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by

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CONTENTS

<u>Cover</u>: Status of the Automated Lightning Detection Systems (ALDS) in the western and northern region of Canada as of April 1, 1985. Direction Finder (DF) coverage based on an effective range of 400 km from each DF site. Information and map compiled by Kelvin G. Hirsch, Fire Research Officer, Canadian Forestry Service, Winnipeg District Office.

FOREWORD

The 1975 Federal Department of the Environment (DOE) Policy on Meteorological Services for Forest Fire Control sets out the responsibilities of the Atmospheric Environment Service (AES) and Canadian Forestry Service (CFS) in provision of fire weather forecasts, fire danger forecasts, and other weather-related services to the various fire control agencies. Briefly, this policy gives AES the responsibility of providing current and forecast fire weather and Fire Weather Indices in accordance with the needs of fire control agencies. The CFS role is that of research and development of improved Indices, research on fire behavior relationships with weather factors, and cooperation with AES in preparation of training aids and manuals. Both AES and CFS share the responsibility of improving meteorological services for fire control in Canada. Van Wagner (1984)[1] recently re-emphasized these specific obligations.

In 1976, six regional committees[2] were formed to facilitate the implementation of the DOE Policy on Meteorological Services for Forest Fire Control. The "charter" for these regional fire weather committees is as follows:

Membership: 1 or more AES representatives designated by AES Regional Director; 1 or more CFS representatives designated by CFS Regional Director; and 1 or more fire management agency representatives designated by the Provincial or territorial chief(s) of forest fire management.

Terms of Reference: Each Regional Committee will make recommendations to the Regional Directors of DOE Services (i.e., AES and CFS) for the development and implementation of a program of Meteorological Services for Forest Fire Control which is suited to the needs of the Region and is within the DOE Policy and Guidelines thereto.

Guidelines: Regional Committees will be responsible for (a) identifying the needs of regional fire management agencies for meteorological services; (b) making recommendations of the services identified in sub-section (a); (c) monitoring the program and implementing changes, as required; (d) coordinating with the Development Committee; and (e) referring to the Development Committee those recommendations which the Regional Directors of DOE Services have been unable to implement.

The function of the Development Committee, referred to above, is to coordinate in consultation with the Regional Committees, the development of meteorological services for forest fire management through contacts, at the technical level, between research and development officers of AES and CFS, operations supervisors in the AES field establishments and technical representatives of fire management agencies.

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[1] Van Wagner, C.E. 1984. Forest fire research in the Canadian Forestry Service. Agriculture Canada, Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, Ont. Information Report PI-X-48. 39 p.

[2] These were aligned on the basis of the existing AES administrative boundaries: Pacific (British Columbia); Western (Yukon, Northwest Territories, and Alberta); Central (Saskatchewan, Manitoba, and northwestern Ontario); Ontario; Quebec; and Atlantic (Nova Scotia, New Brunswick, Newfoundland, and Prince Edward Island).

INTRODUCTION

The first scientific and technical seminar of the Central Region Fire Weather Committee (CRFWC) was held at the Atmospheric Environment Service's (AES) Central Region office in Winnipeg on April 17, 1984. The transactions of that first seminar have been compiled for general distribution[1]. Five presentations were made:

- Review of Operational Weather Forecast Procedures for the 1984 Fire Season -- Daniel A. Vandervyvere
- Synoptic Fire Weather Climatology -- Roger B. Street
- Day-1 Forecasting in Forest Fire Danger Rating -- Peter M. Paul
- Canadian Forest Fire Danger Rating System: an update -- Martin E. Alexander
- The Ash Wednesday Bushfires of 16 February 1983 in South-eastern Australia: video tape -- overview by Martin E. Alexander

The second in a series of what is hoped to be a continuing program of seminars was also held at the AES Central Region office in Winnipeg one year later, April 17, 1985, in conjunction with the CRFWC Technical Sub-committee's annual spring business meeting. Four presentations were made and this report constitutes the "proceedings" of the second seminar. A list of individuals attending the seminar is appended to this report. It is felt that such sessions provide an excellent forum for the exchange of information, ideas, etc. on fire-weather related topics of interest to all CRFWC member agencies.

The partial financial support provided by Winnipeg and Prince Albert district offices of the Canadian Forestry Service for the seminar is gratefully acknowledged.

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CRFWC Seminar Coordinator

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[1] Alexander, M.E. (ed.). 1985. Proceedings of the First Central Region Fire Weather Committee Scientific and Technical Seminar (Apr. 17, Winnipeg, Man.). Government of Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, Alta. Study NOR-5-191 File Report No. 10. 26 p.

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DAILY PEOPLE-CAUSED FOREST FIRE OCCURRENCE PREDICTION[1]

by

David L. Martell[2], Samuel Otukol[2], and Brian J. Stocks[3]

Introduction

This paper, which represents an abbreviated version of Martell et al. (1985), briefly summarizes the results of an analysis of daily people-caused forest fire occurrence in northeastern Ontario, which is described in greater detail by Martell and Otukol (1985). The specific study area is the eight districts of Ontario Ministry of Natural Resources' (OMNR) Northern Region.

Although daily people-caused forest fire occurrence is influenced by many factors, our historical data base was so sparse, we had to limit ourselves to simple models based on the available historical fire occurrence and fire weather data (17 years: 1965-81) and surrogate measures of land use activities. We began with a preliminary analysis to identify important factors that should be included in our models, and the variables that could be used to represent them. It was focused on:

1. The extent to which daily fire occurrence varies throughout the course of a fire season due to seasonal variation in the condition of the forest vegetation and land use activities.

2. The extent to which the day of the week can be used to measure day to day variation in land use activities.

We defined the fire season as beginning on April 15 and ending on October 6, and divided it into 25 seven-day periods. When we examined graphs of the average number of fires per day versus period, we found it was reasonable to partition a fire season into five sub-seasons (i.e., Early Spring, Spring, Early Summer, Summer, and Fall) such that the average number of fires of a particular cause that occurred per day was reasonably constant within each sub-season, or most of the pronounced peaks in average daily fire occurrence fell into one of the sub-seasons. We used such graphs, suggestions from OMNR fire managers, and the seasonal vegetation stages delineated by Haines et al. (1975), to subjectively divide a fire season into the five relatively homogeneous sub-seasons (shown in Table 1).

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[1] *Summary of presentation made by the first author at the Second Central Region Fire Weather Committee Scientific and Technical Seminar, April 17, 1985, Winnipeg, Man.*

[2] *Associate Professor and Research Associate, respectively, Faculty of Forestry, University of Toronto, 203 College Street, Toronto, Ont. M5S 1A1.*

[3] *Head-Fire Research Unit, Canadian Forestry Service, Great Lakes Forest Research Centre, P.O. Box 490, Sault Ste. Marie, Ont. P6A 5M7.*

Table 1. Division of the yearly fire season into sub-seasons for the purpose of daily people-caused forest fire occurrence prediction in the OMNR's Northern Region.

Sub-season	Weekly Period Nos.	Dates
Early Spring	1 - 2	Apr. 15 - Apr. 28
Spring	3 - 8	Apr. 29 - June 9
Early Summer	9 - 15	June 10 - July 28
Summer	16 - 22	July 29 - Sep. 15
Fall	23 - 25	Sep. 16 - Oct. 6

Common sense and experience leads many people to believe that a disproportionate number of people-caused fires occur during or near weekends. Our analysis of the historical data indicated that people-caused fire occurrence, at least in the OMNR Northern Region, does not vary significantly by day of the week.

Logistic Regression Analysis

Given relatively stable land use patterns and vegetation conditions, forest fire occurrence is largely influenced by daily variation in the moisture condition of the forest fuels. The Canadian Forest Fire Weather Index (FWI) System is composed of six codes and indexes, three of which were designed to be measures of the moisture content of selected components of a forest fuel complex (Van Wagner 1974). For example, the Fine Fuel Moisture Code (FFMC), one of the components of the FWI System, is representative of the moisture content of the fine fuel component of a forest fuel complex. When we examined plots of the number of fires per day versus the FFMC, we noticed there is an FFMC threshold value above which the frequency of fire occurrence increases dramatically. The frequency of fire occurrence is low when the FFMC is less than 75[4], but relatively high when the FFMC is greater than 75. That relationship cannot be adequately modeled by linear, logarithmic, or quadratic functions.

We transformed the daily fire occurrence data by assigning a value of 0 to days when no fires occurred, and 1 to days when one or more fires did occur. Our aim was to fit a logistic or S-shaped curve function (see Fig. 1) with the 'yes/no' fire day variable as the dependent variable, and one or more of the FWI System components as independent variables.

The logistic model used to predict the probability of a fire day is as follows:

[1] $P_{est} = \mathrm{Exp}(b_0 + b_1X)/(1 + \mathrm{Exp}(b_0 + b_1X))$

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[4] **Editor's Note:** An FFMC of 75 is equivalent to a fine fuel moisture content of about 28.5% (dry weight basis). Forest fires spread poorly or not at all in surface litter of various kinds at moisture contents over 25-30%.

