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# The prediction of bushfires in central Australia

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**An investigation of the predictability of fire size and occurrence in central Australia on both daily and seasonal scales is described.**

**Using a ten-year record of daily fire incidence, it is shown that using persistence and accurate forecasts of wind direction and pressure tendency, it is possible to skilfully forecast fire occurrence. Application of the same data to the problem of defining days when fire containment will be a problem is less successful. The McArthur Fire Danger Index (Luke and McArthur 1978), as determined using the Mark IV meter for grasslands, is shown to be a better indicator of the area likely to be burned out on a given day than any of the meteorological parameters which constitute it.**

**A spatial average three-year cumulative antecedent rainfall, the blocking index (BI), as defined by the National Meteorological Centre (NMC), the Southern Oscillation Index (SOI) (Troup 1965), and sea surface temperature (SST) anomalies near Indonesia are all correlated with the fire data. The forecasting skill of these parameters is assessed and the SOI, rainfall and the BI are all found to have skill comparable with that of persistence.**

## Introduction

This paper describes the results of a study aimed at defining the fire weather forecasting problem in central Australia. The emphasis is on examining meteorological parameters to determine the skill with which day to day and season to season forecasts of fire occurrence and size can be made.

The large, sparsely populated area covered in this study poses problems for those wishing to institute a strategy for the control of wildfires. Lightning strikes, which account for 58 per cent of fire occurrences in the region (Griffin et al. 1983) may cause ignitions over a vast area. The occurrence of fires and their evolution will depend on day to day influences associated with synoptic weather patterns, and season to season influences, associated mainly with fuel loadings and curings.

The strong relationship between cumulative antecedent rainfall and fire incidence and size in the central Australian rangelands has been demonstrated (Griffin et al. 1983). Seasonal relationships between Australian rainfall patterns and the Southern Oscillation (SO) have been found by McBride and Nicholls (1983) and Coughlan (1983). Nicholls (1983) has also demonstrated a relationship between sea surface temperature (SST) anomalies in the Indonesian region and Australian rainfall patterns. Correlations obtained in the above-mentioned studies have demonstrated the presence of relatively stable planetary-scale anomaly patterns which have a substantial influence on the Australian climate.

The blocking index (BI) as defined by NMC, Melbourne:

$$BI = U_{27.5} + U_{57.5} - (U_{42.5} + U_{47.5})$$

where U is the five-day mean zonal wind component at 500 hPa and the subscript describes latitude (Wright 1974) has been found to have only a weak relationship with rainfall (Ohis 1980). It was nevertheless utilised in this study in an attempt to establish a link between time-averaged weather patterns and fire incidence and size.

In assessing the forecasting skill, the 'perfect prognosis' approach is used. That is, attempts are made to correlate observed meteorological parameters with observations of bush fires. This approach ignores the question of how well the meteorological parameters can be forecast, given that statistically significant relationships can be found between the predictand (i.e. the bushfires) and the various predictors.

## The data

Fire data were available for the pastorally occupied region of the Northern Territory south of the twenty-first parallel, excluding the Simpson and

Western deserts. All fires reported in the region between June 1970 and July 1980 were recorded by the Bush Fires Council of the Northern Territory. The records which were maintained on a day to day basis included: an estimate of the area burned on that day; the location of the fire; the possible cause; the fuel type and other information relating to suppression action. These data were provided by Dr G. Griffin of the CSIRO Division of Wildlife and Rangelands Research.

The midday synoptic observation of Station Level Pressure (SLP), temperature, dew-point temperature ($T_4$), wind speed and the daily maximum temperature for Alice Springs Airport for October and November 1970 through to 1979 were available. A monthly regional rainfall data set was prepared by averaging the monthly rainfalls at five meteorological observation stations; Finke, Jervois, Curtin Springs, Yuendumu and Alice Springs. Cumulative antecedent rainfalls were prepared from these data. The Southern Oscillation Index (SOI) used was that developed by Troup (1965). The sea surface temperature (SST) anomaly data used are a spatial average anomaly for an area of ocean near Indonesia, supplied by N. Nicholls (personal communication).

## Correlation

### Antecedent rainfall

Previous studies have indicated high correlations of annual fire numbers and areas burnt with cumulative antecedent rainfall. Griffin et al. (1983) obtained correlation coefficients as high as 0.9 and 0.7 when three-years cumulative antecedent rainfall was correlated with annual fire numbers and areas burnt, respectively.

