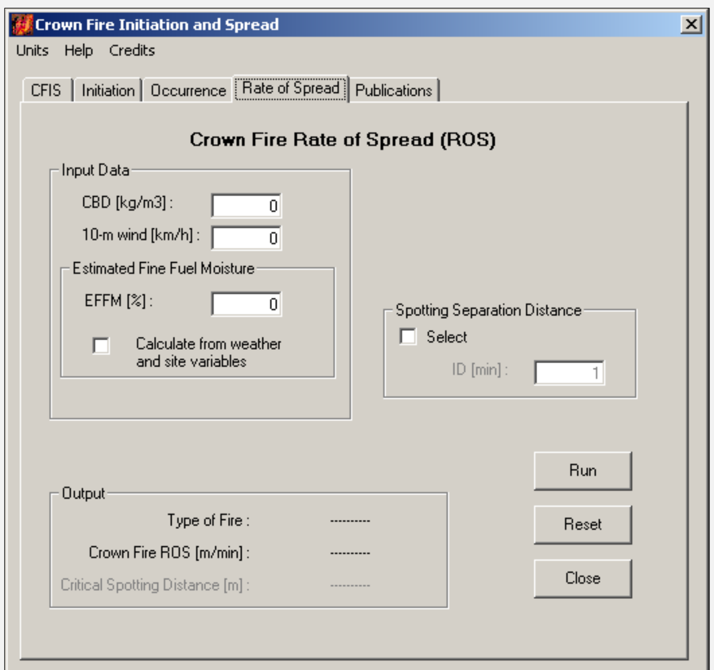


Crown Fire Initiation



Crown Fire Occurrence

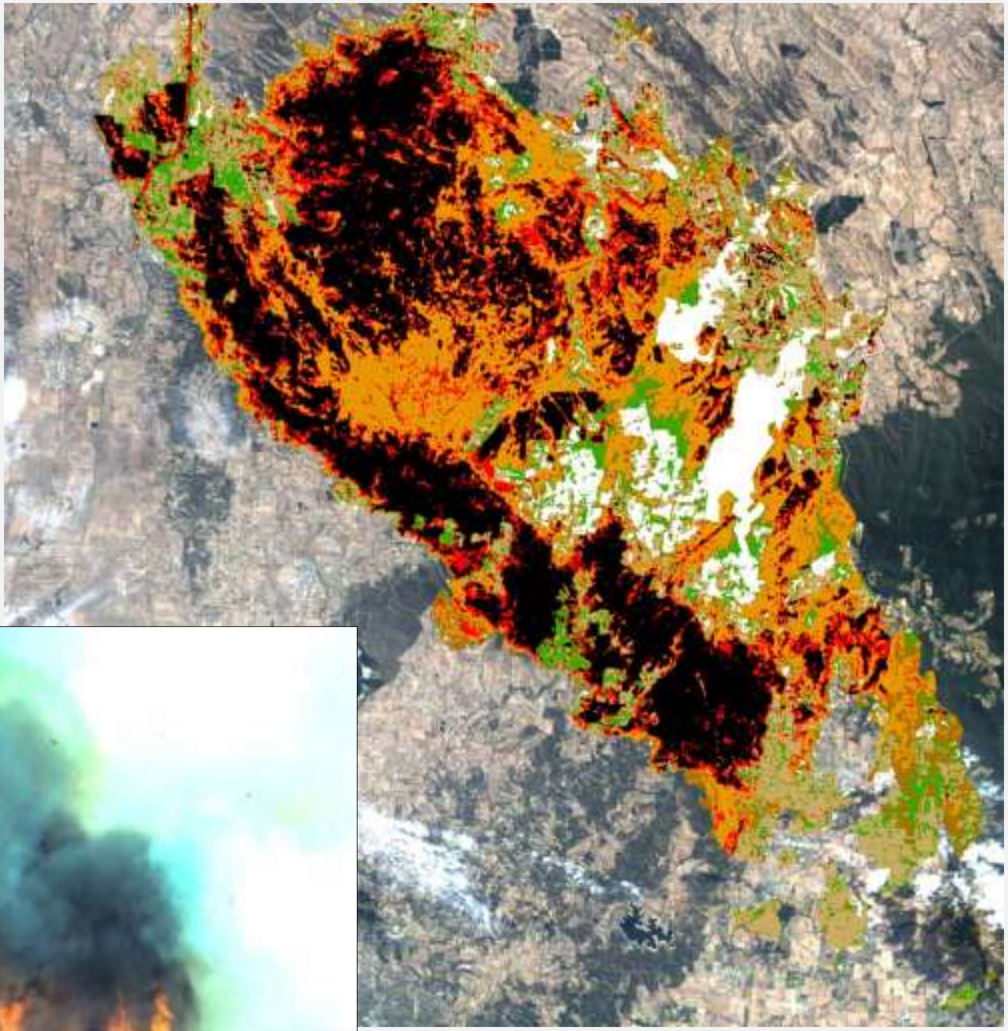
Screen Captures from *CFIS*



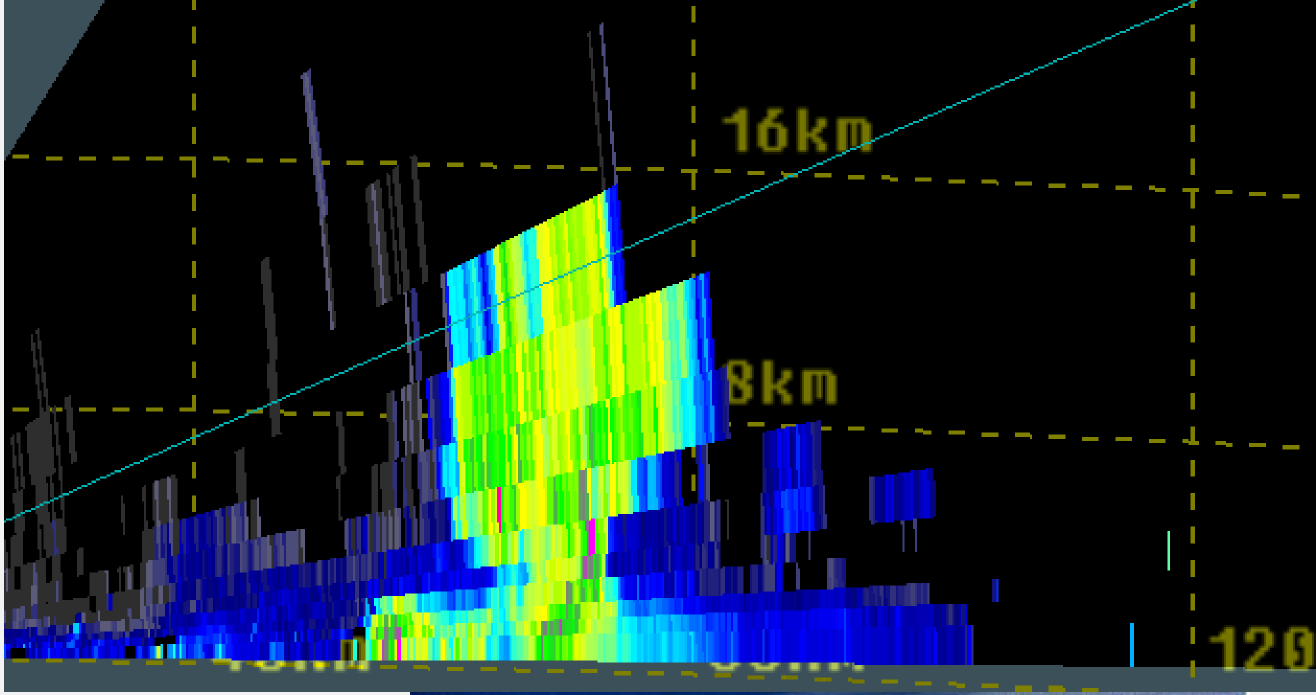
Crown Fire Rate of Spread

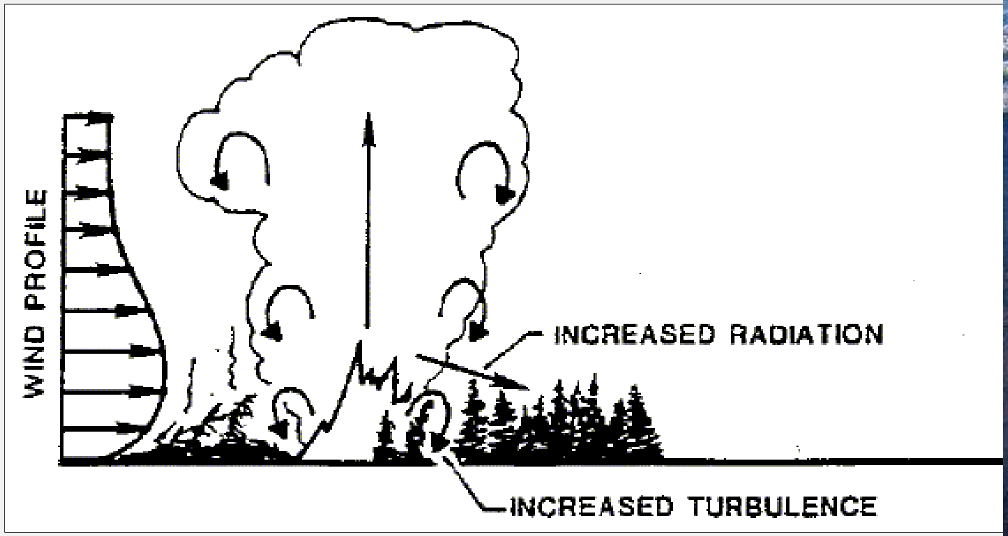
Publications list

Predictability of crown fire spread rates?



Plume behaviour





The predictability of crown fire propagation

Uncertainty associated with model predictions of surface and crown fire rates of spread, (Cruz and Alexander, *in review*)

We compiled data from **48** fire spread model evaluation datasets involving **1265** observations in seven different fuel type groups.

Objective:
– Quantify **uncertainty** with fire spread model predictions
– Quantify the **limits of predictability** of current operational models

Statistics used

$\text{RMSE} = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n}}$	The RMSE is a useful overall measure of model performance. The RMSE provides a measure of the precision of the estimates in the same units as the dependent variable (e.g., rate of fire spread, m/min). A "good" model will provide low values of the RMSE. Because large errors are weighted heavily, this can result in a large RMSE even though the errors may be otherwise small.
$\text{MAE} = \frac{\sum \lvert y_i - \hat{y}_i \rvert}{n}$	MAE, which like the RMSE is expressed in the same units as the original data, is a quantity used to measure how close predictions are to observed value. As the name suggests, the MAE is an average of the absolute error. The MAE is similar to the RMSE but is less sensitive to large errors.
$\text{MAPE} = \frac{\sum \left(\frac{\lvert y_i - \hat{y}_i \rvert}{y_i} \right)}{n} 100$	The MAPE is a very popular measure of the accuracy of a predictive model or system. It represents the summed differences between the individual predicted versus observed values divided by the observed value; multiplying it by 100 makes it a percentage error. If a perfect fit is obtained then the MAPE is zero. A MAPE of 10% is considered a very good result. A MAPE in the range of 20 to 30% or even higher is quite common.
$\text{MBE} = \frac{\sum (\hat{y}_i - y_i)}{n}$	The MBE describes the dispersion or spread of the residual distribution about the estimate of the mean. A positive value indicates an over-prediction trend while a negative is an indication of an under-prediction trend.

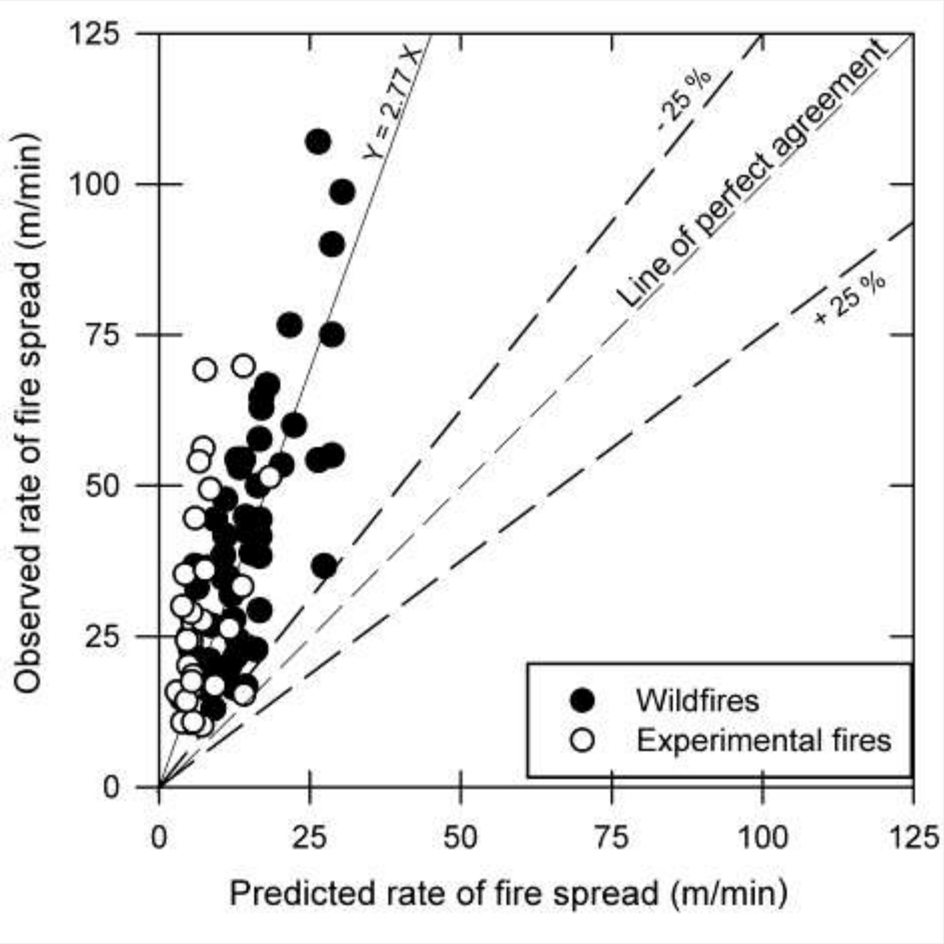
Data types used in evaluation of fire spread models

Fuel types (# of studies)
Grasslands (n = 6)
Shrublands (n = 8)
Logging slash (n = 3)
Conifer forest (n = 17)
Hardwood forest (n = 3)
Mixedwood forest (n = 2)
Eucalypt forest (n = 9)

Fire source
Experimental
Prescribed burn
Wildfire

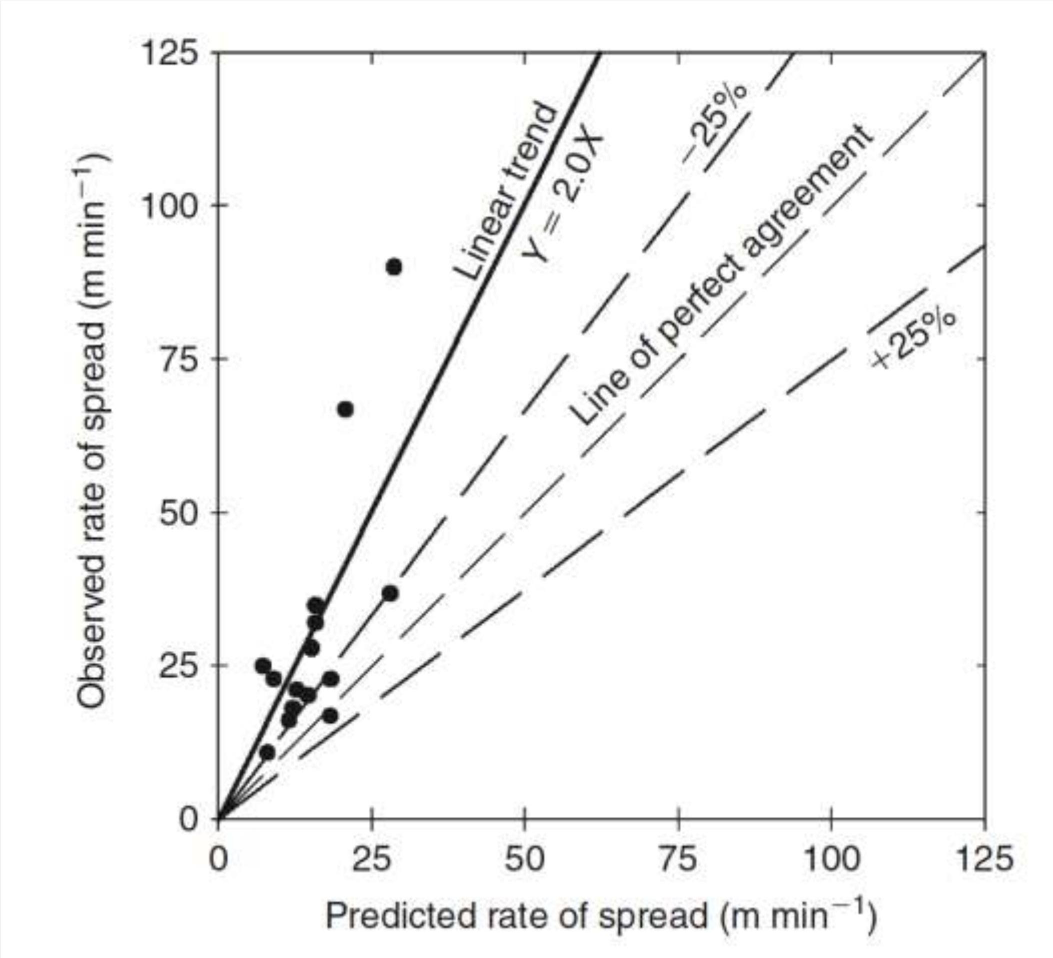
Fire type
Surface fire
Crown fire

Rothermel (1991) model: Comparison against experimental and wildfires – multiple fuel types



