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The orchestra grows! Two new fire models

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ABSTRACT

Fire models will never be exact predictors of fire spread, fire behaviour or fire danger. Fires burning in the open in natural fuels are much too complex to be modelled accurately. Nevertheless, fire models are important and there is a need for a suite, ensemble or orchestra of models which the fire manager and the community can use to meet their particular needs.

This paper reviews some existing models and outlines two models still in their developmental stages that could assist in fire and environmental management. The first is a 'synoptic' model to assist in forecasting possible 'fire activity' in Mallee shrublands.

The second is totally different in character and is an attempt to model meso-scale meteorological parameters. It treats the fire as an input to the fundamental atmospheric equations. The model was developed at the National Centre for Atmospheric Research and it shows promise for predicting fire spread of high intensity wildfires.

INTRODUCTION

In what must be his earliest written comments on fire behaviour studies, Alan McArthur in 1955 wrote that the objectives of his studies on fire behaviour (in *Pinus* species) were....

1. To determine factors which control the rate of spread of fires, and
2. To determine the relative importance of each significant factor.

Such a fundamental study to provide a basis for -

(a) Preparation of a fire danger rating system and so provide a more accurate basis for fire weather forecasting.
(b) Determination of man power and speed-of-attack requirements.
(c) Explanation of normal and abnormal fire behaviour.
(McArthur 1955)

Not much has changed in relation to fire danger forecasting objectives in the last 40 years but a lot has changed in the tools or models available to satisfy these objectives. However, it is doubtful if anyone is completely satisfied with the fire models currently available.

FIRE BEHAVIOUR MODELS FOR AUSTRALIAN USE

No one fire model is going to satisfy all the needs of any fire manager or fire weather forecaster. The wildfire process is very complicated and we are at the mercy of the complexity of the physical and chemical processes involved. A list of the subcomponents of a comprehensive fire model is awesome and an understanding is required in many different and mostly not well understood areas. A comprehensive fire model would require sub-models to describe turbulent combustion and meteorology. On top of all that, a model is required that describes the infinitely variable biological systems, for they determine fuel structure and dynamics.

The use of fire models in the future may be very like the current use of weather models. No weather forecaster relies on only one model but on a whole suite of models. Greater or lesser weight is given to various models depending upon the forecasting range or the particular weather system, to which is added the forecasters' experience. So it may be for fire managers, there will be different models for different needs. Some models will be useful for firefighting, some for prescribed burning, some for high intensity management burns, some for domestic and rural fuel management (Packham 1989).

McArthur's Models

Among the more useful models currently available are the McArthur models of various marks (see for example, Cheney 1981). McArthur models have become such a way of life in Australia, that to some people fire danger is what is produced by a McArthur Meter. The McArthur Fire Danger Meters have tended to be overused and applied outside the range for which they were designed; for example, the dry sclerophyll model being used for both the mallee and wet sclerophyll. McArthurs models are like a large and leaky ship, too valuable to scrap and too expensive to repair. A recent study of reported rates of spread in three intense grass fires by J.C. Noble (Noble 1991) has provided a boost for the Mk4 grassland model and a fatal blow for the Mk5 version. The Mk4 meter gave good predictions whereas the Mk5 (which incorporates fuel as a rate of spread variable) under predicted rate of spread by a factor of three or more.

The 'Red Book'

The Western Australian 'Red Book' fire behaviour model (Burrows and Sneeuwjagt 1988) is based on an empirical approach as was McArthur's . In our opinion it is currently the most useful and satisfying empirical operational fire behaviour model for Australian conditions. It is flexible and continues to develop at a satisfying rate as an increasing number of fuel types are included.

When high fire intensity and crowning behaviour is incorporated into this model we should reach very close to perfection for a fire management operational tool. We fail to see why the rest of the nation continues to ignore it, especially as current software makes it very convenient to use.

Tasmanian Moorland Model

A new fire behaviour model for Tasmanian moorland fuels has been developed by Jon Marsden-Smedley of the Tasmanian Parks, Wildlife and Heritage Service. It includes a buttongrass moorland fire danger index based on fire measurements taken under a wide range of conditions. The index predicts fire behaviour and suppression difficulty in these notoriously flammable fuels. The model will be published as a Parks Service Occasional Paper in the next couple of months.

The Canadian Model

The Canadian Model (Stocks *et al.* 1988) comes closest to disproving our contention that one model is not easy enough for a nation with serious fire problems. It seems to be growing and becoming so increasingly complex that it may yet provide support for this view. However, the Canadians and others seem to like it and it appears to be a suitable choice for fire managers with the fuel types and fire regimes that suit it.

