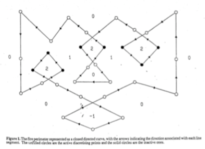
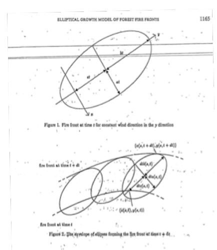
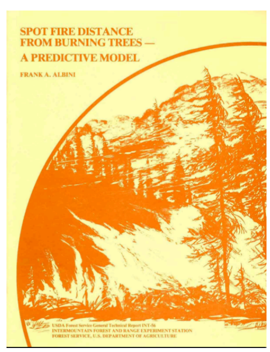
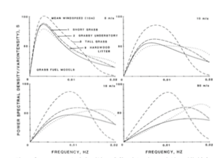
MITACS/GEOIDE Conference
On
Forest Fire Modelling









Hinton Training Center, Hinton AB
June 22-23, 2009

MITACS/GEOIDE Conference on Forest Fire Modelling
June 22-23, 2009 Hinton, Alberta, CANADA

Schedule

Monday, June 22, 2009

8:30-8:45	Introduction
8:45-10:00	**Developing methods of predicting fire behaviour: are we just rolling the dice?** Jim Gould, CSIRO/CFS-Edmonton
10:00-10:30	Questions/Discussion

Coffee

11:00-12:00	**Roundtable Discussion I:** Forest Fire Risk Assessment (Jen Beverly, Canadian Forest Service, Edmonton)

Lunch

1:00-1:30	**Random Set Modeling of Forest Fires**, Jeff Picka, UNB
1:30-2:30	**Roundtable Discussion II:** Stochastic Modelling (W.J. Braun, UWO)
2:30-3:30	**Roundtable Discussion III:** Modelling the Acceleration Phase (Cordy Tymstra, Alberta SRD)

Coffee

3:45-4:45	**Roundtable Discussion IV**: Modelling Wind Effects (A. Bourlioux, Montréal)
4:45-5:15	**The Probability Distributions of Land Surface Wind Speeds**, Yanping He, Victoria

Schedule

Tuesday, June 23, 2009

8:30-9:30	**Intensity and Spread Rate Interactions in Unsteady Wildfires**, John Dold, Manchester
9:30-10:00	Questions/Discussion
10:00-10:30	**Some Pragmatic Thoughts on the Prediction of Spotting in Wildland Fires**, Marty Alexander, CFS-Edmonton

Coffee

10:45-11:45	**Roundtable Discussion IV:** Mapping Forest Carbon (F. He, Alberta)

Lunch

1:15-1:45	**A Mathematical Model of Spotting**, Thomas Hillen, U of A
1:45-2:45	**Roundtable Discussion V:** Fire Spotting (C. Bose, Victoria)

Coffee

3:00-3:30	**Wildfire Modelling of Today and into the Future**, Mary Ann Jenkins, York
3:30-4:00	**Roundtable Discussion VI:** Wrap Up and Future Directions (Bose/Braun and Cordy Tymstra, Alberta SRD)

1 Keynote Talks

1. **Developing methods of predicting fire behaviour: are we just rolling the dice?**

Jim Gould
Senior Forest Fire Science Advisor
Canadian Forest Service

Research Scientist
CSIRO Sustainable Ecosystems- Bushfire Dynamics and Application
Bushfire Cooperative Research Centre

Abstract

The prediction of wildland fire behaviour is a timely application that presents many substantial scientific, computational, and forecasting challenges. In recent years, there has been an explosive increase in the use of models for simulating potential fire behaviour in a wide variety of wildland fire applications. With this increased use has come an increased concern about model assessment. How can we tell if a model of a complex system is a good model? How can we test a model that we wish to use in a predictive mode? Wildland fires have a range of geographical and chronological scales of processes that make it difficult to ascertain the attendant fuel, weather and topography variables with which to test the model's claims. So how do we judge the reliability of the knowledge that a model reputes to provide? Both makers and the users of models want to know whether a model accurately reflects the natural process it claims to represent.

