

The Relationship Between Mean Monthly Fire Potential Indices and Monthly Fire Severity

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Abstract

Thirty-day forecasts of fire potential are needed, and can be computed using a variety of monthly fire weather indices. But which indices are most related to monthly fire severity? Correlation analysis was used to determine the relationships between mean monthly fire potential indices and monthly measures of fire severity at 16 National Weather Service (NWS) stations/National Forests combinations across the contiguous United States for the period 1970 to 1983. The fire potential indices used included standard weather variables, measures of drought, weather-driven fire indices, and precipitation frequency. Six measures of fire severity were used: fires, Class C+ fires (fires 10 acres or greater), acres burned, costs, fire days, and Class C+ fire days. The correlation analysis identified the mean monthly fire potential indices that best track measures of fire severity. Thirty-day fire potential forecasts can be made using the identified fire potential indices.

Résumé

Des prévisions 30 jours des dangers de feu sont nécessaires, et peuvent être calculées à l'aide d'une variété d'indices mensuels forêt-météo. Mais quels indices sont les plus reliés à la gravité mensuelle des incendies? Une analyse de corrélation a été utilisée pour déterminer les relations entre les indices de danger mensuels moyens de feu et les mesures mensuelles de la gravité des incendies dans 16 stations combinées du National Weather Service/forêts nationales d'un bout à l'autre de la partie continentale des États-Unis pour la période allant de 1970 à 1983. Les indices de danger de feu utilisés comprenaient des variables météorologiques normalisées, des mesures de la sécheresse, des indices d'incendie associés à la météo et la fréquence de la précipitation. Six mesures de la gravité des incendies ont été utilisées: incendies, incendies classe C+ (incendies de 10 acres ou plus), nombre d'acres détruits par le feu, coûts, jours d'incendies, et jours d'incendies classe C+. L'analyse de corrélation nous aidera à identifier les indices mensuels moyens de danger de feu qui suivent le mieux les mesures de la gravité des incendies. Cela nous permettra d'effectuer des prévisions des dangers de feu pour 30 jours à l'aide des indices de danger de feu identifiés.

Introduction

Planning for the efficient use of national fire suppression resources requires substantially greater lead time than comparable planning on a local scale. At the Boise Interagency Fire Center, a 30-day forecast of United States fire severity is prepared to depict fire potential nationwide, support requests for supplemental fire-fighting funds, and aid national fire-prevention efforts (Burgan and Hartford 1988). The National Fire-Danger Rating System energy release component and burning index are forecast in each of 46 polygons that cover the contiguous United States (Deeming et al. 1977). Research is currently in progress to develop monthly mean anomaly forecasts

of afternoon dry-bulb and dewpoint temperatures, windspeed, and precipitation amount and frequency (Klein and Whistler 1989). With this information, corresponding 30-day forecasts of fire potential can be computed, using any of a variety of fire weather indices, which are functions of the weather variables listed above. But first we must determine the monthly fire weather indices that are most related to or best correlated with monthly fire severity measures. This paper describes the selection of fire weather indices, which are--in some sense--optimal predictors of monthly fire severity. The second section describes the method used to screen the indices. Results of analysis from selected National Forests are given in the third section. In conclusion, candidate fire weather indices are identified for different sections of the nation, based on the results of these data.

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Methods

We obtained weather and fire data from 16 National Weather Service (NWS) stations and nearby National Forest locations in the United States (Fig. 1). We tried to pick a wide cross section of locations, ensuring that representative vegetation classes and climatic regions were considered.

Thirteen weather variables/indices and 6 measures of fire severity were correlated at each of the 16 locations. We arbitrarily selected the significance level at 0.05. Therefore only cases with correlation coefficients greater than 0.53 were significant.



FIG. 1. Locations of 16 National Weather Service stations and nearby National Forests.

FIRE DATA

Individual fire reports (form 5100-29) for the 16 National Forests were obtained from the Boise Interagency Fire Center, for the period 1970 to 1983. Monthly fire severity was summarized for the following measures:

1. Fires
2. Class C+ Fires (Fires 10 acres or greater)
3. Acres burned
4. Suppression costs (Individual cost classes were summed and the result multiplied by the consumer price index for each year. This resulted in a constant dollar cost over the study period.)
5. Fire days (days with at least one fire)
6. Class C+ Fire days (days with at least one Class C+ Fire)

The order of the fire activity measures has no particular meaning. Fires (1) are easily understood by everyone and are the measure we focus on in this paper. Acres and costs tend to have the largest variability and lowest correlation coefficients with weather as shown by Flannigan and Harrington (1987). Class C and larger fires are of particular interest to fire managers, but occur infrequently in our sample.