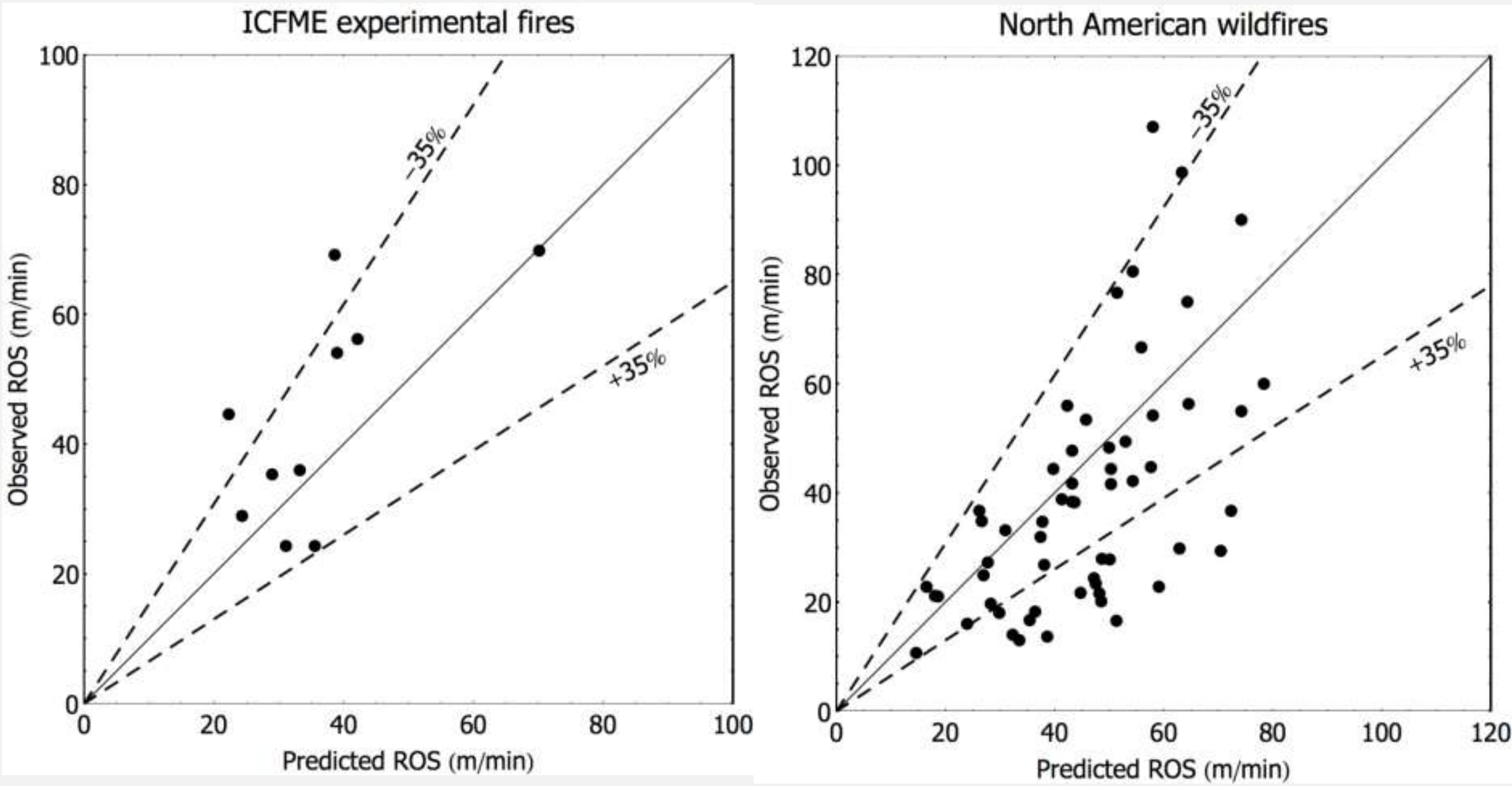
ROS range (m/min)	n	RMSE	MAE	MAPE	MBE
7.5 – 51.4 (Exp)	25	18.9	16.1	**68 %**	16.1
10.7 – 107 (WF)	54	30.7	25.3	**59 %**	25.3

Schaaf et al. (2007) model: Comparison against crowing wildfires in black spruce –feather moss fuel complex)



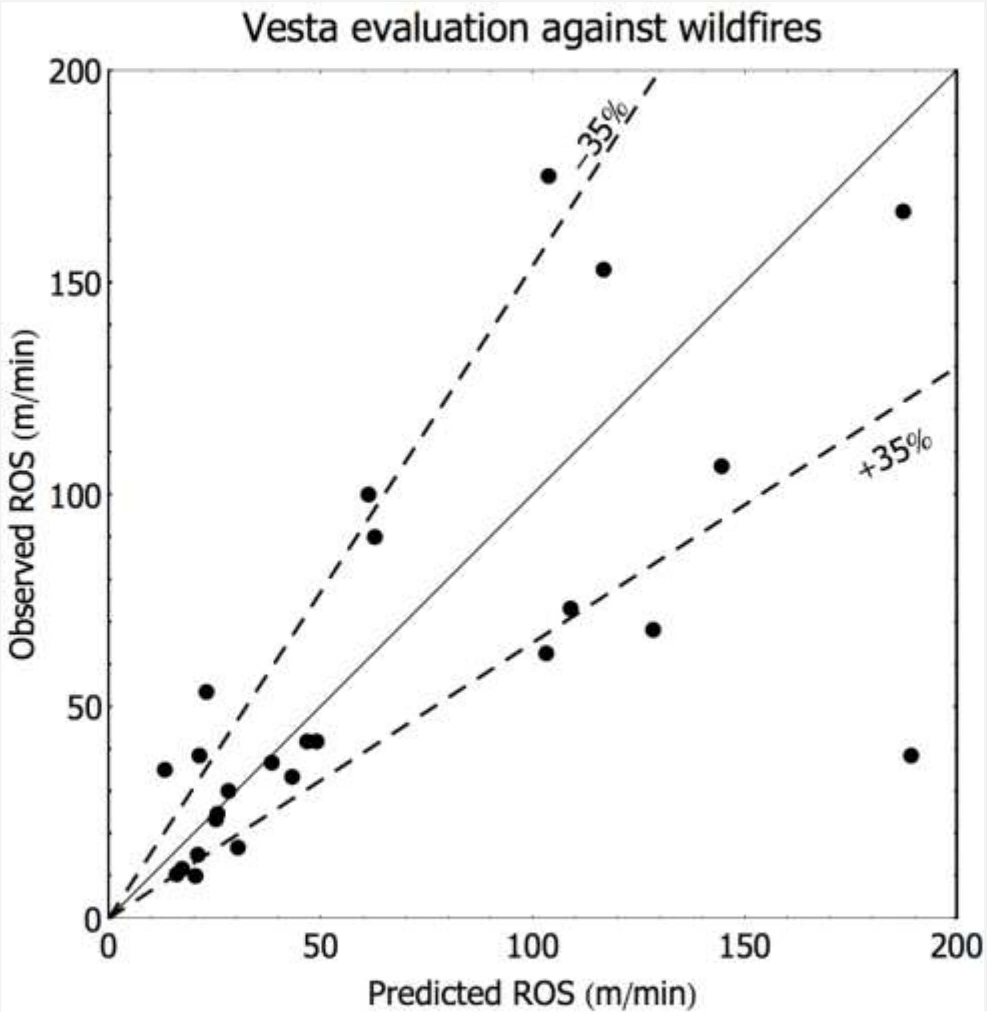
ROS range (m/min)	n	RMSE	MAE	MAPE	MBE
10.7 - 90	15	22.2	15.2	**42%**	15

Cruz et al. (2005) model: Comparison against experimental and wildfires – multiple fuel types



ROS range (m/min)	n	RMSE	MAE	MAPE	MBE
22.3 – 70.1 (Exp)	10	14.5	11.4	**26 %**	7.7
10.7 – 107 (WF)	57	18.9	14.9	**52 %**	-6.6

Cheney et al. (2012) model: Comparison against wildfires – Eucalypt forest



ROS range (m/min)	n	RMSE	MAE	MAPE	MBE
2.5 – 16 (Exp)	16	2.86	2.16	**35 %**	0.03
10 – 175 (WF)	25	41.05	26.4	**54 %**	-6.8

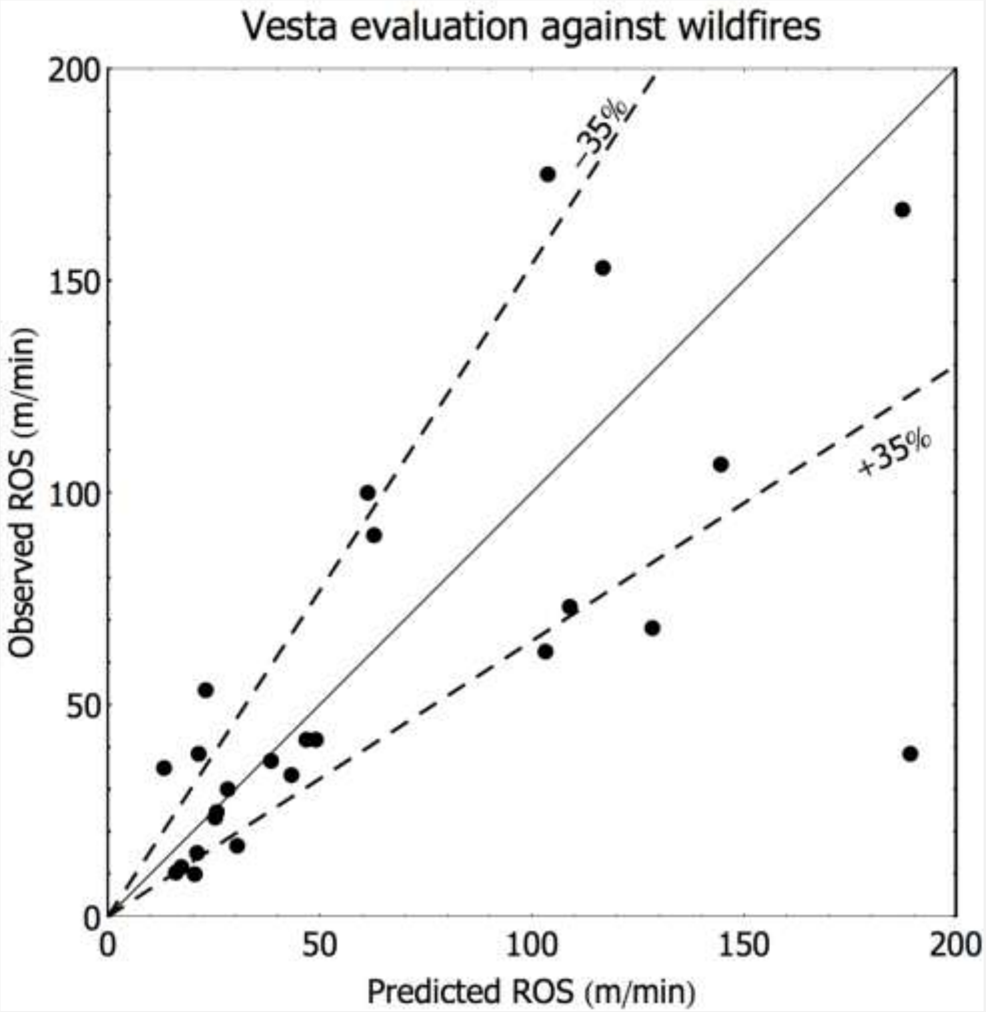
Model evaluation – predictability of crown fire rates of spread

(Cruz and Alexander, *in review*)

Model	Type of fire	Fuel type	MAPE	MBE	Rank
Rothermel (1972)	Surface	Shrubland/AUS	20 %	-1.8	1
Rothermel (1972)	Surface	Palmeto/USA	26 %	0.9	4
Cruz et al. (2005)	**Crown**	**Conifer/CA, USA**	**26 %**	**7.7**	**5**
Rothermel (1972)	Surface	Shrubland/SA	30 %	-2.1	7
Cruz et al. (2005)	**Crown**	**Conifer/CA, USA**	**52 %**	**-6.6**	**17**
Vesta - Cheney et al. (2012)	**Crown**	**Eucalypt/AUS**	**54 %**	**-6.8**	**25**
Rothermel (1972)	Surface	Grassland/SA	86 %	-3.5	45
Rothermel (1972)	Surface	Eucalypt/AUS	95 %	-0.11	46
Griffin and Alan (1984)	Surface	Grassland/AUS	217 %	-43.4	47
Rothermel (1972)	Surface	Conifer/USA	310 %	-0.4	48

Can we define an acceptable error for fire spread model predictions?

On the basis of the analysis of 48 model evaluation datasets and related considerations, it appears that a **±35% error** constitutes a reasonable and conservative standard for fire spread rate model performance



Limitations

and

Assumptions

On the Limitations in Fire Models

"*All fire models simulate reality but fall short of it in varying degrees. In meeting the objective of simplifying relationships, minor factors are neglected and the model is usually based on a single set of idealized conditions. If fire-modeling laws are observed, this will permit approximations close enough for many purposes, but it is easy to forget that they are approximations only. Consequently, there is a strong tendency to apply models beyond their field of usefulness. To avoid this, the assumptions on which they are based and the range of conditions under which the model is valid need to be carefully defined and frequently rechecked.*"

A.A. Brown & K.P. Davis (1973)
Forest Fire: Control & Use. 2nd Edition

Limitations

- Empirical models – broad simplification
- Physical models – uncertain model bounds
- Need more evaluation

Assumptions

- Model specific assumptions
- General prediction assumptions (idealized environment)
- Forecast specific assumptions

The models comprising ***CFIS*** are considered most valid for free-burning fires that have reached a pseudo steady-state, burning in live, boreal or boreal-like conifer forests (i.e., they are <u>not</u> applicable to insect-killed stands).

Level terrain is assumed as the ***CFIS*** does <u>not</u> presently consider the mechanical effects of slope steepness on crown fire behavior.

The models underlying the ***CFIS*** are <u>not</u> applicable to prescribed fire or wildfire situations that involve strong convection activity as a result of the ignition pattern.



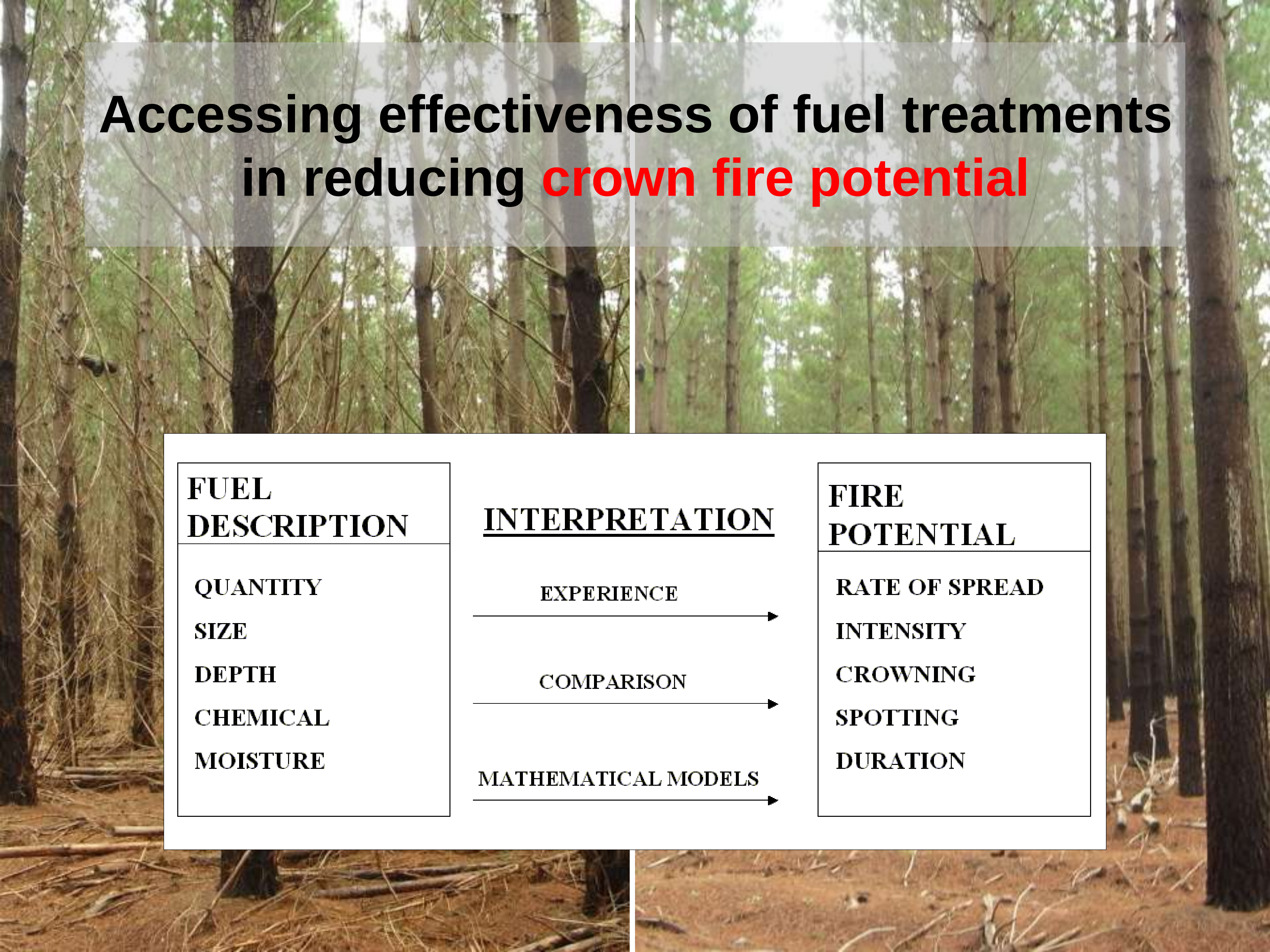
CROWN FIRE BEHAVIOR IN CONIFER FORESTS: A PRE-CONFERENCE WORKSHOP

Applications of Crown Fire Behavior Knowledge

International Association of Wildland Fire 4th Fire Behavior and Fuels Conference

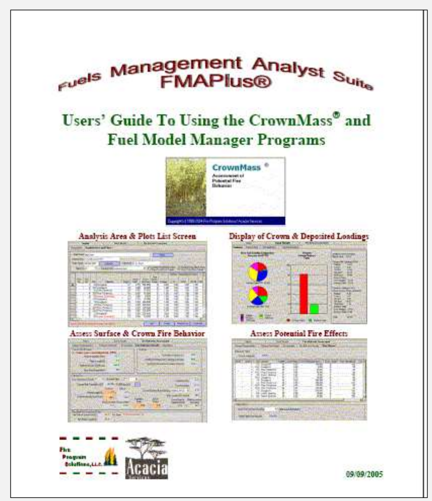
February 18, 2013 – Raleigh, NC

Accessing effectiveness of fuel treatments in reducing crown fire potential



FUEL DESCRIPTION	INTERPRETATION	FIRE POTENTIAL
QUANTITY	EXPERIENCE →	RATE OF SPREAD
SIZE		INTENSITY
DEPTH	COMPARISON →	CROWNING
CHEMICAL		SPOTTING
MOISTURE	MATHEMATICAL MODELS →	DURATION