The inherent uncertainties of models have been widely recognised, and it is now commonly acknowledged that the terms 'validation', 'evaluation', and/or 'sensitivity analysis' are widely used in ways that assert or imply assurance that the model reflects the underlying processes and therefore provides a reliable basis for decision making. The problem of uncertainty is not unique to modelling but it takes on an added dimension when scientific knowledge is used to support public policy. Not all models of wildland fire behaviour are relevant to policy, but many are, and this makes it more important for modellers to articulate the sources of uncertainty in their models, and to think about ways to test for hidden errors or flaws.

There is a variety of approaches to the modelling of fire behaviour, from the purely empirical to the quasi-empirical to the quasi-physical, and finally the purely physical-based approach Regardless of the approach taken, the aim is to develop purposeful, credible model from data and prior knowledge. Fire behaviour models should ideally possess the ability to predict a certain characteristic or phenomenon over a range of scales, including the prediction of quasi-potential rate of spread and responses to individual wind gusts as well as specific details of fire-line shapes and complex fuel attributes. The presence and nature of such fire behaviour details are very much dependent on unresolvable input details (e.g., the specific fuel arrangement or configuration, wind flow over complex terrain or temporal variations in gust winds, etc). Regardless of the type of fire behaviour model developed, some uncertainties still exist that can have a dramatic impact on the predicted outcomes as a result of potential errors or flaws in logic. This presentation will provide some insight into the current state of science, research and challenges that lay ahead for modelling fire behaviour in order to avoid taking the attitude of 'rolling the dice'.

2. **Intensity and Spread Rate Interactions in Unsteady Wildfires**

John Dold
Chair of Applied Mathematics, School of Mathematics
University of Manchester, UK

Abstract

Contrary to popular belief, Byram's first formula for fireline intensity $I = QmR$ (for a fuel load m, spread rate R and energy content of the fuel Q) is only valid if a line-fire is spreading steadily, when it represents a straightforward energy balance. In unsteady fires the spread rate and intensity are not so directly linked, as experimental observations demonstrate. Physical considerations show that intensity must, in fact, evolve as spread rate changes over a time-scale of the order of the burnout time τ_{b}. In fact, Byram offered a second formula for fireline intensity of the form $I = d \times Qm/\tau_{\mathrm{b}}$ where d is the flame depth and Byram called Qm/τ_{b} the 'reaction intensity'. Since flame depth is the distance travelled by the flame over a burnout time (or spread rate integrated over the burnout time) this formula suggests that intensity arises mainly from an accumulation of flame depth brought about by whatever variations the spread rate has undergone over the previous burnout time τ_{b}. In fact, Byram offered a second formula for fireline intensity of the form $I = d \times Qm/\tau_{\mathrm{b}}$ where d is the flame depth and Byram called Qm/τ_{b} the 'reaction intensity'. Since flame depth is the distance travelled by the flame over a burnout time (or spread rate integrated over the burnout time) this formula suggests that intensity arises mainly from an accumulation of flame depth brought about by whatever variations the spread rate has undergone over the previous burnout time. Clearly, under steady conditions when $R = d/\tau_{\mathrm{b}}$, both formulae become equivalent while Byram's second formula more accurately describes the intensity under unsteady conditions.

The latter formula can be improved with more sophisticated treatments of, for example, pyrolysis initiation and completion in a vegetation layer. It is even possible to account for the stratified nature of most vegetation. These approaches will be discussed in the talk. However, the simpler formula due to Byram $I = d \times Qm/\tau_{\mathrm{b}}$ contains all of the ingredients needed to describe unsteady behaviour with at least qualitative accuracy.

It is useful to identify the dimensionless ratio $B = QmR/I$, which may appropriately be called the 'Byram number', which would necessarily be equal to one under steady conditions. On the other hand if it is greater than one at any time then the spread rate exceeds the steady spread rate that would be associated with the intensity at that moment. The converse holds if the Byram number is less than one. This is useful in identifying accelerating and decelerating fires or growing and decaying intensities.

Knowing how intensity is built up by the spread rate, the behaviour of an unsteady fire then depends on how the spread rate is influenced, in turn, by the intensity. It may be stressed that, for unsteady fires, intensity is a factor that must be considered in addition to the normal conditions of fuel (F), topography (σ) and weather (w) in determining the spread rate. Under steady conditions, Byram's first formula $I = QmR$ must hold so that the spread rate can be considered to depend only on fuel, topography and weather. Although, the more general dependence of spread rate on intensity is not known at this time, some more or less educated guesses can be made.

