A Study of the Relation of Meteorological Variables to Monthly Provincial Area Burned by Wildfire in Canada (1953–80)

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ABSTRACT

The relation between meteorological variables and the monthly area burned by wildfire from May to August 1953–80 in nine Canadian "provinces" was investigated. A purely statistical approach to estimating the monthly provincial area burned, using meteorological variables as predictors, succeeded in explaining 30% of the variance west of Lake Nipigon and about 11% east of Lake Nipigon.

Long sequences of days with less than 1.5 mm of rain or days with relative humidities less than 60% proved to have the highest correlation with area burned. These long sequences were assumed to be associated with blocking highs in the westerlies.

Bad fire months were independent of rainfall amount but significantly dependent on rainfall frequency, temperature, and relative humidity.

1. Introduction

This is the third report in a series which deals with monthly "provincial"[1] area burned by wildfire in Canada for the years 1953–80. The first report (Harrington, 1982) presented a statistical analysis of the area burned by wildfire. The second report (Harrington et al., 1983) investigated the relation of components of the Canadian Forest Fire Weather Index (FWI) (Canadian Forestry Service, 1984; Van Wagner and Pickett, 1985; Van Wagner, 1987) to monthly provincial area burned by wildfire. In this third and final report we study the relationship of simple arrangements of meteorological variables to monthly provincial area burned by wildfire.

Area burned is determined by a complex set of variables including the size of the sample area, the period under consideration, the extent of flammable forest, the topography, the presence or absence of lakes or roads, fuel characteristics, season, latitude, fire control policies and priorities, fire control organizational size and efficiency, fire site accessibility, the number of simultaneous fires, and the weather. Of these, the weather cannot be expected to explain a large fraction of the year-to-year variance in monthly provincial area burned. In the second report in this series it was shown that components of the fire weather index (FWI) explained about 35% of the variance in monthly provincial area burned in the western provinces of Canada and about 12% in the east. A 35% explained variance by components of the FWI alone is considered highly significant by at least one fire expert (Simard, personal communication).

In this paper we relate monthly provincial area burned by wildfire to simple meteorological variables. Our purpose is to determine the extent to which the variance in area burned is explained by these variables, to develop insight into the causes of "bad" fire months, and to develop a statistical description of weather conditions associated with bad fire months.

2. Data

Monthly provincial area burned data were obtained for the major portion of the fire season in Canada (May to September) during the 28-yr period (1953–80) for which reliable data were available (Ramsey and Higgins, 1981). For this study the month of September was not included because September, with only 1.3% of the annual area burned, is not normally considered part of the main fire season (Harrington, 1982). The original area burned data in hectares has been converted to a relative measure by dividing each monthly figure by the average monthly burn in the province during the 1953–80 period.

Meteorological data for the same years and extending back into April were obtained on magnetic tape from the Atmospheric Environment Service. An attempt was made to obtain records including temperature, relative humidity, rainfall, and wind speed for five stations in

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[1] The provinces include British Columbia, the Yukon and Northwest Territories combined, Alberta, Saskatchewan, Manitoba, western Ontario (west of Lake Nipigon), eastern Ontario, Quebec, and the combined Atlantic Provinces.

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each province over the full 28-year period. The number of stations in each province ranged from three to five, with several of these consisting of composites from two nearby stations and a few located in nonforested areas (Harrington et al., 1983). Monthly, 700 hectopascal (hPa) height anomalies for the forested region of each province were estimated by eye from the monthly anomaly maps in the Monthly Weather Review (U.S. Weather Bureau, 1953–80 series).

3. Procedure

Meteorological variables such as temperature, dewpoint, relative humidity (RH), and wind speed were taken from noon local standard time (LST) observations and averaged for each month. The 24-h precipitation at each station was summed for each month. Additional variables were obtained from the basic dataset. A list of these variables and their abbreviated names is given in Table 1.

TABLE 1. Meteorological variables.

1	DEWPT	Mean monthly dewpoint (°C)
2	HTANOM	700 hPa monthly height anomaly for the forested regions of the province (m)
3	MAXT	Maximum temperature for the month (°C)
4	MINRH	Minimum relative humidity for the month (%)
5	NDD	Number of dry days in a month (daily precipitation less than 1.5 mm)
6	NDLRH	Number of days in a month with low relative humidity (RH below 60%)
7	PRECIP	Monthly precipitation (mm)
8	PRECANOM*	Monthly precipitation anomaly (monthly precipitation minus the 30-year normal (1951–80)) (mm)
9	RH	Mean monthly relative humidity (%)
10	SEQDD	Weighted sequence of dry days (daily precipitation less than 1.5 mm)
11	SEQLRH	Weighted sequence of days with low relative humidity (RH below 60%)
12	SPRECIP	Seasonal precipitation (beginning 1 April) (mm)
13	SPREAD	Difference between temperature and dewpoint means (°C)
14	TANOM†	Monthly temperature anomaly (monthly temperature minus 28-yr normal (1953–80)) (°C)
15	TEMP	Mean monthly temperature (°C)
16	WDD	Mean windspeed on dry days (km/h)
17	WIND	Mean monthly windspeed (km/h)
18	WLRH	Mean windspeed on days with low relative humidity (km/h)
19	WWDD	Weighted sum of windspeed on dry days (km/h)
20	WWLRH	Weighted sum of windspeed on days with low relative humidity (km/h)

* 30-yr normal (1951–80) monthly precipitation values were obtained from published data (Environment Canada, 1982).