Systems used to available to evaluate crown fire potential in the US

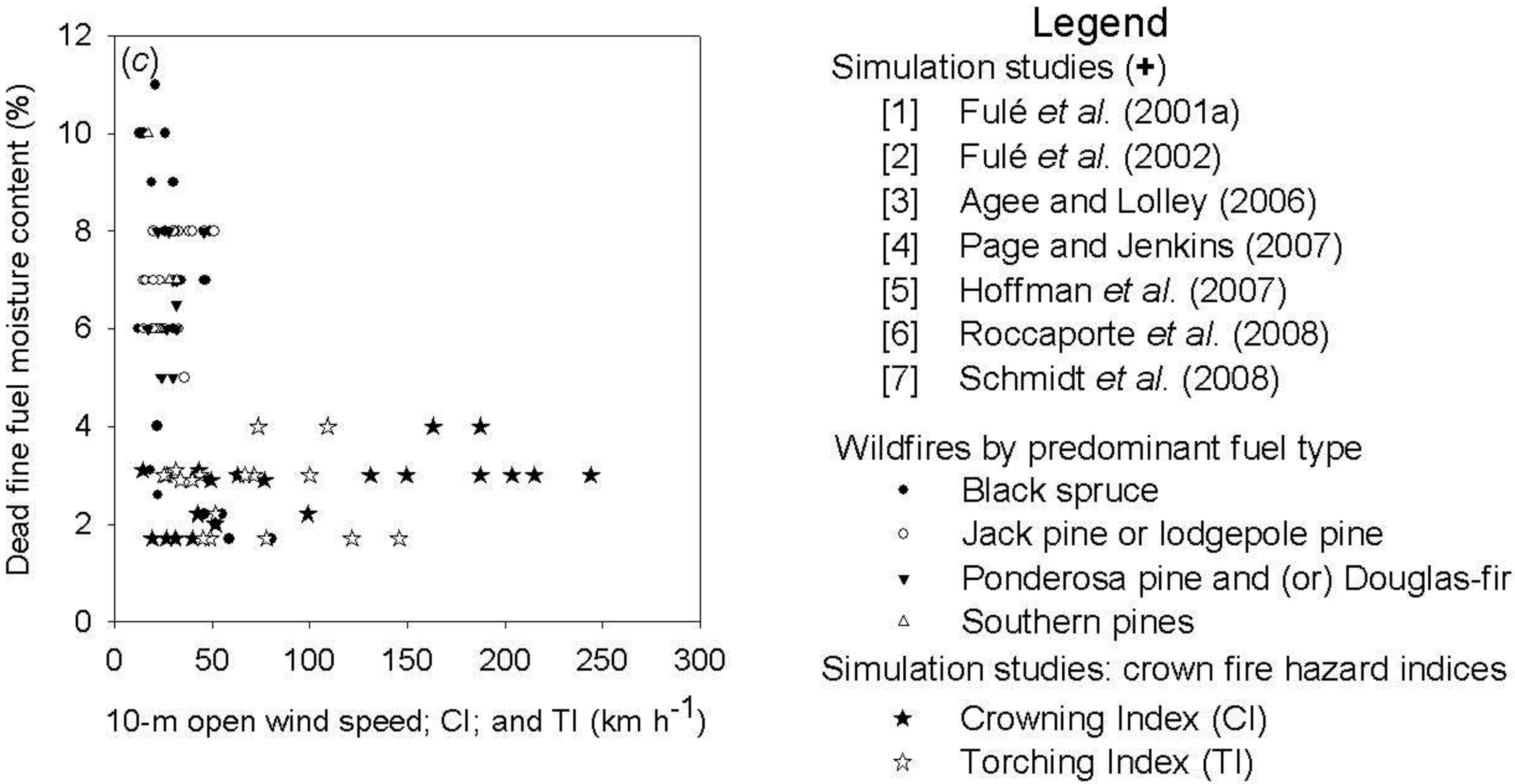


Torching and Crowning indexes (Scott and Reinhardt 2001)

Torching Index—The open (6.1-m) windspeed at which crown fire activity can initiate for the specified **fire environment**.

Crowning Index—The open (6.1-m) windspeed at which **active crown fire** is possible for the specified **fire environment**.

Crown fire potential: a critique of current approaches and recent **simulation studies** Cruz and Alexander (2010), *IJWF*



Crown fire potential: a critique of current approaches and recent **simulation studies** Cruz and Alexander (2010), *IJWF*

The principal sources of underprediction bias were:

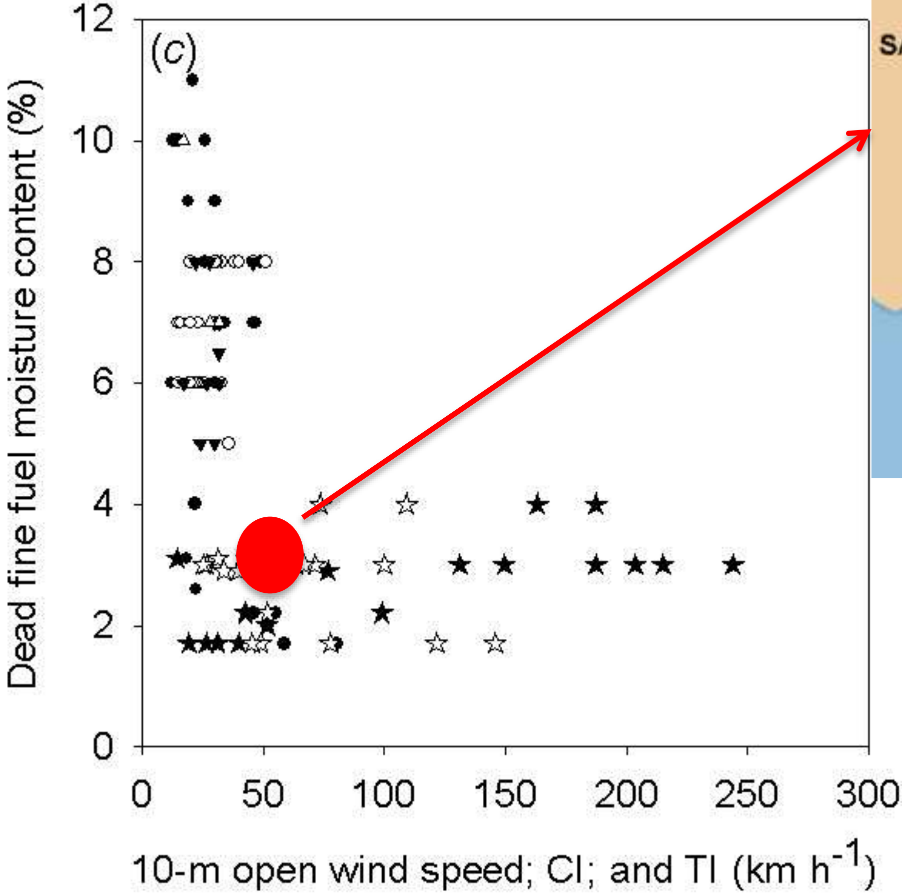
(1) **Incompatible model linkages**;

(2) Use of surface and crown fire rate of spread models that have **inherent underprediction biases** themselves;

(3) A reduction in crown fire rate of spread based on the use of **unsubstantiated crown fraction burned** functions;

(4) The use of **uncalibrated custom fuel models** to represent surface fuelbeds was considered as fourth potential source of bias.

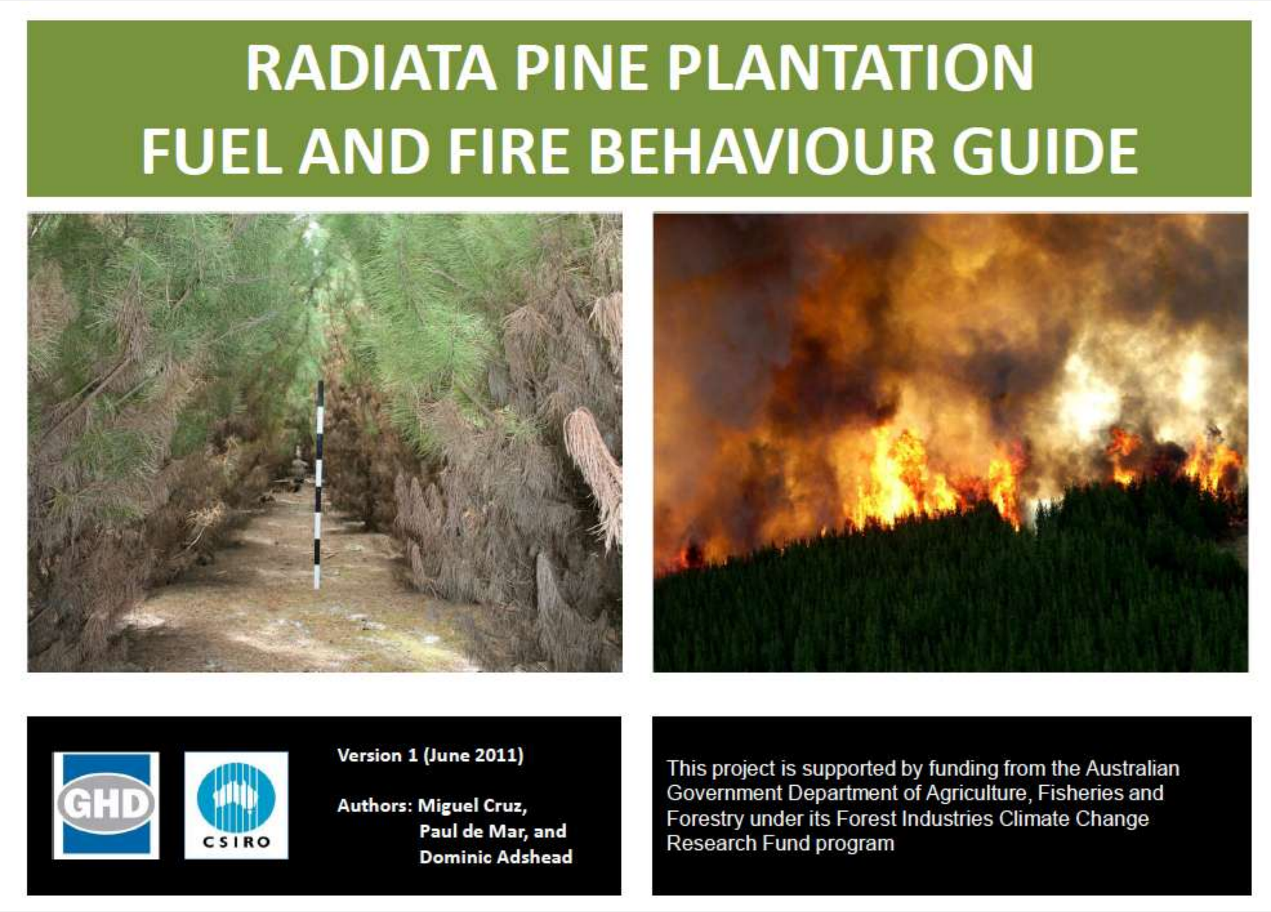
2009 Black Saturday fires, VIC, Australia



From: Cruz and Alexander (2010)

Crown Fire Free Zones through pruning and thinning

Pine plantation pyrometrics



Cruz, Alexander and Fernandes (2008), Development of a model system to predict wildfire behaviour in pine plantations. *Australian Forestry*

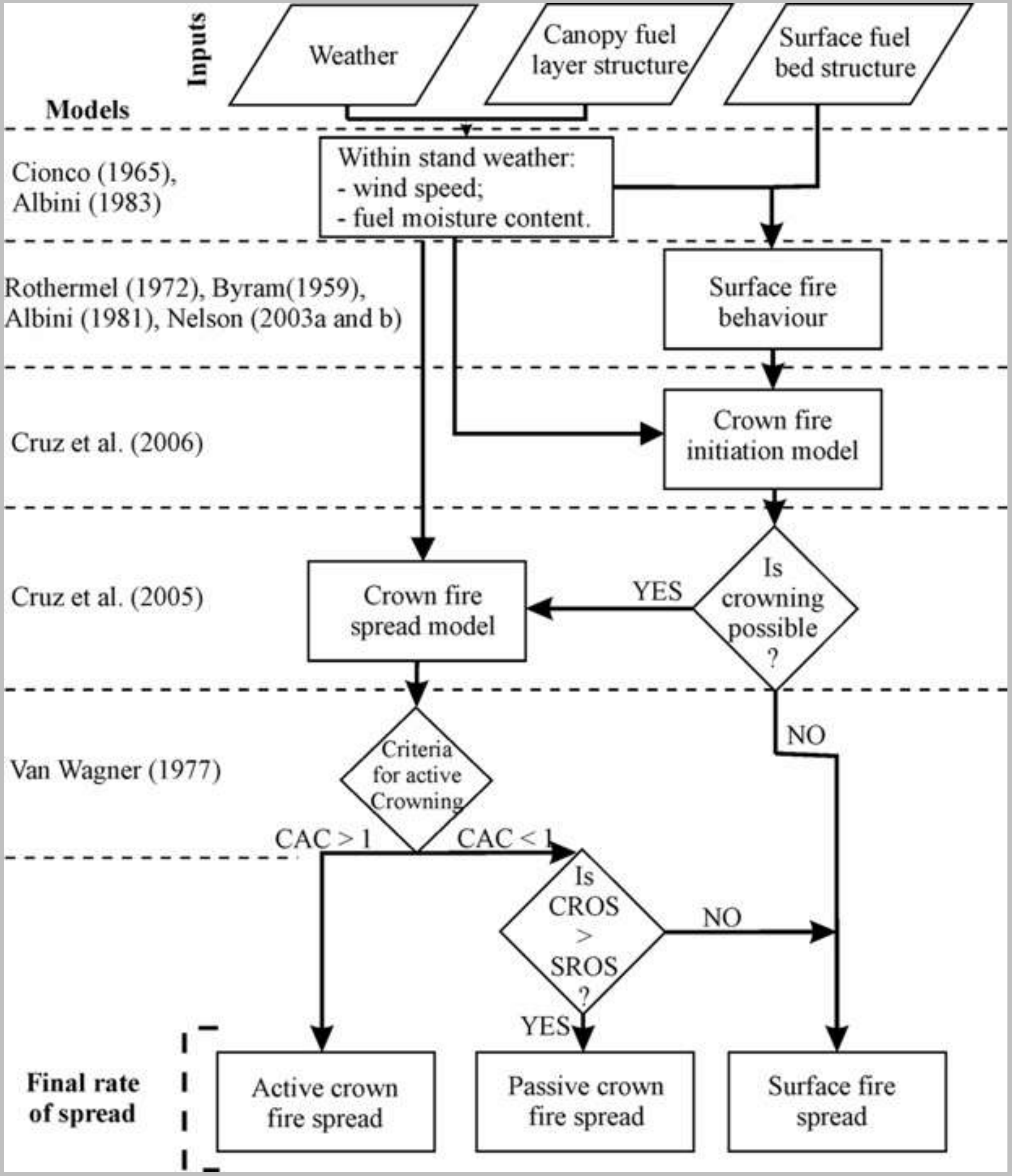
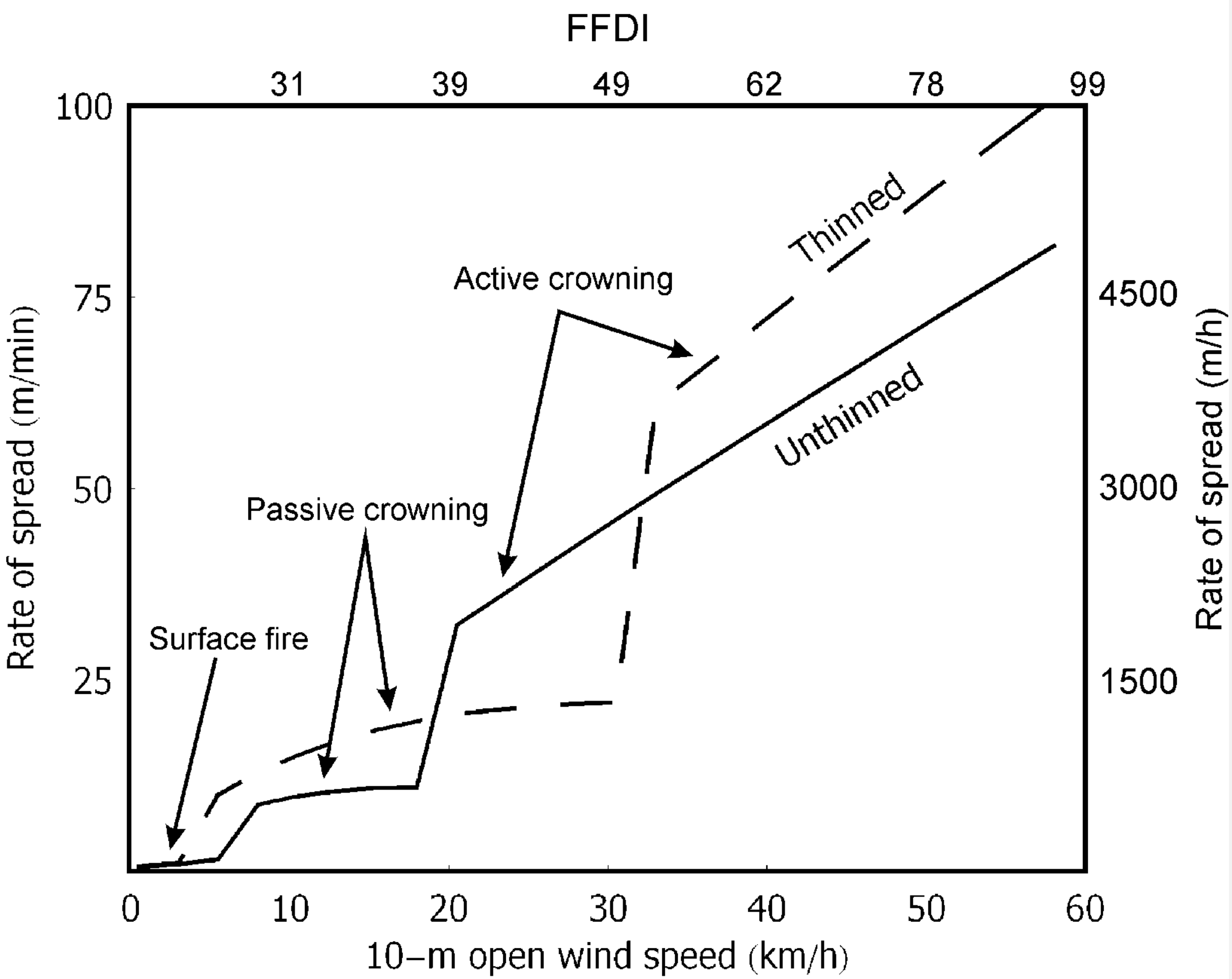


