

**PROCEEDINGS
OF THE
SEVENTH CENTRAL REGION FIRE WEATHER COMMITTEE
SCIENTIFIC AND TECHNICAL SEMINAR**

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Compiled and Edited

by

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Front Cover: Initial attack times map calculated by the
Intelligent Fire Management Information System
(IFMIS) for the Prince Albert Region, Saskatchewan
on July 14, 1989 (provided by K.R. Anderson).

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 Forestry Canada (formerly the Canadian Forestry Service) in provision of fire weather forecasts, fire danger forecasts, and other weather-related services to the various fire control agencies in Canada. Briefly, this policy gives AES the responsibility of providing current and forecast fire weather and fire danger indexes in accordance with the needs of fire control agencies. The Forestry Canada role is that of research and development of improved fire weather indices, research on fire behavior relationships with weather factors, and cooperation with AES in preparation of training aids and manuals. Both AES and Forestry Canada share the responsibility of improving meteorological services for fire control in Canada.

In 1976, six regional committees were formed to facilitate the implementation of the DOE Policy on Meteorological Services for Forest Fire Control. These committees were aligned on the basis of the existing AES administrative boundaries, namely: 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). The original "charter" for these regional fire weather committees was stated as follows.

Membership: 1 or more AES representatives designated by AES Regional Director; 1 or more Forestry Canada representatives designated by Forestry Canada 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 Forestry Canada) 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.

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 subsection (a);

- (c) monitoring the program and implementing changes, as required;
- (d) coordinating with the Development Committee; and
- (e) referring to the Development Committee the recommendations that 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. This is to be done through contacts at the technical level between representatives of the fire management agencies and research and development officers of AES and Forestry Canada as well as operational supervisors in the AES field establishments.

It is also worth noting that the original DOE policy as established in 1976 is currently under review. In recent years AES, and to some extent Forestry Canada, have begun to review the fire weather related services they provide to the fire management agencies in Canada. This has resulted from a number of changes in internal policy (such as cost recovery of "non-essential" services by AES) and has necessitated the development of an official policy on Meteorological Services for Forest Fire Management. Such a policy is expected to be completed in the near future.

INTRODUCTION

The Central Region Fire Weather Committee (CRFWC) currently holds two meetings each year. Annual business meetings, which started in 1976, are usually held between the months of November and January while the Technical Sub-Committee, formed in 1983, meets in April. CRFWC member agencies currently include:

- Atmospheric Environment Service, Prairie Region,
- Canadian Parks Service, Prairie and Northern Region,
- Forestry Canada, Northwest Region,
- Manitoba Natural Resources,
- Ontario Ministry of Natural Resources (Sub-Committee participants only), and
- Saskatchewan Parks and Renewable Resources.

In conjunction with the Technical Sub-Committee meeting, which has always been held in Winnipeg, a half-day Scientific and Technical Seminar is usually conducted. The purpose of these seminars is to "provide opportunity for the presentation and discussion of scientific and technical papers on subjects relating to forest fire meteorology in the region". Normally 4 or 5 presentations are made at each seminar and though the topics have been very diverse, attempts have always been made to obtain a balance in the program between fire and meteorological oriented subjects as well as between operational and research topics. A listing of the presentations from the previous six seminars is located at the back of this document.

The CRFWC seminar series has proven to be an excellent forum for the exchange of information and ideas on current and/or timely fire weather related topics. It has attempted to enhance the operational programs of the member agencies of the CRFWC and its future success will continue to rely on the direct and indirect support provided by each agency.

The assistance of D. Vandevyvere and R. Raddatz (AES) with local arrangements and K.G. Hirsch (Forestry Canada) for facilitating the presentations is gratefully acknowledged. Finally, a special word of thanks is extended to all of the presenters for participating in the seventh CRFWC seminar and making it a success.

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SEASONAL TRENDS IN THE DROUGHT CODE COMPONENT OF THE CANADIAN FOREST FIRE WEATHER INDEX SYSTEM^{1,2}

by

R.S. McAlpine³

Introduction

The Drought Code (DC) component of the Canadian Forest Fire Weather Index (FWI) System is an indicator of the moisture content of deep organic layers, large downed wood, and the availability of water in small streams and swamps (Van Wagner 1987). A reduction in the moisture content of these deep organic layers aggravates problems experienced in forest fire containment and extinguishment; fires burn deeper and with greater vigour simply because more fuel is available for combustion (Alexander 1983). While the other moisture codes of the FWI System address fuels influenced by more recent past weather (timelags⁴ of 2/3 of a day for the Fine Fuel Moisture Code (FFMC) and 12 days for the Duff Moisture Code (DMC)) (Van Wagner 1987), only the DC, with a timelag of 52 days is an indicator of potential long term drought.