† The 28-yr normal is derived from this dataset.

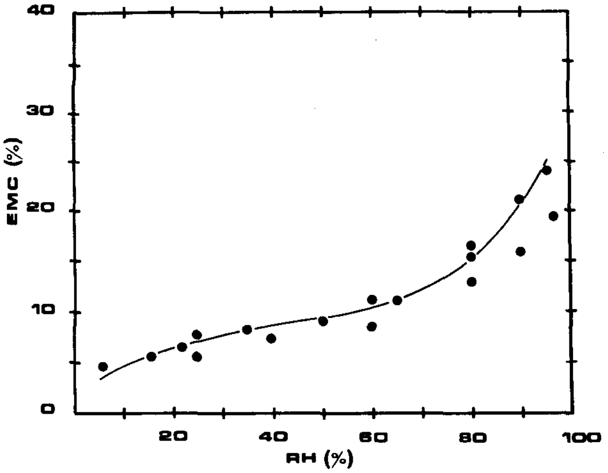

FIG. 1. Equilibrium moisture content (EMC) versus relative humidity for red pine litter absorption.

Many studies of the relationship of fire to weather helped identify the most likely meteorological predictors[2] of area burned. Among these studies were investigations of atmospheric conditions related to blowup fires (Byram, 1954), the relationship between upper-level jet streams and forest fires (Schaefer, 1957), the effect of hours of sunshine on fire season severity (Turner, 1970), the effect of short wave troughs on fire runs (Brotak, 1976), the role of the upper ridge on wildfire behavior (Newark, 1975; Nimchuk, 1983), the synoptic weather types associated with critical fire weather (Schroeder et al., 1964), and the role of meteorological variables in specific fires (Flannigan and Harrington, 1987; Quintilio et al., 1977; Stocks and Walker, 1973; Stocks, 1975).

At the outset, drought was considered to be a likely major contributor to monthly area burned. Through a process of trial and error it was determined that the best predictor was likely to consist of the sequences of "dry days", each sequence weighted depending on its length. The definitions of a dry day included daily precipitation amounts ranging from 0–5 mm in 0.5 mm increments. Weights were assigned to each day in the sequence according to the square, the square root, various logarithmic and exponential functions, and various arithmetic series. By varying the weighting scheme and the definition of a dry day interactively, we found that the most variance in area burned was explained by defining a dry day as a 24-hour period, ending at 1200 LST, receiving less than 1.5 mm of precipitation, and by choosing as the monthly weight

$$\mathrm{SEQDD} = \sum_{j=1}^{m} w_j$$

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[2] In this paper the term "predictor" refers not to prediction but to terms which make significant contributions to the explanation of the variance in area-burned statistics.