It is necessary for fire behaviour models to be designed for particular climates. The Canadian and the American models are mostly designed for areas of high rainfall and lush green forests where fuel availability is determined by fuel dryness alone. In contrast, the Mediterranean climates with frequent fires, minimum summer rainfall and little winter snow cure, require models specific for those conditions. Perhaps after the appearance of a fire tornado in Australia in the form of Marty Alexander, the Canadian model may find some usefulness in Australian pines. We should observe and emulate the wonderful presentation and product support for their fire model.

The US Rothermel Model

The current operational Rothermel model (Rothermel 1972) seems to be useful in Australia in heathlands (Catchpole 1987; Catchpole *et al.* 1993). It has been shown to be useful in a variety of US fuels (Andrews 1980) and the 'new' one with the considerable involvement of the Catchpoles may have an extensive application in Australia (as encompassed in the BEHAVE fire prediction system, see Burgan and Rothermel 1984; Andrews 1986, 1989). Whether any 'new' model finds a place in Australian fire management will depend as much on promotion, marketing and ease of use as effectiveness and accuracy.

TWO MORE MODELS

Krusel Fire Activity Model

The main original aim of McArthur and Luke as they went about their fire behaviour studies was to provide the Bureau of Meteorology with a tool that would permit the forecasting of 'fire danger'. McArthur assumed that fire danger was the same as difficulty of suppression (see for example, McArthur 1958). However, other definitions take account of risk. A whole semantic debate always follows any consideration or attempt to define the term 'fire danger'.

Krusel *et al.* (1993) considered the problem of forecasting fire danger on the synoptic scale, i.e. 1000 km or 24 hours. The purpose of the study was to satisfy the need for both private and public organizations and individuals to know the likelihood that serious fire will occur over the following daily forecasting period.

The motive for developing the model came from feelings of dissatisfaction when using the McArthur Forest Fire Danger Meter Mk5 in the Mallee areas of Vic, NSW and SA. The McArthur Meter gives high fire danger classes for almost every day during the declared fire danger period. There is a severe over-warning situation.

Krusel *et al.* avoided the problems of many different definitions of fire danger by generating the concept of fire activity.

'In Australia there is no consensus on the best definition of fire activity. Foster (1976), for example, defined 'serious' fires in terms of : duration of fire; number of lives lost; area burnt; structures lost and estimated cost of damage. Cheney (1976) catalogued bushfire disasters in Australia from 1945-1975 by: duration of fire; number of days of extreme FDI; area burnt; lives lost; type of property damage; and value of damage (Consumer Price Index adjusted). Newspaper reports tend to focus on the loss of life, damage to property and on the magnitude of the suppression effort involved.'

In response to this confusion Krusel *et al.* introduced the concept of fire activity as a function of the number of fires recorded on a day, the total area burnt, the number of persons recorded as fighting the fires and the number of units attending. The indicators were put into categories and fire activity was the average of the categories of the four indicators equally weighted. Table 1 gives the criteria that were used to categorize the indicators of the activity.

The methodology was to determine the meteorological and fuel parameters that best predicted fire activity. Correlations were determined from nine years of data in the Victorian Mallee shrubland and then tested on the next two years of data.

Table 2 provides the selection criteria for estimating the fire activity categories from various meteorological parameters. The category that is determined is the highest category for that particular parameter.

Table 3 shows the efficiency of various meteorological parameters as predictors of fire activity and the number of days over a period of nine years on which a fire weather warning would be issued.

It turns out that the McArthur model provides only a 1.6 per cent probability of correctly predicting a day of high fire activity. By combining a variety of meteorological parameters the probability of detection can be made some three times better. Whilst a 4-5 per cent probability of detection does not sound impressive, the use of the new technique would cut down the number of days on which fire danger is warned by two thirds.

In another approach using these data Dowe and Krusel (1993) constructed a minimum message length decision tree. This alternative form of analysis has produced very similar results. The tree is shown in Figure 1 and the symbols used are indicated in Table 4.

Krusel has extended this study to the dry sclerophyll fuels where the McArthur Forest Fire Danger Index and the Krusel models have been shown to have a similar performance (Krusel *et al.* 1993). This is a fortunate result that confirms that McArthur has a predictive capacity in the fuels in which it was intended and that the Krusel method is a useful fire predictor.

TABLE 1

Criteria for definition of fire activity categories in the Victorian Mallee.