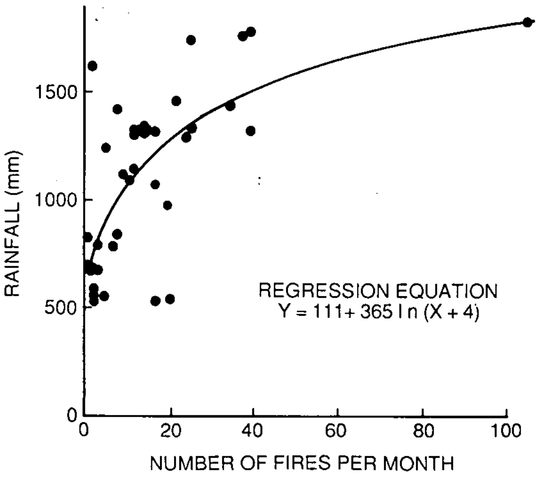
In this study, where data for the months October to January were used, correlations between cumulative antecedent rainfall and areas burnt were produced for periods between six months and four years. The best correlation was found to occur at three years with both 2.5 and 3.5 years showing only slightly lower correlations. At three years the correlation between rainfall and area burned was 0.63 and that between rainfall and fire numbers, shown in Fig. 1, was 0.65.

These values represent 40 and 42 per cent of the variance respectively (significant at the 95 per cent level). Because the rainfall time series exhibited a high degree of autocorrelation, significances were calculated using the method suggested by Sciremammano (1979).

### The Southern Oscillation Index (SOI) and sea surface temperature (SST)

Under the assumption that the major influence of both the SOI and SST anomaly would be through rainfall, cumulative antecedent sums of these latter variables were prepared. It was also felt that the observed time-lags of up to 12 months between these parameters and rainfall would be roughly accounted for in the process. The correlation between the three years cumulative antecedent SOI and the area burned explained 21 per cent of the variance, while the corresponding correlation between SST anomaly and fire area was found to be negligible.

**Fig. 1** **The scatter graph of fires per month against the three years cumulative antecedent rainfall with the line of best fit.**



### The blocking index

A combined blocking index was constructed from daily data supplied by the Extended Prognosis Section NMC, Melbourne. These daily data gave the index at the longitudes 90°E, 110°E, 150°E, 160°E, 170°E. Monthly means of these were converted into a combined blocking index (CBI):

$$CBI = BI_{150} + BI_{160} + BI_{170} - BI_{90} - BI_{110} - BI_{130}$$

(These are longitudes in the Australian region at which the index is routinely calculated.)

The assumption employed in the utilisation of the CBI is that it represents an average weather pattern conducive to wildfires. While it is true that many different patterns could produce similar blocking indices (Wright 1974), it was felt that the pattern which would predominate in a situation of high CBI would be a slow-moving, meridional high pressure system over southeastern Australia or the Tasman Sea combined with a long-wave trough in Western Australian longitudes. This situation, with troughs amplifying into central Australia, could be postulated as the principal situation associated with severe fire weather in central Australia.

The Combined Blocking Index (CBI) when correlated with fire areas and fire numbers produced lines of best fit explaining only 16 and 12 per cent of the variance respectively. High blocking numbers appeared to correlate quite well with large areas burnt, indicating that better results could probably be obtained by restricting a study in this area to strongly positive values of the CBI.

**Meteorological parameters**

In a post-analysis sense some measure of the degree of difficulty of fire containment on any day is given by the area burnt out by bushfires. The varying topography, vegetation and containment measures will detract from the correlations sought between area burned and some meteorological parameters. It was felt that, on balance, the paucity of containment measures possible in the large and sparsely populated area, and the relative homogeneity of the vegetation, would lend themselves to this type of study.

In this analysis, where the months October and November were used, relationships were sought between the area burnt out and an array of meteorological parameters. Correlations between each parameter and area burnt were calculated. In order to restrict the study to major events, only areas in excess of one thousand square kilometers were considered.

Figure 2 shows the scatter graph for the daily midday wind speed at Alice Springs against the daily area burnt. The line of best fit explains 15 per cent of the variance. Calculated in a similar fashion, the correlation beween the daily maximum temperature and the midday temperature against the area burnt explained only 8 per cent and 11 per cent of the variance respectively. The correlation between relative humidity and area burnt explained only 2 per cent of the variance, displaying a weak tendency for increasing area burnt with increasing relative humidity. Correlations were also sought between wind direction, station level pressure and area burnt. The lines of best fit in these cases accounted for 7 per cent and 9 per cent of the variance respectively.

