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DROUGHT PERSISTENCE AT FORESTED CANADIAN STATIONS

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1. Introduction

During a study of the relationship between various meteorological variables and the area burned by wildfire on a monthly, provincial basis (Flannigan and Harrington, 1987), it was discovered that area burned was significantly correlated with the duration of dry spells but uncorrelated with rain amount. We decided, therefore, to conduct a statistical analysis of the duration of dry spells at forested stations in Canada with an eye to predicting the return periods of those long spells associated with bad fire years.

The voluminous literature on the probability of sequences of rain days or dry days will be reviewed in a subsequent paper. Here we will give an abbreviated report on our approach and on significant findings.

The pioneering work in this area was performed by E.V. Newnham (1916) who showed that the probabilities of rain or no-rain days were not constants, but depended on the condition on the previous day. For example, the probability of rain after a dry day at Aberdeen, Scotland was 0.50, but increased to 0.67 if the previous day were wet. He showed that for some stations the probability became still higher if the previous two or three days were wet. At Aberdeen, for example, the probability of rain after two rain days rose to 0.70 and after three to 0.76, thereafter remaining constant.

Persistence can be taken into account in the case of rare events by modifying the Poisson series in a manner demonstrated by Eggenberger and Polya (1923). Their distribution allows the mean to slowly increase throughout the series. As will be seen further along in this paper, a gradual increase in probability with increasing duration of a dry spell would help to explain the observed increase in transitional probabilities observed in much of our data; however, the Eggenberger-Polya distribution fails to provide a good fit to the data where the occurrence of sequences are not rare events.

Williams (1947) found that a logarithmic series conformed closely to the distribution of dry day sequences but not of wet day sequences. A glance at his curves showed that even for the dry day sequences the fit became poor when the sequences became long.

Markov chain* models were first used in estimating the distribution of wet and dry day sequences by Gabriel and Neumann (1957, 1962). They were able to show that a first order Markov chain adequately described the distribution of sequences of wet and dry days during the rainy season in Tel Aviv, but failed for dry day sequences in the summer dry season.

Berger and Goossens (1983) compared the adequacy of a number of models in describing the distribution of dry day sequences at Uccle in Belgium. The models tested were; the modified Poisson series of Eggenberger and Polya (1923), the logarithmic series of Williams (1947), a geometric series of Neumann (1955), a Markov chain model as described by Erikson (1965), and a modified Markov chain model derived by Dingens, et al. (1970). They found that the Dingens model produced the best fit but that it did not significantly improve on the simple Markov chain model. They proceeded to determine the most appropriate order of the best fitting Markov chain for various stations in Belgium (Goossens and Berger, 1984).

Chin (1977) applied a Markov chain model to precipitation records at a representative sample of stations across the United States. He divided the year into winter and summer seasons, generally finding that the best fit to the data required a Markov chain of order one in winter and two in summer.

We applied the same methods used by Berger and Goossens (1983) to 28 years of data taken during the forest fire season, April to September, from 41 stations located in the forested region of Canada. Our data differed slightly, because our definition of a rain day was one in which 1.5 mm or more precipitation fell within 24 hours; whereas, other authors used a threshold value of 0.25 mm. The higher threshold is more appropriate when considering the effect on area burned (Flannigan and Harrington, 1987) but results in a higher frequency of long dry spells.

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* A first order Markov chain is one in which the probability of occurrence of a dry day, for example, is dependent only upon whether the previous day were wet or dry. A second order Markov chain is one in which two previous days must be considered.

Table 1. The order of the Erickson and Dingens Markov chain models achieving the best fit to the distribution of sequence of dry days using a X^2 test of significance.

Station	Erickson		Dingens	
	Order	Signif.	Order	Signif.
B.C.				
Victoria	4	.70	8	.98
Fort Nelson	2	.99	2	.99
Cranbrook	6	.90	8	.98
Smithers	4	.90	5	.98
Williams Lake	2	.99	2	.99
Yukon-NWT				
Yellowknife	2	.99	2	.99
Dawson	2	.90	5	.98
Fort Simpson	1	.95	2	.98
Whitehorse	4	.95	4	.99
Fort Smith	2	.99	2	.99
Alberta				
Whitecourt	2	.99	2	.99
Slave Lake	2	.90	7	.98
Rocky Mtn. House	2	.99	2	.99
Fort McMurray	2	.90	2	.90
Saskatchewan				
Cold Lake	2	.95	2	.95
N. Battleford	2	.95	2	.95
Hudson Bay	3	.99	3	.99
Prince Albert	5	.95	7	.99
Manitoba				
Winnipeg	1	.99	2	.99
Bisset	5	.99	3	.99
The Pas	1	.99	2	.99
Dauphin	1	.99	2	.99
Thompson	2	.99	2	.99
Western Ontario				
Lansdowne House	1	.98	3	.95
Kenora	1	.99	2	.99
Sioux Lockout	5	.95	5	.98
Armstrong	1	.99	2	.99
Thunder Bay	1	.99	2	.99
Eastern Ontario				
Earlton	1	.99	2	.99
Kapuskasing	1	.99	2	.99
Timmins	1	.99	2	.99
Petawawa	1	.99	2	.99
Muskoka	1	.99	2	.99
Quebec				
Maniwaki	1	.99	2	.99
Roberval	1	.99	2	.99
Val D'Or	1	.99	2	.99
Atlantic Provinces				
Charlottetown	2	.99	2	.99
Gander	2	.99	2	.99
Goose Bay	1	.98	2	.98
Fredericton	2	.99	2	.99
Truro	2	.99	2	.99