Historically the DC is a descendant of the Stored Moisture Index (SMI) designed to "take into account the drying pattern over the entire season" (Turner 1966). Turner suggested that, as an aid to interpreting SMI values, the current year's SMI values should be plotted on a graph with SMI values of one recent wet year and one dry year. The intention was to give the fire manager some reference to interpret the daily index value. This concept was not included in subsequent documentation of DC development (Turner 1972, Van Wagner 1987). Muraro and Lawson (1970) did, however, compare observed SMI values with a recent dry year to "red flag" a potential problem situation. Nikleva (1973) explored the DC

¹ Presentation made at the Seventh Central Region Fire Weather Committee Scientific and Technical Seminar, April 4, 1990, Winnipeg, Manitoba.

² This paper is also published as a Forestry Canada Information Report (PI-X-97E/F) by the Petawawa National Forestry Institute.

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⁴ Timelag is defined as "The drying time under stated conditions of temperature, relative humidity, wind speed, and time of the year required for dead fuels to lose about two-thirds (2/3) of the difference between their initial moisture content and their equilibrium moisture content".

climatology for Prince George, B.C. thoroughly by providing a 10-year average seasonal DC graph with the driest and wettest years for the period. In fact, Nikleva (1973) examined seasonal trends for all codes and indexes of the FWI System. However, only the DC showed a consistent seasonal trend, a steady rise in DC values over the fire season peaking in August with a slight decline in September.

Over the course of a fire season all fire weather stations in Canada experience comparable trends in DC values (Harrington et al. 1983, Nikleva 1973). The actual DC value on any particular date can vary greatly from station to station across the country due to differences in annual precipitation and temperature. This seasonal trend, however, regardless of actual DC values, is representative for most, if not all, Canadian fire weather stations.

The present report documents the annual trend in DC values for selected fire weather stations in Canada and gives information on the variability of the DC values from year to year. The graphs are intended to give fire managers a better idea of how their current DC values compare with historical averages, and help to indicate potential problem situations.

Background to the Drought Code

Complete background information on the development, structure, and application of the DC is contained elsewhere (Turner 1972, Turner and Lawson 1978, Alexander 1982, Van Wagner 1987). Following is a brief account of the development to provide perspective for the application suggested here.

The SMI, predecessor to the DC, provided an estimate of the moisture content of the soil with higher numbers indicating wetter soil conditions (Turner 1966, 1972). The scale for the SMI ranged from 0 to 800, with each unit change representing 0.01 inches of available water. The maximum value of 800 thus represents eight inches of available water held in the soil. The basis for the SMI (and hence the DC) is simply to keep a budget of stored moisture, accounting for losses and gains. Moisture losses are the result of evaporation and transpiration, while precipitation accounts for moisture gains. Total precipitation in the equations for the DC is reduced by 2.8 mm per 24 h period to allow for canopy and surface fuel interception (Turner 1966, 1972). Evaporation and transpiration losses are first estimated as a maximum potential evapotranspiration based on temperature (to establish evapotranspiration rate) and date (to allow for day length influence). Secondly, this maximum potential evapotranspiration value is scaled by the available soil moisture to reflect the fact that as soil moisture contents are reduced (below saturation) moisture is increasingly difficult to remove from the soil (Turner 1966, 1972).

Conversion of the original SMI, for inclusion in the FWI System as the DC, involved reversing the scale so that higher DC values indicated dryer conditions (rather than vice versa) and adjusting the required daily maximum temperature to the FWI System standard noon local standard time (Turner 1972). Finally, a standardized overwinter adjustment methodology, to allow for the carry over of drought conditions from year to year, was adopted (Turner and Lawson 1978, Van Wagner 1987).

Methods

Fire weather data from 35 Atmospheric Environment Service (AES) weather stations (Figure 1 and Appendix A) for the period 1953-1980 were available from a past study (Harrington et al 1983). These data were augmented with recent weather data to cover the period 1953-1987 (35 years). For each station DC values were computed for each day throughout the fire season⁵ for all 35 years.

The resulting DC values were analyzed to derive the daily mean and standard deviation. The mean daily DC values were then plotted (with the means + 1 s.d. and the means - 1 s.d.) for the fire season for each of the 35 weather stations. Average monthly DC values during the fire season for each fire weather station were plotted, with the weather stations organized in a roughly west to east orientation to determine geographical trends.

Generally, weather stations in Canada receive enough overwinter precipitation to start the DC at the normal spring starting value of 15 (Turner and Lawson 1978, Alexander 1982). Because it is normal to assume a DC starting value of 15 and because there was insufficient data to adjust the DC starting value for overwinter drought, no overwinter carryover of drought conditions were made for the daily DC calculations.