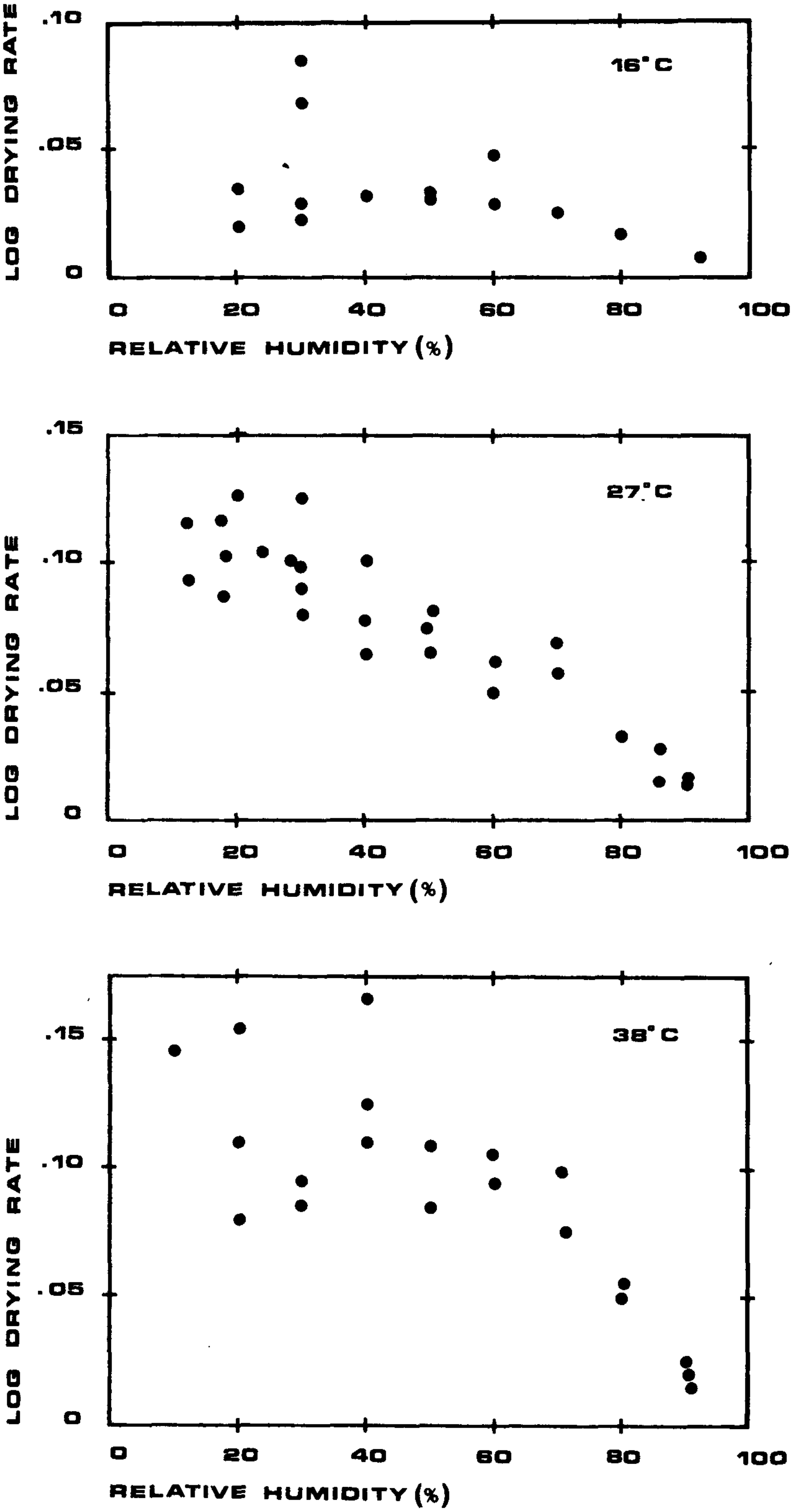

FIG. 2. The logarithm of the drying rate versus relative humidity at 16°, 27° and 38°C.

TABLE 2. Correlation matrix between area burned and

	Variable[‡]									
	AREAB	DEWPT	HTANOM	MAXT	MINRH	NDD	NDLRH	PRECIP	PRECANOM	RH
AREAB*	1.00									
DEWPT	.12	1.00								
HTANOM	.38	.21	1.00							
MAXT	.26	.51	.53	1.00						
MINRH	−.09	.64	−.18	−.06	1.00					
NDD	.19	−.32	.52	.29	−.43	1.00				
NDLRH	.20	−.55	.37	.12	−.69	.73	1.00			
PRECIP	−.17	.34	−.39	−.17	.38	−.85	−.63	1.00		
PRECANOM	−.20	.10	−.43	−.32	.23	−.80	−.53	.96[†]	1.00	
RH	−.17	.66	−.35	−.11	.77	−.75	−.94[†]	.68	.55	1.00
SEQDD	.31	−.22	.43	.24	−.35	.66	.48	−.52	−.48	−.54
SEQLRH	.23	−.31	.26	.18	−.43	.51	.66	−.41	−.37	−.65
SPRECIP	−.01	.76	−.03	.21	.71	−.51	−.68	.55	.39	.76
SPREAD	.22	−.60	.41	.19	−.78	.75	.91[†]	−.66	−.55	−.99[†]
TANOM	.37	.16	.75	.60	−.38	.55	.53	−.44	−.46	−.52
TEMP	.32	.79[†]	.59	.78	.20	.18	.01	−.09	−.30	.07
WIND	.00	−.51	−.11	−.23	−.39	.22	.29	−.28	−.16	−.36
WDD	.07	−.54	.15	−.05	−.52	.61	.55	−.56	−.44	−.61
WLRH	.12	−.64	.16	−.04	−.68	.60	.83[†]	−.54	−.42	−.82[†]
WWDD	.21	−.32	.30	.13	−.39	.61	.45	−.49	−.43	−.52
WWLRH	.13	−.38	.17	.09	−.44	.48	.62	−.41	−.35	−.64

[‡] Meteorological variables defined in Table 1.

[*] AREAB is the monthly area burned by wildfire in B.C.

[†] Correlations between these variables are high (correlation between ±.80–1.00) at most stations.

where

$$w_j = \sum_{i=1}^{n_j} i = n_j(n_j + 1)/2,$$

where n_j is the number of days in the jth sequence in a month, $j = 1, 2 \cdots m$, and m is the total number of dry day sequences in a month. Similarly, a variable incorporating a weighted product of the wind speed and the length of a dry spell is

$$\mathrm{WWDD} = \sum_{j=1}^{m} \sum_{i=1}^{n_j} W_{ij} \cdot i$$

where W_{ij} is the wind speed on the ith day of the jth dry day sequence.

The limiting value of precipitation in the definition of a dry day (1.5 mm) closely fits the estimates of maximum water holding capacity of various forest canopies. For example, Rutter (1975) reports interception storage capacities of 1.0 to 2.1 mm for coniferous forests and 1.0 mm for deciduous forests in summer. A similar value of 1.3 mm was found by Simpson et al. (1985) for a Douglas-fir forest. Spittlehouse and Black (1981) use a larger value for a Douglas-fir forest equal to 3.0 mm/day, but this value includes some loss due to evaporation. Although the limiting value of 1.5 mm found for the definition of a dry day may be fortuitous, it is interesting that this independently determined value occurs at just the point at which precipitation begins to penetrate the canopy and reach the ground.

The values of the weight applied to any dry spell, of n consecutive days, is proportional to $n(n + 1)$. This sequence sum has an intuitive appeal because, on the average, one can assume that a fire will increase its linear dimensions in proportion to the number of days that it burns and, therefore, its area in proportion to the square of that time period. Furthermore, the longer a dry spell lasts, the greater will be the chance of a fire start and the greater will be the chance of a major fire run.

A low RH day was defined in a manner identical to that used for defining a dry day. The tested threshold values ranged from 30%–70% RH in increments of 5%. Weighted sequences, derived in the same manner as for the sequences of dry days, were computed for each station and correlated with area burned. The explained variances were averaged across all the stations and the RH threshold yielding the highest average explained variance was chosen. The definition of a low RH day became one with a noon RH reading of less than 60%.