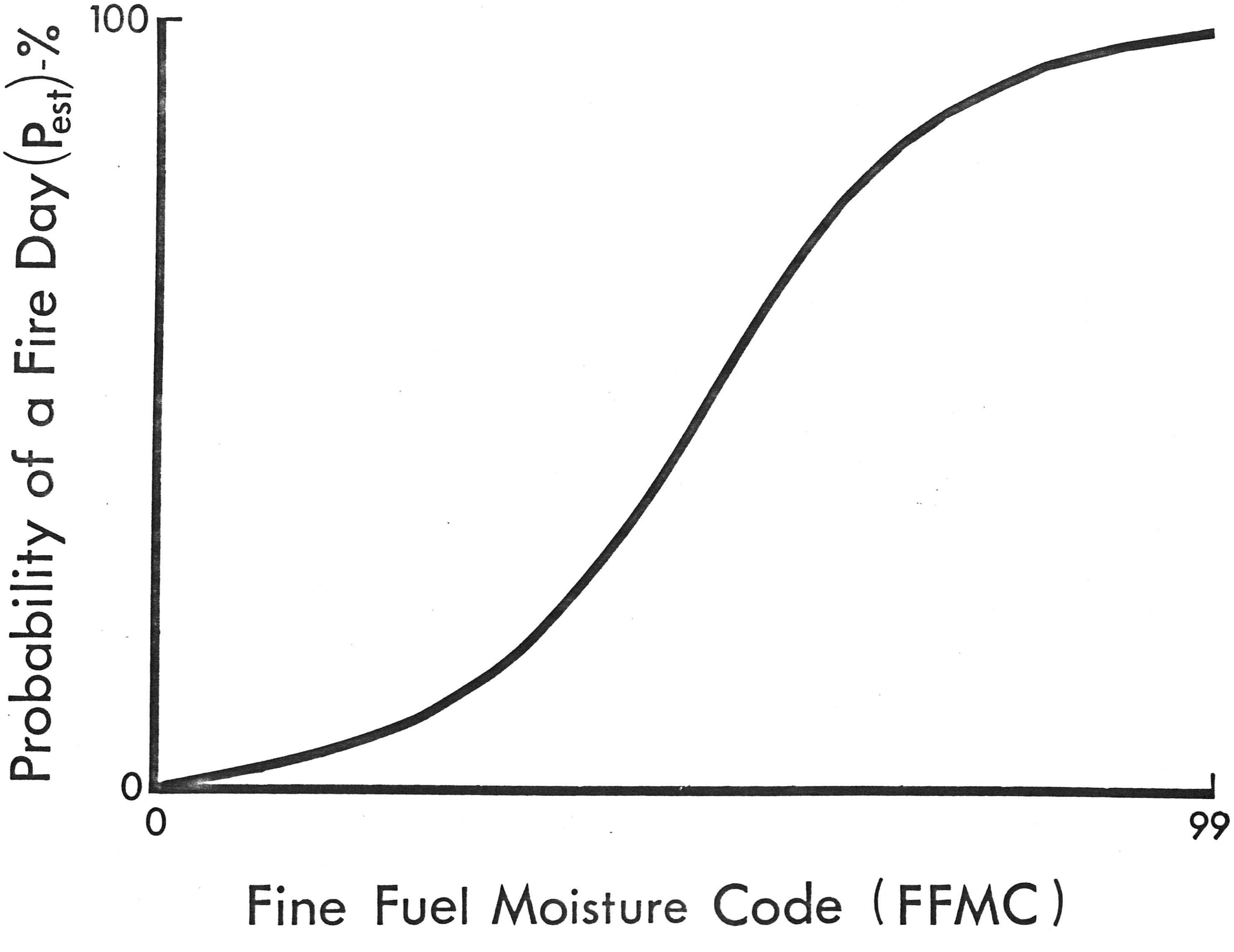


Figure 1. Illustration of the "logistic curve function" applied to the problem of forest fire occurrence prediction. The "S-shaped" curve depicted above is simply a graphical representation of Equation [1] given in the text. Interpretation: the chance of a people-caused fire occurring gradually increases as the moisture content of the fine fuels decrease (or the FFMC value increases).

where, P_{est} = predicted probability of a fire day

X = fire danger index(es) on the day for which the prediction is required (e.g., FFMC)

b_o and b_1 = regression coefficients

The historical fire occurrence and fire weather data bases for a particular district, sub-season, and cause are used to determine the regression coefficients.

Model Development

We used the SAS PROC LOGIST computer program (Harrel 1983) which is based on the maximum likelihood estimate (MLE) method, to develop our logistic regression equations. A lack of data for Early Spring and Fall precluded the derivation of prediction models for those two sub-seasons.

Table 2 shows the FWI System components we selected for each cause and sub-season. We used those variables to derive 192 logistic regression equations for predicting daily people-caused fire occurrence in eight OMNR Northern Region districts (8 specific causes x 3 sub-seasons x 8 Districts = 192 combinations).

Table 2. Fire danger indexes[1] selected for the logistic regression equations for each cause and sub-season in OMNR's Northern Region.

Specific Cause	Sub-season Spring	 Early Summer	 Summer
Recreation	FFMC	BUI	FFMC, BUI
Resident	FFMC	FFMC	FWI
Miscellaneous	FFMC	DMC	BUI
Railway	FFMC	FFMC	FFMC
Industrial (forestry)	FFMC	BUI	BUI
Industrial (other)	FFMC	FFMC	FWI
Incendiary	FFMC	FWI	FWI
Unknown	FFMC	FFMC	BUI

[1] FFMC - Fine Fuel Moisture Code; DMC - Duff Moisture Code; BUI - Buildup Index; and FWI - Fire Weather Index.

An example of one of the 192 logistic regression models is given below in Equation [2]. It can be used to predict the probability of a Recreation fire day during the Spring in the Kirkland Lake District.

$$[2] \quad P_{est} = \mathrm{Exp}\ (-22.02 + 0.233\ \mathrm{FFMC})/(1 + \mathrm{Exp}\ (-22.02 + 0.233\ \mathrm{FFMC}))$$

For example, the predicted probability is 0.18 (or there is a 18% chance) that one or more Recreation fires will occur in the Kirkland Lake District on a Spring day when the FFMC = 88. Conversely, the probability that no such fires will occur is 0.82 (or an 82% chance).

Prediction Models

The logistic regression models discussed above can be used, together with daily forecast or actual FWI System components, to predict the probability of a fire day in the Northern Region by cause, district, and sub-season (i.e., the probability that one or more fires of a specified cause will occur in a certain district on a particular day). But fire managers often need to predict the probability that 0, 1, 2, 3, ..., n fires will occur during a particular day. Such probabilities can readily be estimated by assuming the probability distribution of the number of fires of a given cause that will occur each day is "Poisson", and using probabilistic fire day predictions produced by the logistic regression models, to estimate the expected number of fires that will occur. The mathematical details are given here for completeness.

The probability that x fires of a specific cause will occur during a particular day is given by the following formula for the Poisson distribution (see Fig. 2):

$$[3] \quad P(x) = \frac{\lambda^{x} e^{-\lambda}}{x!}$$

where, $P(x)$ = probability that x fires will occur

λ = expected number of fires per day

The probability that one or more fires will occur is:

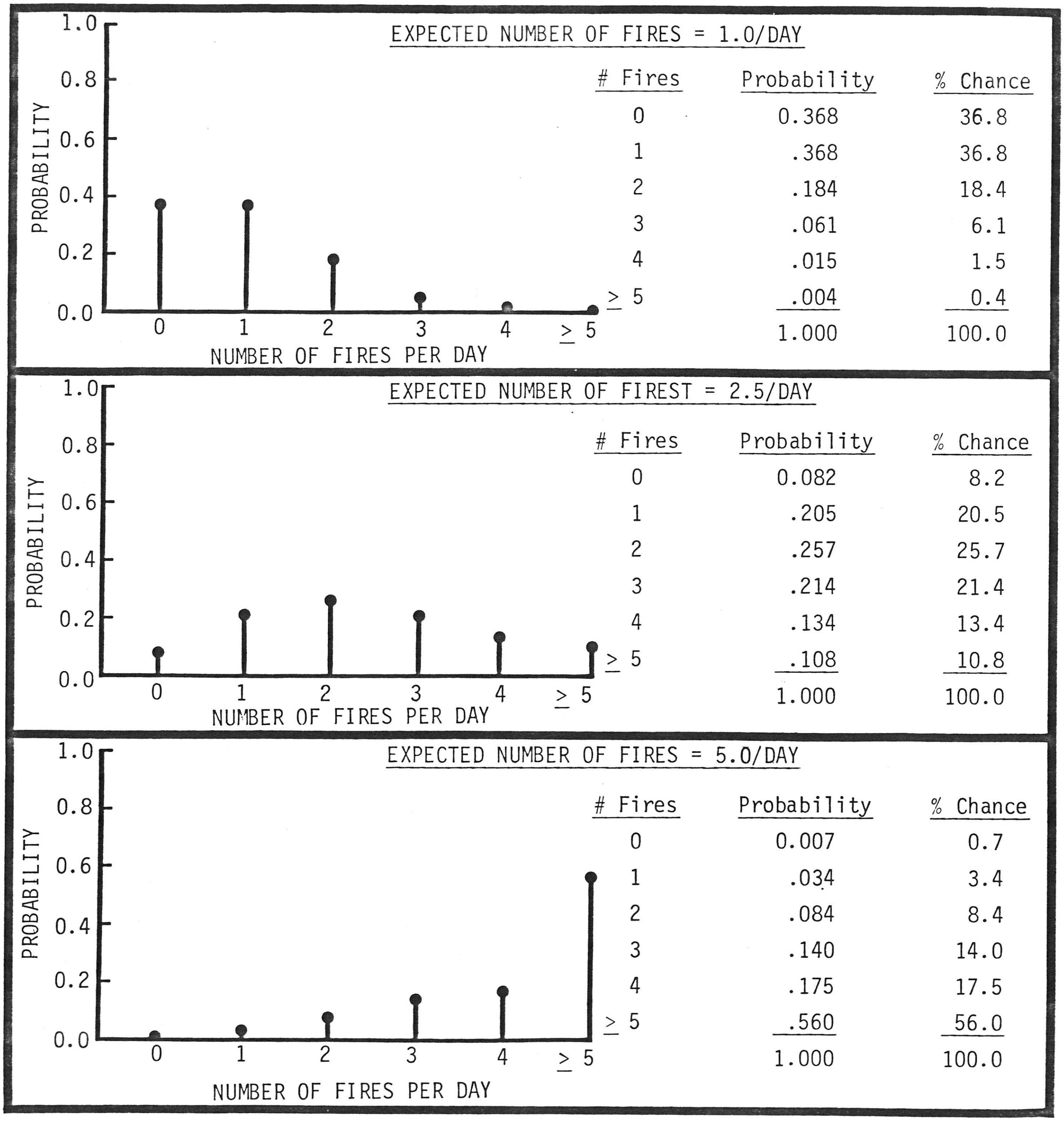
$$[4] \quad P(x \geq 1) = 1 - e^{-\lambda}$$