The three variables considered above (temperature, relative humidity and wind speed) comprise the meteorological components of the McArthur Fire Danger Index (FDI) (Luke and McArthur 1978). Relative humidity appears to be positively correlated with area burnt rather than negatively (as is assumed in the FDI). Temperature appears to be only weakly related to the fire containment problem and wind speed more highly correlated.

The midday FDI was correlated with the area burnt, assuming fuel conditions of 90 per cent curing and 5 t/ha (the FDI was calculated using the expression given by Purton (1982). The scatter was quite broad and the line of best fit explained 9 per cent of the variance. Essentially, the analysis of these data yielded a null result. The unrepresentativeness of Alice Springs may have been partly responsible.

It is desirable to calculate an FDI using actual fuel quantities and curing levels. Unfortunately incomplete records of the graziers' estimates of these parameters have been maintained. Synthetic fuel loadings were generated by considering three-year cumulative antecedent rainfalls. It was assumed that the fuel loadings varied in a linear fashion between the extreme maximum and minimum three-year cumulative antecedent rainfall years. On the basis of observations, the minimum was assumed to be 3 tonnes per hectare (t/ha) and the maximum, 7 t/ha. It was also assumed that the native grasses (not spinifex) undergo an increase in curing from 80 per cent on the first of October to 95 per cent on the first of November in a quasi-exponential manner as shown in Fig. 3. With these assumptions, fuel curing may be crudely estimated for any given day in the study period. These assumptions are consistent with the conclusions of Griffin et al. (1983).

Using these synthetically generated fuel quantities and curings, 'synthetic' daily FDIs were calculated using the midday observations of temperature, relative

**Fig. 2** The scatter graph of midday wind speed against daily area burnt out by fires with the line of best fit. (Significant at the 95% level.)

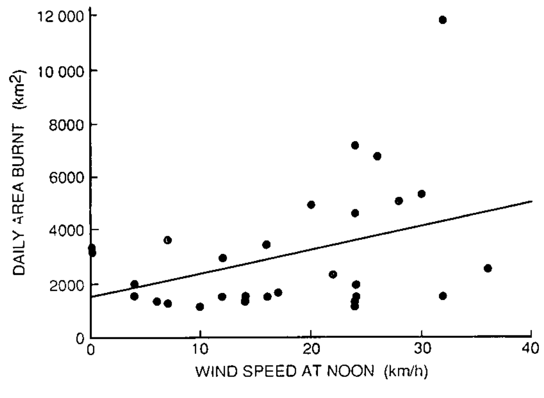


**Fig. 3** Assumed variation of curing with day number after 1 October.

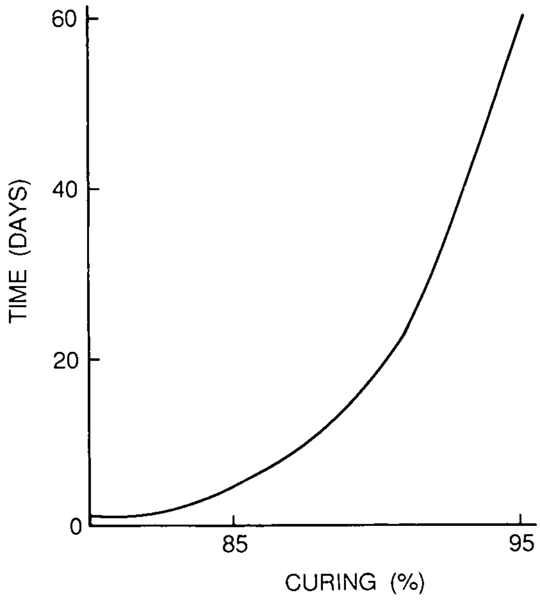
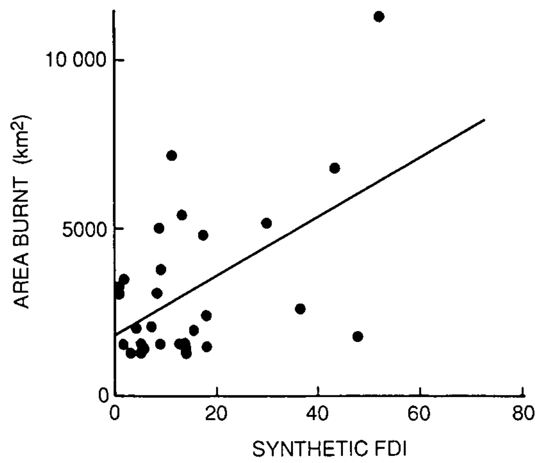