Selection of 60% RH as the critical threshold in the definition of low RH days comes as a surprise. However, it can be explained logically in terms of two interacting factors. When a lower critical threshold is selected, an occasional cloudy day may have little effect upon the fuel moisture but may severely reduce the number of low RH days in a sequence. When a higher critical threshold is selected, the fuel moisture increases rapidly with RH, quickly rising to a level which restricts fire spread. This appears logical in view of the broad inflection point in the fuel moisture–RH sorption isotherm near 50% as shown by Van Wagner (1972) (Fig.

meteorological variables for Smithers, B.C., 1953–80.

Variable[‡]										
SEQDD	SEQLRH	SPRECIP	SPREAD	TANOM	TEMP	WIND	WDD	WLRH	WWDD	WWLRH
1.00										
.66	1.00									
−.33	−.32	1.00								
.56	.66	−.72	1.00							
.47	.42	−.19	.60	1.00						
.16	.12	.40	.02	.66	1.00					
.23	.20	−.56	.33	−.03	−.39	1.00				
.50	.37	−.67	.59	.23	−.22	.88[†]	1.00			
.47	.55	−.75	.79[†]	.33	−.20	.72	.85[†]	1.00		
.94[†]	.52	−.40	.53	.33	.01	.41	.63	.55	1.00	
.59	.96[†]	−.38	.64	.32	.01	.35	.49	.64	.50	1.00

1). Furthermore, at RH values exceeding 60%, the rate of drying of jack pine litter appears to decrease rapidly as shown in Fig. 2 (Van Wagner, 1979). Although there is a major difference between a threshold value of 60% in determining the number of low RH days in a month and a monthly mean RH below 60%, it is interesting to note that a mean monthly RH above approximately 60% is clearly associated with a negligible monthly provincial area burned (Fig. 3).

The weighted sum of wind speeds for both dry days (WWDD) and days with low RH (WWLRH) was calculated by multiplying the weight for the day by the wind speeds and summing for the month. This procedure weights both the length of dry weather and the strength of the wind. If the wind speed is constant for a sequence of dry weather days then the sum is just the product of the wind speed and $n(n + 1)/2$.

Area-burned data for 41 individual weather stations and for the pooled stations within each province were correlated with the variables in Table 1 using an SAS forward stepwise linear regression (SAS Institute Inc., 1985). Terms were accepted only if they met the rather stringent 0.05 significance level, which corresponds to an F value to enter of 4.0; terms were removed when they failed to meet the 0.05 significance level. The relatively high F value chosen reduced the number of predictors selected by chance. Such chance correlations are likely when using a relatively short period of record and many predictors.

There are several commonly occurring problems which arise in using meteorological variables in multiple regression schemes. One of the more serious is the lack of independence of the predictors. For example, relative humidity and temperature–dewpoint spread are virtually perfectly negatively correlated, as illustrated in a correlation matrix, typical of many, from Smithers, B.C. (Table 2). When two such variables are selected in a multiple regression scheme, their coefficients are often unreasonably large and of opposite sign. In such cases it is necessary to remove one.

Truly valid statistical tests of multiple regression analyses require normality in the data. Despite this requirement many geophysical applications are carried out with nonnormal data. It is argued that it is relationships that are sought, not exact statistical prescriptions. In our case, the data are decidedly nonnormal, particularly those for the predictand area burned. We run the risk of finding relationships resulting from the chance correlations of variables with extreme fire months. However, our goal is not to develop a prediction equation for area burned but, rather, to determine which variables are most strongly correlated with extremes of area burned. Normalization of the data would defeat our purpose.

Independent datasets can be derived from the original data using principal component analysis. The explained variance using multiple regression on the principal components is compared to that on the raw meteorological data in Table 3. Also shown is the maximum explained variance using all of the meteorological data regardless of significance. The significant principal components explained about 75% of this maximum in the west, 54% in the east, and 69% overall. This contrasts with the significant raw data which explained 57% in the west, 42% in the east, and 52% overall. Despite the superiority of the principal components in explaining variance in area burned, we chose to consider only the meteorological variables as providing more insight into the causes of large fires.

4. Results and Discussion

The data of Table 3 show that from 0% to 41% of the variance in monthly provincial area burned by wildfire could be explained by statistical screening of a selected group of meteorological variables measured at weather stations generally located in forested areas of Canada. The results are best, west of Lake Nipigon, where the explained variance averages 23%, but poor, east of Lake Nipigon, where only 11% of the variance is explained. The difference between east and west is brought about by the presence in the far west of a mean upper-level high pressure ridge and in the east of an upper trough. Long spells of dry weather are commonly associated with the upper ridge and with the generally northwesterly flow aloft from the Great Plains to western Ontario. East of Lake Nipigon the mean upper flow curves eastward and northward in a broad trough of low pressure generally associated with intermittent cloudy periods with showers. Large fires are rare in this area. The generally poor results in the east may also be a consequence of fewer and smaller fires and, therefore, better human control. Poor data may also account for some loss of explained variance. In the Atlantic Provinces the terrain and weather regimes are extremely varied, and in Quebec only three reliable weather stations could be found to represent a vast area.