The probability that one or more fires of a specified cause will occur, which we denote by P_{est}, can be predicted by using the appropriate logistic regression model. We can then equate $P(x \geq 1)$ to P_{est}, and solve for λ as shown in Equation [5].

$$[5] \quad \lambda = -\mathrm{Ln}(1 - P_{est})$$

Once we have an estimate of λ, Equation [3] can be used to predict the probabilities that 0, 1, 2, 3, ..., n fires will occur.

The logistic regression models can be used to predict the daily probability of fire occurrence by district, specific cause, and sub-season (e.g., the probability that one or more Recreation fires will occur in Kirkland Lake District during a spring day). Although such detailed information can be used to help plan daily prevention, detection, and initial attack resource deployment measures, fire managers also require district and regional aggregate predictions of daily fire occurrence, such as the probability that one or more people-caused fires will occur in a region. One important property of the Poisson probability distribution is the fact that such aggregate predictions can be obtained by simply summing the expected number of fires for each district, to obtain a regional expected number of fires. This regional expected value can then be used to make probabilistic predictions concerning daily regional fire occurrence.



EXPECTED NUMBER OF FIRES = 1.0/DAY

# Fires	Probability	% Chance
0	0.368	36.8
1	.368	36.8
2	.184	18.4
3	.061	6.1
4	.015	1.5
≥ 5	.004	0.4
	1.000	100.0

EXPECTED NUMBER OF FIREST = 2.5/DAY

# Fires	Probability	% Chance
0	0.082	8.2
1	.205	20.5
2	.257	25.7
3	.214	21.4
4	.134	13.4
≥ 5	.108	10.8
	1.000	100.0

EXPECTED NUMBER OF FIRES = 5.0/DAY

# Fires	Probability	% Chance
0	0.007	0.7
1	.034	3.4
2	.084	8.4
3	.140	14.0
4	.175	17.5
≥ 5	.560	56.0
	1.000	100.0

Figure 2. Illustration of the "Poisson probability distribution" applied to the problem of forest fire occurrence prediction. The fire occurrence probability graphs and tabulations presented above are simply representations of Equation [3] given in the text.

Daily Fire Occurrence Prediction System

We developed a FORTRAN computer program that uses the logistic regression models to predict daily people-caused forest fire occurrence by specific cause in OMNR's Northern Region districts. The probability that one or more fires will occur is computed for each of the eight districts in the Northern Region. The Poisson distribution is then used to compute the daily probability that 0, 1, 2, 3, ..., *n* fires will occur. The daily fire occurrence predictions were evaluated with the quadratic scoring rule described by Winkler and Murphy (1968), which is designed such that the score assigned to a probabilistic prediction ranges from -1 to +1, and increases as the predicted probability assigned to the actual outcome increases.

Operational Field Test

We field tested our people-caused fire occurrence prediction system in the Northern Region from June 10 to August 31, 1984, a relatively wet period. The system performed better during the Early Summer season than it did during the Summer season. Recreation fire occurrence predictions were not as accurate as those produced for the occurrence of other specific causes.

Discussion

The fire danger indexes we selected for predicting daily people-caused fire occurrence by specific cause in each season are compatible with what we know about seasonal variation in the moisture condition of forest fuels and its potential impact on people-caused fire incidence. The FFMC was the most important index in the Spring when fine fuels play an important role in fire ignition and spread. The BUI, DMC, and FWI, which are indicative of the moisture content status of the heavier fuels, are appropriate for predicting fire occurrence during both the Early Summer and Summer seasons. The results of the 1984 field test suggest that our people-caused fire occurrence prediction system will perform well under low fire danger conditions, but further testing is required to ascertain its validity during more demanding dry periods.

Acknowledgements

This research was supported by the Program for Research by Universities in Forestry (PRUF) of the Canadian Forestry Service (DSS Contract Number OSU83-00140). We thank the many OMNR and Great Lakes Forest Research Centre personnel who recorded, compiled, coded, keyed, and pre-processed the data we used in our analysis. We also thank the staff of the OMNR's Aviation and Fire Management Centre (A&FMC), the fire managers in the Northern Region, and P. Chai, who made it possible for us to conduct the 1984 field test.

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Harrell, F.E., Jr. 1983. The LOGIST procedure. *In* SUGI Supplemental Library Users Guide, 1983 Edition, S.P. Joyner, editor. SAS Institute Inc., Cary, North Carolina.

Martell, D.L.; Otukol, S. 1985. Development of mathematical models for predicting daily people-caused forest fire occurrence in Ontario. University of Toronto, Faculty of Forestry, Toronto, Ontario. 83 p.

Martell, D.L.; Otukol, S.; Stocks, B.J. 1985. A daily people-caused fire occurrence prediction model. Pages 208-215 *In* Proceedings of the Eight Conference on Fire and Forest Meteorology (Apr. 29-May 2, Detroit, Mich.). Society of American Foresters, Bethesda, Maryland.

Van Wagner, C.E. 1974. Structure of the Canadian Forest Fire Weather Index. Environment Canada, Canadian Forestry Service, Ottawa, Ontario. Publication No. 1333. 44 p.

Winkler, R.L.; Murphy, A.H. 1968. "Good" probability assessors. Journal of Applied Meteorology 7(5):751-758.

Editor's Notes: The following list of publications represents D.L. Martell's earlier research work on people-caused forest fire occurrence prediction:

Cunningham, A.A.; Martell, D.L. 1973. A stochastic model for the occurrence of man-caused forest fires. Canadian Journal of Forest Research 3(2):282-287.

Cunningham, A.A.; Martell, D.L. 1976. The use of subjective probability assessments to predict forest fire occurrence. Canadian Journal of Forest Research 6(3):348-356.

Martell, D.L. 1973. Fine Fuel Moisture Code as an indicator of the occurrence of man caused forest fires. Ontario Department of Lands & Forests, Environmental Protection Branch, Toronto, Ont. Fire Control Bulletin No. 6. 2 p.

Martell, D.L. 1976. The use of historical data to predict forest fire occurrence. Ontario Ministry of Natural Resources, Forest Fire Control Branch, Toronto, Ont. Information Report IR-3. 19 p. [re-issued as A&FMC Report No. 4].

Fire occurrence must be viewed as being a chance process rather than a deterministic one. This necessitates the use of probabilistic prediction schemes such as the one described by D.L. Martell and his co-workers. As a result, fire managers will require training in these advanced concepts in order to make proper interpretations of the model outputs.

It's worth emphasizing the significance of the two types of historical data, and a corresponding long-term record, which are used in the development of the people-caused forest fire occurrence prediction models -- daily fire weather observations (which are required for calculation of fire danger indexes) and individual forest fire reports. The best model results and in turn the most reliable predictions will obviously be obtained by having a representative fire weather station network, in which sound quality control standards are maintained. Similarly, it underscores the importance, when completing the fire report form, of obtaining the best possible estimate of the fire occurrence date (if definitely unknown) and making a reasonably thorough investigation of the specific cause (when it is in doubt).