Results and Discussions

Appendix B shows the mean daily DC values over the course of the fire season for the selected weather stations. The general trend seen in each case is a slowly rising DC value, peaking in mid- to late August and then either declining or maintaining the same value. In a few cases the DC values continued to rise in the latter part of the fire season, but these values increased at a reduced rate. This reduced rate of increase in the late season is due to the reduced day length affecting the DC drying phase and is not a function of seasonal precipitation. While there are variations in precipitation amounts for specific locations on a monthly basis, rainfall amount in September generally does not

⁵ For the purpose of this report, the fire season was assumed to start on April 1 and end on September 30. While specific years or locations might require different start and end dates, the dates used cover the average fire season for most parts of Canada.



Figure 1. Map of Canada showing AES weather stations used for this study./
Répartition des stations météorologiques canadiennes du SEA sur lesquelles se fonde la présente étude.

exceed that of August.

Appendix C shows the geographical trend in DC values roughly west to east. The Victoria weather station exhibits the highest DC values throughout the season. The interior of British Columbia, in general, has comparatively high DC values followed by a drop in these values on the lee side of the continental divide. The central plains again have comparatively high DC values with the values slowly dropping to the east coast. These geographical trends are reflected in the mean monthly rainfall patterns documented by the Climatic Atlas of Canada (Anon. 1986). Thus, consistently low summer rainfall in southeast Vancouver Island and in the interior of British Columbia results in high DC values. The east face of the Rocky Mountains has comparatively low DC values due to greater amounts of summertime precipitation, often caused by rainy cyclonic systems during the summer (Hare and Thomas 1972). The central prairies have relatively low summer precipitation, which leads to high DC values. Ontario and Quebec are prone to precipitation from storms which frequently track through the region. The Atlantic provinces are affected by the ocean and are prone to receive precipitation from hurricane remnants moving up the coast (Hare and Thomas 1972) as well as extratropical (synoptic) systems.

Canada has more than 1000 fire weather stations, making it difficult to analyze the present weather data of seasonal DC trends for all stations. From graphs of the variation of monthly DC value with geographical location (Appendix C), it is apparent that there is usually little variation among nearby weather stations. However, this does not hold true when an intervening physical land feature affects weather patterns. The local similarity of mean DC values allows fire weather stations not referred to in this report to use the graphs of an available nearby weather station to characterize the local DC seasonal trend. Sufficient accuracy can be obtained by using a station within the region to indicate how the current DC value compares with the long term trend.

The two dotted lines on plots in Appendix B illustrate the mean DC plus and minus one standard deviation. These lines indicate the variability of calculated DC values over the 35-year period. While it is unlikely that observed DC values will precisely follow the plotted mean DC line, 2/3 of all observed DC values will fall within the area between the upper and lower standard deviation lines. It is expected that many years will have values above or below the mean DC line and that, on average, one of every six years will be above the upper or below the lower standard deviation line. The farther above the upper deviation line that the observed DC value falls, the more unusual the situation (one in 10 years, one in 20 years, etc.). If an extreme deviation occurs early in the fire season, and the trend continues, it may herald a midsummer drought. (The deviation from normal at the beginning of the fire season may not be high compared to readings later in the summer). Also plotted on the graphs in Appendix B are the maximum computed DC values for the weather stations observed during the 35-

year period. These lines should give fire managers a further benchmark from which to gauge current values.

Overwinter adjustment of the DC starting value would cause observed springtime DC values to exceed the maximum values calculated in this paper. This high DC value will be carried forward until a heavy precipitation event brings about more normal values. This is in fact a true representation of field conditions in the spring. Figure 2 documents an example of an overwinter adjusted DC which falls back into more seasonable values at the beginning of June when sufficient rainfall (in this case 95.1 mm over 9 days) depresses the DC.

Strong seasonal trends in the DC preclude the use of a categorization scheme (Stocks 1974) to define low, medium, high, etc. categories. For example, a DC value of 275 on May 7 should be interpreted very differently from the same value on August 29, while the category rating would remain unchanged.

Interpretation of specific DC values for fire behavior use is not dependent on the particular date. Thus an observed DC value of 200 in June is interpreted, from a fire behavior standpoint, similarly to a DC of 200 in August. Other date-dependent factors not addressed by the DC may have a significant influence on fire behavior (for example, leaf flush, succulent vegetation development, leaf drop) but for the purposes of the DC the value is the same.