Diagram of information flow for fire behaviour prediction in pine plantations

Sample Simulation of Fire Behavior Potential in 12 y.o. Radiata Pine Plantations (per Williams 1978)

Effect of wind speed on rate of spread (*Cruz et al*. 2008; AF)



Unthinned

W **= 0.5 kg/m²**

FSG **= 0.6 m**

CBD **= 0.1 kg/m³**

EFFM **= 7 %**

Thinned*

W **= 1.1 kg/m²**

FSG **= 1.7 m**

CBD **= 0.05 kg/m³**

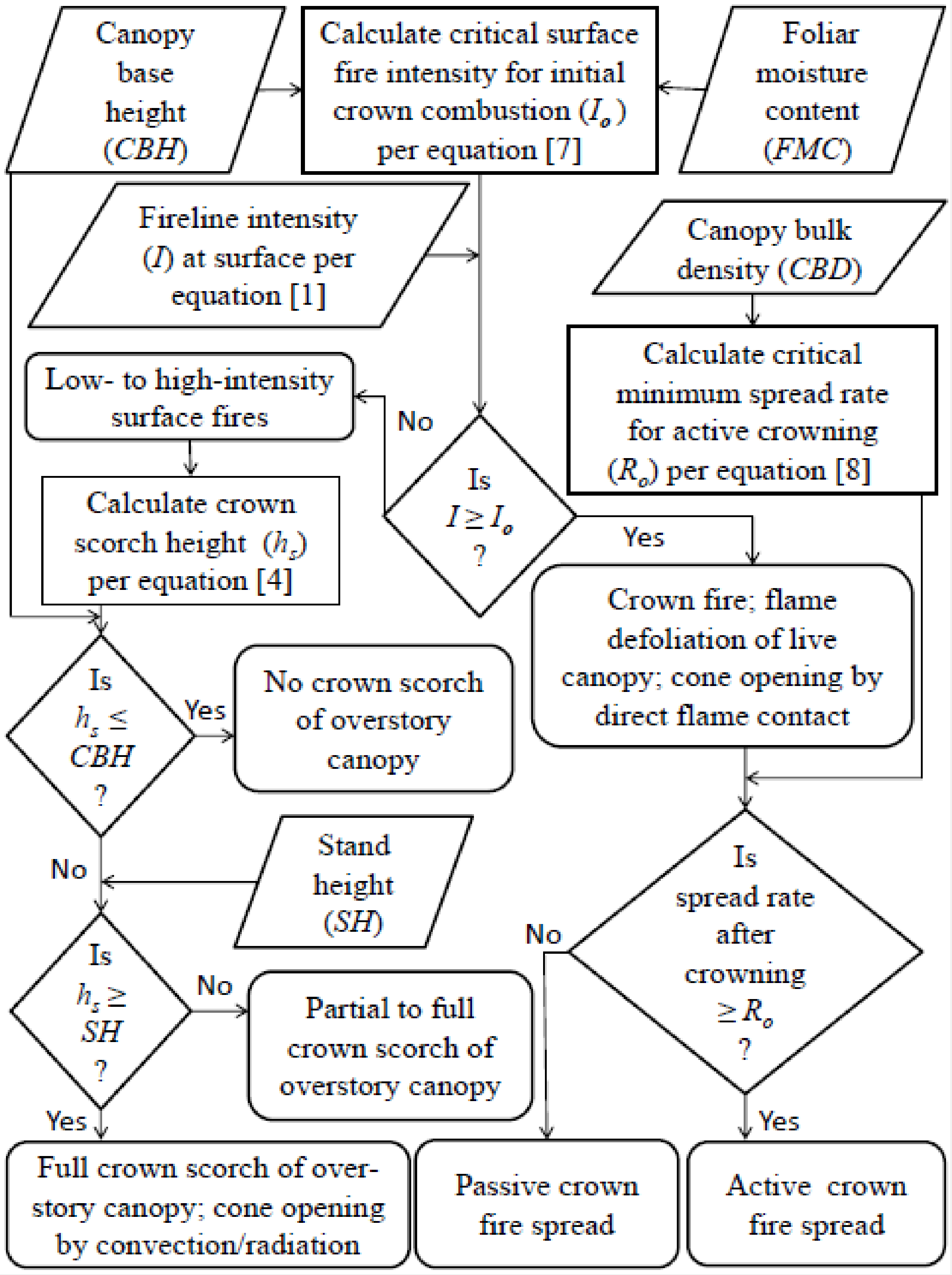
EFFM **= 5 %**

***50% basal area reduction**

Serotinous cones of jack pine and lodgepole pine:

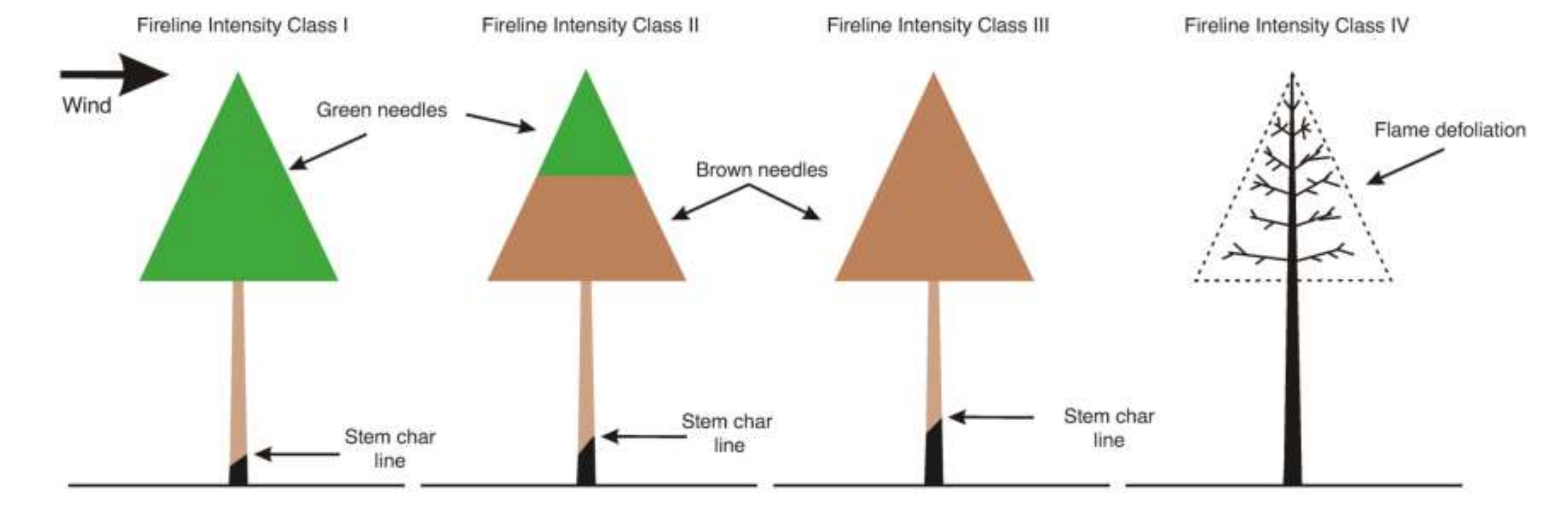
sealed shut by a resinous bond at the tips of the cone scales require high temperatures for them to open

HEAT

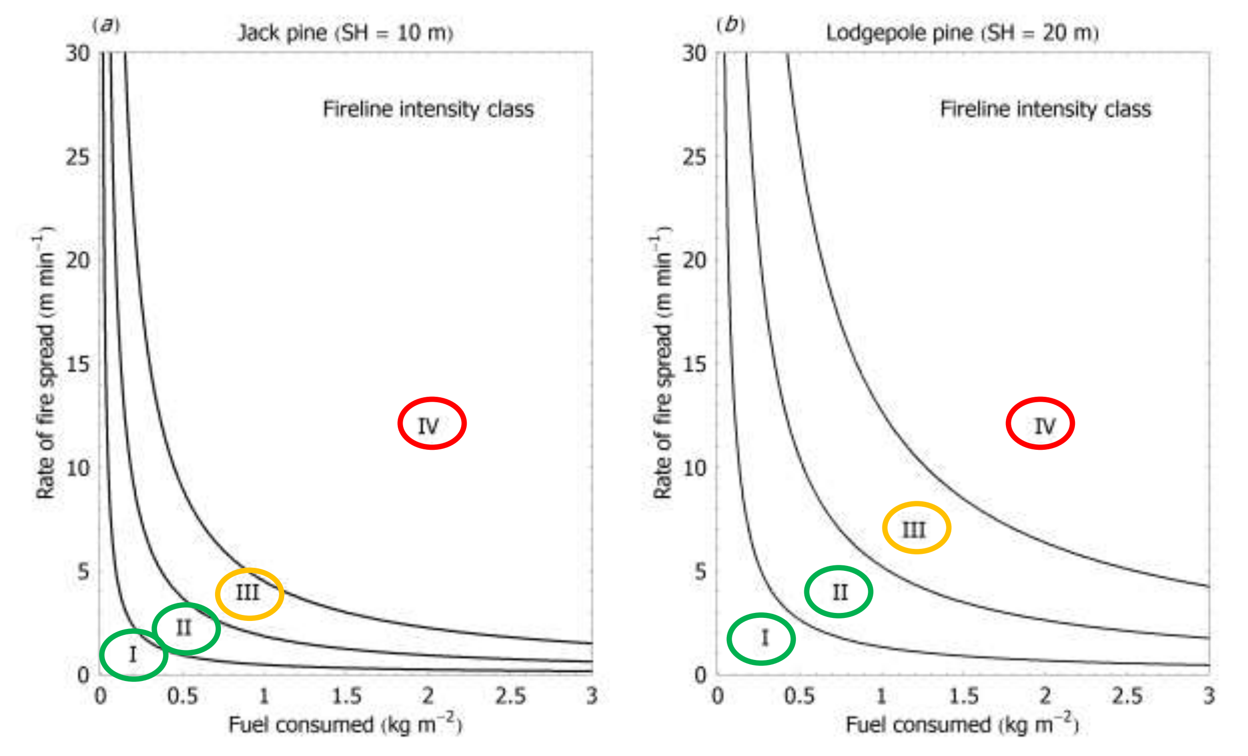


The flow of processes involved in the methodology

Four categories of canopy fire impact and cone opening or lack thereof:



Modelling the impacts of surface and crown fire behavior on serotinous cone opening in jack pine and lodgepole pine forests.



Rate of spread, fuel consumption and fireline intensity can be used to define thresholds for opening serotinous cones and release of seed in JP & LP.

Fireline intensity class

I – low intensity surface fire, no crown scorch, no cone opening

II – mod intensity surface fire, part to full crown scorch , no cone opening

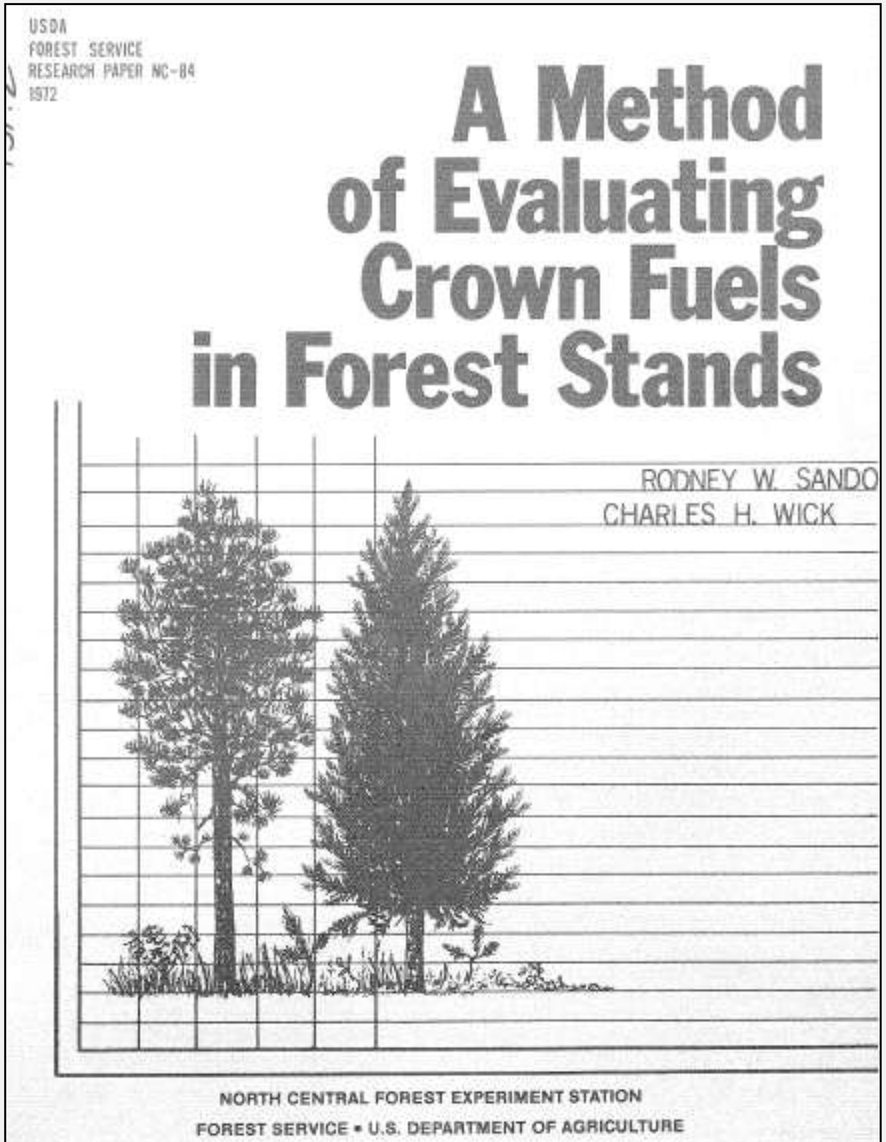
III – high intesnity surface fire, full crown scorch, cone opening via convective & radiative heating

IV – crown fire, defoliation of crown, cone opening & charring via flame contact

On the Limitations in Fire Models

"*All fire models simulate reality but fall short of it in varying degrees. In meeting the objective of simplifying relationships, minor factors are neglected and the model is usually based on a single set of idealized conditions. If fire-modeling laws are observed, this will permit approximations close enough for many purposes, but it is easy to forget that they are approximations only. Consequently, there is a strong tendency to apply models beyond their field of usefulness. To avoid this, the assumptions on which they are based and the range of conditions under which the model is valid need to be carefully defined and frequently rechecked.*"

A.A. Brown & K.P. Davis (1973)
Forest Fire: Control & Use. 2nd Edition

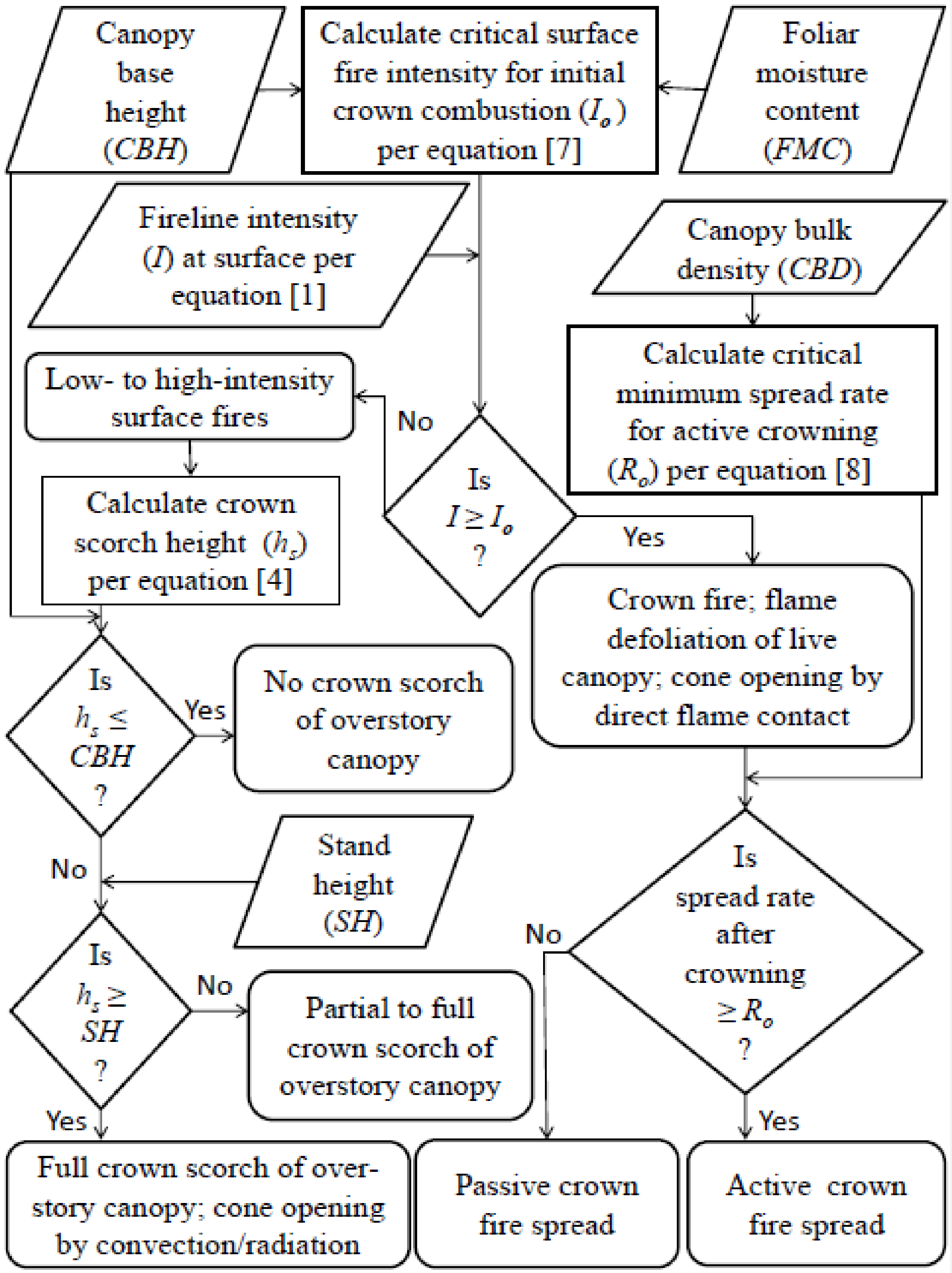


“Little is known about the amount of fuel required to support combustion vertically.”