THE LIGHTNING LOCATION & PROTECTION (LLP) SYSTEM: Alberta's Operational Experience[1]

by

Nicholas Nimchuk[2]

Introduction

A majority of wildfire control agencies in Canada now employ magnetic direction finding lightning detection equipment manufactured by Lightning Location and Protection, Inc. (LLP) of Tucson, Arizona. The agency networks vary widely in their effective geographical coverage, associated hardware, modes of access available to users and in the application of the data to fire management. The Alberta Forest Service's (AFS) Forest Protection Branch is uniquely able to incorporate LLP data into their fire suppression activities and operational fire-weather forecasting program. Alberta has now used the LLP network system for four full fire seasons. This experience has profoundly altered fire suppression and detection practices, and in addition has clearly demonstrated the utility of LLP data in synoptic scale fire-weather forecasting.

Requirements of An Operational Lightning Detection System

The problems in fire management addressed by lightning detection systems are the timely detection of active lightning-caused wildfires and identification of areas in which holdover fires are probable. The goals, simply stated, are:

- to enhance the effectiveness of initial attack suppression through a more strategic deployment of resources,
- increase the detection efficiency and economy of fire patrols, and
- provide additional input for fire-weather forecasting operations.

To achieve these goals, a lightning detection system must meet three basic requirements:

1. **The data must be accessible to the fire manager in a usable format in real time.** Under certain fire danger conditions, the AFS's Pre-Suppression and Preparedness System (PPRS) (Gray and Janz 1985) requires the deployment of sufficient resources to achieve a 15-min initial attack objective. That is, resources must arrive at the fire site within 15 min of its detection. Under less severe fire danger situations the objectives are reduced to 30 or 60 mins. Lightning data that is inaccessible within these objectives

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[1] *Summary of a presentation made at the Second Central Region Fire Weather Committee Scientific and Technical Seminar, April 17, 1985, Winnipeg, Man.*

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is of limited value in the initial attack role. Real-time lightning data is now considered imperative in AFS suppression operations.

2. **The system should achieve a reasonable degree of accuracy.** Given precise directional antenna orientation and electronically clean direction finder sites, the accuracy of a given LLP network is influenced most strongly by the density of direction finders (DF) and the area contained within the "baselines" of the network. Larger errors are expected in a low density system and within areas in proximity to the baseline defined by two DFs. In Alberta, an extensive network of manned lookout towers has provided valuable LLP verification data that would otherwise be difficult to obtain elsewhere (N. Nimchuk and B. Janz, manuscript in preparation). It is not unusual for a given lookout tower to be struck several times by lightning during the fire season. Comparison of LLP data to reports of direct lightning strikes to lookouts has indicated errors of 10-15 km in baseline and low DF density areas, while 2-5 km is more typical in higher DF density areas outside of baseline regions. In many instances, errors of less than 1.0 km were observed. Errors of these magnitudes are quite acceptable in fire control or fire-weather forecasting operations. Although some may argue a higher degree of accuracy is necessary for fuel/ignition models, the system's errors are easily adjusted for in practical application.

3. **The system's hardware should function reliably and be amenable to field maintenance.** In total, the AFS network contains nearly 100 individual LLP and peripheral mechanical devices. Due to the size and complexity of the AFS LLP network (Fig. 1), an electronics technician position has been dedicated to the maintenance of the system. Only isolated failures of LLP hardware have occurred and were usually remedied through circuit board or component replacement. More frequent repairs were required of peripheral hardware such as printers and modems (not LLP products) which can be attributed to general wear and tear normally expected with such equipment. Undoubtedly the cause of most system or partial system failures has been interruptions on the dedicated communications circuits. Such failures are largely beyond the control of the user. Experience has shown that the status of the data links should be closely monitored and problems brought to the attention of the telecommunications agency immediately. Generally communications problems are rectifiable within a few hours but have occasionally taken several hours for the telephone company to sort out. Overall, the reliability of LLP equipment in the Alberta network has been excellent. The services of a knowledgeable technician also contributes greatly to maintaining a high degree of system reliability.

Application of LLP Data in AFS Fire Management

The fire control mandate of the Alberta Forest Service is to suppress all wildfires occurring within provincial protection areas. Consequently the effectiveness of initial attack is a crucial factor in fulfilling this mandate. Historically, fire control agencies have generally not responded to increasing fire danger by bolstering their resources until fires broke out and ran. The AFS's PPRS applies the fire weather forecast to the current fuel moisture codes of the Canadian Forest Fire Weather Index (FWI) System and calculates an expected fire danger indexes for the following burning period. The fire manager is then required to "man-up" or "man-down" to a predetermined resource

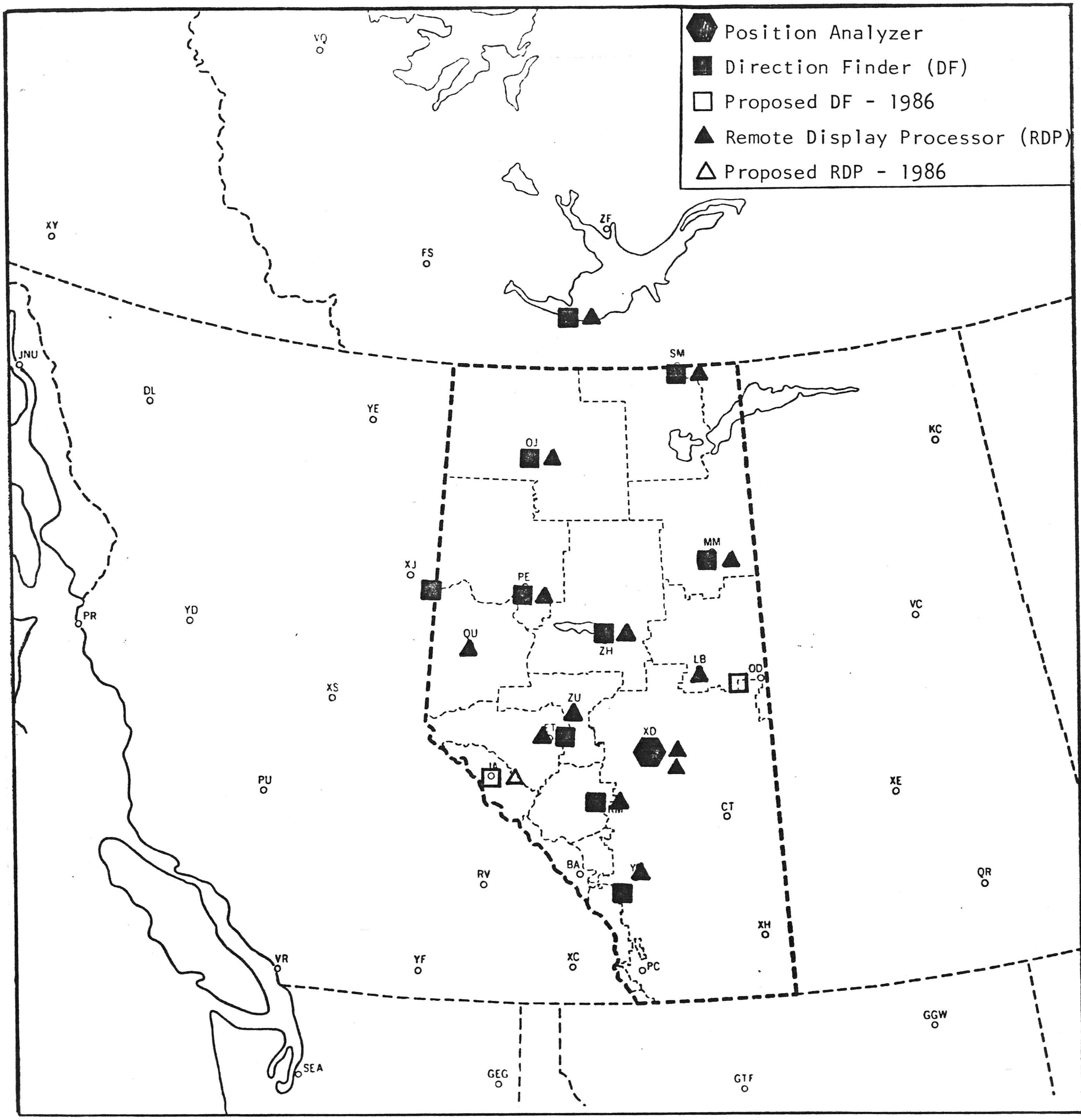

Figure 1. Status of the Alberta Forest Service's automated lightning detection network as of October 1, 1985.

level correlated with the anticipated fire danger conditions. (The resource or manning levels are determined by 24-h forecast mean values of Fine Fuel Moisture Code (FFMC), Buildup Index (BUI) and Drought Code (DC) for the given protection area.) As the anticipated fire danger increases, the initial attack time objectives decrease. The maximum levels of preparedness require sufficient resources to achieve a 15-min initial attack time objective within the fire manager's protection area. Unfortunately, extreme Initial Spread Index (ISI) values in some fuel types can drive a lightning fire start beyond initial attack capability in well under 15 min.

In many instances, AFS fire managers have utilized the LLP system to reduce initial attack times to significantly less than the PPRS objectives. The LLP Remote Display Processor (RDP) provides an excellent depiction of active storm motion and with experience the motion of particular storms may be extrapolated with reasonable accuracy over a period of several hours. Given the advantage of this valuable lead time, fire managers have deployed initial attack resources to the threatened area well in advance of the lightning crossing into their jurisdiction. As the storm enters the protection area, airborne initial attack crews follow directly behind it taking suppressive action on new fire starts as they occur.