**Fig. 4** As for Fig. 3, except 'synthetic' FDI.



humidity and wind speed at Alice Spings. The scatter of these FDIs against area burnt out is given in Fig. 4. The line of best fit explains approximately 27 per cent of the variance. The relatively satisfactory performance of this synthetic FDI when compared with all other parameters is somewhat reassuring. The decisive variable appears to have been fuel quantity.

## Forecasting skill

### Random chance and persistence

The table below gives the 2x2 contingency table derived using the occurrence/non-occurrence of a fire on a day (D-1) to forecast the same conditions on the following day (D).

| | *Forecast* | | |
|---|---|---|---|
| | Fire | No Fire | Total |
| *Observation* | | | |
| Fire | 67 | 74 | 141 |
| No Fire | 74 | 396 | 470 |

Hanssen and Kuipers (1965) define the probability of a fire given a fire on the previous day as:

$P(o/o) = (67/141) = 0.48$

In this case, covering 611 days, there were 141 days of one or more bushfires, thus a random forecast of fire occurrence would have a 0.23 chance of success. In the analyses which follow it should be borne in mind that a predictor which has a probability of success of the order of random chance displays no skill. However predictors which demonstrate a probability of success close to that of persistence (0.48) could be considered suitable for use in operational forecasting.

### Meteorological variables

Initially, the meteorological parameters of wind speed, temperature, relative humidity and maximum temperature were examined as predictors of fire occurrence. Because these three parameters have been combined successfully with a parameter of fuel state in the McArthur FDI to provide an index of difficulty of fire containment, they were felt to be a useful starting point in the search for a fire occurrence index.

Figure 5 shows the probability of making a correct forecast of fire occurrence using the wind speed as the predictor. Each bar shows the probability of fire occurrence for a wind speed on the abscissa. It is apparent that there is no threshold wind speed above which there is an appreciable improvement on persistence. Figures 6 and 7 show similar probability bar graphs using midday temperature and maximum temperature as predictors respectively. Once again these predictors show no skill, that is, there appear to be no temperatures (either midday or daily maximum) above which fire occurrence is highly probable. Figure 8 shows the probability of fire occurrence using relative humidity as the predictor. This probability graph was computed by examining whether or not fires occurred for relative humidities equal to, or less than the given value. Once again, the predictor shows no skill.

It is possible to combine the midday observations of temperature, wind speed and relative humidity along with non-varying fuel states and assess whether or not the McArthur FDI provides a good forecast of fire occurrence. Since the FDI is an index of how fast a fire will spread once started it is in a limiting sense, a measure of how successful ignition of a fire will be. It can thus, in the presence of fire igniters, act as a measure of fire occurrence.

Assuming a curing of 90 per cent and a fuel quantity of 5 tonne/hectare (t/ha) the FDI was calculated, and

**Fig. 5** **Probability of a correct daily forecast of bushfire occurrence for midday wind speed above a specified threshold.**