Monthly summary data for all measures of fire severity were obtained for every month at each location. We then used fire occurrence to determine

the fire season at each location to compare with the weather variables (Haines and Johnson 1975). Months with less than 10 percent of the number of fires occurring during the peak month were eliminated from the study. Out of a possible 192 station months for study, 104 were judged to be in the fire season, and used in this study.

WEATHER DATA

We obtained daily weather data from 16 NWS first order reporting stations in the United States. These stations are primarily located at airports near major cities. We chose NWS stations instead of fire weather stations for two reasons. First, the monthly mean anomaly forecasts are being formulated for these stations; and second, the NWS stations have little or no missing data. We considered using fire weather stations because of their proximity to the fires, but most of these stations have incomplete data sets.

WEATHER VARIABLES

Using daily weather observations, we were able to obtain monthly mean or total values of the following variables:

1. Precipitation amount, cm. (PA)
2. Precipitation frequency (days > 0.25 cm.) (PF)
3. 1300 LST temperature, °F (T)
4. 1300 LST relative humidity, % (RH)
5. 1300 LST windspeed, mph (W)

These five weather variables were tested as significant predictors of fires. Except for precipitation frequency, these weather variables are similar to those that fire weather observers would record on a daily basis (Fisher and Hardy 1976).

CALCULATED INDICES

With the above weather variables available, more complicated expressions of fire-danger are possible. The only monthly fire-danger indices found in the literature were formulated by Chandler et al. (1983). Their three indices used monthly mean values of temperature and relative humidity as input, and provided outputs in meaningful units of fire-danger.

1. Intensity component (INT):

$$\text{INT} = (110 - 1.373(\text{RH})) - 0.54(10.2 - T) \quad (1)$$

where RH = monthly mean 1300 LST relative humidity, (%)
and T = monthly mean 1300 LST temperature (°C).

The intensity component equation was incorrect in their text. Personal communications with the authors indicate that Eq. (1) is the correct formulation.

2. Spread component (SPD):

$$\text{SPD} = 124 \times 10^{-0.0142(\text{RH})} \quad (2)$$

3. Burning index (BI):

$$\text{BI} = (\text{INT})(\text{SPD})/60 \quad (3)$$

where INT = intensity component and SPD = spread component.

Two other calculated indices are the equilibrium moisture content and the fire weather index.

1. The equilibrium moisture content (EQMC) equation was developed by Nelson (1964) for the 1964 National Fire-Danger Rating System. For the range of monthly mean temperatures and relative humidities, Eq. (4) is equivalent to that in Simard (1968).

$$\text{EQMC} = e^{(0.8872 + 0.8507\ln(\text{RH}) - 0.4747\ln(\text{T}))} \quad (4)$$

where T = mean monthly 1300 LST temperature in °F, and RH = mean monthly 1300 LST relative humidity.

2. The fire weather index (FWI) was developed by Fosberg (1978).

$$\text{FWI} = n (1 + W^2)^{1/2} / 0.3002 \quad (5)$$

where W is the windspeed (mph) and n is a moisture damping coefficient

$$n = 1 - 2 (m/30) + 1.5 (m/30)^2 - 0.5 (m/30)^3 \quad (6)$$

where m is the equilibrium moisture content.

DROUGHT INDICES

The NWS issues monthly drought indices. These indices have been shown to correlate with fire occurrence (Haines and Main, 1978a, Haines et al. 1978b). However, 30-day forecasts of these indices are not available at this time. In particular, the Z-Index, or moisture anomaly index, a required step in calculating the Palmer Drought Index (Palmer 1965), has a high correlation with fire occurrence. We obtained historical monthly values of the following three drought indices for the period 1931 to 1982 from NOAA National Climatic Data Center (NCDC):

1. Palmer Drought Index (PDI)

An agricultural drought index that compares current soil moisture conditions to the long term normal or expected conditions.

2. Palmer Hydrological Index (PHI)

A water-balance index that compares current to expected conditions. The PHI will often be the same as the PDI.

3. Z-index (Z)

The current monthly departure from normal (average) moisture balance. This index has NO

memory and can be "WET" during long drought periods.