Lightning that develops within a protection area is frequently detected by the LLP system before it is visually detected by lookouts. Early detection of developing lightning activity under severe conditions also provides the fire manager with additional lead time to respond with initial attack resources. The LLP has also detected isolated lightning activity (1-3 flashes) not observed by the nearest lookout that ultimately resulted in fires during the same or subsequent burning period. Clearly the LLP system in conjunction with the PPRS has fundamentally changed the approach to initial attack in Alberta.

The LLP has also left its impact on aerial patrol methods and holdover fire detection. Previously patrol routes were generally fixed with some allowance for values at risk, fire danger conditions and recent lightning activity reported by lookouts. More often than not, patrols would adhere to the fixed routes that may have bypassed higher risk areas and needlessly scanned low risk areas. The RDP provides hardcopy maps of past lightning activity for most time windows the fire manager requires. Alberta RDPs are capable of storing and recalling the most recent 25 000 flashes. Unless an exceptional amount of recent lightning has occurred this amount of storage provides an archive of several days. Patrols are supplied with the maps and plan their routes accordingly. Under more severe fire danger conditions, "loaded patrols" are often utilized and have simultaneously detected and suppressed holdover fires. The LLP data additionally provides guidance to lookouts that may not have observed nocturnal lightning or are hindered by poor visibility. Some forests have reported a 60% reduction in aerial detection patrol costs during the past few seasons in comparison to other active fire seasons prior to the development of the AFS LLP system. Undoubtedly the LLP system has enhanced the capability of fire managers in Alberta and can be considered a key component of the province's comprehensive fire suppression organization.

The LLP System and Fire-Weather Forecasting

The AFS is unique among provincial and territorial fire control organizations in having its own full-time, dedicated fire-weather section. The section provides forecasting and related fire-weather services to fire management on an operational basis. Perhaps the second most difficult task of a fire-weather meteorologist is the forecasting of winds and their effects on potential fire behavior at some specified location. Forecasting the location, incidence and ignition potential of lightning must certainly rank as the most difficult challenge. Predictive models of lightning fire occurrence will continue to have limited success until lightning forecasts are capable of confidently indicating where, how much and how effective.

Existing climatological literature provides a superficial assessment of lightning incidence and distribution. Past and current observation methods are unable to quantify the occurrence of cloud-to-ground lightning and suffer the systematic errors of a widely dispersed observation network. On initial exposure to the LLP, the most striking feature is the seemingly phenomenal amount of lightning and the extensive area over which it occurs. The LLP data has shown the incidence of lightning is much higher than is indicated in present climatological records. Severe weather forecasting techniques utilize what could be called the "classical" atmospheric parameters of stability, moisture and dynamics. These techniques perform reasonably well on the synoptic scale as indicators of thunderstorm development. Given the ability of the classical parameters to give a qualified answer to the question "if and where?", they give no definite clue as to "how much?". Alberta's experience has shown that although the indicators point to thunderstorm activity, there is no way to determine if the activity will yield 1000 or 10 000 lightning strikes. Severe weather techniques do not utilize parameters linked to the electrical state of the atmosphere and will likely continue to have little success in quantitative lightning forecasting.

The LLP is capable of displaying the motion of several active thunderstorms in real time. Simple extrapolation of storm motion is the most direct LLP technique. Given a knowledge of the most current and the prognostic steering flow, more refined extrapolations are possible. This capability is particularly valuable in situations where storms develop in the British Columbia interior and threaten to track eastward.

The LLP has also proven to be an extremely useful indicator of changes in the upper-level synoptic circulation. Fire danger conditions rapidly increase under a blocking upper ridge circulation. A stagnant ridging situation over Alberta usually requires the presence of an upper low or trough somewhere along the west coast. The breakdown of this pattern by the trough moving inland brings a high risk of extreme fire behavior to existing fires and additional lightning starts. On numerous occasions the LLP has flagged the initial eastward motion of the Pacific trough. Lightning often precedes the trough in the British Columbia interior by several hours. In these situations it is highly probable that lightning will develop in Alberta within 12 hours. The LLP data and most recent upper air analyses provide a good indication of where the lightning will occur. Effectively the LLP is able to depict a synoptic-scale adjustment in real time.

Alberta's LLP experience has led to significant and undoubtly long term changes in AFS fire management. In a relatively short time, the LLP system has become a powerful tool in the fire manager's arsenal and will continue to play a vital role in fire control and fire-weather forecasting operations.

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OPERATIONAL LIGHTNING FIRE OCCURRENCE PREDICTION IN ONTARIO[1]

by

Richard A. White[2]

Fire occurrence prediction in Ontario is currently in a state of transition. Perhaps some of the reason for this transition can be tied to changes to the Province's Fire Management organization made in 1984. At that time Ontario instituted a change from a decentralized fire organization, in which the responsibility for daily strategic planning was carried out in each of 35 local District Fire Centres, to a centralized one in which the daily strategic plan is developed for a whole region by the Regional Duty Officer.

Prior to 1984, daily decisions regarding manpower levels, equipment availability, etc. were based on an analysis of fire weather, fuels and risk made at the district level by the Fire Control Supervisor who had a local knowledge of the conditions which existed in his District. Under ***Centralized Fire Control***, the Regional Duty Officer is responsible for preparing a strategic plan for a much larger and more diverse area. This is leading us to a greater reliance on computer-based decision support systems. The systems currently under development include data base management systems to allow more efficient use of resources as well as models to assist in predicting the occurrence and growth of wildland fires.

Lightning fire occurrence prediction in its present form consists of a careful analysis of the environmental factors which lead to the ignition of lightning fires. At the present this could be considered to be a manual analysis carried out by the Regional Duty Officer or a member(s) of his planning team. The process begins with the monitoring of weather patterns in the Region. Both recent weather and forecasted weather are taken into consideration. Lightning occurrence is detected by our lightning locator network system and fed to Remote Display Processors (RDPs) in each of the regional fire centres. During the fire season 1985, the system will consist of 13 Direction Finder (DF) stations which will provide coverage for all of northern Ontario. When lightning has been detected, a risk analysis of each storm is carried out. The general location of the lightning storm is noted. The pattern of the lightning is looked at. Areas on the fringe of the storm with small concentrations of strikes which may have been outside of the rain track are identified. An attempt is made to identify the characteristics of the storm, the speed and direction of movement and the amount of rainfall which may have come from the storm. The major fuel complexes in the area of the storm are considered as well as the moisture content of the fuels. What we are looking for in this analysis is to identify lightning occurrence in dry, low rainfall areas and in fuels which will be conducive to ignition. The Regional

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[1] *Summary of presentation made at the Second Central Region Fire Weather Committee Scientific and Technical Seminar, April 17, 1985, Winnipeg, Man.*

[2] *Operations Officer, Fire Environment Program, Aviation and Fire Management Centre, Ontario Ministry of Natural Resources, P.O. Box 310, Sault Ste. Marie, Ont. P6A 5L8.*

Duty Officer and his planning team will then assess the risk over the whole region and identify the areas within the Region which are most likely to produce lightning fires during the next burning period. They will use this information as they develop the strategic operation plan for the Region. This process seems to be quite effective in alerting managers to the potential of lightning fire starts. It is still however, very difficult to predict numbers of fires which might be expected to arrive from a given storm.

Research into lightning fire occurrence prediction continues, particularly at the Petawawa National Forestry Institute (PNFI). Two lightning fire prediction models developed by Dr. P.H. Kourtz and his staff at the PNFI are currently being tested under operational conditions at the Northern Region Fire Centre in Timmins. The computer programs are presently being tested using a Digital 1123 microcomputer.

The program "ZAPPY" produces a prediction of lightning fire occurrences during the next burning period based on weather conditions and combinations of storm severity and amount of rainfall. Predictions are made for each of four quadrants of the region (NW, NE, SW, SE) and show an expected number of fires as well as the percent chance of three or more fires occurring in the quadrant. The program does not directly access lightning occurrence information from the lightning locator system. The planning team must input a subjective evaluation of storm severity and rainfall for each quadrant. Three levels of severity are considered -- light, medium, and heavy -- as well as three levels of rainfall -- wet, medium, and dry.

"SPARKY" is also a lightning caused fire occurrence prediction program. It references a database for current and forecast fire weather and Canadian Forest Fire Weather Index System component values. This program is also able to directly access information from the lightning locator network system through a sub-program called "Capture". The program predicts new fire arrivals from current day's lightning activity as well as from holdover fires from previous storms. The program output is in the form of three maps:

1. Cell lightning map, showing the number of strikes per basemap cell on the current day.

2. Fire prediction map, showing the percent chance of 1 or more fires for each basemap cell.

3. Cell danger map, combining the predicted fires with basemap values information.

The program also produces an expected number and maximum number of fires for the region as a whole.

Both "ZAPPY" and "SPARKY" have received only limited testing in the Northern Region. At present it would appear that the output tends to over estimate the occurrence of lightning fires within the region. During the summer of 1985 the programs will receive a more intensive testing.

Editor's Note: The following is a list of publications related to the author's presentation.