Thus, modelling unsteady fire behaviour can proceed with these two ingredients: the accumulation of intensity from earlier spread rates; and the dependence of spread rate on intensity.

Generic forms of the latter dependence can be used to identify basic types of unsteady fire behaviour. In particular, a power law $R \propto I^{\nu}$ with $0 < \nu < 1$, generates a stable steady spread rate; any weak or

strong ignition would evolve, after a while, towards this basic speed. If the power ν exceeds one, then there is an unstable steady spread rate, so that a weak ignition would always die out while a strong enough ignition would lead to eruptive fire growth. The Byram number makes a clear distinction between all of these forms of behaviour. For the simple linear dependence, $R = B \times I/Qm$, a fire erupts if $B > 1$ and dies out if $B < 1$. The simple hypothetical relation $R \propto I^\nu$ helps towards considering how a fire would respond to more complex forms of dependence that occur in practice.

What determines this dependence is a deeper issue. One factor that must play a significant role is the attachment or separation of the flow at a flame. Spreading under mild wind conditions with mild slope, the strong buoyancy produced by a fire normally ensures that the flow separates from the ground. This being so, the flame length is known to scale with intensity to a power of about 2/3. Since flame length is a determinant in the rate of radiative heat flux reaching fresh vegetation, one would thus normally expect to find $\nu < 1$ under these conditions. A suitable model might then adopt the form $R = R_\mathrm{s} \times \big(I/(QmR_\mathrm{s})\big)^\nu$ where $R_\mathrm{s}(F, \sigma, w)$ is the steady spread rate at any given fuel, topography and weather conditions. Indeed, if there is also a moderate wind, an increased intensity would make the flames more resistant to being bent over by the wind, helping to reduce the value of ν yet further.

However, up steep enough slopes or in strong enough winds the flow can become attached in spite of (and in some cases partly because of) buoyancy. This should engender much stronger degrees of heat transfer to vegetation. Some experimental results will be presented showing a connection that was observed between eruptive growth and flow attachment.

Considering the issue of attachment and separation more deeply, it is possible to postulate genuinely bimodal forms of dependence of spread rate on intensity. For example, a fire of low intensity may not be able to cause separation in a moderate wind, leading to a relatively large spread rate. But if the spread rate causes the intensity to rise sufficiently to induce separation, the power fed into fresh vegetation would then fall, leading to a sharp drop in spread rate although any further increase in intensity, however caused, might then lead to an increase in the spread rate once more. Relations of this sort could, quite naturally, lead to oscillatory or periodically surging forms of fire spread, as has been reported in some cases.

In summary, most current knowledge of wildfire behaviour has been built up through seeking steady relations for fire spread, with a few notable exceptions. This work is useful for many practical purposes, but not all. Eruptive fires form a notable example in which unsteady behaviour (in fact rapid acceleration) is precisely what makes them so deadly. The problem is made worse by the fact that an understanding which is based on assuming (at least) quasi-steady forms of fire-spread, completely fails to predict such fires. If too much trust is based on this limited knowledge base then eruptive fires are seen as unpredictable and therefore unexpected, which makes them even more dangerous. A key physical point in understanding what drives such fires, while also underpinning any unsteady fire behaviour, lies in identifying the proper link between intensity and spread rate. Intensity is determined by the earlier behaviour of the fire, or the past values of the spread rate, and not its instantaneous value.

2 Roundtable Discussions

Roundtable I: Fire Risk Assessment. (Chair: Jen Beverly, CFS Edmonton).

This roundtable session will address modelling issues related to wildfire risk assessment. The session will begin with a short presentation that reviews some current approaches to wildfire risk assessment and summarizes a selection of research challenges and methodological limitations. This will be followed by an open discussion aimed at further identifying research challenges and areas for methodological improvements that could be pursued through collaborative efforts among fire risk researchers, mathematicians and statisticians.