Better results are obtained when all of the weather stations in our data are pooled for each province. The mean variance explained in the west increases to 31% but remains at 11% in the east. Differences between the means of the variances explained for individual stations and the variances explained by the pooled data are significant at the 2% level using a χ^2 test. We propose that this improvement is due to the highly variable nature of summer precipitation, such that pooled data give a better picture of overall rainfall than do data from individual stations.

The variance explained using the meteorological variables was almost identical to that using components of the FWI[3] (Harrington et al., 1983). However, the use of meteorological variables gave more insight into possible specific causes of the large fires which result in more than 94% of the total area burned (Ramsey and Higgins, 1986).

Variables selected by the stepwise linear multiple regression program are shown in Table 3 for the individual stations and also for the combined stations in each province. Eight of the 20 variables comprise more than 85% of those selected. The frequency of selection for the individual stations and for the combined stations is shown in Table 4.

The eight most frequently chosen variables, considering only the individual stations, were the 700 hPa height anomaly, maximum temperature for the month, weighted sequence of days with low relative humidity, weighted sequence of the wind speed during dry days, weighted sequence of dry days, temperature–dewpoint spread, temperature anomaly, and temperature. Some of these were highly correlated. For example, the correlation between the weighted sequence of wind speed during dry days and the weighted sequence of dry days was 0.94. Including the wind appears to confer a small advantage; therefore, one can drop the weighted sequence of dry days without a significant loss of explained variance. Other variables were so highly correlated that one or the other was never selected. For example, the temperature–dewpoint spread was frequently selected whereas the highly correlated variables, relative humidity and number of days with low relative humidity, were never selected. The choice of temperature-dew point spread was brought about by its greater numerical range. Relative humidity, with a correlation of 0.99 with temperature-dewpoint spread, would be an equally adequate predictor.

The correlation at Smithers, B.C. between monthly mean noon temperature and dewpoint, maximum temperature, and temperature anomaly was 0.79, 0.78, and 0.66, respectively. The four together comprise over one-quarter of the total selections made. Yet, there are sufficient differences between them to discourage combining them into a single variable. Of these the extreme monthly maximum temperature was the most frequently selected predictor.

The correlation between the weighted sequence of days with low relative humidity and the weighted sequence of wind on low relative humidity days was 0.96 at Smithers and similarly high at the other stations. These, when combined, comprise 15% of the predictors selected. Correlations between the weighted sequence of days with relative humidities below 60% and other variables containing relative humidity were generally about 0.6. Correlations with variables related to dry days were generally in the 50% range. Combined drought variables account for 18% of the selected predictors, with the weighted wind on dry days predominating. The temperature–dewpoint spread accounted for about 8% of the selected predictors and, combined with closely related humidity variables, accounted for 12%. Height anomaly and temperature anomaly were

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[3] The FWI system was not designed to explain monthly provincial area burned.

TABLE 3. Explained variance and variables selected by stepwise regression for individual and combined stations across Canada.

	Using all variables	Meteorological data untransformed		Principal components of meteorological data	
Station	Variance explained	Variance explained	Variables selected	Variance explained	Number of components
British Columbia					
Fort Nelson	.38	.24	HTANOM, SEQLRH	.26	3
Kimberley-Cranbrook	.47	.28	SEQLRH, HTANOM	.35	5
Smithers	.41	.14	HTANOM	.31	6
Victoria	.29	.17	TANOM	.16	2
Williams Lake	.27	.18	HTANOM, SEQDD	.18	3
British Columbia	.47	.34	SEQLRH, SEQDD, TEMP	.35	4
Yukon-Northwest Territories					
Fort Simpson	.59	.31	TEMP, WINDLRH, HTANOM	.55	8
Yellowknife	.41	.30	SPREAD, MAXT, HTANOM	.36	6
Fort Smith	.43	.19	MAXT, HTANOM	.31	5
Dawson-Burwash	.50	.19	TEMP	.37	7
Whitehorse	.29	.14	TEMP, WIND	.22	2
Yukon-Northwest Territories	.37	.22	TEMP, SPREAD	.29	6
Alberta					
Fort McMurray	.34	.24	WWDD	.26	3
Rocky Mountain House	.58	.28	WWDD	.52	8
Wagner-Slave Lake	.36	.14	SPREAD	.28	5
Whitecourt	.26	.09	WWDD	.16	3
Alberta	.53	.24	WWDD	.44	6
Saskatchewan					
Cold Lake	.48	.14	TANOM	.39	6
Hudson Bay	.50	.30	SEQLRH, MAXT, HTANOM	.42	7
North Battleford	.44	.24	HTANOM, SEQLRH, PRECIP	.40	7
Prince Albert	.56	.33	SEQLRH, MAXT, HTANOM	.48	6
Saskatchewan	.55	.30	MAXT, SEQDD	.50	6
Manitoba					
Gimli-Bisset	.54	.35	WWDD	.46	4
Dauphin	.38	.25	SPREAD, HTANOM	.27	5
The Pas	.46	.33	SEQLRH, MAXT, DEWPT	.32	6
Wabowden-Thompson	.40	.26	SEQDD, MAXT, MINRH	.33	5
Winnipeg	.51	.39	WWDD	.46	4
Manitoba	.59	.36	WWDD, MAXT	.50	5
Western Ontario					
Armstrong	.24	.18	SEQDD, MAXT	.10	2
Kenora	.51	.41	WWLRH, MAXT	.38	5
Lansdowne House	.18	.05	HTANOM	.06	1
Sioux Lookout	.34	.22	SEQLRH	.22	3
Thunder Bay	.21	.07	TANOM	.05	1
Western Ontario	.46	.34	SEQLRH	.37	6
Eastern Ontario					
Earlton	.39	.18	SEQDD, MINRH	.30	6
Kapuskasing	.34	.22	SEQLRH	.24	4
Muskoka	.27	.14	WWDD, HTANOM	.19	3
Killaloe-Petawawa	.27	.13	MINRH, HTANOM	.08	2
Timmins	.33	.15	SPREAD	.17	4
Eastern Ontario	.32	.12	SPREAD	.15	3
Quebec					
Maniwaki	.17	.07	HTANOM	.04	1
Bagotville-Roberval	.30	.15	SEQLRH, TEMP	.27	5
Val d'or	.26	.09	TANOM	.14	3
Quebec	.29	.12	TEMP, MINRH	.21	4
Atlantic provinces					
Campbelton-Charlo	.13	.04	MAXT	.00	0
Fredericton	.23	None		.09	2
Gander	.31	.10	SPREAD	.20	3
Goose Bay	.20	.09	MAXT, WWDD	.04	1
Copperlake-Truro	.22	.08	SEQDD	.06	1
Atlantic provinces	.23	.09	NDD, MAXT	.05	4