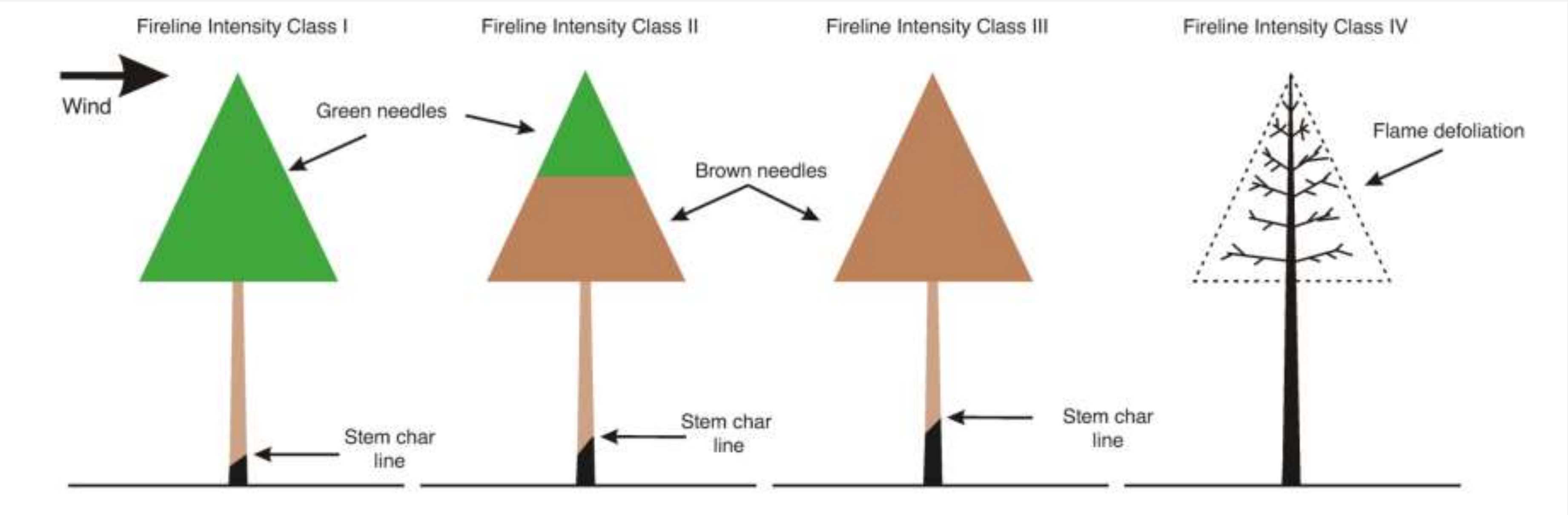
Serortinous cones of jack pine and lodgepole pine:

sealed shut by a resinous bond at the tips of the cone scales require high temperatures for them to open

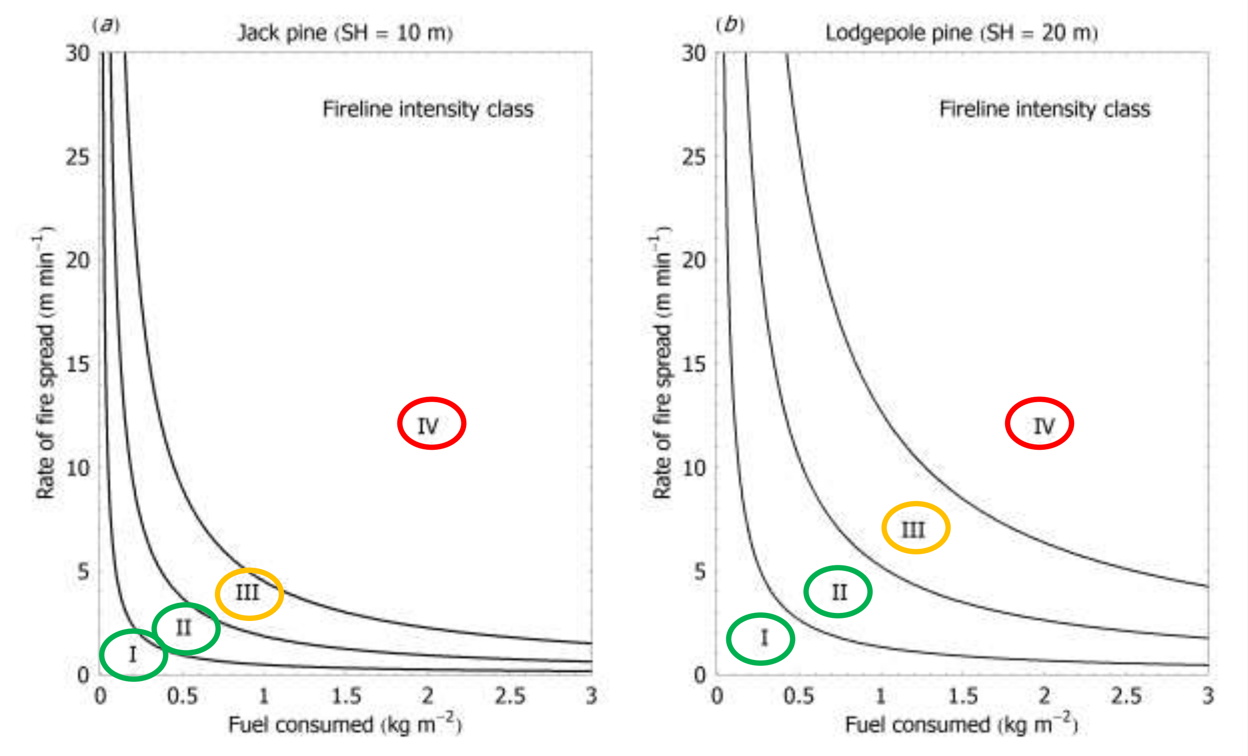
HEAT



The flow of processes involved in the methodology


Fireline Intensity Class I
Fireline Intensity Class II
Fireline Intensity Class III
Fireline Intensity Class IV
Wind
Green needles
Brown needles
Flame defoliation
Stem char line
Stem char line
Stem char line

Modelling the impacts of surface and crown fire behavior on serotinous cone opening in jack pine and lodgepole pine forests.



Rate of spread, fuel consumption and fireline intensity can be used to define thresholds for opening serotinous cones and release of seed in JP & LP.

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IV – crown fire, defoliation of crown, cone opening & charring via flame contact

CROWN FIRE BEHAVIOR IN CONIFER FORESTS: A PRE-CONFERENCE WORKSHOP

Future Outlook to the Understanding and Prediction of Crown Fire Behavior

International Association of Wildland Fire 4th Fire Behavior and Fuels Conference

February 18, 2013 – Raleigh, NC

Research Needs and Knowledge Gaps

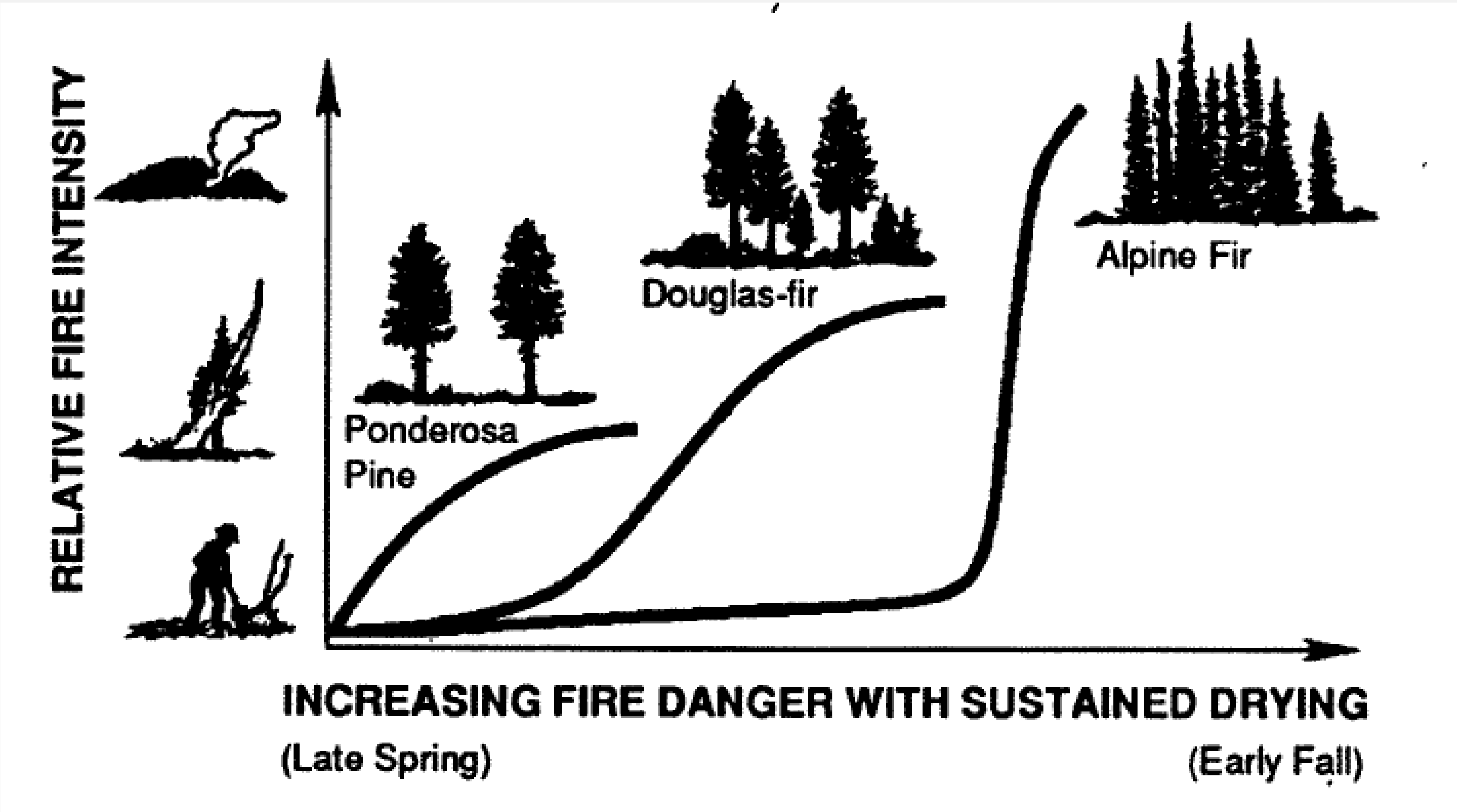
Topics Considered Worthy of Investigation/Study:

- ❑ Vertical fire spread (critical ***CBD***) into the overstory canopy and ladder fuel effects (e.g., bark flakes).
- ❑ Crown fuel consumption by size class
- ❑ Crown fire flame size model
- ❑ Additional emphasis placed on the prediction of surface fire rate of spread and flame front characteristics (e.g., residence time, intensity).

> "*The prediction of surface fire behavior is, in fact, probably more difficult that the prediction of crowning potential, because of the multiplicity of possible forest floor and understory fuel complexes*." – Van Wagner (1979)

❑ Crown Fire Potential in Dead Canopy Fuels

❑ Heavy Fuel Moisture Threshold in Mature, High Elevation Stands



Williams and Rothermel (1992)

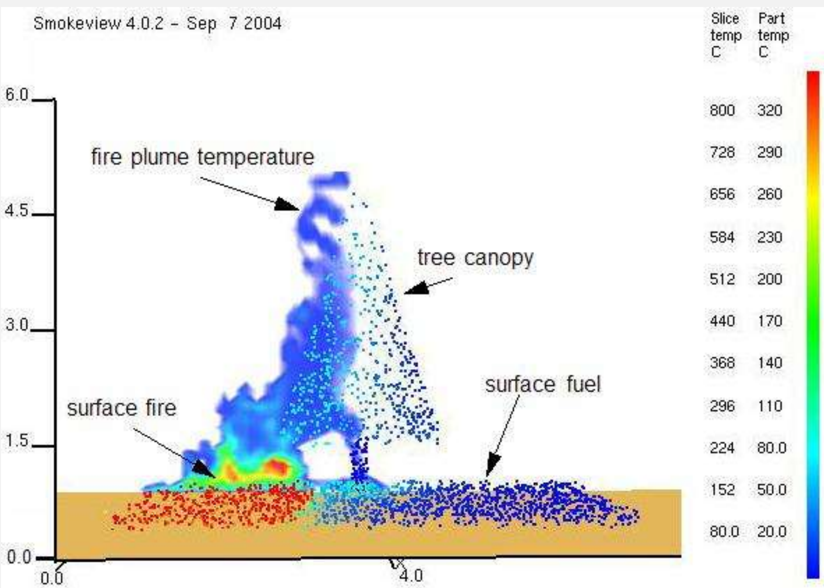
The "Two Solitudes" in Wildland Fire Behavior Research

Empirical Approach

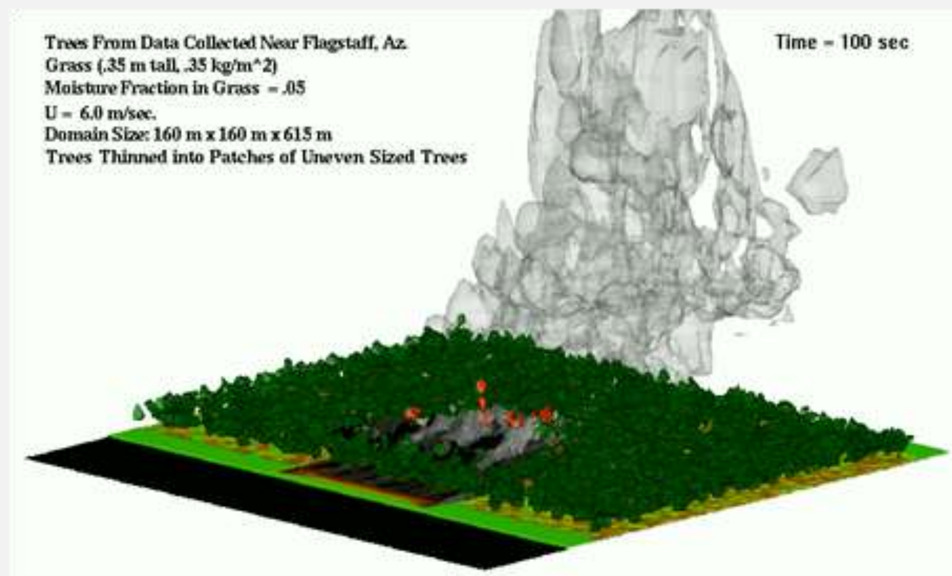
Physical/Theoretical Approach

Physics-based Fire Behavior Simulators

WFDS

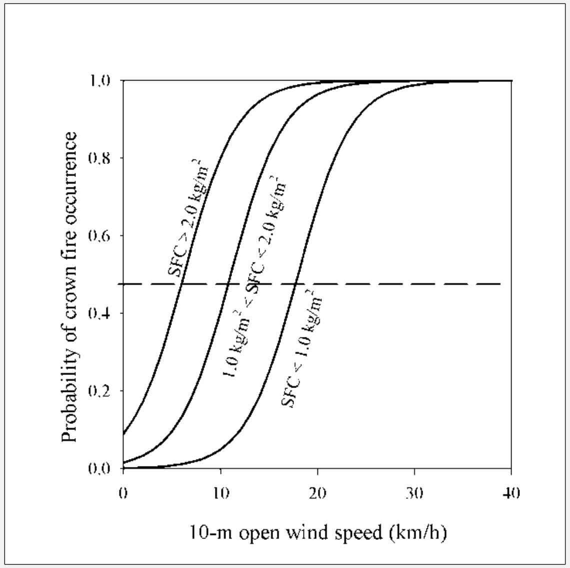


FIRETEC



The most effective means of judging potential fire behavior is considered to be the coupling of (1) <u>mathematical modelling</u> with (2) <u>experienced judgement</u> (e.g., "expert opinion"), and (3) published <u>case study knowledge</u> (e.g., wildfires and operational prescribed fires

1



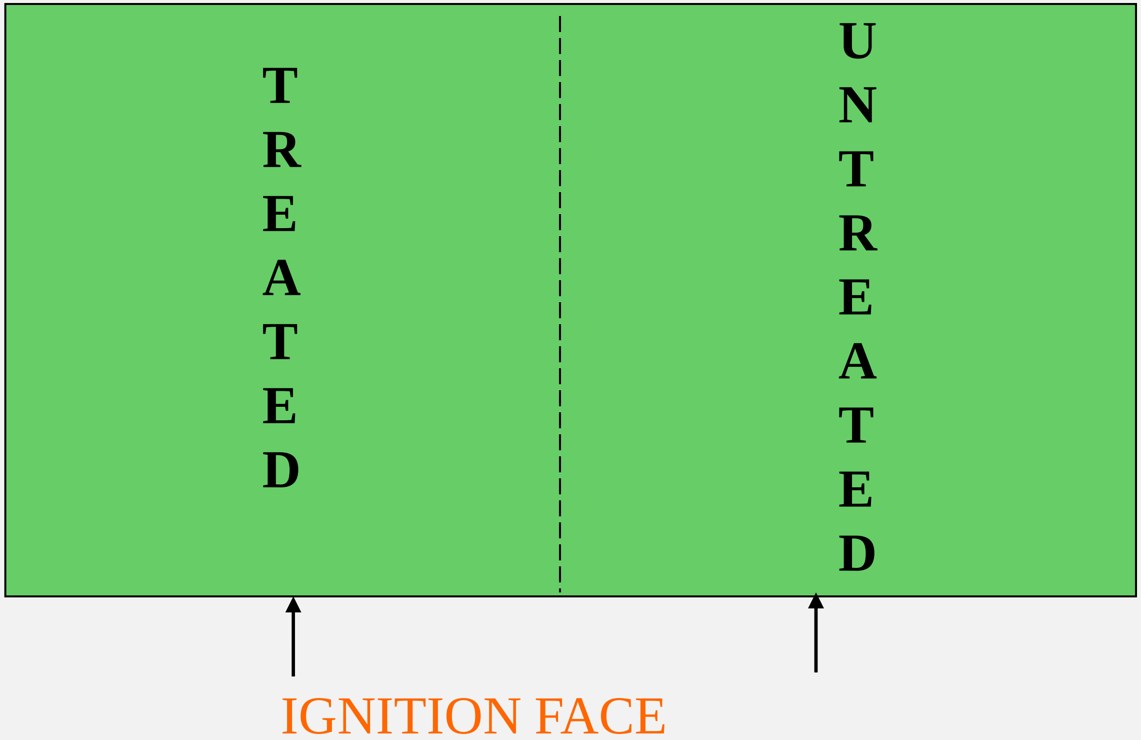
2

3

Conducting Experimental Crown Fires and Operational Prescribed Fire Opportunities


