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McArthur's fire-danger meters expressed as equations

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Abstract

McArthur's fire-danger meters for grasslands (Mark 3) and forests (Mark 5) have been widely used in Australia for fire-danger forecasting and as a guide to fire behaviour. We present a set of equations to describe the data provided on these meters plus equations pertinent to the recently-produced Mark 5 grassland meter. The equations provide a simple method of describing the forecasting system and are particularly useful for machine processing, and modelling.

Introduction

McArthur's fire danger meters, conceived and updated during the last decade or so (McArthur 1966, 1967), have been an important development both for fire-danger forecasting and for the interpretation of fire behaviour. The earlier forest and grassland meters were designed for use in 'high eucalypt forest' and in pastures of the southern tablelands of New South Wales (and the Australian Capital Territory) respectively while the latest grassland meter (Mark 5) has wider applicability. They result from extensive observations; for example, over 800 fires for the forest meter, and have been constructed without pre-conceived notions of the functional relationships between the variables (A. G. McArthur pers. comm. 1976).

The expression of results in the form of a meter is clearly unsuitable for applications to modelling or for comparing the results with those found elsewhere. A series of equations has been derived which express the data shown on the meters. We have chosen to fit the equations to the meters rather than to the original data, since many of the original data were not available and because there are advantages in having direct equivalence between the equations and the meters.

Methods

Data were taken from the meters either by measuring displacements along the scales, by taking it directly from the tables on the backs of the meter or from hand-drawn graphs supplied by A. G. McArthur. Functions describing the relationships between these data and the meteorological variables were derived. Most functions were simple and readily linearized and gave an almost exact fit to the data of the meters. The separate functions were then combined to give a single equation relating the meteorological variables to the Fire Danger Index and to the fire characteristics presented on the meters.

All calculations were based on the metric meters. Note, however, that the drought index on the forest fire danger meter is expressed in units equivalent to points of rainfall but metric units are used in all the equations. The equations are intended to describe the meters as accurately as possible, although no implications of the accuracy of the meters themselves are intended.

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Results

The equations derived for the grassland fire danger meter Mark 3 are shown below:

$$F = 2.0*\exp(-23.6 + 5.01*\ln(C) + 0.0281*T - 0.226\sqrt{H} + 0.633\sqrt{V})$$

$$R = 0.13*F$$

Symbols and units are described in Table 1. This meter has been replaced by the Mark 5 version and the equations are as follows:

$$M = (97.7 + 4.06*H) / (T + 6.0) - 0.00854*H + 3000.0/C - 30.0$$

$$F = 3.35*W*\exp(-0.0897*M + 0.0403*V) \quad \text{for } M < 18.8\%$$

$$F = 0.299*W*\exp(-1.686 + 0.0403*V) *(30 - M) \quad \text{for } 18.8\% \leqslant M < 30.0\%$$

$$R = 0.13*F$$

The equation for the forest fire danger index from the Mark 5 meter is:

$$F = 2.0*\exp(-0.450 + 0.987*\ln(D) - 0.0345*H + 0.0338*T + 0.0234*V)$$

This equation can be simplified with a very small loss of accuracy (the maximum absolute difference from the above equation is less than 2.5 units).

$$F = 1.25*D*\exp[(T - H)/30.0) + 0.0234*V]$$

The equations for the other relevant information on the meter are:

$$R = 0.0012*F*W$$

$$R_\theta = R*\exp(0.069*\theta)$$

$$Z = 13.0*R + 0.24*W - 2.0$$

$$S = R*(4.17 - 0.033*W) - 0.36$$

The drought factor is a discontinuous (step) variable derived from categories of the Keech-Byram drought index (Keech & Byram 1968). The method described above was used to derive a function for drought factor from the required meteorological variables. The resultant, albeit complicated, equation is:

$$D = 0.191*(I + 104)*(N + 1)^{1.5}/(3.52*(N + 1)^{1.5} + P - 1)$$

This equation does not produce an exact fit to the meter but should be sufficient for most purposes.

Discussion

McArthur's meters have considerable use in fire-danger forecasting in Australia today. The indices derived from the meters are said to be directly related to the chance of a fire igniting, its rate of spread and the difficulty of suppression. The indices have been used in many regions although they were derived for specific forest and grassland types. They are an important aspect of forecasting and provide a basis for the explanation of fire behaviour in the plant communities for which they were designed.

The meters contain a number of approximations and are for 'average' pastures in the case of the grassland meter MK 3, and are said only to provide 'reasonable accuracy' in the case of the forest meter. Of perhaps greater importance to the use of the grassland meters in practice, however, is the accuracy of assessing 'degree of cur-

TABLE 1. Explanation of symbols used in the text

Symbol	Variable	Units
C	Degree of curing	percent
D	Drought factor	–
F	Fire danger index	–
H	Relative humidity	percent
I	Keetch-Byram drought index	(mm equivalents)
M	Fuel moisture content	percent
N	Time since rain	days
P	Amount of precipitation	mm
R	Rate of forward spread of fire on level to undulating ground	km hr^{-1}
R_θ	Rate of forward spread on ground of slope θ	km hr^{-1}
S	Distance of spotting from flame front	km
T	Air temperature	°C
V	Average wind velocity in the open at a height of 10 m	km hr^{-1}
W	Fuel weight	tonnes ha^{-1}
Z	Flame height	m
θ	Slope of ground surface	degrees

ing' or assessing the appropriateness of meteorological data from localities at a distance from the fire. The latter would apply particularly to wind velocity, a variable to which danger indices and rates of spread are very sensitive. Wind fluctuates widely even in a single locality within a short time period and thereby alters the index substantially. In forcasting, the meters are used to provide *ranges* of the indices only; for example, high, moderate, low, etc. In fire-behaviour studies, however, more detail is required and the meters are used most critically for these purposes. The equations provided are as suitable for these tasks as the meters. Note that the equations are simply a different way of expressing McArthur's data: they do not affect the accuracy of the predictions.

The major value of the equations is that they can be used in computer systems for the automatic computation of fire-danger indices or potential rates of spread from weather data. They can also be used in a system of hazard indices for fire planning as has been suggested by Gill (1977). The equations could also be used in historical analyses of weather records in relation to fire occurrence after the manner of Vines (1969), although records of curing of grasslands are not kept for long periods by the Bureau of Meteorology. The equations have been used in models of the long term dynamics of forests subject to wildfire and prescribed fires (H. H. Shugart & I. R. Noble pers. comm.).

For forecasting of fire danger the meters may remain basically the same in the near future but for description of fire behaviour the use of new methods of fuel moisture estimation (Dexter & Williams 1976) may provide an improvement which can be used directly in the Mk 5 grassland formulae.

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