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USE OF THE 500 mb HEIGHT ANOMALY CHART IN FIRE MANAGEMENT[1]

by

Ben Janz[2]

Introduction

The success of any forest fire control organization depends in part on its ability to anticipate weather conditions that can lead to fire problems. The 500 mb height anomaly chart (Fig. 1), if properly interpreted, is a useful tool in assessing potential fire occurrence/behavior and in certain situations can "flag" potentially critical or severe fire behavior conditions. (An "anomaly" represents a departure or deviation from the normal or long-term average.)

Background Information

One of the basic meteorological elements is atmospheric or barometric pressure -- i.e., the pressure exerted by the atmosphere upon the "column" of air lying directly above the point in question (Huschke 1959). The most common unit system is the millibar (mb). [The recommended SI unit is the kilopascal or kPa (1 kPa = 10 mb).] Most fire managers have at least a basic understanding of how atmospheric pressure variations affect weather and in turn potential fire behavior (Schroeder and Buck 1970). Pressure values at the earth's surface vary considerably in time and space but the average value is in the neighborhood of about 1000 mb. Meteorologists measure the height above mean-sea level (MSL) at which the pressure reaches a certain value. For example, the 500 mb height is the elevation (approximately 5500 m above MSL) at which the 500 mb pressure level is reached (i.e., about 1/2 of the pressure at the earth's surface).

Often we talk as though each section of the atmosphere acts independently. This is not so -- the atmosphere functions as a complete unit. In other words, certain events occurring at one level are generally associated with certain events at another level. For example, an upper high pressure ridge is usually associated (in summer) with a ridge and warm weather at the surface. When the ridge moves or breaks down we usually observe warm, windy weather with a possibility of dry lightning followed by cool, showery weather.

Meteorologists have sliced the atmosphere into different layers to facilitate monitoring and data gathering. The 500 mb level is one of the layers that has been found convenient for analysis and forecast purposes. The 500 mb layer can be thought of as an undulating blanket surrounding the earth. The pressure as measured from the top of the atmosphere to every point on this blanket is 500 mb. Surface weather of course is the greatest determinant on fire behavior. However, the circulation at higher levels can influence an

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[1] *Summary of a presentation made at the Second Central Region Fire Weather Committee Scientific and Technical Seminar, April 17, 1985, Winnipeg, Man.*

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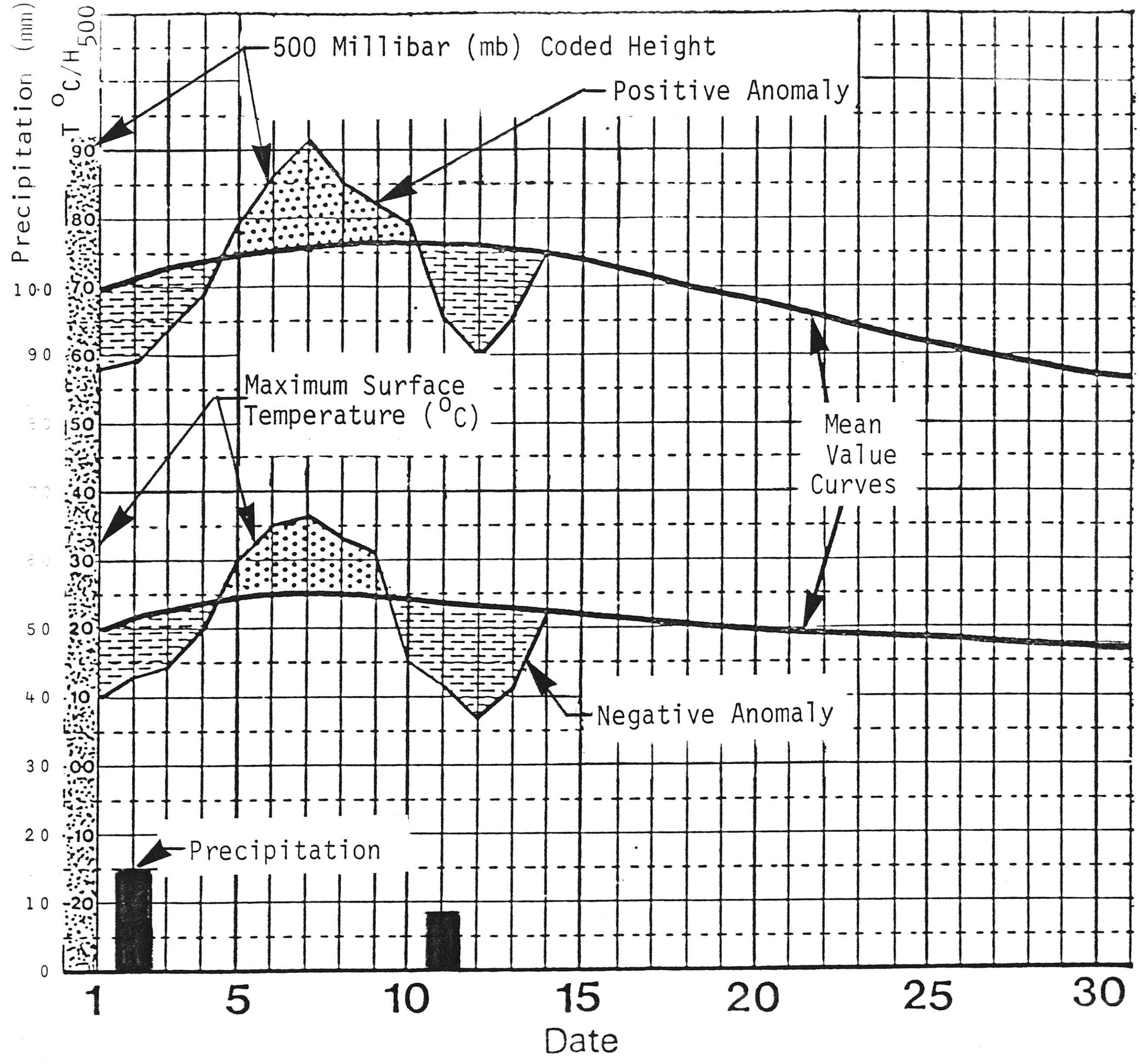

Figure 1. Example of the 500 mb height/maximum surface temperature anomalies chart with daily precipitation amounts (24-h total).

ongoing fire directly by affecting convection column development and indirectly via the surface weather pattern.

Operational Use of the Anomaly Chart

The basic 500 mb height anomaly chart used by the Alberta Forest is illustrated in Figure 1.

Atmospheric pressure level heights are normally expressed in geopotential metres (m) above mean sea-level (MSL). For example, the 500 mb height usually ranges from 5300 to 5900 m above MSL over Alberta during late spring and summer. For chart plotting purposes, the first and last digits of the height value are deleted (e.g., a height of 5640 m is plotted as 64). This coding allows for the 500 mb heights and maximum surface temperatures, expressed in degrees Celsius (°C), to be displayed along a common vertical axis.

The anomaly chart is initially prepared by drawing curves of the long-term average daily 500 mb heights and the average daily maximum surface temperature specific to a certain station/area of interest at the beginning of the fire season. The mean 500 mb height is determined from an analysis of the upper air record of a selected station or from published maps of mean 500 mb heights for a particular area/region.

On a daily basis the actual 1200 h GMT 500 mb height and daily maximum surface temperature values for a station/area are then plotted chronologically and then connected by straight lines which are in turn compared to the long-term average or normal represented by the two "mean value curves". Values above the mean curves indicate a **positive anomaly** and those below represent a **negative anomaly**, which are entered in red and blue, respectively, for display purposes. The 24-h daily precipitation total (i.e., 1200 to 1200 h LST), expressed in millimetres (mm), is also plotted for a representative station.

If an anomaly chart is plotted over a period of a few months it soon becomes apparent that there are alternating periods of **positive** and **negative** anomalies. There may also be periods where the anomalies do not depart a great deal from the long-term average. Basically, the periods of negative anomaly correspond to periods where the upper air circulation at 500 mb favors troughs. A positive anomaly is indicative of periods where the atmosphere seems to favor upper ridge development. Fluctuating anomalies from a slightly negative to slightly positive situation generally represents zonal circulation conditions. A rapid change from a positive to negative anomaly is an indication of an upper ridge breakdown.

In operational applications, it has been found useful to include at least one additional parameter to the anomaly chart -- a plot of the number of daily fire starts in a designated area around a station or particular region. Thus, the complete anomaly chart provides an ongoing weather record of the fire season.

Predictions of the 24-h, 48-h, and 72-h 500 mb heights can be entered in light pencil or dashed lines to provide an indication of the anomaly trend. These forecasts are becoming fairly acceptable. Although the absolute values are often not that exact, the trend is usually quite good (i.e., higher or lower than the previous day).

Historical Problem Fire Situations and Anomaly Behavior

Case Study No. 1 - Northwestern Ontario/Southeastern Manitoba Fires of September 1983 (refer to Figure 2) - Significant Features:

- prolonged 500 mb height anomaly during most of August and early September.

- highly positive 500 mb height anomaly and very high surface temperatures during period August 25 to September 2 (26.8-34.6°C).