Summary

The DC component of the FWI System is an indicator of long term drought. It is not as influenced by day to day weather patterns to the same extent as other components of the FWI System; instead it shows definite seasonal trends influenced by the climate of a region. The seasonal trend in DC values precludes the use of danger classes for the DC; a single value early in the spring, while being very high for that time of the year, may only fall into a midrange of the whole season. The graphs of seasonal trends presented can be used to determine how the observed DC values compare with the last 35 years of DC values for the station. Unusually dry (or wet) years will show up as being above (or below) the one standard deviation line. Although the over 1000 fire weather stations in Canada could not be presented in this report, the difference in DC values and trends between neighbouring weather stations is minor in most cases and allows regions with several weather stations to be characterized with the single graph from a representative weather station. Overwinter adjustment of the DC (Turner and Lawson 1978, Alexander 1982), which brings forward a high springtime DC value, will show up on the graphs as unseasonably dry, and this is a true representation of field conditions.

Drought Code / Indice de sécheresse

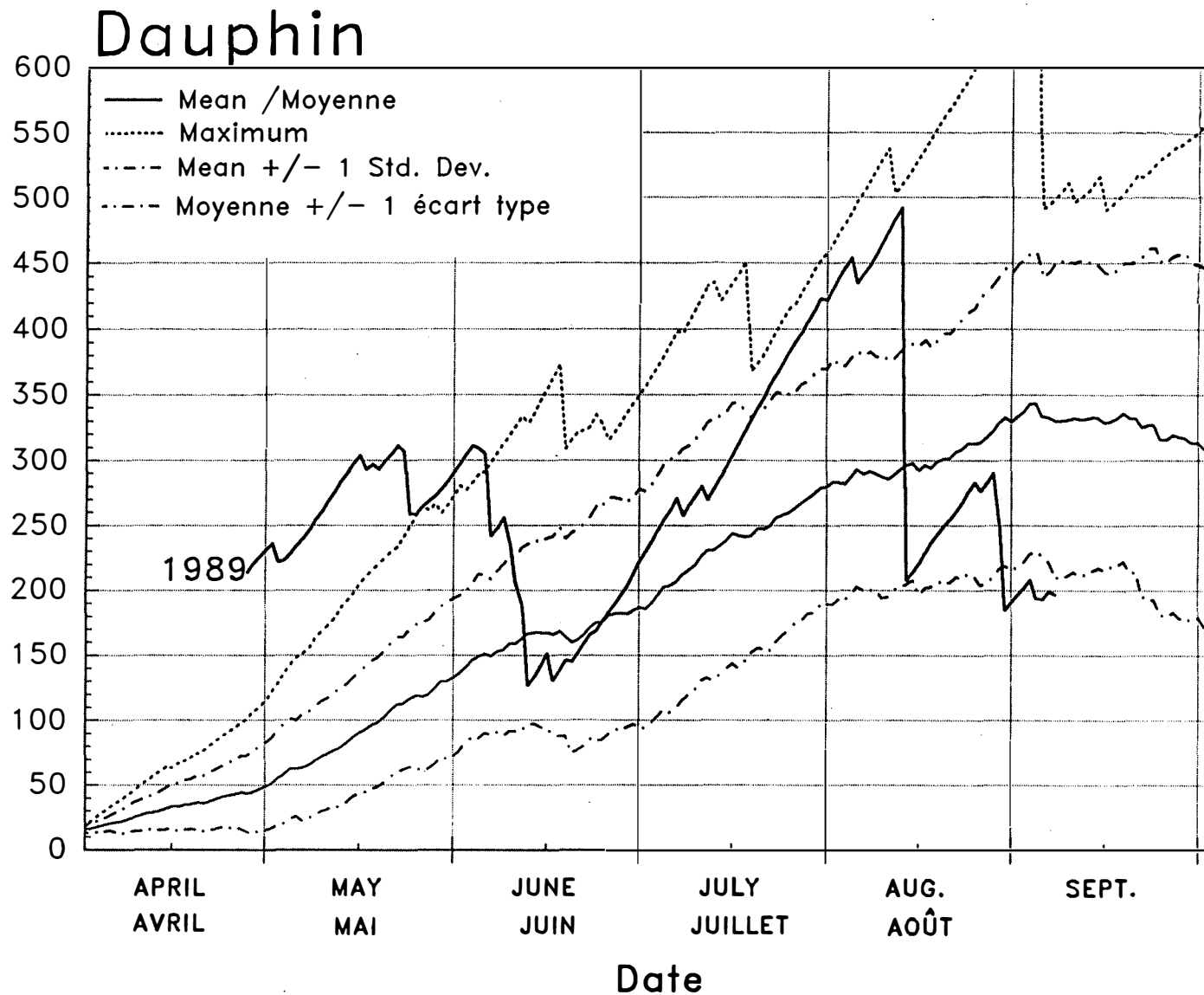


Figure 2. Dauphin, Manitoba, 1989. The overwinter adjusted DC value received sufficient precipitation to depress it into the average range, but unseasonably hot dry weather throughout July raised the DC well above average by early August.