TABLE 4. Statistics on the selection of variables in regression analysis.

	Individual stations		Combined stations	
Variable	No. of times selected	Selected first	No. of times selected	Selected first
HTANOM	15	6	0	0
MAXT	10	3	3	1
SEQLRH	9	7	2	2
WWDD	7	6	2	2
SPREAD	5	5	2	1
SEQDD	5	4	2	0
TANOM	4	4	0	0
TEMP	4	3	3	2
MINRH	3	1	1	0
WWLRH	1	1	0	0
DEWPT	1	0	0	0
PRECIP	1	0	0	0
WIND	1	0	0	0
WLRH	1	0	0	0
NDD	0	0	1	1
NDLRH	0	0	0	0
PRECANOM	0	0	0	0
RH	0	0	0	0
SPRECIP	0	0	0	0
WDD	0	0	0	0

correlated at the 0.75 level. Other correlations with height anomaly were lower: maximum temperature, 0.53; temperature, 0.59; and number of dry days, 0.52. Height anomaly was the single most frequently selected variable, accounting for about 22% of the selections. The effect of long spells of dry weather can be seen by combining the weighted sums of low relative humidity, the weighted sums of dry days and the similar variables involving wind. These account for 33% of all selections. When data from weather stations in each province were combined, the height anomaly failed to appear in any selection. This is a surprising and, as yet, unexplained result. Combined maximum temperature and mean temperature comprised 38% of the selections for the combined data, long sequences of dry weather accounted for 38% of the selections, low relative humidity for 19%, and the number of dry days for the remaining 5%.

Variables missing from the list of the multiple regression selections were as informative as the selections themselves. Rainfall, the number of dry days in a month, the precipitation anomaly, and seasonal precipitation all appear relatively unimportant. The weighted sequence of dry days was one of the most frequently selected variables. Apparently, it is the timing of rainfall, not the amount, which is important. Furthermore, it is the continuity of a dry spell rather than the total number of dry days in a month which is a determining factor in terms of area burned. This conclusion, which agrees with the observations of many professionals in the field, has important implications in terms of the effect of possible future climatic change. Future increases or decreases in precipitation will have less bearing on damage by forest fire than will the occurrence of lengthy spells without rain. Long spells of weather, either wet or dry, warm or cold, are associated with stationary flow patterns in the westerlies. Stationary high pressure areas, particularly those associated with blocking patterns, are well known to be associated with severe fire weather (Newark, 1975; Stocks and Street, 1983). Therefore, in terms of future climatic change, it will be changes in the frequency and duration of blocking highs rather than changes in the rainfall that will determine whether the area burned increases or decreases.

Long sequences of days with low relative humidity were more highly correlated with area burned than were other measures of RH. However, average RH, especially as represented by the temperature–dewpoint spread and the minimum RH for the month also proved to be correlated with area burned. The effect of RH differs from that of precipitation in that RH is more representative of the surface layers of the soil and, therefore, the frequency of precipitation, whereas precipitation amount may have a larger influence on the soil moisture at a depth which is not significant in terms of fire potential.

High temperatures as represented by either the maximum temperature or the temperature anomaly correlated well with area burned. This result is not unexpected because high temperatures increase the vapor pressure in the fuel moisture, thereby increasing the fuel drying rate. High temperatures are also associated with the clear skies and southerly winds found in the central and western portions of high pressure cells. Extremes of temperature are generally associated with stationary or slow moving high pressure ridges. The great significance of maximum temperature could be attributed to its association with blocking ridges, or it could simply reflect the fact that fire area often expands dramatically on only a few critical days of high temperature and strong winds (Stocks and Walker, 1973).

Wind turned out to be weakly correlated with area burned. There are a number of reasons why this should be so. With a few exceptions, strong surface winds tend to occur in conjunction with the strong temperature gradients associated with fronts. Frontal weather is usually cloudy, cool, and often rainy, thereby reducing the spread of major fires. Fronts can also result in lightning which may start fires or, if relatively dry, can lead to fire runs in the strong winds preceding and following the frontal passage. Fronts will, therefore, have a mixed effect sometimes dampening and sometimes promoting fire activity. Averaged over a month, the frontal effect is likely to be small, as also is the effect of the associated strong winds. Wind, in conjunction with high temperatures and the existence of one or more large fires, would undoubtedly be a highly significant variable.