Results

We used simple correlation methods to search for significant fire severity predictors using the discussed weather variables and calculated indices. Each of the 104 monthly data sets used in the study contained 14 years of data. Individual correlations had to exceed 0.53 to be significant at the 5 percent level. Correlations for July between the NWS station at Rapid City, South Dakota and the Black Hills National Forest show how well fire severity might be predicted at a single forest for a single month (Table 1). The highest correlation with fire occurrence was PHI ($r = -0.86$), and with costs it was FWI ($r = 0.68$). These correlations are between observed monthly weather variables and indices and monthly fire severity measures. When we say "predicted" we would be using 30-day forecast weather variables and indices. Consequently, it would require perfect forecasts for the correlations to hold exactly.

We also looked at which weather variable or calculated index has the highest correlation with the measures of fire severity at 14 NWS station/National Forest combinations (Table 2). The Cherokee and Monongahela National Forests are not listed because they did not meet the criteria for a fire season in July. As occurred at Rapid City, South Dakota/Black Hills National Forest, there were strong relationships between the mean monthly weather variable and calculated indices and monthly fire severity at International Falls, Minnesota/Superior National Forest, and Missoula, Montana/Lolo National Forest. The relationships were weak at Yakima, Washington/Wenatchee National Forest, and Boise, Idaho/Sawtooth National Forest.

Table 1. Correlation coefficients between the 13 monthly mean weather variables and calculated indices at the Rapid City, South Dakota, National Weather Station and six measures of monthly fire severity at the Black Hills National Forest for July 1970 to 1983. Highest correlation for each measure of monthly fire severity is underlined.

Variables and Indices	Fire severity measure					
	Fires	Class C+	Acres	Costs	Fire Days	Class C+
		Fires			Fire Days	Fire Days
PDI	-0.84	<u>-0.66</u>	-0.51	-0.48	<u>-0.91</u>	-0.53
PHI	<u>-0.86</u>	<u>-0.65</u>	-0.53	-0.49	<u>-0.90</u>	<u>-0.54</u>
Z	<u>-0.61</u>	-0.51	-0.50	-0.48	-0.67	<u>-0.35</u>
PA	-0.26	0.11	-0.35	-0.40	-0.18	0.30
PF	-0.52	-0.10	-0.54	-0.61	-0.51	0.03
T	0.79	0.49	0.57	0.59	0.83	0.40
RH	-0.56	-0.35	-0.53	-0.56	-0.58	-0.17
W	0.36	0.26	0.53	0.53	0.34	0.20
INT	0.60	0.37	0.55	0.58	0.61	0.19
SPD	0.62	0.38	0.60	0.62	0.62	0.18
BI	0.65	0.41	0.64	0.66	0.65	0.20
EQMC	-0.61	-0.38	-0.55	-0.58	-0.63	-0.20
FWI	0.57	0.37	<u>0.66</u>	<u>0.68</u>	0.56	0.23

Table 2. The monthly mean weather variable or calculated index that has the most significant correlations with specified measures of monthly fire severity at each National Weather Service station and nearby National Forest for July during the years 1970 to 1983. The correlation coefficient is listed below the weather variable or index identifier.

NWS station and National Forest	Fire severity measure					
	Fires	Class C+ Fires	Acres	Costs	Fire Days	Class C+ Fire Days
Houghton Lake, MI Huron Manistee NF	FWI 0.43	T 0.63	PF 0.36	EQMC -0.35	FWI 0.59	T 0.63
International Falls, MN Superior NF	FWI 0.82	FWI 0.69	FWI 0.61	FWI 0.63	BI 0.78	W 0.64
Rapid City, SD Black Hills NF	PDI -0.84	PHI -0.65	FWI 0.66	FWI 0.68	PDI -0.91	PHI -0.54
Tallahassee, FL Apalachicola, NF	PDI -0.53	W -0.46	W -0.51	PDI -0.53	PF -0.52	T 0.35
Little Rock, AK Ouachita NF	BI 0.83	BI 0.68	BI 0.66	PHI -0.40	Z -0.77	BI 0.72
Missoula, MT Lolo NF	PDI -0.67	Z -0.78	Z -0.80	Z -0.76	RH -0.83	Z -0.81
Yakima, WA Wenatchee, NF	T 0.37	T 0.26	PF 0.51	PDI -0.43	PDI -0.46	PDI -0.26
Boise, ID Sawtooth NF	RH 0.42	PA -0.20	PA 0.40	T -0.41	T -0.25	PA -0.30
Medford, OR Rogue River NF	BI 0.56	PDI -0.51	W -0.31	PDI -0.61	BI -0.52	PDI -0.51
Salt Lake City, UT Wasatch NF	SPD 0.34	W 0.63	W 0.58	PF 0.44	SPD 0.67	W 0.62
Reno, NV Tahoe NF	BI 0.34	PF 0.49	PF 0.74	PHI -0.40	INT 0.53	PF 0.49
Albuquerque, NM Cibola NF	T 0.61	Z -0.51	INT 0.36	PA 0.38	PF 0.54	PF 0.50
Flagstaff, AZ Coconino NF	PHI -0.51	T -0.56	T -0.51	Z -0.37	Z 0.66	T -0.63
Los Angeles, CA Angeles NF	SPD 0.60	SPD 0.57	PDI 0.35	BI -0.34	PF -0.53	SPD 0.61