Dauphin (Manitoba), 1989. L'indice corrigé de sécheresse, pour tenir compte de l'effet de l'hiver, est abaissé en raison de précipitations suffisantes qui le ramènent dans l'intervalle des moyennes, mais le temps exceptionnellement chaud et sec de juillet le relève bien au-dessus de la moyenne dès le début d'août.

References

- Alexander, M.E. 1982. Calculating spring Drought Code starting values in the prairie provinces and Northwest Territories. Environ. Can., Can. For. Serv., Northern For. Res. Centre, Edmonton, Alta. Forest Manage. Note No. 12.
- Alexander, M.E. 1983. Tables for determining spring Drought Code starting values in west-central and Northern Canada. Environ. Can., Can. For. Serv., Northern For. Res. Centre, Edmonton, Alta. Forest Manage. Note No. 19.
- Anonymous. 1986. Climatic atlas climatique - Canada: a series of maps portraying Canada's climate. Map series 2-precipitation. Environ. Can., Atmos. Environ. Serv. Can., Ottawa.
- Hare, F.K.; Thomas, M.K. 1974. Climate Canada. Wiley Publ., Toronto, Ontario.
- Harrington, J.B.; Flannigan, M.D.; Van Wagner, C.E. 1983. Study of the relation of components of the Fire Weather Index to monthly provincial area burned by wildfire in Canada, 1953-80. Environ. Can., Can. For. Serv., Petawawa Natl. For. Inst., Ont. Inf. Rep. PI-X-25.
- Merrill, D.F.; Alexander, M.E. eds. 1987. Glossary of forest fire management terms. Fourth edition. Natl. Research Counc. Can., Can. Comm. For. Fire Manage., Ottawa, Ont. Publ. No. NRCC 26516.
- Muraro, S.J.; Lawson, B.D. 1970. Prediction of duff moisture distribution for prescribed burning. Can. Dep. Fish. and For., Can. For. Serv., Pacific For. Res. Centre, Victoria, B.C. Inf. Rep. BC-X-46.
- Nikleva, S. 1973. Fire Weather Index climatology for Prince George, B.C. Environ. Can., Atmos. Environ. Serv., Pacific Reg., Vancouver, B.C.
- Stocks, B.J. 1974. Wildfires and the Fire Weather Index System in Ontario. Environ. Can., Can. For. Serv., Great Lakes Forest Res. Centre, Sault Ste. Marie, Ontario. Inf. Rep. 0-X-213.
- Turner, J.A. 1966. The stored moisture index / A guide to slash burning. British Columbia Forest Serv., Protection Div.
- Turner, J.A. 1972. Drought Code component of the Canadian Forest Fire Behavior System. Environ. Can., Can. For. Serv., Ottawa, Ont. Publ. No. 1316.
- Turner, J.A.; Lawson, B.D. 1978. Weather in the Canadian Forest Fire Danger Rating System: a user guide to national standards and practices. Environ. Can., Can. For. Serv., Pacific For. Res. Centre, Victoria, B.C. Inf. Rep. BC-X-177.

Van Wagner, C.E. 1987. Development and structure of the Canadian Forest Fire Weather Index System. Can. For. Serv., Ottawa, Ont. For. Tech. Rep. 35.

Appendix A

Details of Weather Station operation by region (from
Harrington et al. 1983)

British Columbia

Victoria
Smithers
Fort Nelson
Williams Lake
Kimberley-Cranbrook (1953-69 from Kimberley
1970-87 from Cranbrook)

Yukon - NWT

Whitehorse
Yellowknife
Fort Smith
Dawson-Burwash (1953-66 from Dawson
1967-87 from Burwash)

Alberta

Rocky Mountain House
Fort McMurray
Wagner-Slave Lake (1953-71 from Wagner
1972-87 from Slave Lake)
Whitecourt

Saskatchewan

Cold Lake
North Battleford
Prince Albert
Hudson Bay

Manitoba

Winnipeg
Gimli-Bisset (1953-68 from Gimli
1969-87 from Bisset)
The Pas
Dauphin
Wabowden-Thompson (1953-70 from Wabowden
1971-87 from Bisset)

Western Ontario

Kenora
Sioux Lookout
Thunder Bay

Appendix A (cont)