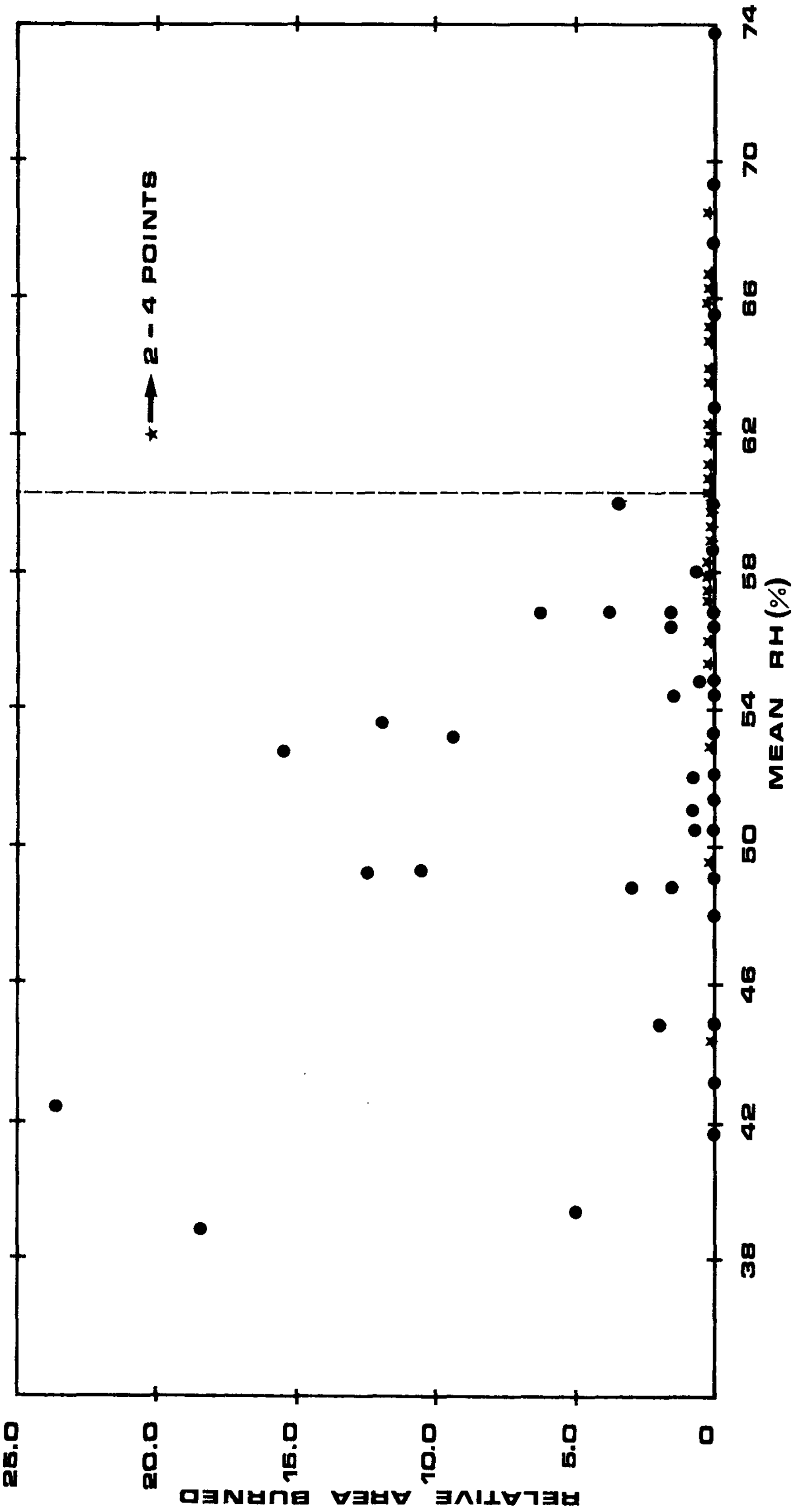

FIG. 3. Relative area burned versus relative humidity for Kenora, western Ontario.