CATEGORY	PERCENTILE	AREA (ha)	No. OF FIRES PER DAY	PERSONS ATTENDING	FIRE UNITS ATTENDING	No. OF DAYS SELECTED
7	>99.0	14001+	7+	180+	32+	6
6	<=99.0, <97.5	5051-14000	5-6	74-179	16-31	9
5	<=97.5, >95.0	2001-5050	4	53-73	8-15	31
4	<=95.0, >85.0	46 - 2000	3	30-52	4-7	79
3	<=85.0, >75.0	9 - 45	2	21-29	2-3	154
2	<=75.0, >50.0	2-8	1	11-20	2	264
1	<50.0	0-1	1	0-10	1	336
0		0	0	0	0	2353

developed a complex non-hydrostatic meso-model. Non-hydrostatic means that vertical air accelerations are explicitly treated in the model equations. The computing requirements for such models are large and as a result they are expensive.

The Clark model has been successful in demonstrating the mechanisms of atmospheric processes involving strong buoyant forces. The severe downslope windstorm is an example, a model output is shown in Figure 2.

The gusts associated with these types of windstorm have a characteristic periodicity of several minutes. The gusts descend onto a particular zone downwind of the Rocky Mountain range. They are of an intensity capable of causing considerable property damage and are now know to result from the breaking of atmospheric waves which had been generated by the steep upwind topography.

Work is proceeding on including a bushfire component within the Clark model. A prototype has been applied to the Tasmanian environment to get a feel for its ability to model some of the wind field peculiarities of that very 'bumpy' State. A simple model was developed of the heat and mass transfer (at meso-scale) in a high intensity crown fire under the Hobart 1967 conditions. The simple model was too gross and blew up the meso-model. The fire model assumed that all the surface energy was used in drying the canopy before canopy ignition. It is probable that only some 25 per cent of the heat produced by ground combustion is used in canopy drying.

The spread rate was far too high, probably a factor of twenty, prompting a search for a better physical model of fire and a negative feedback mechanism.

The initial attempts have used the McArthur model as a predictor of fire behaviour, the meso-model supplying the meteorological parameters for insertion into the McArthur Forest Fire Danger Meter. It is hoped that this empirical component can be relaxed over the next stage of model development.

If fire is a convectively driven phenomenon then a convective parameter based on vorticity dynamics may well be needed for predicting both rate of spread and energy release.

The Clark meso-model is currently a research model and one that is usually run on a supercomputer. On the Cray Y-MP it runs about nine times real time and so is unlikely to ever become an operational model in its present form. Modelling technology is improving very rapidly and it is expected that in a few years a real time workstation model may be available.

The work is complex and confusing but the results look promising.