Eastern Ontario

Earlton
Kapuskasing
Timmins
Muskoka

Quebec

Bagotville-Roberval (1953-56 from Bagotville
1957-87 from Roberval)
Val d'or

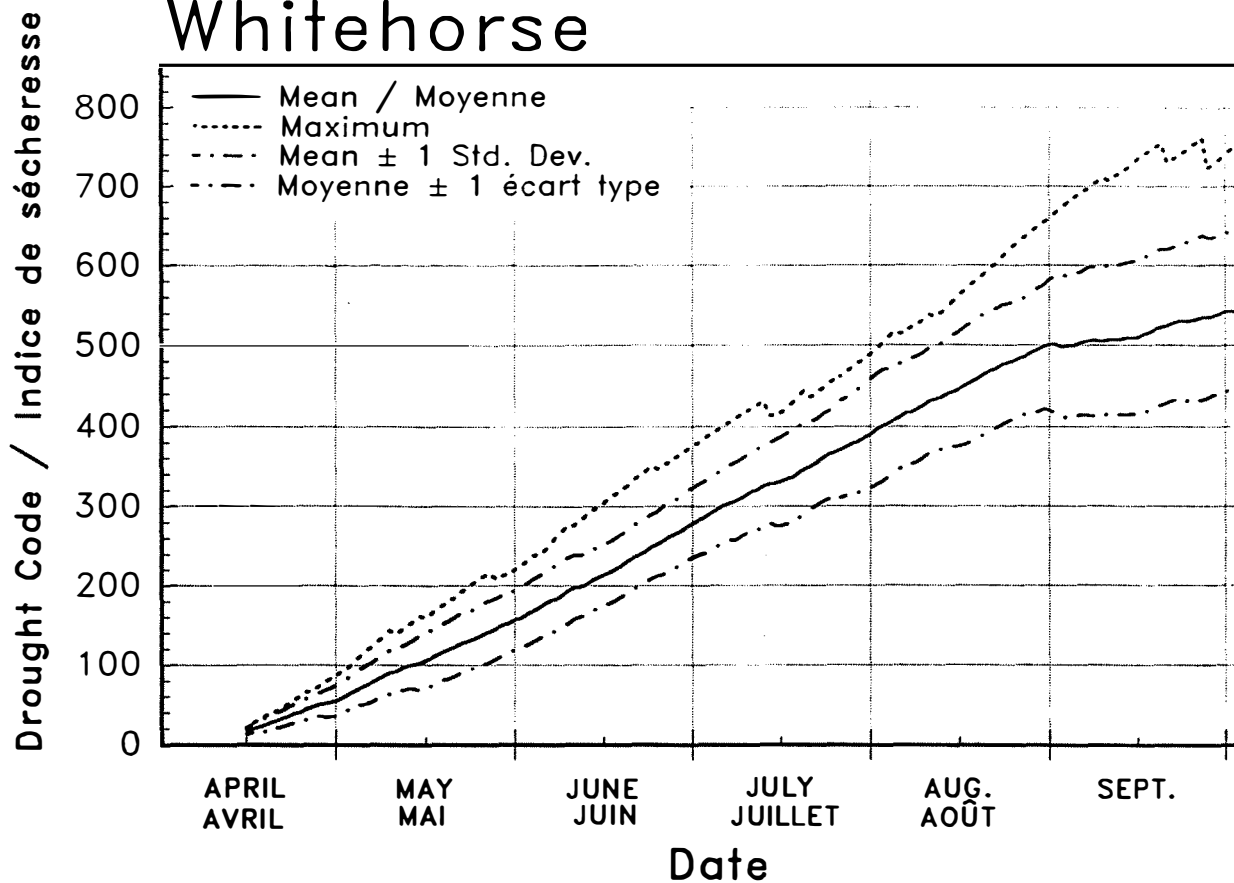
Atlantic Provinces

Campbellton-Charlo (1953-66 from Campbellton
1967-87 from Charlo)
Gander
Goose Bay
Fredericton