Experimental Fires

e.g., ICFME Treated/Untreated Plot - burnt June 14, 2000



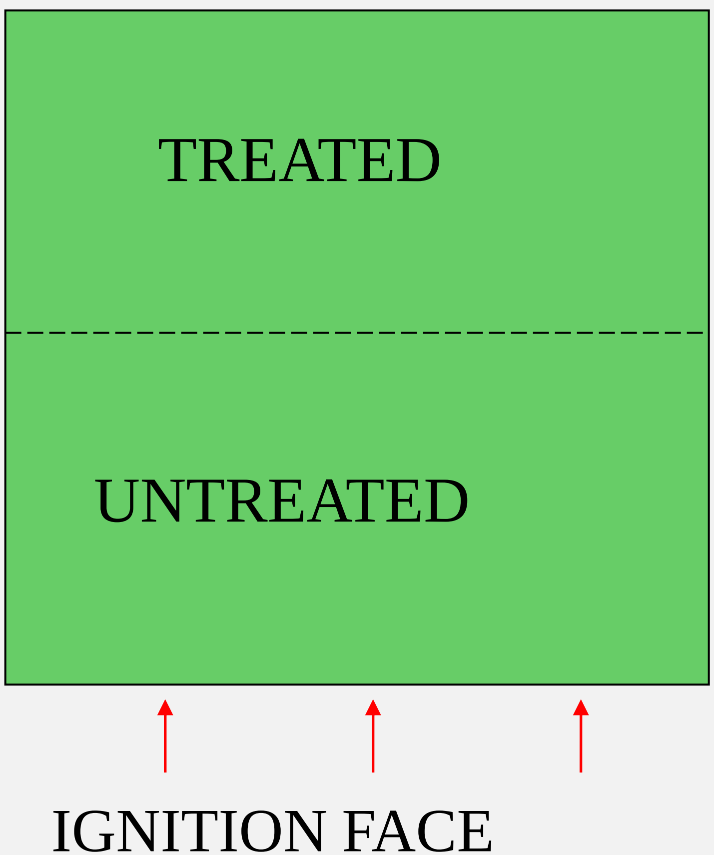
<u>Strengths</u>:

- Any differences should be readily apparent
- Lull in wind speed not a problem

<u>Limitations</u>:

- Plot face exposure problem (fuel moisture)
- Subject to shift in wind direction after ignition
- Question of one half influencing the other

Alternative Approach to Conducting Experimental Fires for Gauging Fuel Treatment Effectiveness



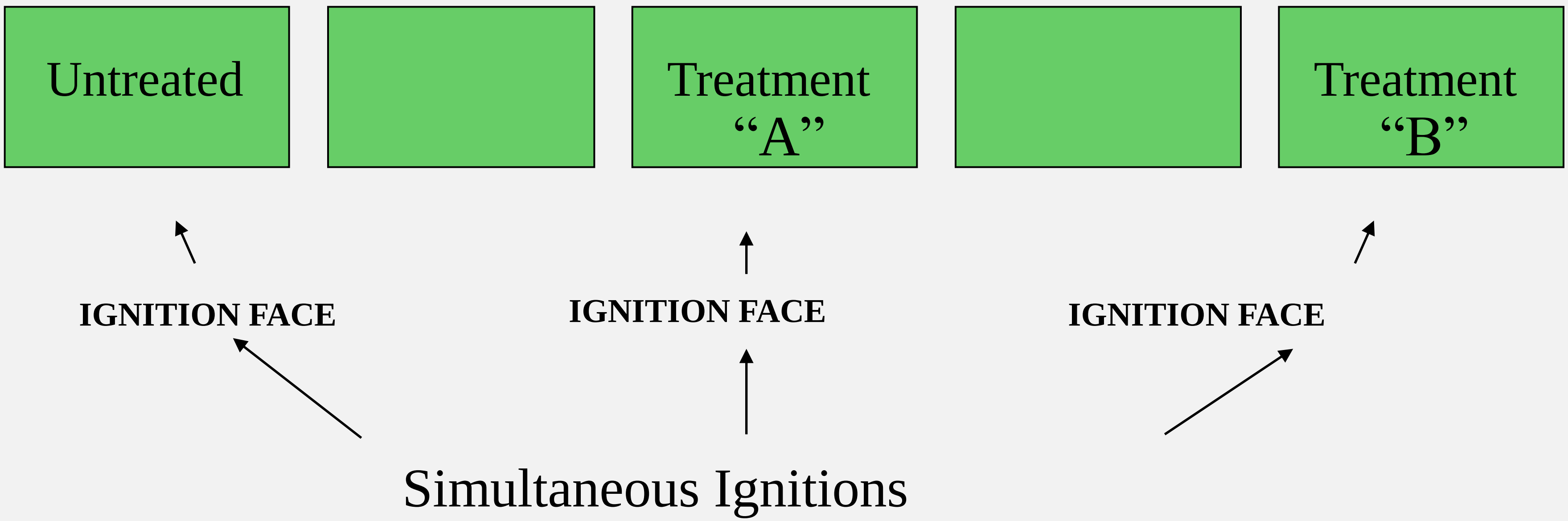
Strength:

- Provided wind speed remains relatively constant, provides direct evidence of treatment effect

Limitation:

- Subject to shift in wind direction after ignition
- Winds could drop off at or near the interface boundary between the two plots

Alternative Approach to Conducting Experimental Fires for Gauging Fuel Treatment Effectiveness



<u>Strengths</u>:
- Lull in wind speed not a problem
- Provides direct evidence of treatment effect

<u>Limitation</u>:
- Subject to shift in wind direction after ignition

Operational Prescribed Fires

Wildfire Observation and Documentation

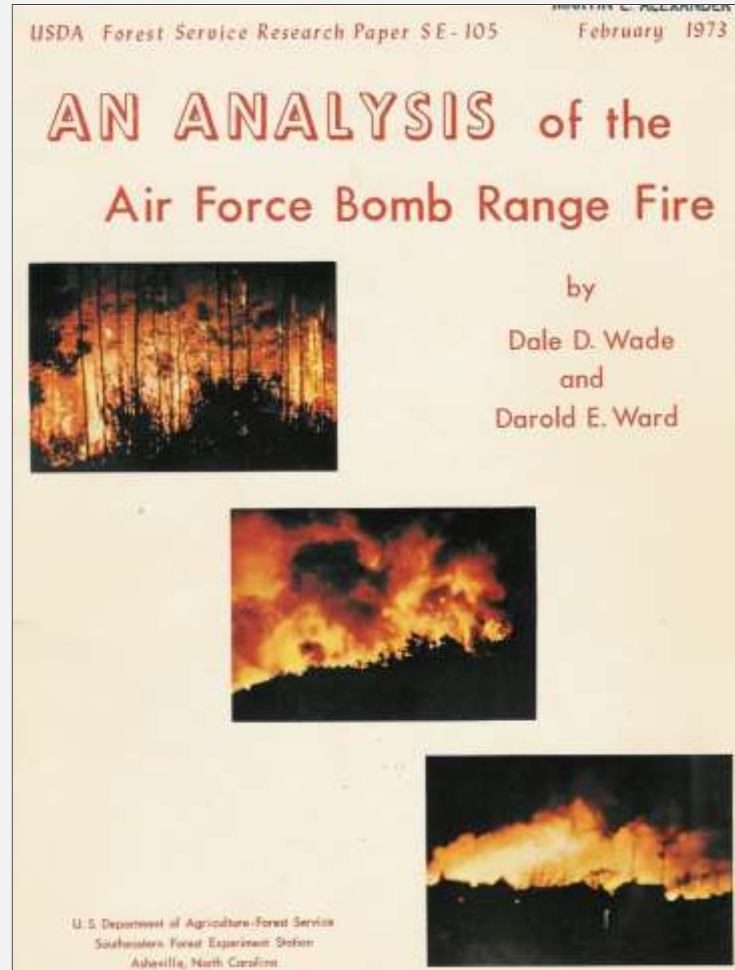
- Detection
- Initial attack
- Later stages of suppression
- After containment




Fire Documentation Team – Southern Forest Fire Laboratory (SFFL), Macon, GA

SFFL Mobile Fire Laboratory

inside laboratory trailer



USDA Forest Service Research Paper SE-105 February 1973

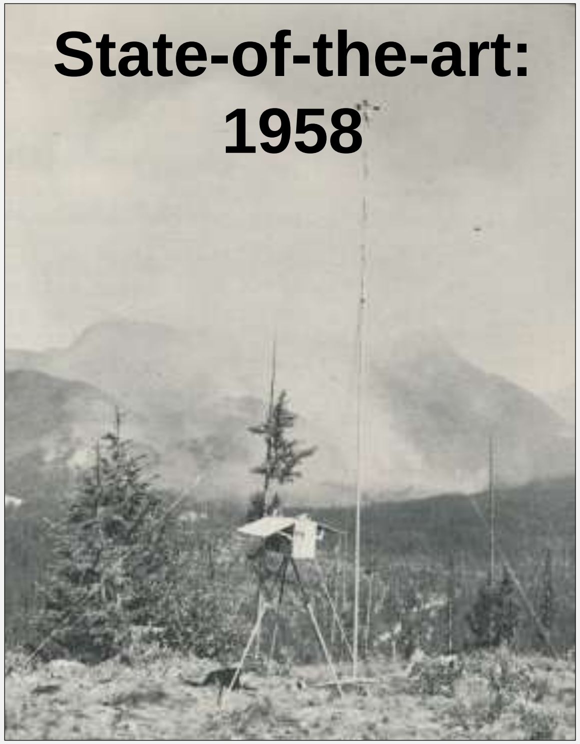
AN ANALYSIS of the Air Force Bomb Range Fire

by

Dale D. Wade and Darold E. Ward

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

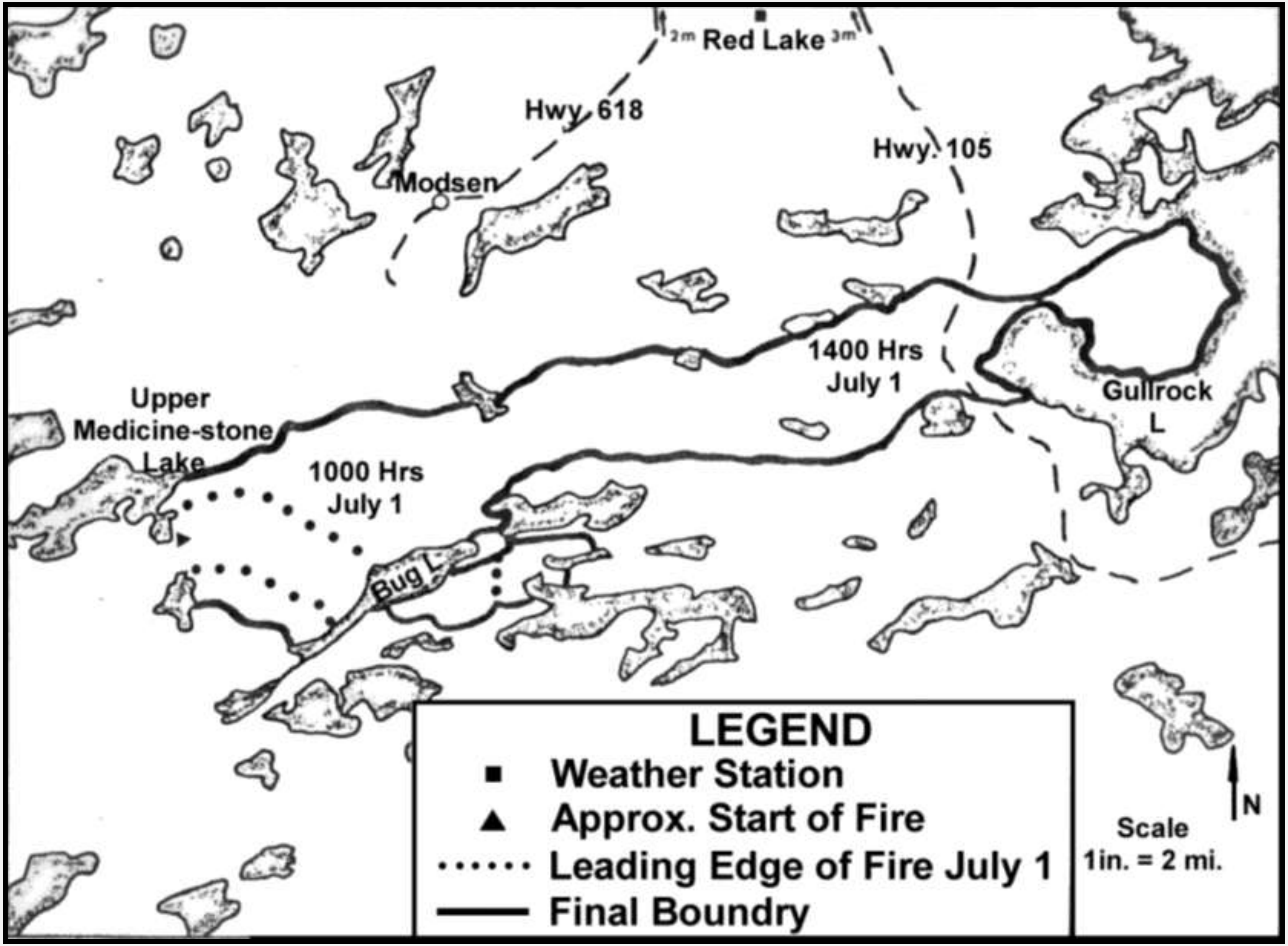
Technological advances in photography, remote sensing and weather monitoring over the years has greatly facilitated matters. However, good representative or site-specific wind readings, for example, are still difficult to obtain.



State-of-the-art: 1958

Today: RAWS

Red Lake 35-61 Fire - Northern Ontario



Fire Progress Map


Everyone has a photographic memory.
Some just don't have film!

“We are just too busy to do case studies.”

Is a permanent, dedicated group a possibility?

A Case for Wildland Fire Behavior Research Units

It … e recognition of the human dimen-
si… lity incidents (Braun and Latapie
19… ecent case histories (e.g., Maclean
19… l vividly recall the daylong presenta-
tio… alifornia Department of Forestry Fire
Ac… fire case histories given at the Forest
Te… AB, in the mid-1980s. His case
stu… he importance of human factors as
we… uting factors.

The Staff Ride Approach to Wildland Fire Behavior and Firefighter Safety Awareness Training: A Commentary

Natural Resources Canada / Ressources naturelles Canada
Canadian Forest Service / Service canadien des forêts

Martin E. Alexander

I felt very fortunate to have been able to participate in all three phases of the Dude Fire Staff Ride that took place on March 3–5, 1999. Like the other staff ride participants, I found the whole experience to be extremely beneficial to my gaining a deeper understanding of the complexities involved in fire behavior and the associated firefighter fatalities resulting from the major run of the Dude Fire on the afternoon of June 26, 1990.

I am thus greatly honored to have been asked to contribute this essay for the special issue of *Fire Management Today* dealing with the Dude Fire Staff Ride. I sincerely hope that the comments offered here, based in part on the Dude Fire Staff Ride experience coupled with a 30-year career in wildland fire, will lead to enhancements as well as extensions of the staff ride concept in the future for training fire behavior analysts (FBANs) and in further developing firefighter safety awareness training.

Strengths and Limitations

Prior to the Dude Fire Staff Ride, I had only a superficial appreciation for this incident based on bits and pieces of information gleaned from

Dr. Marty Alexander is a senior fire behavior research officer with the Canadian Forest Service at the Northern Forestry Centre, Edmonton, Alberta.

> My experience on the Dude Fire Staff Ride suggests that the wildland fire community has an excellent opportunity to develop its own unique staff ride tool.

various sources over the years (e.g., Campbell 1995; Gleason 1991; Goens and Andrews 1998; Johns 1996; Mangan 1996; MTDC 1990; NFES 1998a; NFPA 1990; Putnam 1995a; Rosato 1991; Rothermel 1991), including the official accident investigation report (USDA Forest Service 1990), and a conversation I had with Dude Fire veteran Paul Gleason in Missoula, MT, in June 1994.

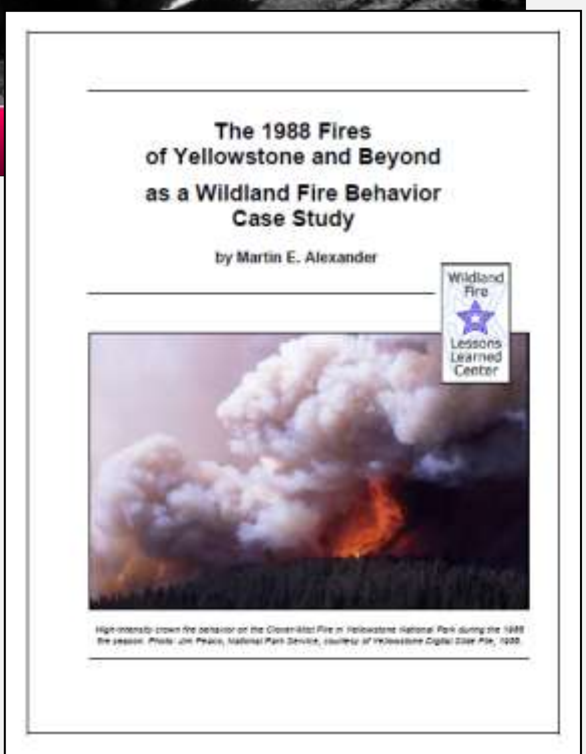
Although the wildland fire community's adaptation of the military staff ride (Robertson 1987) concept provides a powerful learning technique, we need to recognize that it isn't necessarily a cure-all for increasing wildland firefighter safety awareness. Instead, it is just another tool in our toolkit. Nonetheless, my experience on the Dude Fire Staff Ride suggests that the wildland fire community has an

Participants in the Dude Fire Staff Ride at the fire shelter deployment site. Photo: USDA Forest Service, Missoula Technology Development Center, Missoula, MT, 1999.

Volume 62 • No. 4 • Fall 2002 25

Alexander (2002)

The "Case" for Case Studies


The 1988 Fires of Yellowstone and Beyond as a Wildland Fire Behavior Case Study

by Martin E. Alexander


Wildland Fire Behavior Case Studies and the 1938 Honey Fire Controversy

Martin E. Alexander and Stephen W. Taylor

The story of the Honey Fire and the ensuing controversy is as much about human behavior as it is about fire behavior.