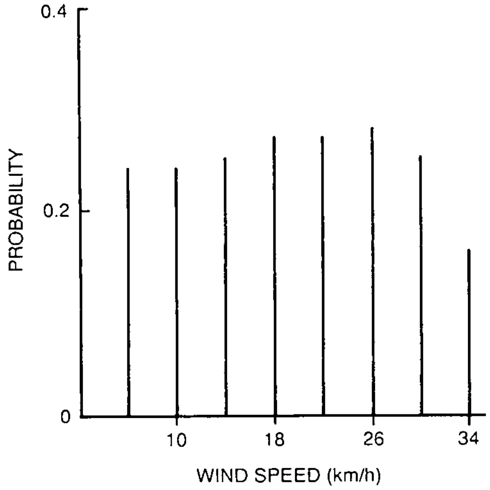


**Fig. 6** As for Fig. 5 except midday temperature.

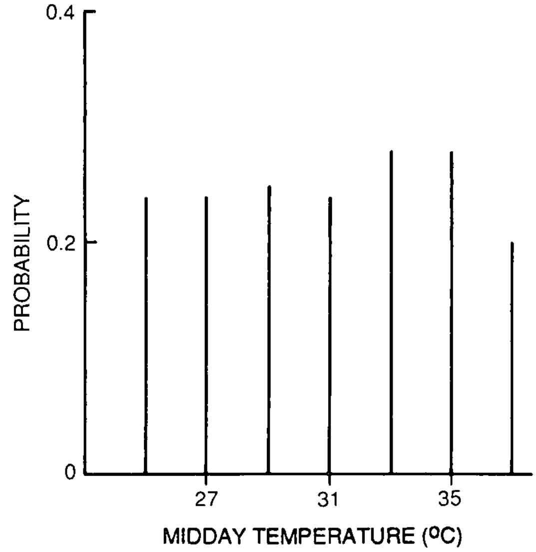


**Fig. 7** As for Fig. 5 except daily maximum temperature.

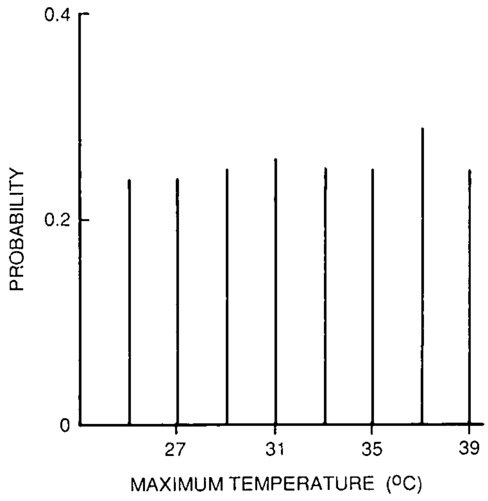


**Fig. 8** Probability of a correct daily forecast of bushfire occurrence for midday relative humidity below a specified threshold.

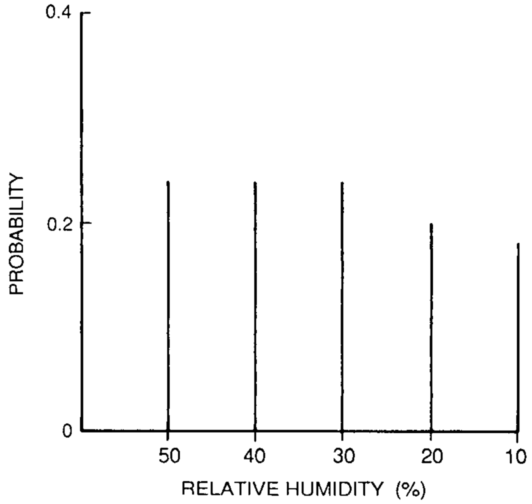
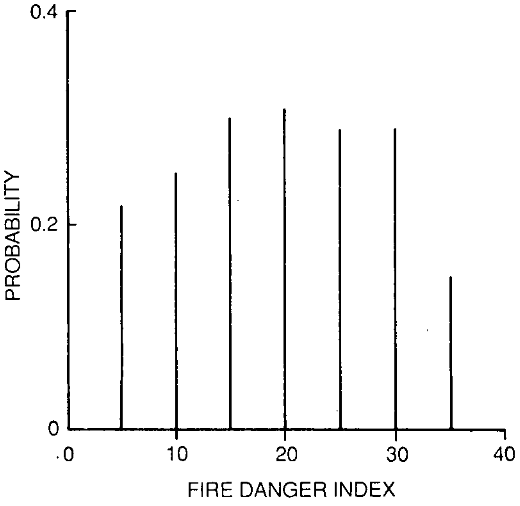


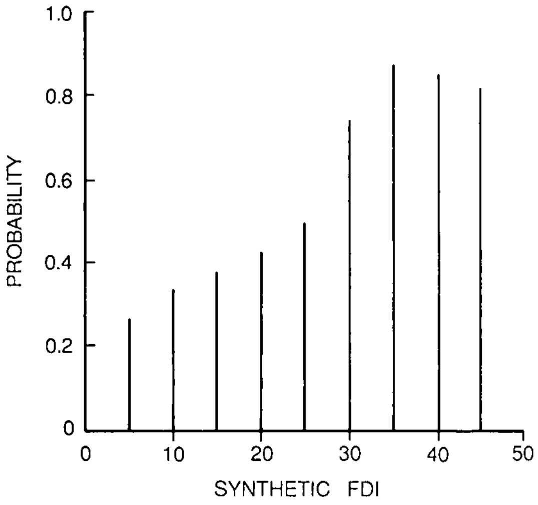
**Fig. 9** Probability of a correct daily forecast of bushfire occurrence for FDI above a specified threshold (fuel 5 t/ha, curing of 90%).



used as the predictor. Figure 9 shows the resulting probability bar graph. There is considerable increase in skill over any of the three individual predictors taken alone, however the chance of a correct forecast given the FDI exceeds 20 at midday still falls well below that given by persistence.