Figure 2 indicates the weather variables and indices most significantly related to July fire occurrence across the contiguous United States. The burning index (BI) of Chandler et al. (1983) most accurately predicts fires along the west coast. The Palmer Drought Index (PDI) is the most significant fire occurrence predictor from western Montana to the Dakotas. Florida fires are also significantly related to the PDI.

We looked at maps like Figure 2 for each month. For example, in January only the southernmost parts of California and the southeastern corner of the United States are in their fire seasons. In southern California, the Palmer Z-Index (Z) is the best predictor of fires. The BI is significant in Florida. In Arkansas, the PDI is the best predictor.

In April most of the Western United States still has winter weather. In southern California precipitation frequency (PF) is a good predictor of fire occurrence. Throughout the East, the BI is a good indicator of fires. In northern Minnesota PF and temperature are significant. No significant weather variables or indices were found for Michigan. In Arkansas, the FWI was significant.

By October the fire season in the High Plains has passed. In the Mississippi Valley, the Z-index is a good predictor of fires. Farther east the BI is significant. Throughout the Rockies the BI is also the best predictor. In southern California, the Z-Index and PF are best.

Conclusions

Historical weather variables and indices, summarized by month, were a significant predictor of fire severity at many locations throughout the fire season. If monthly mean temperature, relative humidity, and precipitation frequency can be predicted accurately, between one-half and one-third of the next month's fire severity could then be anticipated.

We tabulated the significant weather variables and indices for each month at locations that were in fire season. We hoped to find a single weather variable, or perhaps two variables or indices, that could be used at all locations, in all months, to predict fire occurrence. What we found were striking east-west and north-south differences in almost all months. For example, in July the Burning Index (BI) most accurately predicted fires along the west coast, the Palmer Drought Index (PDI) was the most significant predictor from western Montana to the Dakotas, and further south in Arkansas the BI and in Florida the PDI were consistent predictors. Not only were there regional differences, but different weather variables or indices or both may be needed at the same location, at different times of the year. We found that in southern California in January the PDI is the best predictor of fires, in April precipitation frequency (PF) is a good predictor, in July it is the BI, and in October the Z-Index and PF are best.

Monthly mean windspeed usually was not a significant predictor for any of the fire measures at any time of the year for most locations. This is most likely because windspeed is too erratic to be used successfully as a monthly mean variable.

The simple linear models discussed are only the beginning of a long search for optimal, and perhaps nonlinear, predictive models that relate monthly mean weather variables and indices to monthly fire severity. The results shown here are sufficient to indicate that monthly fire prediction can be done and is a fruitful line of research.

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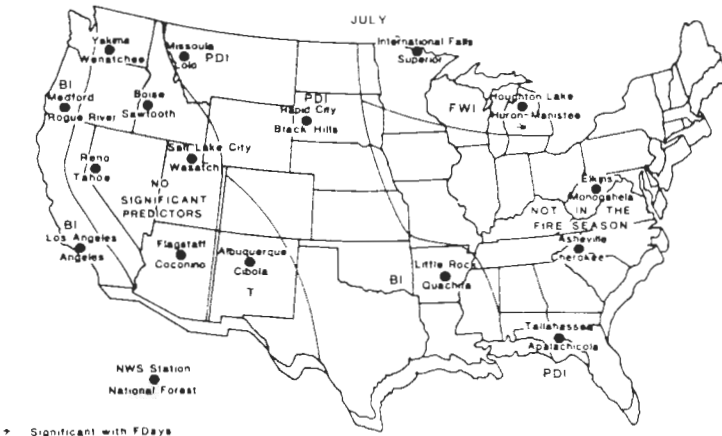


FIG. 2. Weather variables or calculated indices at National Weather Service stations that are most significantly related to fire occurrences on nearby National Forests in July. The significance level is arbitrarily set at 0.05.

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