Rountable II: Stochastic Modelling. (Chair: John Braun, Western)

PROMETHEUS is a deterministic fire spread simulator which is driven by a combination of empirical and physics-based models. Because of uncertainty in the input measurements (moisture, wind, fuel type and continuity, topography) and their forecasts, and because of the unpredictable nature of fire itself, it is desirable to incorporate this uncertainty into the simulator in the form of stochastic noise. How to do this in the best possible way is unclear at present. Burn-P3 represents one approach: weather streams from different stations are run through the *Prometheus* model. This approach, then, partially, accounts for different kinds of weather that could be expected, but it does not account for a large portion of the error that arises from the use of the empirical models in deriving rates of spread. A statistical bootstrapping approach has been proposed; this approach is more likely to provide better assessments of the true amount of uncertainty. The bad news is that there is likely much more uncertainty surrounding fire spread than fire managers would like.

Rountable III: Modelling Wind Effects. (Chair: Anne Bourlioux, Université de Montréal)

Wind plays a key role in forest fire dynamics. In PROMETHEUS, the wind velocity and direction are updated on a time scale on the order of one hour, with a spatial resolution on the order of 10 to 100 km. Those data are then fed into the empirical estimation for the local rate of spread. One objective of the discussion is to identify the most promising approaches to improve this wind-fire interaction model. Here are some examples:

- Wind data is provided on a much coarser scale than the geographic data grid, in particular, topography. There exists a hierarchy of increasingly complex fluid dynamics models (mass conserving, momentum conserving) that can predict small scale information on the flow over the topography given the large scale driving wind.
- If wind fluctuations, in particular, gusts, are not resolved explicitely, what would be the best strategy to account for them via the empirical rate of spread ?
- For fires of sufficient intensities, one might expect significant feedback of the fire on the local wind. When and how should that be included in a modelling tool such as PROMETHEUS ?

Roundtable IV. Mapping Forest Carbon. (Chair: Fanliang He, Alberta)

Ecosystems support biodiversity and also provide goods and services that are essential to maintain the well-being of humans. One of the key ecosystem services is the ability of regulating climate through ecosystem storage of carbon. This ability is typically measured as ecosystem productivity. The relationship between biodiversity and ecosystem productivity is of great interest both in science and in management. A positive relationship is a duo justification for biodiversity conservation. However, the current knowledge about the role of plant diversity in contributing to ecosystem functioning is mainly derived from small scale experiments with grasslands and is highly controversial. Much of the problem arises from the difference in experimental design and observational scale, statistical interpretation of results, and the control of confounding factors. A big unanswered question is: To what extent do the experimental results represent the relationship in natural ecosystems? Without the knowledge about natural ecosystems, the significance of the many ecosystem functioning experiments is questionable. We propose to study the relationship between biodiversity and forest ecosystem functioning in Alberta through the PSP and ABMI program. In this presentation, we will discuss: (1) methods to estimate net primary productivity in Alberta, (2) modeling growth and mortality of trees in relating to climate change, (3) mapping spatial distribution of biomass, and (4) testing the correlation between plant diversity and productivity across Alberta.

Roundtable V: Fire Spotting (Chair: Chris Bose, Victoria)

The realistic modelling of fire spotting represents a major and current challenge for mathematicians and computer scientists working in the forest- and bush- fire simulation field. Complicated physical processes are involved, first in the lofting of actively burning material as firebrands, then in their trajectories and thermal properties while in flight, and finally, their propensity to ignite woody material on landing (creating spot fires). In its entirety, this process is at best loosely understood at this time and it is unreasonable to expect to develop effective deterministic models – a probabilistic approach is therefore necessary. There is general agreement that the literature on the mathematical modelling of spotting starts with the 1979 paper of F. Albini: *Spot fire distance from burning trees – a predictive model, USDA Forest Services, General Technical Report INT-56.* Only a handful of papers have continued and extended this work in the intervening years. Of particular relevance to the PROMETHEUS project is long range spotting (> 500m) since it is felt that the contribution to rate of spread by shorter range spotting is already accounted for in spread parameters from the experimental FBP database. Unfortunately, such long range lofting events are the most difficult to model. As an extreme example, the Australian bushfire modelling project is intensely focussed on spotting – in open range and grassland fire spread, spotting contributes relatively more significantly to spread rates and ‘long range’ is extraordinarily long – up to 30 km ahead of the active fire front is reported. Spotting distances in the Canadian arena are estimated at < 8 km. A reasonable goal for this workshop is to identify a plausible stochastic model appropriate for the Canadian landscape, to correlate its properties with observations by forest fire-fighting personnel, and to suggest future data-gathering exercises that could be used to calibrate such a model.