Using the synthetic FDI as a predictor for fire occurrence, the probability bar graph shown in Fig. 10 was generated. This graph suggests that fire occurrence in the central Australian area can be forecast with some confidence. However, as seen from the preceding analysis, the meteorological variables are contributing little to the apparent skill of the FDI, the addition of synthetic fuel quantities and curings providing the vital elements.

**Fig. 10** As for Fig. 9, except 'synthetic' FDI (fuel quantity and curing estimated).



At this point in the analysis it may be postulated that a very accurate index giving the probability of fire occurrence could be generated by some combination of the three elements:

(a) persistence;
(b) fuel quantity;
(c) degree of curing.

However, the work of Griffin et al. (1983) demonstrates that annually around 58 per cent of bush fires are thunderstorm generated, and that in November the percentage is considerably higher. This suggests that meteorological parameters other than temperature, wind speed and relative humidity are related to fire occurrence in central Australia.

A probability plot of fire occurrence by wind direction (Fig. 11) reveals that fire occurrence is most probable for a wind from the northwest. A similar probability plot using pressure tendency as the predictor (Fig. 12) shows that rapidly falling barometric pressure is highly correlated with fire occurrence. Finally, a probability plot using station level pressure at Alice Springs Airport as the predictor (Fig. 13) shows this to be the meteorological parameter most likely to yield a correct forecast of fire occurrence, despite the fact that it performed poorly when correlated with area burnt.

That these three meteorological variables should all reveal greater skill in forecasting fire occurrence in central Australia than temperature, wind speed and relative humidity is not surprising. Thunderstorm activity is generally associated with a trough of low pressure, preceded by convergent northwesterly winds moving through the Alice Springs area from west to east, a situation proposed earlier to justify the construction of the CBI.

**Fig. 11** Probability of a correct daily forecast of fire occurrence for the midday wind originating with ±22.5 deg. of the given direction.

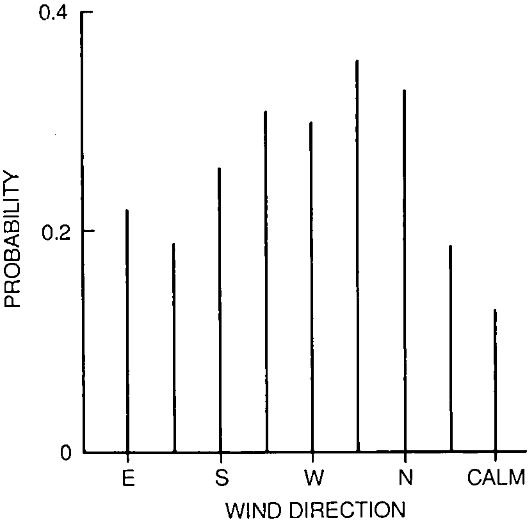
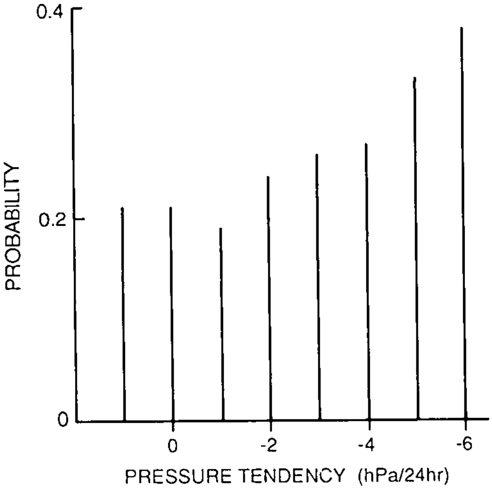


**Fig. 12** Probability of daily fire occurrence for 24-hour pressure tendency less than a specified threshold.



## Seasonal prediction

The skill of the cumulative antecedent rainfall, the CBI, the SOI and the SST as predictors of area burnt was also tested. Using the methods suggested by Hanssen and Kuipers (1965) an assessment was made of the proportion of correct fire forecasts which could

Fig. 13 As for Fig. 12, except midday station level pressure.