The Story of the Honey Fire

Synopsis of the Honey Fire Case Study

Volume 70 • No. 1 • 2010

15

CROWN FIRE BEHAVIOR IN CONIFER FORESTS: A PRE-CONFERENCE WORKSHOP

Thoughts on Wildfire Observation and Documentation

The FBAT experience

International Association of Wildland Fire 4th Fire Behavior and Fuels Conference

February 18, 2013 – Raleigh, NC

Background

It is important to continue to learn more about fire behavior in relation to fuels and weather within wildfires. It is not possible to address these needs completely in a burn chamber or even on most prescribed burns. ICFME and Frostfire experiments provided valuable information but still cannot replicate the conditions that are found in free burning wildfires.

Monitoring goals

1. Directly measure fuel treatment effectiveness
2. Measure fire behavior and effects and their relationship to pre-fire fuels, fire history, and treatments
3. Measure effects of fire on archeological/biological resources
4. Build a dataset useful for calibration of consumption, smoke production, and fire behavior models

Background

JoAnn Fites-Kaufman, AMSET team leader started the "Rapid Response" team in **2002**

Worked with Missoula to build the equipment, tested it on prescribed fire in Yosemite

In **2003**, she received a JFSP grant as one of the "Rapid Response" teams

The primary objective was to prototype in-situ measurements during wildfires of changes in fire behavior through fuel treatments, past land-use activities, or old fires.

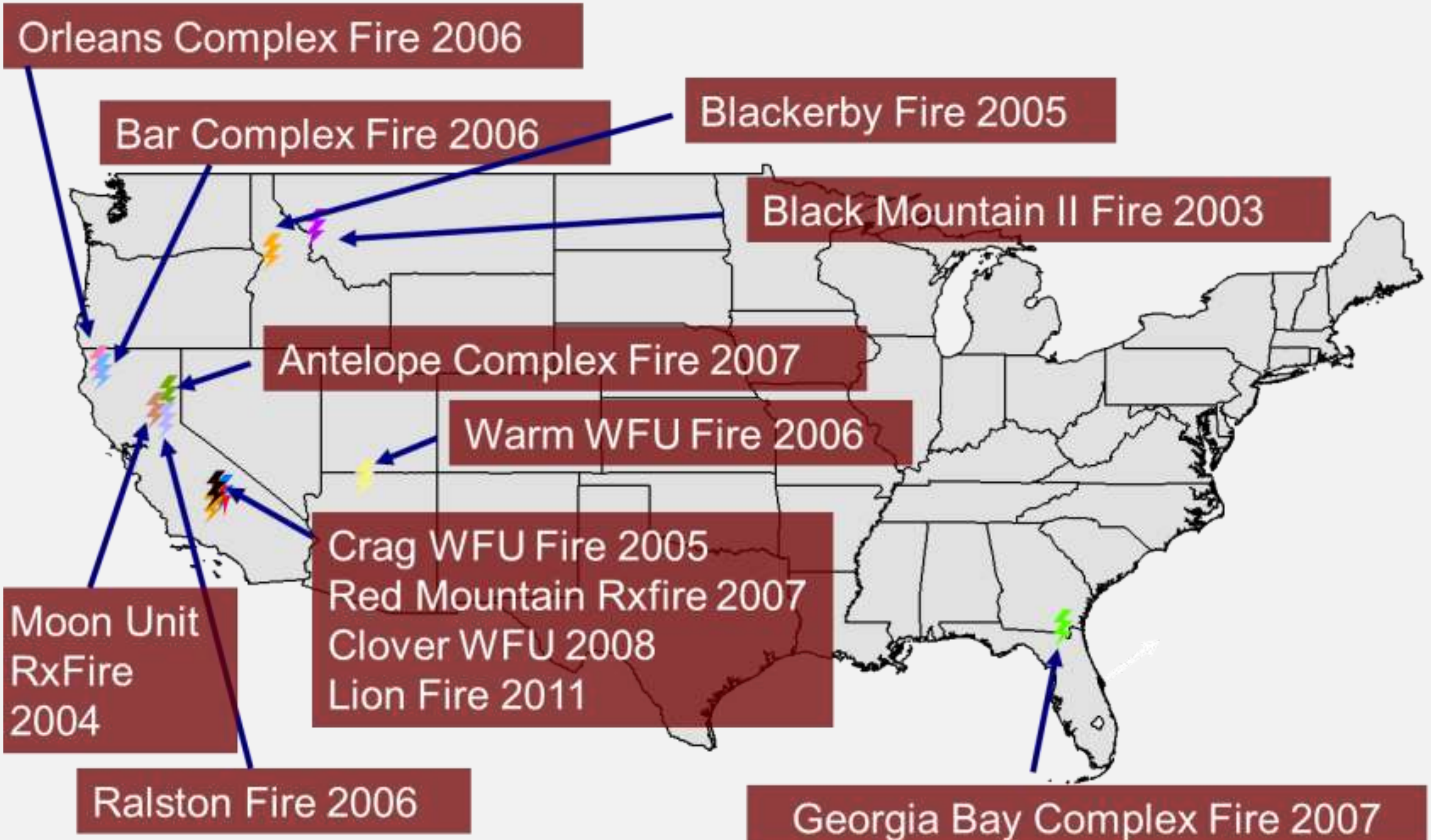
2004 - present – cobbled together funding from R5 and WO to maintain the equipment, ordered by incidents to head out to fires

2005 – changed name to FBAT (Fire Behavior Assessment Team)

2013 - forming a collaboration with the Calaveras Wildland Fire Module, STF

Fires visited

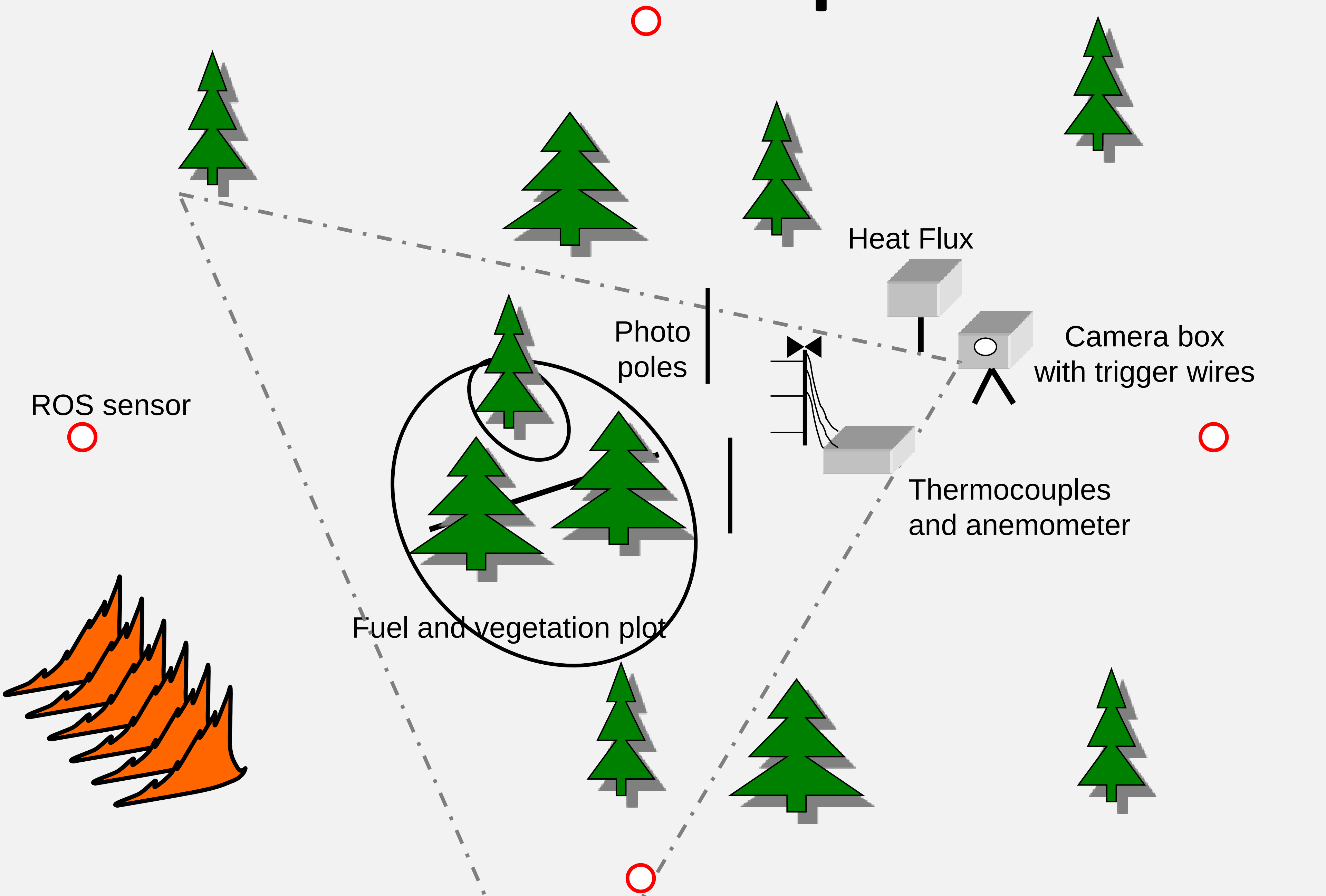
Collected fire behavior and fuels data at 13 fires (137 sites with 115 burned)



Site selection & data collection

- Early years – a bit like the “tornado chasers” if the SIT report looked busy we went to the busiest location with the most fires with the most extreme fire behavior
- Now – have to be invited and ordered through ROSS
- Opportunistic sampling – set up where it is most likely to burn and we can swiftly and safely access
- Pre- and post-fire fuels and fire behavior data collected at each site
  - 2 “teams” one on fire behavior equipment one on fuels
- Site set-up takes ~45 min

Site set-up


Heat Flux
Photo
poles
Camera box
with trigger wires
ROS sensor
Thermocouples
and anemometer
Fuel and vegetation plot

Fire proofed camera boxes

Set up 1 or 2 cameras per plot

Handheld Sony camera – 80 min video

Strung out wire with connectors to a LANC box which turns on the camera when the circuit is broken

Heat flux sensor

Heat flux was measured using a Medtherm sensor containing both a radiometer and thermal flux transducer.

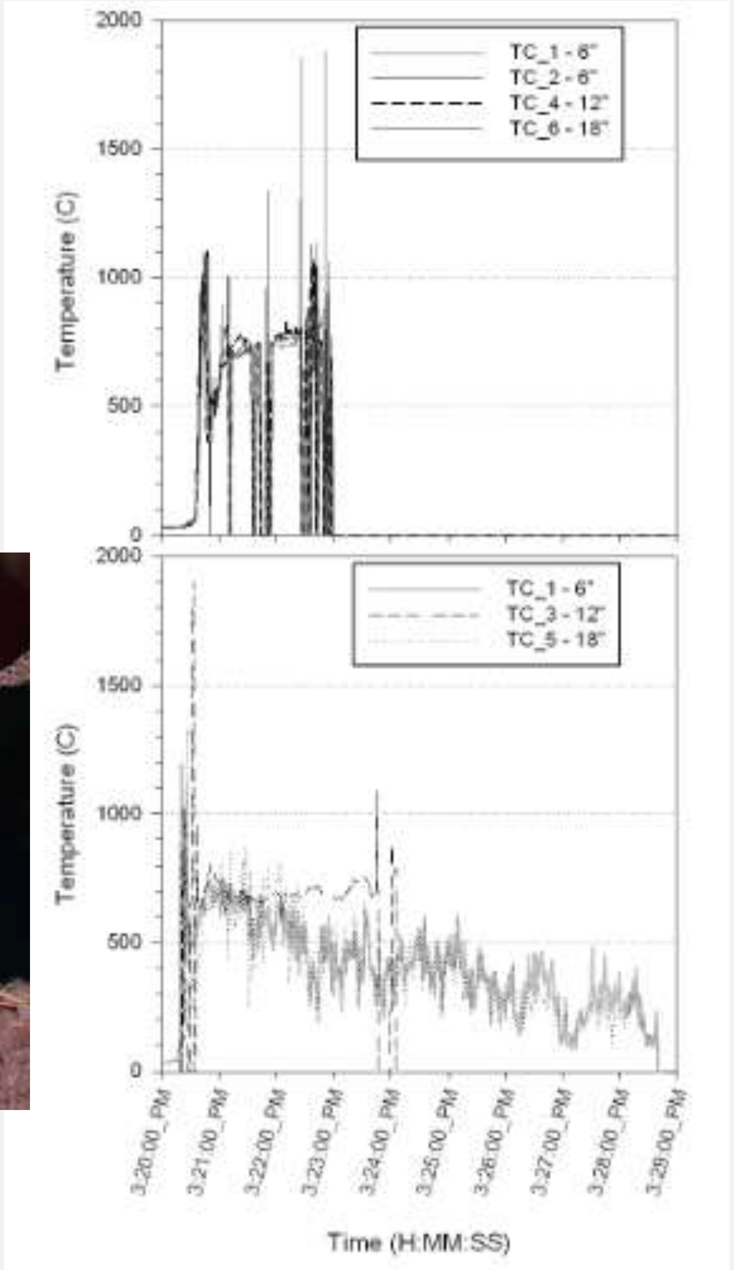
Total and radiant heat fluxes were computed by integration of the area under distribution curves over time for different time intervals.

Convective heat flux was computed from the difference between total and radiant heat fluxes.

Thermocouples

Set them up at different heights “clipped” to a pole with Campbell Sci data loggers buried in an ammo box.

Or set up in triangles/chevrons for ROS with MadgeTech data loggers

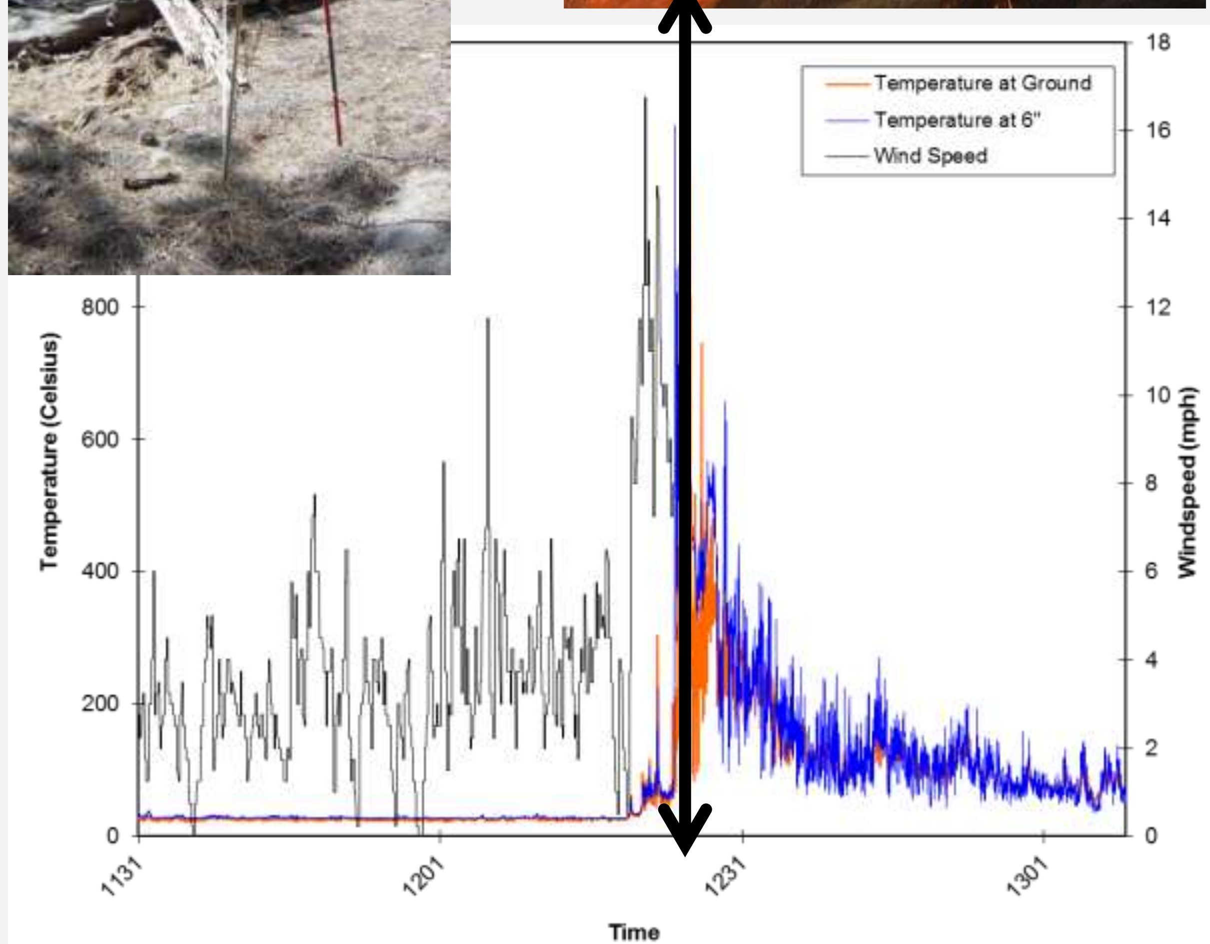


Anemometer

Addition of in stand windspeed – 10 s average

Plastic blades so they only have windspeed leading up to the flaming front

No direction



Calculating ROS

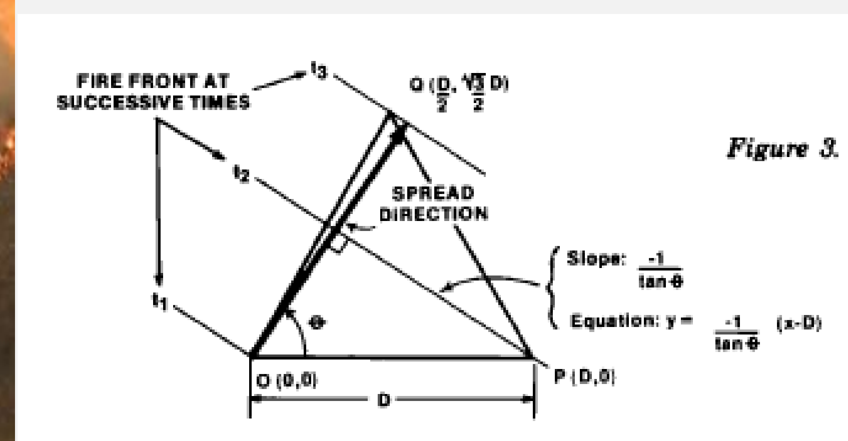
Via camera footage

Using photo poles for reference – know the distance between poles and camera then use time on video

Via ROS sensors

Simard (1982) method of estimating rate of spread using applied trigonometry.