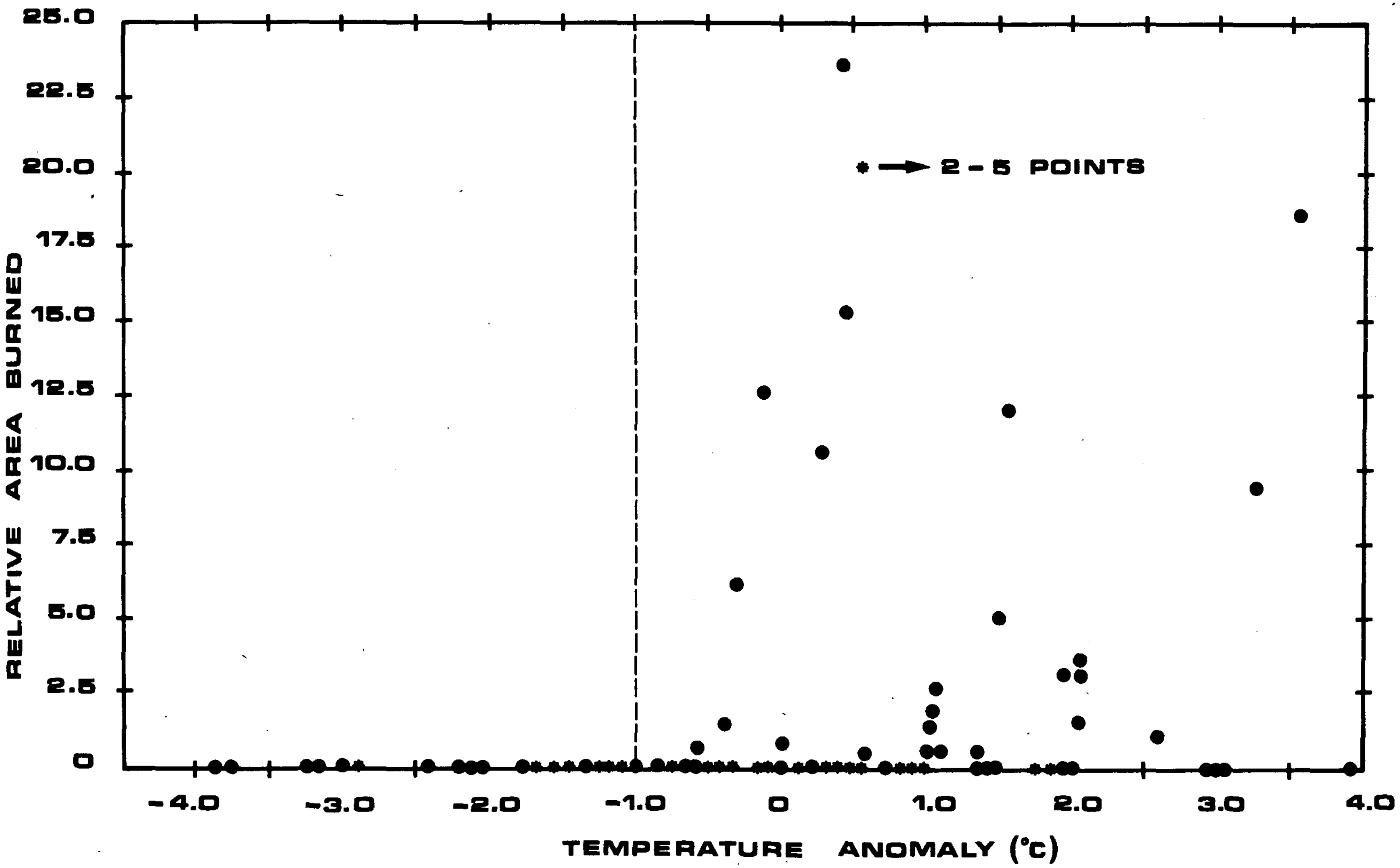

FIG. 4. Relative area burned versus temperature anomaly at Thunder Bay, western Ontario.

Taken by itself on a monthly basis it proves to be of negligible value. When windspeeds are weighted according to the sequence of dry days they slightly increase the explained variance in area burned.

The 700 hPa height anomaly was the most frequently chosen predictor of area burned and the third most frequently chosen as the most significant predictor. It was commonly selected in conjunction with weighted sequences of dry days, low humidities, or maximum temperatures. The reason that both high pressure and long sequences of dry weather are important may be that every long-wave ridge does not produce weather conducive to fire. The source region of air flowing into the ridge may be too cold or moist. Weak frontal troughs passing through the ridge may dampen the forest periodically. Showers may occur in the cold northerly winds east of the ridge or cloud, and showers may periodically invade the warm southerly flow west of the ridge. More information than the simple existence of a ridge is required if area burned is to be predicted.

Several meteorological variables plotted against area burned reveal what appears to be a threshold value above which relative area burned rarely, if ever, exceeded 1.00. Variables including mean RH, mean temperature, temperature anomaly, 700 hPa height anomaly, temperature–dewpoint spread, and seasonal precipitation displayed this threshold characteristic. For example, the plot of area burned versus relative humidity for Kenora, Ontario (Figure 3) shows a threshold value at 60% RH. Similarly, a plot of area burned versus temperature anomaly for Thunder Bay, Ontario (Fig. 4) shows relatively little area burned for anomalies less than −1°C. A judicious use of such thresholds at individual stations could conceivably lead to improved predictions. However, threshold values for various variables can differ from station to station. No attempt was made to look systematically for such values.

5. Conclusions

A purely statistical approach to estimating the monthly provincial area burned by wildfire, using meteorological variables as predictors, succeeded in explaining about 30% of the variance west of Lake Nipigon and about 11% in eastern Canada. These percentages are about the same as those from a similar analysis using components of the fire weather index.

Long sequences of days without rain (<1.5 mm) and days with low relative humidities (<60%) proved to have the strongest relation to area burned. The 1.5 mm rainfall threshold, as independently determined from our data, closely approximates published figures on interception by a forest canopy. The 60% relative humidity threshold, also independently obtained, more or less conforms to the broad region where woody fuel begins to absorb moisture rapidly. It was assumed that the long periods of dry weather associated with large areas burned were the product of blocking high pressure areas. This conclusion was supported by the frequent appearance of the 700 hPa height anomaly among variables selected by multiple regression as significantly related to area burned. Maximum temperature and low relative humidity, both strongly related to drying conditions, were also frequently chosen variables.

The absence of significant correlations with rainfall, numbers of dry days in a month, or numbers of days with low relative humidities led us to conclude that large area burned is strongly influenced by the length of dry periods and little influenced by the amount of rainfall or by short frequent spells of dry weather.

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