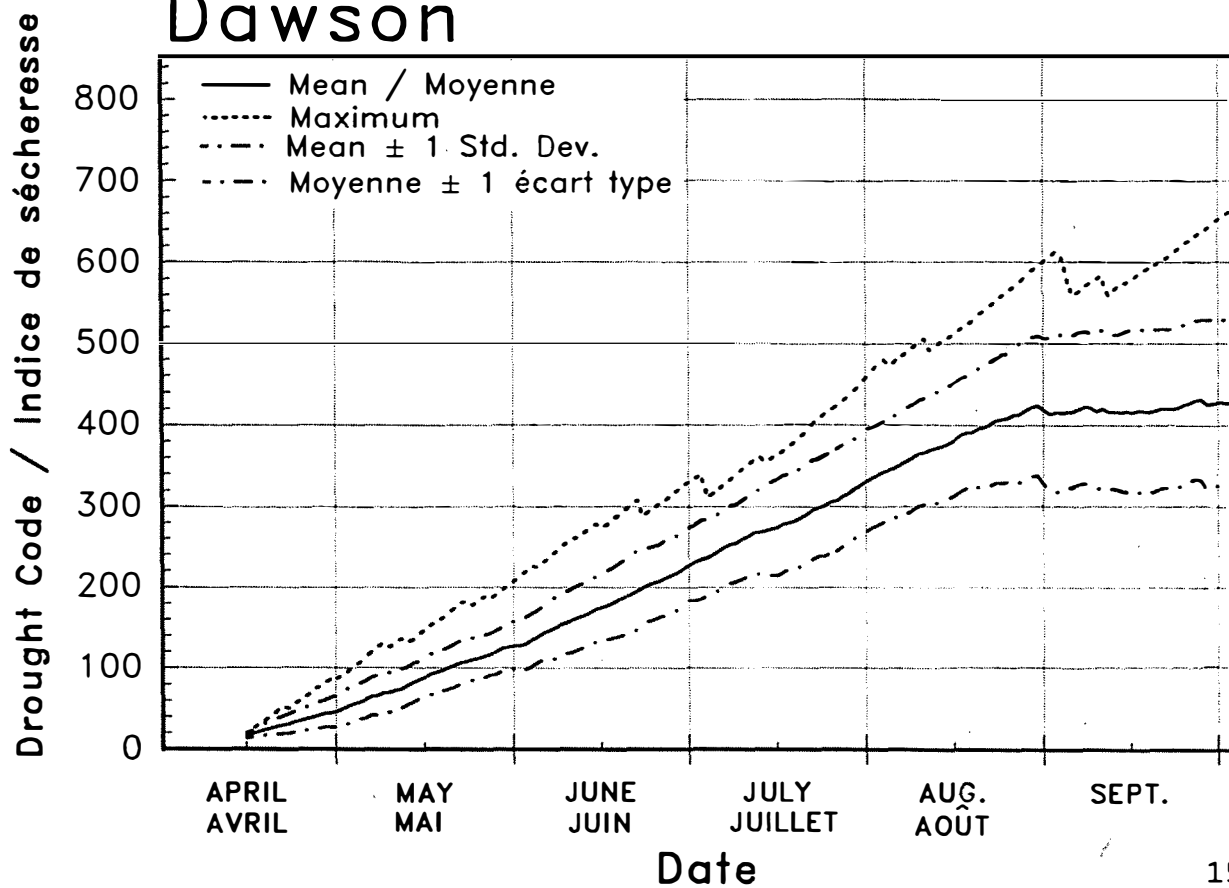
Appendix B

Weather Station DC trends by region