Roundtable VI: Wrap Up and Future Directions (Co-Chairs: Bose/Braun/Tymstra)

3 Short Presentations

1. **Random Set Modeling of Forest Fires**

Jeff Picka
Department of Math and Stats
University of New Brunswick

Abstract

Modeling the burn region of a forest fire is complicated by two problems: how to account for the inability of any model to fully capture the complex details of a particular fire, and how to assure that a proposed model represents the behaviour of a real fire. A modeling strategy is proposed which deals with the first problem by means of stochastic models, and deals with the second by means of random set and multivariate statistics.

2. **The Probability Distributions of Land Surface Wind Speeds**

Yanping He
School of Earth and Ocean Science
University of Victoria

Abstract

This talk presents recent joint work with YH, Adam Hugh Monahan, Aiguo Dai, and Norm McFarlane.

Knowledge of probability distributions of surface wind speeds (SWS) is essential for surface flux estimation, wind power estimation, and wind risk assessments. The two- parameter Weibull distribution is the most widely used empirical distribution for SWS, in which the PDF is characterized by a particular relationship between the mean, standard deviation, and skewness. Over North America, non-Weibull behavior of SWS is found at night over rough surfaces in all seasons; only the daytime PDF is found to collapse well into the Weibull distribution in all cases. An idealized model shows that SWS skewness has a much greater rate of change with both the mean and standard deviation of surface buoyancy flux under conditions of stable stratification than that of unstable stratification. Over global land, observed seasonal shift of Non-Weibull SWS-PDF is consistent with the observed seasonal shift of wind coupling depth between free atmosphere and land surface. Weibull behavior of SWS-PDF is found in middle to high latitude during daytime when free atmosphere winds strongly influence surface momentum budget. Nighttime Non-Weibull SWS-PDF is more frequent in regions from tropics into the middle-latitudes with strong land surface influence and stable surface conditions. The CCCMa SCM15F is capable to simulate SWS-PDF relationship of free atmosphere winds with forced surface in an idealized uncoupled case study.

3. **Some Pragmatic Thoughts on the Prediction of Spotting in Wildland Fires**

Marty Alexander
Senior Fire Behavior Research Officer
Canadian Forest Service, Northern Forestry Centre, Edmonton, AB

Abstract

The author will offer some practical insights into the issue of spotting associated with wildland fires from the perspective of observing wildfires, experimental outdoor fires, and prescribed fires at a variety of scales and in different fuel types since 1972 in the U.S., Canada, Australia and New Zealand. This presentation will draw upon material as presented by the author at the national Wildland Fire Behavior Specialist courses of the Canadian Interagency Forest Fire Centre from 1996-2008 and his involvement in the spotting and breaching functions associated with the development of the PROMETHEUS wildland fire growth model. He will also touch on a simple model developed with Miguel Cruz (CSIRO Australia) that provides estimates of the minimum separation distance required to increase a fires overall rate of advance and finally talk about the work undertaken to extend Albinis concepts of maximum spotting distance to active crown fires.

4. **A Mathematical Model of Spotting**

Thomas Hillen
Professor, Mathematics and Statistics
University of Alberta

Abstract

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Based on Albini's ideas for spotting, I will present a hyperbolic model for flying fire brands. This model needs as input realistic models for the flight path of a burning branch and for the combustion during flight. If these are knwon, a branch-landing distribution can be found. In a second model, we use this landing distribution to investigate if spotting can accelerate a fire front. This is ongoing work with Jon Martin (Alberta) and Xiaoqiang Zhao (Memorial).

5. **Wildfire Modelling of Today and into the Future**

Mary Ann Jenkins
Department of Earth and Space Science and Engineering
Faculty of Pure and Applied Science
York University

Abstract

The influence of wind on the behaviour of large outdoor fires is so dominant as to make knowledge of wind speed and wind direction the primary concern of the so-called Wildland Urban Interface (WUI) fire behavior forecaster. I will present an overview of the most recent developments taking place in the United States to provide a real-time forecast of wild and WUI fires. In my presentation I discuss two numerical models, the WRF (Weather and Regional Forecasting Model) and the WFDS (WUI Fire Dynamics Simulator), how the first will provide an accurate wind firecast, and how the second coupled with the first can supply an accurate fire spread and fire behavior forecast.