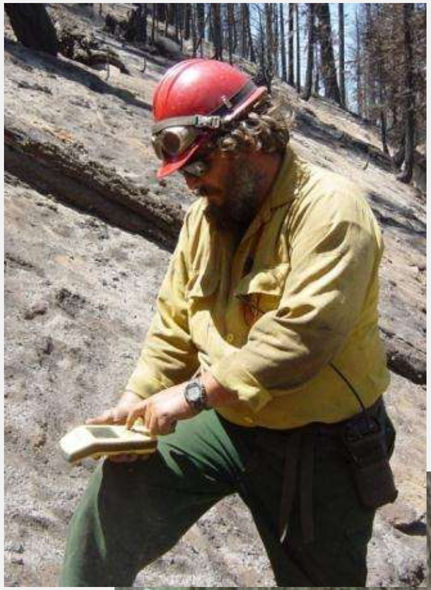
Used time stamp from RASP and/or temperature & time from thermocouples



Fuels & Vegetation

General plot info

- GPS plot center
- Mark plot center and transect end
- Photos NSEW, up & down transect



Trees

- Variable radius prism plots for pole-sized and overstory trees
- Canopy metrics calculated using FVS or FMA Plus

Fuels & Vegetation

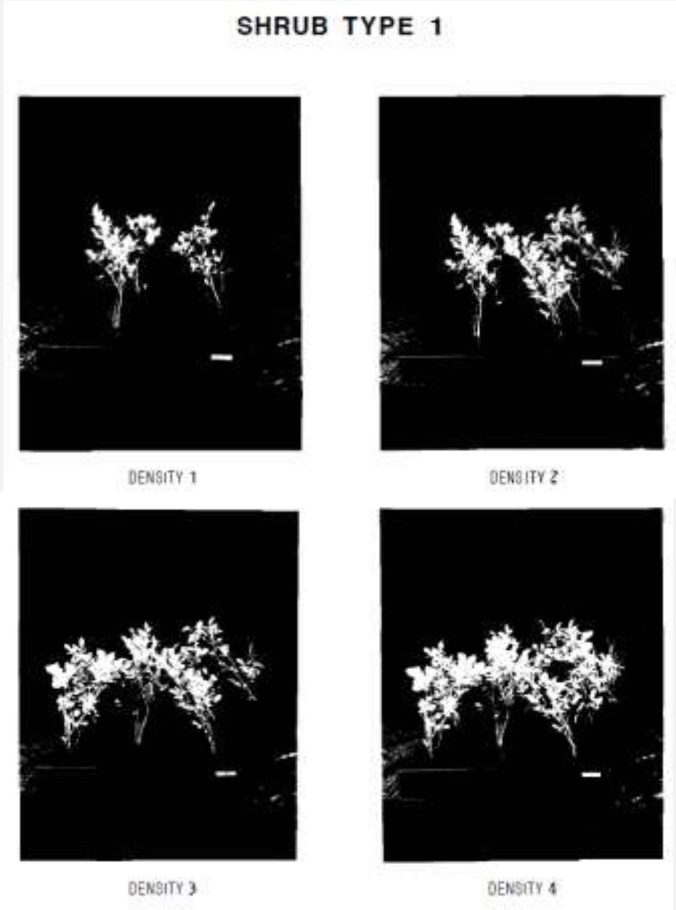
<u>Fuels and understory plants</u>

One 50 ft transect – fuels line intercept

Vegetation 3 ft belt using Burgan & Rothermel (1984) methods

Measured both before and after fire

In view of the camera



Fuels & Vegetation

Fuel moistures

- 2-3 samples/plot litter and 1-hour dead fuel
- 2-3 samples 10-hour dead fuel
- 2-3 samples/plot live fuel moisture (tree & shrub)

Typically from arms length and at the time of site set-up (can be up to a week before fire hits)

Samples processed <18hrs after collection

Dried in oven for approx. 24 hrs

“Rapid Response” team

RAPID-RESPONSE FIRE BEHAVIOR RESEARCH AND REAL-TIME MONITORING

Carol J. Henson

Fire managers planning projects often evaluate the effect of fuel treatments and other land use activities on potential wildfire behavior. To make these assessments, managers typically rely on fuel and fire behavior modeling before a fire or fire research afterward. In 2002, the Adaptive Management Services Enterprise Team launched a unique research project: The team collected fire behavior data during actual wildfires.

The real-time project, funded by the Joint Fire Sciences Program and the Fire and Aviation Management Staff in the USDA Forest Service's Pacific Southwest Region, focused on providing fire managers with quantitative information. Researchers, successful in meeting many objectives, are expanding operations and seeking additional funding and support.

Getting Started

From 1999 to 2004, JoAnn Fites-Kaufman, team leader and the project's principal investigator, worked extensively with incident management teams on wildfires. Fites-Kaufman became familiar with fire operations and developed operational research procedures.

In 2002, with the support of the Forest Service's Missoula Fire Lab and Missoula Technology and Development Center, Fites-Kaufman and Tiffany Norman, the team's technology specialist, developed equipment to use in studies on safety zones and crown fires. The Development Center made special fire-resistant boxes for video cameras and a heat trigger device to safely videotape fire behavior during a wildland fire. The equipment was tested in California on a prescribed fire in Yosemite National Park in 2002 and on prescribed burns on the Tahoe and Plumas National Forests in 2003 (fig. 1).

Carol Henson is a fire behavior analyst for the USDA Forest Service, Pacific Southwest Region, Vallejo, CA.

Figure 1—*Testing a buried heat flux sensor during project development on a prescribed burn in California. Photo: Adaptive Management Services Enterprise Team, USDA Forest Service Tahoe National Forest, Nevada City, CA, 2002.*

In May 2003, the Rapid Response and Research Team (RRT) was formed. The team was trained in operational and scientific procedures, including fireline safety. Team members included Fites-Kaufman, firefighters, a fire behavior analyst, and field technicians with firefighting experience. Objectives for the 2003 fire season were to:

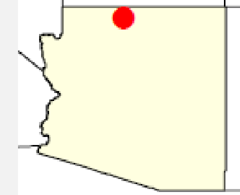
- Prototype fire behavior research on wildfires;
- Design equipment and test sensor operation and layout on selected sites;
- Establish operational procedures and methods for collecting data;
- Work successfully with incident management teams on active fires;
- Observe and measure fire behavior in fuel treatment areas; and
- Measure prefire fuel conditions to identify the metrics applicable to wildland fire behavior and to refine fuels inventories, maps, and monitoring data.

A research team collected data during actual wildfires, a unique study on fire behavior.

Evaluating a Fire Season

The RRT evaluated nine wildfires on six national forests during the summer of 2003 (table 1). Equip-ment was installed and fuel plots were determined to capture fire behavior as it passed through the research sites (fig. 2). The layout design was based on successful research by Professor Phil Omi of Colorado State University, Fort Collins, CO, in reconstructing changes in fire behavior after fires (Pollet and Omi 2002). Detailed fuel plots were taken using the Brown's Planar Intersect method and measurements of crown fuels with laser devices.

Warm WFU Fire 2006 site 4



Ponderosa pine dominates the overstory. Gambel oak present in the understory or low sub-canopy, as clumps (missed by fuels plot). Canopy base height 2 ft, CBD 0.4 kg/m3.

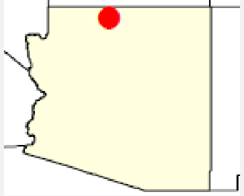
PP fuel moisture 77-82%

Tree cover		**Understory cover**	
Overstory	Pole	Shrub	Grass
20	40	1	15

Small surface fuels (ton/ac)			
1-hr	10-hr	100-hr	1000-hr
0.05	0.30	0	0

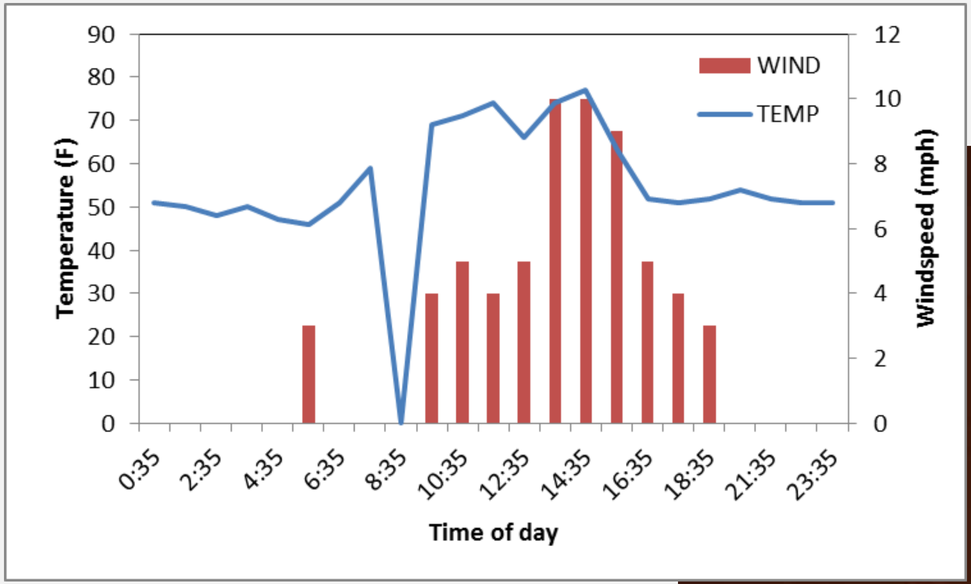
BA (ft2/acre)	**Trees/ac**	**QMD (in)**
80	7484	1.4

Warm WFU Fire 2006 site 2

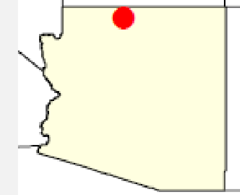


Transitioned from high intensity surface to active crowning with fire whirls.

Flame length (ft)	ROS (ch/ac)	Duration (min)
<1/2 to 120	2-45	6



Warm WFU Fire 2006 site 2



100% consumption of pre-fire woody fuels and litter, and 75% duff.

Soil severity rating of 3 - moderate, ash and some patches of charred litter or duff.

100% torch of midstory trees, 3-50% torch of overstory trees and 30-90% scorch

Georgia Bay Complex 2007
Pre-fire conditions site 5

15 year old plantation of slash pine, sparse palmetto and gallberry in the understory.

Cover by Life Form (%)		
Tree	Shrub/palmetto	Other
80	10-15	0

Canopy characteristics			
Basal area (ft2/ac)	Canopy height (ft)	Canopy base height (ft)	Canopy bulk density (kg/m3)
190	34	21	0.127

Georgia Bay Complex 2007
Spot fires coalesce into crown fire
site 5 - VIDEO

Georgia Bay Complex 2007
Post-fire conditions site 5

Soil severity rating				
Very high	High	Moderate	Low	Unburned
10%	85%	5%	0%	0%

Summary of immediate post fire effects

Understory			Midstory Trees		Overstory Trees		
Non-shrubs	Shrubs	Seedlings	Scorch	Torch	Scorch	Torch	Char height
% consumption			% crown		% crown		ft
n/a	100 leaves & 90-100 stems	n/a	100	100	100	100	13-52

Successes

Flexibility is a MUST! This is one of the only groups that has attempted and succeeded at doing this.

Collaboration – data being used by California Air Resources Board with other fires formulating estimates of carbon stocks and greenhouse gas emissions and FOFEM consumption calibration.

Learned a lot from our mistakes and equipment failures.

The site set-up has been an evolution overtime:
Added ROS,
Added anemometers,
Added photo poles.

Equipment lessons learned

Equipment survivability

Although we don’t want to disturb the fuels, if the data is lost we still did not succeed. Learned to clear around the data boxes better – bare mineral soil & to bury them deeper!

Equipment failures

42 attempts at ROS, 20 totally failed, 10 partially failed, switched from RASPs to MadgeTech with thermocouple (helped but not 100% success)

Equipment lessons learned

Smoke

Smoke blocks the view from the video camera – use of IR cameras would help – we purchased one so far

Not every idea is a good idea….

Failed attempts = "LA boxes"

Army medical box with anemometer & thermocouple sticking up about 1ft

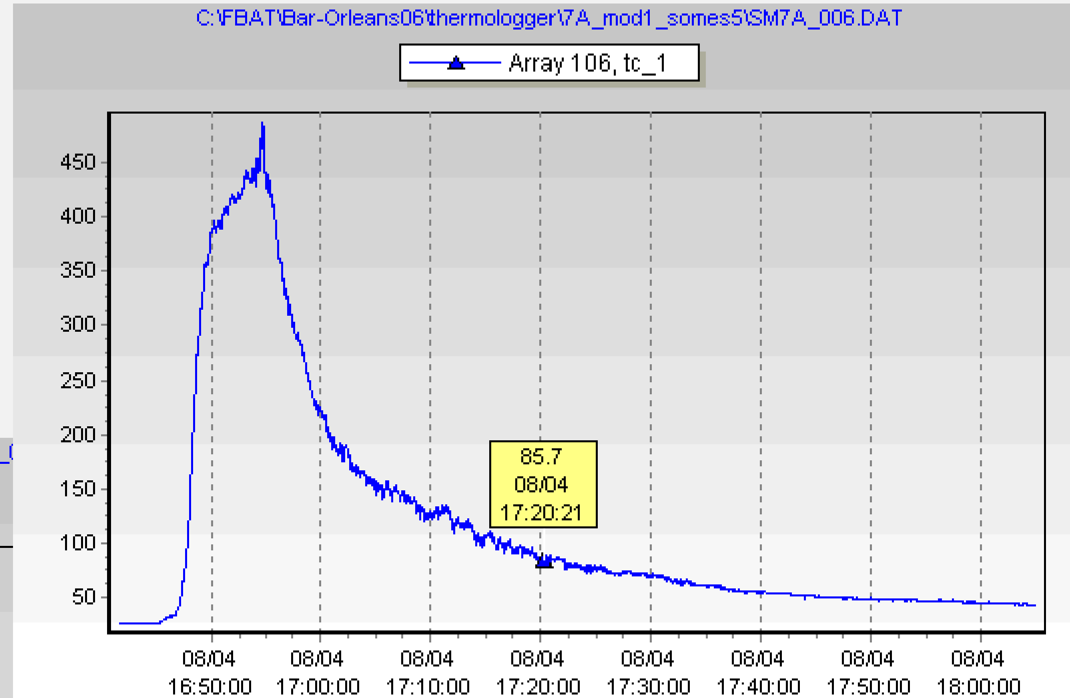
Aerial drop of thermocouples

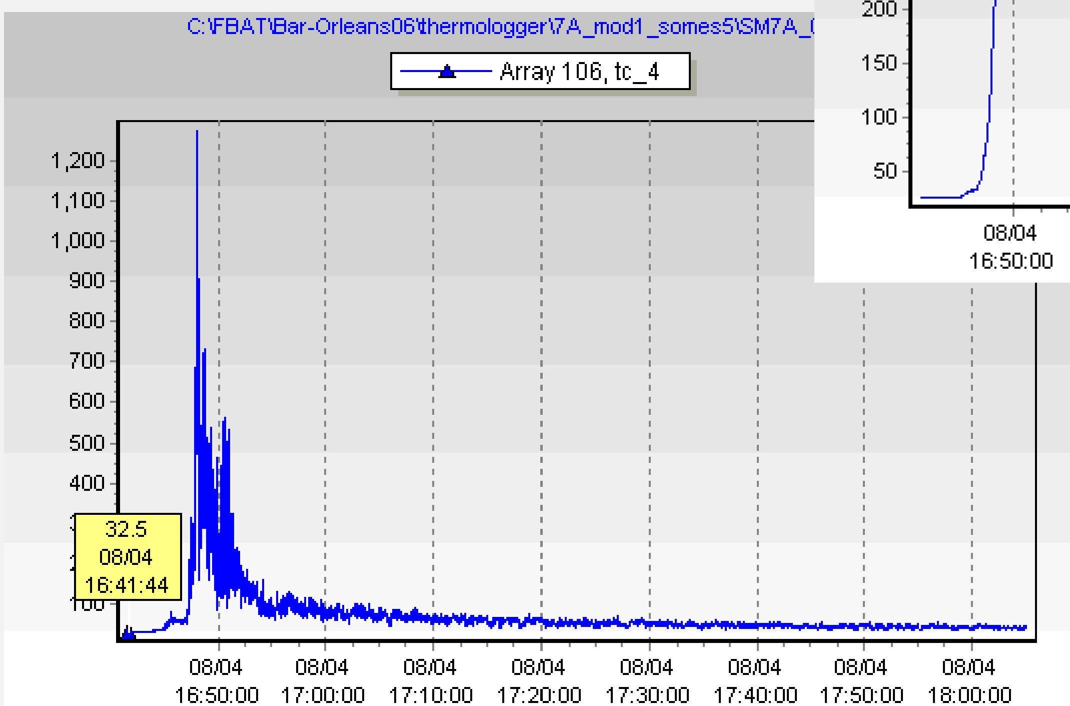
Got a fire to do it (love those AK teams), but couldn't find the sensors after….

Now what?

What can we do with what we have?

Residence times at different heights, in different fuel types.





Now what?

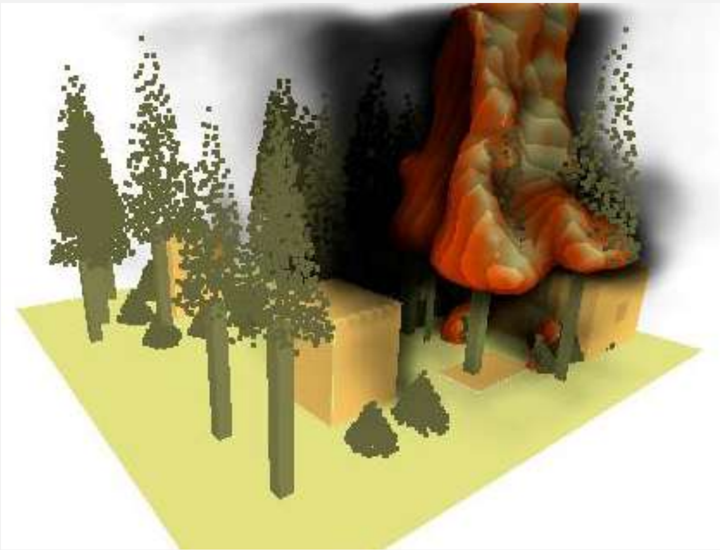
What can we do with what we have?

Better study the coalescence of the spot fires we caught on tape

Now what?

What can we do with what we have?

Potentially use the data to help validate physics based models or stand-level fire behavior in models. If lucky can gather data in multiple sites that all fall within a single fire run for larger-scale calibration.



Now what?

What can we do with what we have?

Learn more about the ladder fuel effect on crown fire initiation