Our results were similar to those of Berger and Goossens (1983) in that the Dingens model achieved the best fit overall, but required higher orders than the Erickson model, Table 1. The order of the Markov chain (Erickson model) is high on the west coast, decreasing to two over the prairies, to one over Ontario and Quebec and rising to two again over the Atlantic provinces. This pattern conforms to that found by Lowry and Guthrie (1968) and Mimikou (1984) who show that the order of a Markov process increases as the probability of occurrence increases. On the west coast the probability of a dry day is high because of the influence of the Pacific high pressure area, Fig. 1. As we proceed eastward in Canada the chance of summer rainfall increases and the order decreases, except on the east coast where cool Atlantic waters dampen convective activity and reduce summer precipitation.

The frequency with which dry spells occur declines somewhat logarithmically with spell duration as noted by Williams (1947). The data for North Battleford, Saskatchewan, shown in Fig. 2, are typical of those at most Canadian stations. The frequency of occurrence of a day without rain does decrease semi-logarithmically during the first week, but then decreases more slowly, until it trails off into a long tail. The observations for North Battleford and for most Canadian stations conform to the description of summer dry spells at Tel Aviv as described by Gabriel and Neumann (1957). A simple Markov chain fits the bulk of the data extremely well, as shown by the good X^2 fit of Table 1, but fails to explain the frequency of the long dry spells which are of such concern with respect to area burned by forest fires.

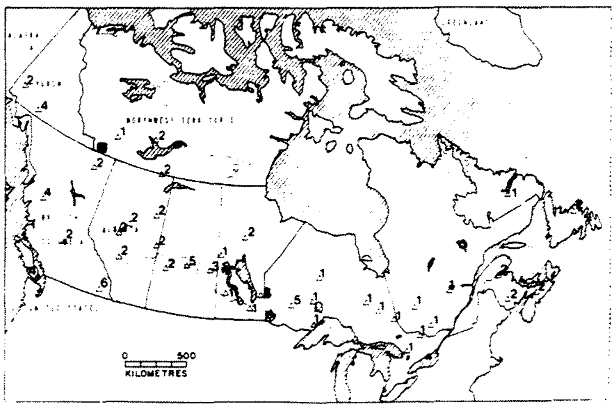

Fig. 1. The order of the Markov chain providing the best fit to the frequency distribution of sequences of dry days at forested stations in Canada.

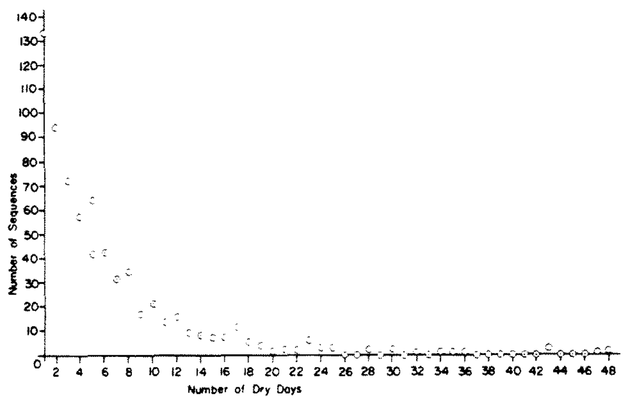

Fig. 2. The frequency of occurrence of sequences of dry days for the period 1953-1980 during April to September at North Battleford, Saskatchewan. (A dry day is defined as one with less than 1.5 mm of precipitation.).

The lack of fit in the tails of the distributions is illustrated more clearly by examining the conditional probabilities, Fig. 3. Here we see a curve which at first appears to follow a second or third order Markov process but then begins an almost linear increase toward a higher plateau. The level of the higher plateau is not clear from our data because the record becomes erratic where the observations are too scattered.

To summarize: although Markov chain distributions fit most dry day sequences accurately over the bulk of the data points, they failed to fit the tails of the distribution and, therefore, failed to predict the occurrence of the long dry spells of significance in bad fire years. At Tel Aviv the same problem was attributed to the higher probability of drought during the Mediterranean summer. In Canada, it is proposed that the tail of the distribution may be caused by the occurrence of blocking ridges in the Westerlies. Preliminary analyses using two probabilities, one for normal weather sequences and a second for periods during 'blocking', appear to explain the tail of the data more successfully. Research is continuing along this line of investigation.

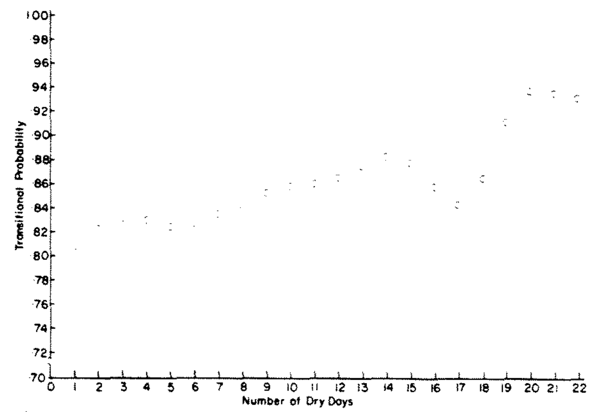

Fig. 3. The transitional probability of an additional dry day after a sequence of dry days. The transitional probabilities were computed from the original data after smoothing by a five point binomial smoothing function operating on the logarithms of the frequencies.

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