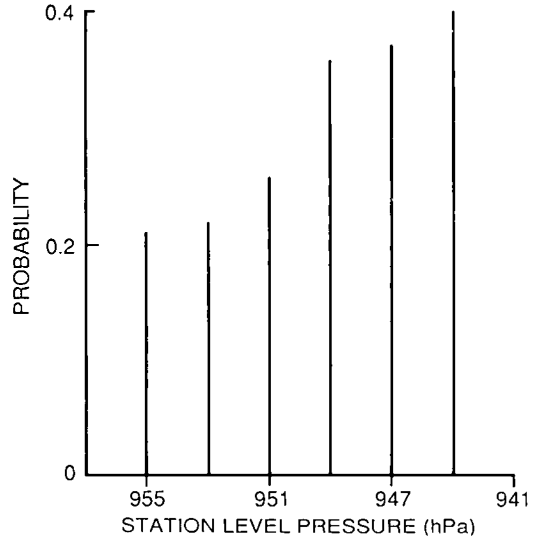


Fig. 14 The probability of a correct forecast of monthly areas burnt >4000 km$^2$ for different values of three years cumulative antecedent rainfall. The persistence, $P_p$, is shown by a dashed line.

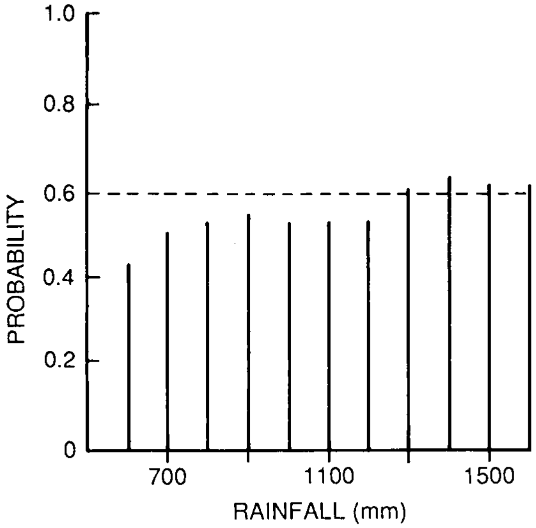


Fig. 15 The probability of a correct forecast of monthly area burnt >4000 km$^2$ for different values of the Combined Blocking Index (CBI). The persistence, $P_p$, is shown by a dashed line.

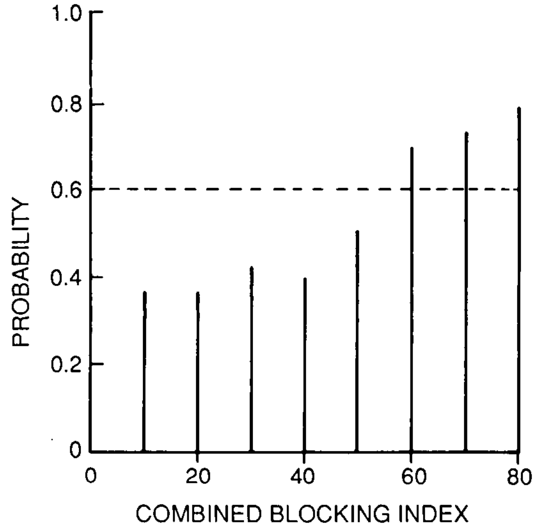
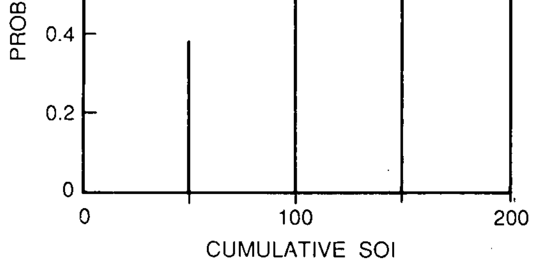
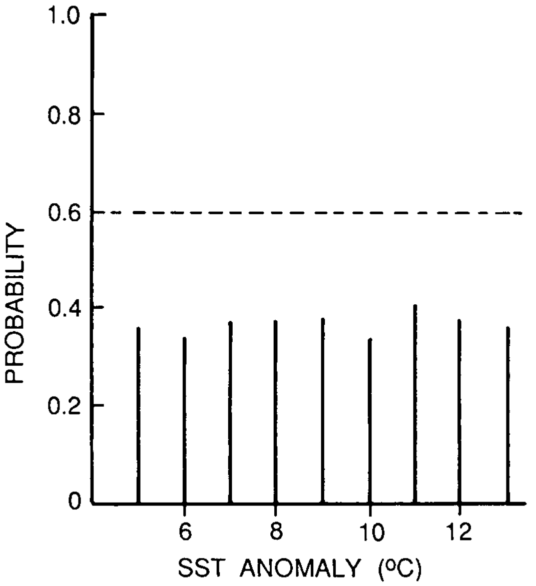