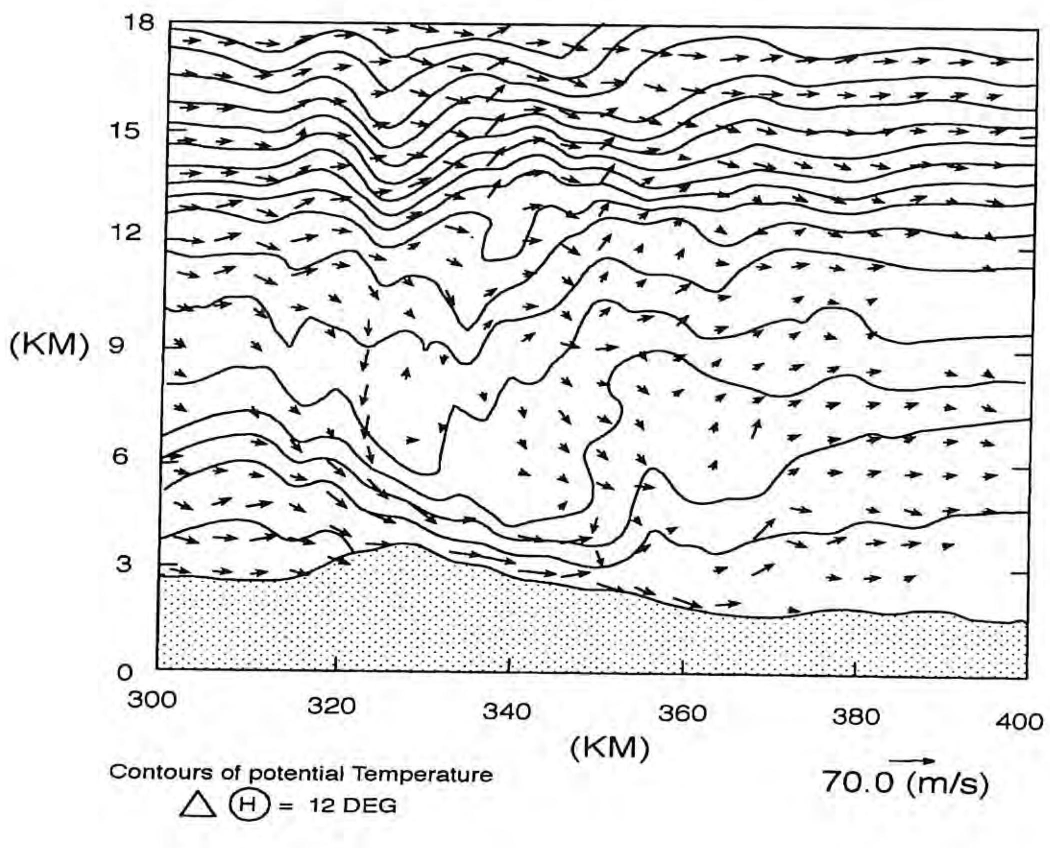

Figure 2. Downslope windstorm Rocky Mountains.

CONCLUSION

There is in existence a range of fire models of different types, all of which can be useful for fire management. They include the Western Australian Red Book model that could be put to much more use than it has been so far.

The Krusel model for fire activity forecasting in Mallee and dry sclerophyll fuels should be given a careful testing in either its simple or decision tree form.

An exciting possibility is the application of non-hydrostatic meso-meteorological models to predicting fire weather interaction including convection and even fire behaviour.

The times ahead are exciting and we must maintain the momentum.

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REFERENCES

Burrows, N.D. and Sneeuwjagt, R.J. (1988). McArthur's Forest Fire Danger Meter and the Forest Fire Behaviour Tables for Western Australia: Derivation, Applications and Limitations. Conference on Bushfire Modelling and Fire Danger Rating Systems, CSIRO, Canberra.

Catchpole, E.A., Catchpole, W.R. and Rothermel, R.C. (1993). Fire Behaviour Experiments in Mixed Fuel Complexes. *International Journal of Wildland Fire* **3**, 45.

Cheney, N.P. (1981). Fire Behaviour. In: Gill, A.M., Groves, R.H. and Noble, I.R. (Eds) *Fire and the Australian Biota.* Australian Acadamy of Science, Canberra.

Cheney, N.P. (1976). Bushfire Disasters in Australia 1945-1975. *Australian Forestry* **39**, 245-268

Foster, T. (1976). *Bushfire, History, Prevention and Control.* Reed, New South Wales, 247 pages.

Clark, T.L. (1977). A small scale numerical model using a terrain following co-ordinate transformation. *Journal of Computing Physics* **24**, 186-215.

Clark, T.L. and Farley, R.D. (1984). Severe downslope windstorm calculations in two and three spatial dimensions using anelastic interactive grid nesting: a possible mechanism for gustiness. *Journal of Atmospheric Science* **41**, 329-350.

Dowe, D.L. and Krusel, N. (1993). A decision tree model of bushfire activity. *Technical Report No 93/190,* Department of Computer Science, Monash University, Clayton 3168, Australia.

Dowe, D.L. and Krusel, N. (1993). A decision tree model for bushfire activity. Sixth Australian joint conference on artificial intelligence, Melbourne, November 1993.

Krusel, N., Packham, D.R. and Tapper, N. (1993). Wildfire activity in the mallee shrubland of Victoria, Australia. *International Journal of Wildland Fire* **3**, 217-288.

McArthur, A.G. (1955). Extracts from 'Progress report on fire behaviour studies conducted by the forestry and timber bureau during the 1954-55 fire season'. Internal report to Director General of the Forestry and Timber Bureau, Canberra.

Noble, J.C. (1991). Behaviour of a very fast grassland wildfire on the Riverine Plain of Southeastern Australia. *International Journal of Wildland Fire* **1**, 189-196.

Packham, D.R. (1989). Background to Fire Behaviour Models. Proceedings of the Third Australian Fire Weather Conference, 18-20 May, Hobart, Bureau of Meteorology, Melbourne.

Stocks, B.J., Lawson, B.D., Alexander, M.E., Van Wagner, C.E., McAlpine, R.S., Lynham, T.J. and Dube, D.E. (1991). The Canadian System of Forest Fire Danger Rating. In: Cheney, N.P. and Gill, A.M. (Eds) Proceedings of Conference on Bushfire Modelling and Fire Danger Rating Systems, 11-12 July 1988, CSIRO, Canberra. pp 9-18.