- note precipitation distribution in August -- although less than 50% of normal for the month it was distributed in such a way that the fine fuels remained fairly moist. Fine Fuel Moisture Code (FFMC) never reached 90 during August. Buildup Index (BUI) increased rapidly after August 29 (i.e., rapid recovery following light rain during August 23-28).

- 1300 h CDT fire danger conditions on September 3 -- "Black Saturday" -- at Kenora A, Ont.: FFMC - 92, Duff Moisture Code (DMC) - 38, Drought Code (DC) - 415, Initial Spread Index (ISI) - 21, BUI - 61, and Fire Weather Index (FWI) - 40 (B.J. Stocks, pers. comm.). -- note that this is during the period when 500 mb height dropping rapidly. Multiple fire outbreaks/major fire runs occurred in northwestern Ontario (Kincaid 1985) and southeastern Manitoba.

- in retrospect -- August with its favorable precipitation distribution, but quite dry, and lack of fire problems may have given a false sense of security. The highly positive 500 mb height anomaly contributed to a very rapid drying of fine fuels and the rapid drop in early September spelled trouble (this height drop was correctly forecast 48 hrs in advance by the numerical progs).

Case Study No. 2 - West-Central Canada Fires During the 1980 Spring Fire Season (refer to Figure 3) - Significant Features:

- unusually high positive 500 mb height and surface temperature anomalies during April and much of May.

- lack of any significant precipitation during April and first 24 days of May.

- note steady increase of BUI with most rapid increase during periods of high 500 mb anomaly (April 28 to May 5 and May 18-26).

- May 18 - origin of McKenzie and Woody Lake fires in central and southeastern Saskatchewan, respectively, -- make "explosive" runs on May 19 and 20 coinciding with rapid drop, albeit temporary, in 500 mb height - 1300 h CDT fire danger conditions at Hudson Bay A, Sask.: FFMC - 94, DMC - 129, DC - 207, ISI - 34, BUI - 129, and FWI - 75 (M.E. Alexander, pers. comm.).

- May 5 peak in FWI - there were no ongoing fires and no new fire starts, hence no fire problems - however, the peak of FWI = 67 indicates that the potential for severe fire behavior existed.

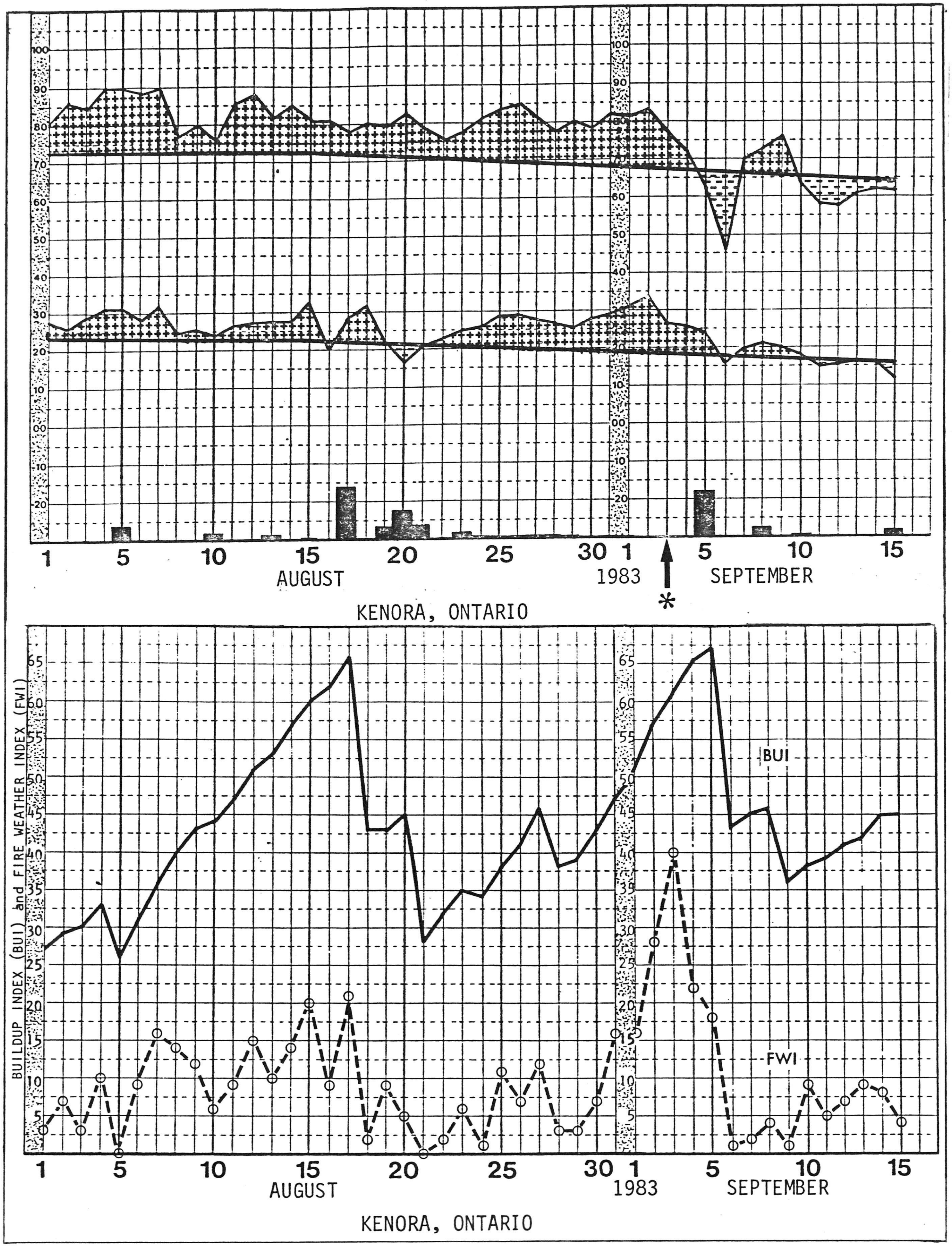

Figure 2. Charts of 500 mb height/maximum temperature anomalies with daily precipitation amounts (upper) and fire danger indexes (Buildup Index - BUI and Fire Weather Index - FWI) at Kenora, Ontario (lower), August/September 1983. Ongoing wildfires in northwestern Ontario and southeastern Manitoba made major runs on September 3 (*).

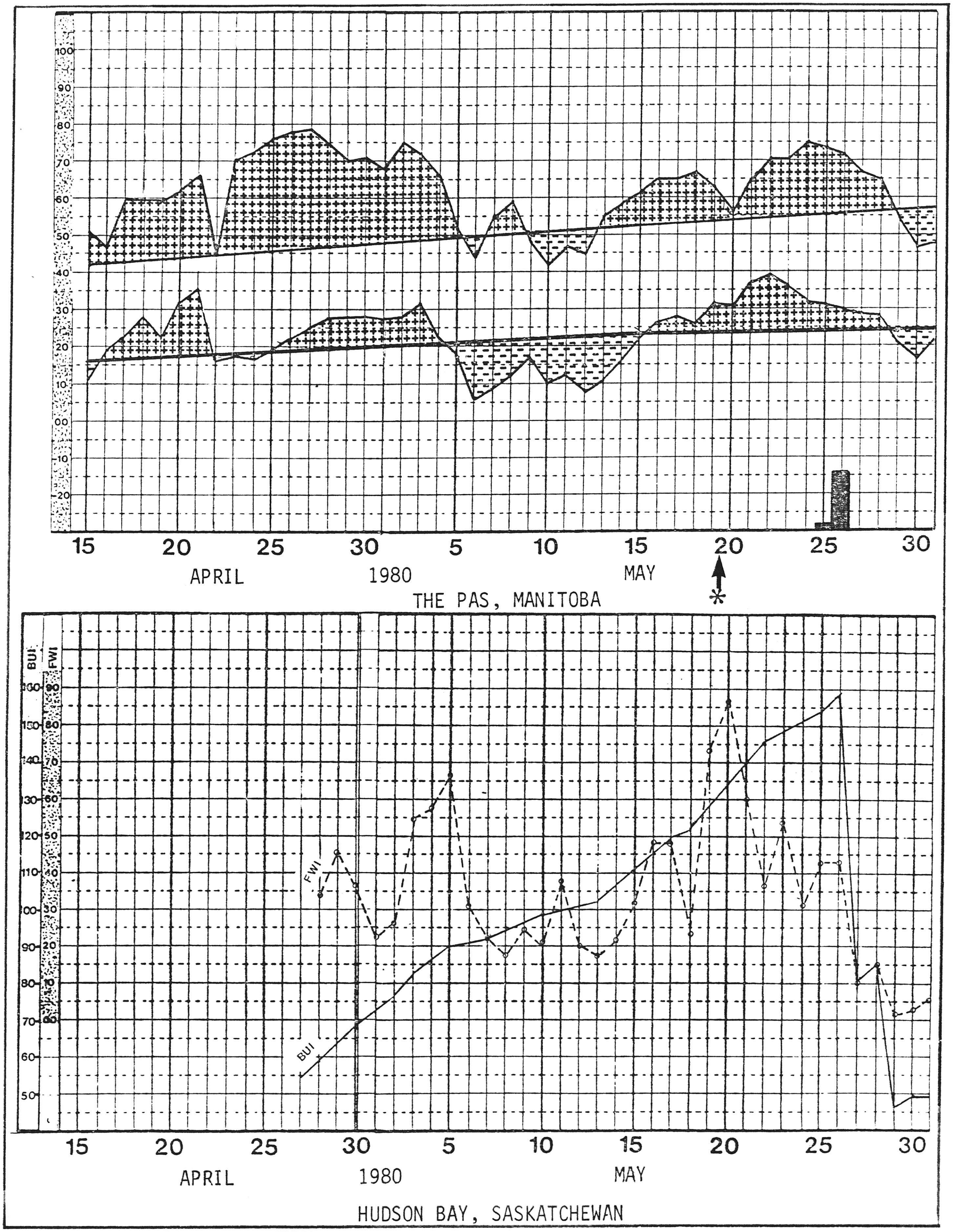

Figure 3. Charts of 500 mb height/maximum temperature anomalies with daily precipitation amounts (upper) at The Pas, Manitoba and fire danger indexes (Buildup Index - BUI and Fire Weather Index - FWI) at Hudson Bay, Saskatchewan (lower), April/May, 1980. Ongoing wildfires in central and southeastern Saskatchewan make major runs on May 19 and 20 (*).