Fig. 16 The probability of a correct forecast of monthly area burnt >4000 km$^2$ for different values of the three years cumulative antecedent SOI. The persistence, $P_p$, is showed by a dashed line.



be obtained using rainfall, CBI, SOI and SST anomaly as predictors. In each of the cases depicted, the results for which are shown in Figs 14, 15, 16 and 17, the predictand selected, based on a median value, was an area equal to or exceeding 4000 sq km burned out in any of the months between October and January for the period January 1970 to December 1979. The predictor, one of the previously mentioned parameters, was tested at increasing values to determine if there were values for which the predictor operated with more accuracy than persistence. In each figure $P_a$ (=0.37) represents the random probability of a correct forecast. This is simply the ratio of the number of months when the aggregate area burnt was in excess of 4000 sq km to the total number of months. The probability attributable to

**Fig. 17 The probability of a correct forecast of monthly area burned >4000 km$^2$ for different values of three years cumulative antecedent sea surface temperature anomaly. The persistence score $P_p$, is shown by a dashed line.**



persistence, $P_P = (.60)$, is the ratio of correct forecasts of aggregate area exceeding 4000 sq km burnt, using the previous month as a predictor, to the total number of these events.

Both the antecedent cumulative SOI and the CBI show scores comparable with or better than persistence for predictors above a certain value. The three-year cumulative antecedent rainfall shows skill comparable with persistence for predictors above about 1300 mm. The SST anomaly shows no value as a predictor.

The data in this paper suggest that there is a threshold value of cumulative antecedent rainfall above which fuel loadings rapidly increase. The strong sensitivity to cumulative rainfall shown in Fig. 1 reflects the relationship in the vicinity of this value. It would be reasonable to expect that a more extensive study would reveal decreasing sensitivity with increasing rainfall. The CBI and to a lesser extent, the SOI showed some value as predictors despite the poor correlation results. An explanation for this behaviour lies in the fact that both were uncorrelated at low values while showing some correlation at high values. To further explore this relationship, the SOI was correlated with the blocking index at each latitude as well as with the CBI. No significant correlations were found.

# Discussion

The analysis of fire data from the central Australian region has focused attention on areas where accurate forecasts of great utility are possible.

Pre-season forecasts giving a broad indication of the likely severity of the pending fire season appear to be possible. The high correlation between the three-year cumulative antecedent rainfall and fire occurrence and size show this to be a valuable indicator. The fact that the CBI demonstrated some skill as a predictor while having little or no correlation with the rainfall gives cause for belief that seasonal prediction could be further enhanced with input related to seasonal weather patterns.

Weekly forecasts could be prepared during the season. These would be divided into two areas covering the problems of occurrence and containment.

Forecasts of fire occurrence would be based on a combination of the variables:

(a) persistence;
(b) fuel state;
(c) forecast wind direction;
(d) forecast pressure tendency.

The optimal combination of these variables would be best determined by acquiring the meteorological data base for the entire central Australian fire season, in computer compatible form and statistically generating the index from a seasonal perspective.

Forecasts of fire spread could be usefully made based on the two variables:

(a) fuel state;
(b) wind speed.

Once again the index should be analysed using a seasonal data set. In both of the above cases the accuracy of the fuel state information is critical. It should be noted that in this instance the forecast of fire spread relates to an anticipated area burned out and not to an actual rate of spread.

A fuel state index such as that supplied by the three-year cumulative antecedent rainfall would be further enhanced by input from remote sensing. A weekly average vegetation index (as described by Honey 1984 and Duggan et al. 1982) could be used to supply correction to the data. Estimates of the curing would be made considering the time of year and some short term cumulative antecedent rainfall (of the order of weeks). Calibration of any indices to be made using physical observations.

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