Observations of Fire Occurrence/Behavior in Relation to the Anomaly

The following general observations are based on a comparison of the height anomaly and wildfire behavior in Alberta over a five year period 1980-1984.

1. Prolonged negative or near-normal height anomalies:

   - no serious fire problems during such periods (This does not imply the absence of fires or new starts. There can be multiple-lightning fire start situations).
   - the most important observation -- new fire starts are generally contained without too much difficulty and ongoing fires do not make major runs.

2. Rapid increase in the height anomaly:

   - normally a very low risk of lightning fire starts.
   - very rapid increase in FFMC, DMC, and BUI.
   - normally pleasant, warm, dry weather.

3. Prolonged period of positive height anomaly:

   - continued drying out of all fuels including the deep duff.
   - persistently high to extreme FFMC and DMC values (FFMCs may peak in low or mid 90s).
   - DMC and DC continue to increase.
   - dips in height anomaly may be accompanied by new lightning fire starts.
   - ongoing fires may give problems.

4. Drop in height anomaly (i.e., from large positive value to negative value):

   - most extreme fire behavior appears to be associated with a very rapid drop in the 500 mb height anomaly.
   - A RAPID DROP FROM HIGHLY POSITIVE TO NEGATIVE HEIGHT ANOMALY FAVORS POTENTIALLY EXTREME FIRE BEHAVIOR (AND POSSIBLY NEW LIGHTNING STARTS).
   - **Note:** Any drop in the 500 mb height anomaly should be taken seriously by a fire manager (The absence of extreme fire behavior with a rapid drop should not be viewed as a 'false alarm'. If there are no ongoing fires and no new starts during the 'drop' period there can be no fire behavior to worry about).
   - historically the most extreme ISI values have been associated with rapid drops in the 500 mb height anomaly.

Implications for Fire Management

It must be clearly understood that the monitoring of the 500 mb height anomaly is not, and is not intended to be, a substitute or replacement but rather a supplement to other more direct measures relating to the evaluation of wildland fire potential (e.g., fire danger forecasting). However, if the 500 mb height forecast is properly interpreted, in conjunction with information on an area's current seasonal weather history and fire business, it can be a simple yet extremely useful indicator to potential wildfire occurrence and behavior in the next 24 to 48 hours, without the encumberance normally associated with reference to the "nitty-gritty" of surface weather parameters.

Further Reading

Further case history examples and a more detailed discussion of the use of the 500 mb height anomaly in fire management can be found in Nimchuk (1983a, 1983b), Nimchuk and Janz (1984), Janz and Nimchuk (1985), and Gray and Janz (1985).

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ADDENDUM TO THE LITERATURE ON AUSTRALIA'S 1983 "ASH WEDNESDAY" FIRES[1]

compiled by

Martin E. Alexander[2]

A video tape of the Ash Wednesday bushfires that occurred on February 16, 1983 in south-eastern Australia was shown at the first Central Region Fire Weather Committee (CRFWC) scientific and technical seminar in April 1984. A bibliography of published material dealing with this wildfire situation accompanied the overview prepared for inclusion in the proceedings[1]. In this regard, note that Cheney's (1985) conference paper has now been published and appears as pages 75-83 in Canadian Forestry Service Information Report NOR-X-271. In addition, Australia's Bureau of Meteorology has now released its final report on the Ash Wednesday fires (see below). Here's a few additional contributions to the growing list of references on the Ash Wednesday fires:

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LIST OF SEMINAR ATTENDEES

Name	*Title*	*Affiliation*[1]
ALEXANDER, Marty	Fire Research Officer	CFS, NoFRC, Edmonton
ATKINSON, Barrie	Sci. Serv. Meteorologist	AES, Central Region, Winnipeg
BARRETTE, Vincent	Operations Officer (seasonal)	CIFFC, Winnipeg
BOITEAU, Marc	Fire Ranger	MDNR, NE Region, Thompson
BOIVIN, Jean-Guy	Aircraft/Communications Officer	CIFFC, Winnipeg
BUCK, Bob	Fire Operations Supervisor	MDNR, FM & C, Winnipeg
CARELTON, W.C.	Sr. District Supervisor	MDNR, Interlake Region, Ashern
CARPICK, Jack	Supt.-Stn. Standards&Requirements	AES, Central Region, Winnipeg
DUBE, Dennis	Superintendent of Forestry	Winnipeg Parks & Recreation Dept.
EMES, Don	Regional Superintendent	MDNR, NE Region, Thompson
GAUTHIER, Tim	Fire Ranger	MDNR, Eastern Region, Beausejour
GORHAM, Keith	Planning & Tech. Serv. Officer	SDPRR, FFCB, Prince Albert
HELD, Isser	Meteorologist	AES, PRWC, Winnipeg
HENRY, Dale	Regional Chief-Weather Services	AES, Central Region, Winnipeg
HIRSCH, Kelvin	Fire Research Officer	CFS, District Office, Winnipeg
HOLDHAM, Doug	Meteorologist	AES, PRWC, Winnipeg
HUCK, Bob	Fire Control Officer	MDNR, NW Region, The Pas
JANZ, Ben	Fire Weather Supervisor	AFS, Fire Weather Section, Edmonton
KELLER, Walter	Fire Control Officer	MDNR, NE Region, Thompson
KLAPONSKI, Carol	Chief Meteorologist	AES, Central Region, Winnipeg
LAWSON, Bevan	Meteorologist	AES, PRWC, Winnipeg
LEGAL, Louis	Supervising Meteorologist	AES, PRWC, Winnipeg
MacDONALD, Brian	Warden Services Officer	Parks Canada, Prairie Reg., Winnipeg
MACHNEE, Gerald	Meteorologist	AES, PRWC, Winnipeg
MARCHANT, Tom	Fire Control Officer	MDNR, Interlake Region, Gimli
MARTELL, Dave	Associate Professor	Univ. of Toronto - Forestry Faculty
McALPINE, Rob	Fire Research Officer	CFS, NoFRC, Edmonton
MELNICK, Ken	Fire Ranger	MDNR, NW Region, Snow Lake
NIMCHUK, Nick	Meteorologist	AFS, Fire Weather Section, Edmonton
PIERCE, Marv	Officer-in-Charge	AES, WWO, Winnipeg
RADDATZ, Rick	Sci. Serv. Meteorologist	AES, Central Region, Winnipeg
ROUTLEDGE, Heather	Meteorologist	AES, PRWC, Winnipeg
RUSSELL, Art	Forestry Focal Pt. Forecaster	AES, OWC, Toronto
SCHAEFER, Garry	Chief-Scientific Services	AES, Central Region, Winnipeg
SCHAFER, David	Fire Ranger	MDNR, Eastern Region, Lac Du Bonnet
SENCHUK, Ed	Fire Control Officer	MDNR, Western Region, Swan River
SHIPLEY, Bill	Fire Management Officer	MDNR, FM&C, Winnipeg
VANDEVYERE, Danny	Meteorologist	AES, PRWC, Winnipeg
WHITE, Dick	Fire Operations Officer	OMNR, A&FMC, Sault Ste. Marie

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[1] **ABBREVIATIONS:** CFS = Canadian Forestry Service; NoFRC = Northern Forest Research Centre; AES = Atmospheric Environment Service; CIFFC = Canadian Interagency Forest Fire Centre; MDNR = Manitoba Department of Natural Resources; SDPRR = Saskatchewan Department of Parks and Renewable Resources; PRWC = Prairie Weather Centre; AFS = Alberta Forest Service; WWO = Winnipeg Weather Office; OWC = Ontario Weather Centre; FM&C = Fire Management and Communications section; OMNR = Ontario Ministry of Natural Resources; and A&FMC = Aviation and Fire Management Centre.

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PROCEEDINGS OF THE SECOND CENTRAL REGION FIRE WEATHER COMMITTEE SCIENTIFIC AND TECHNICAL SEMINAR - April 17,1985, Winnipeg, Manitoba