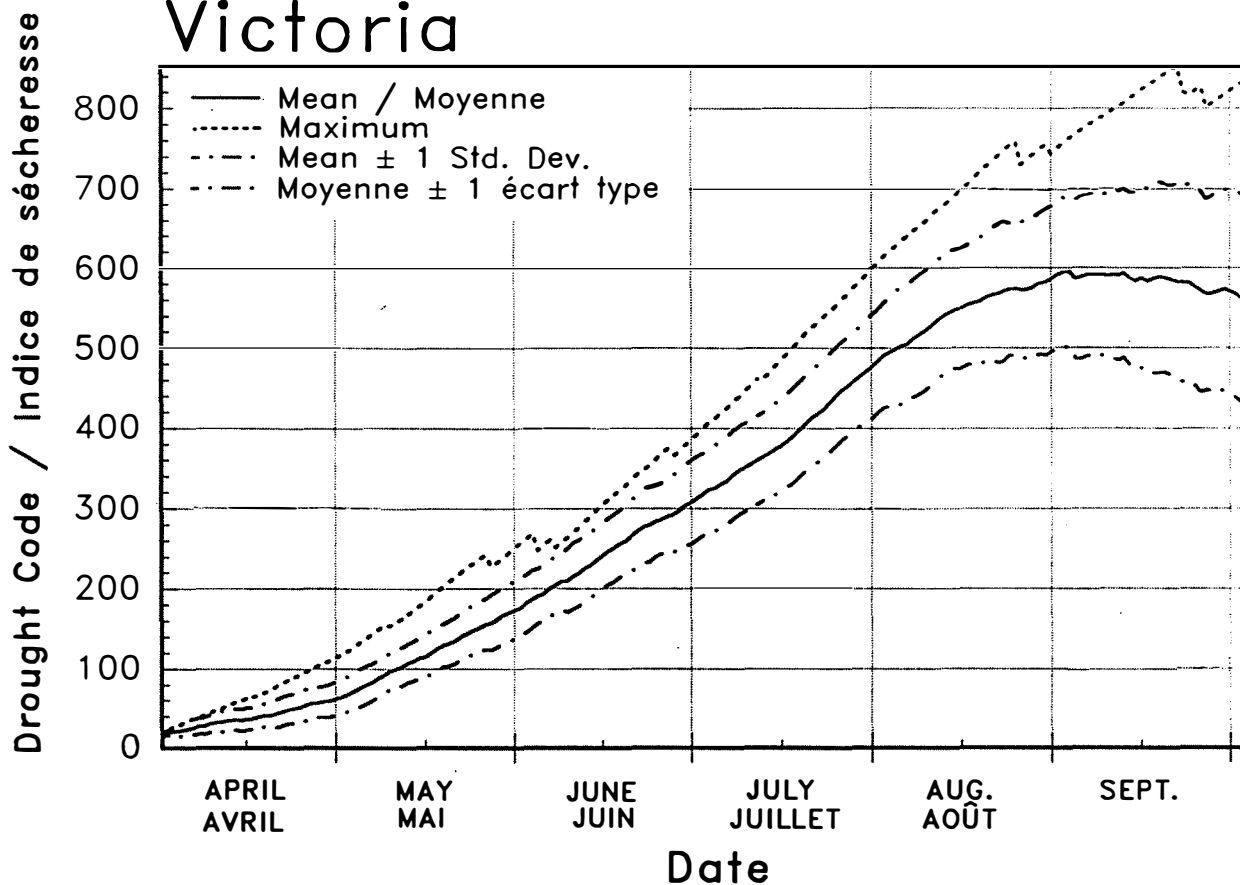
Whitehorse



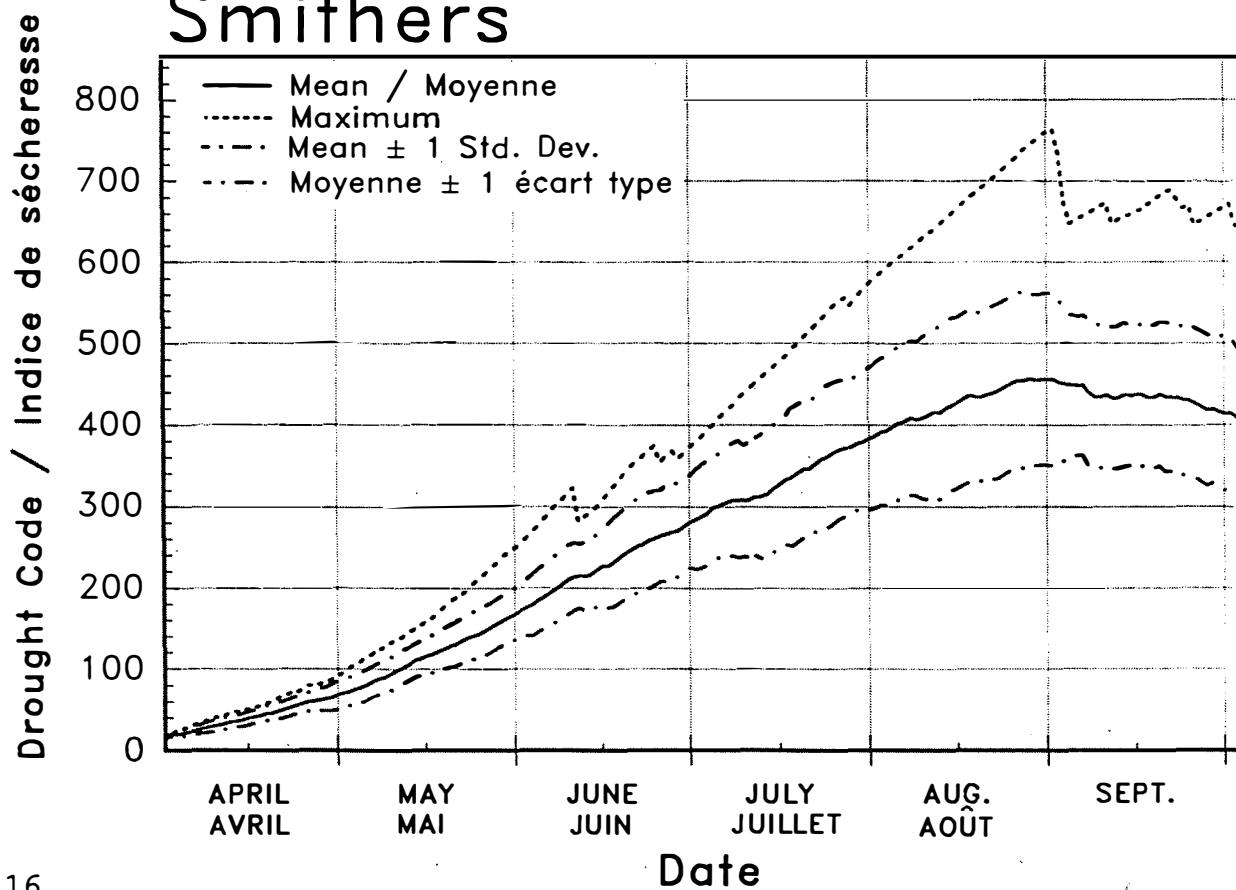
Dawson



Victoria

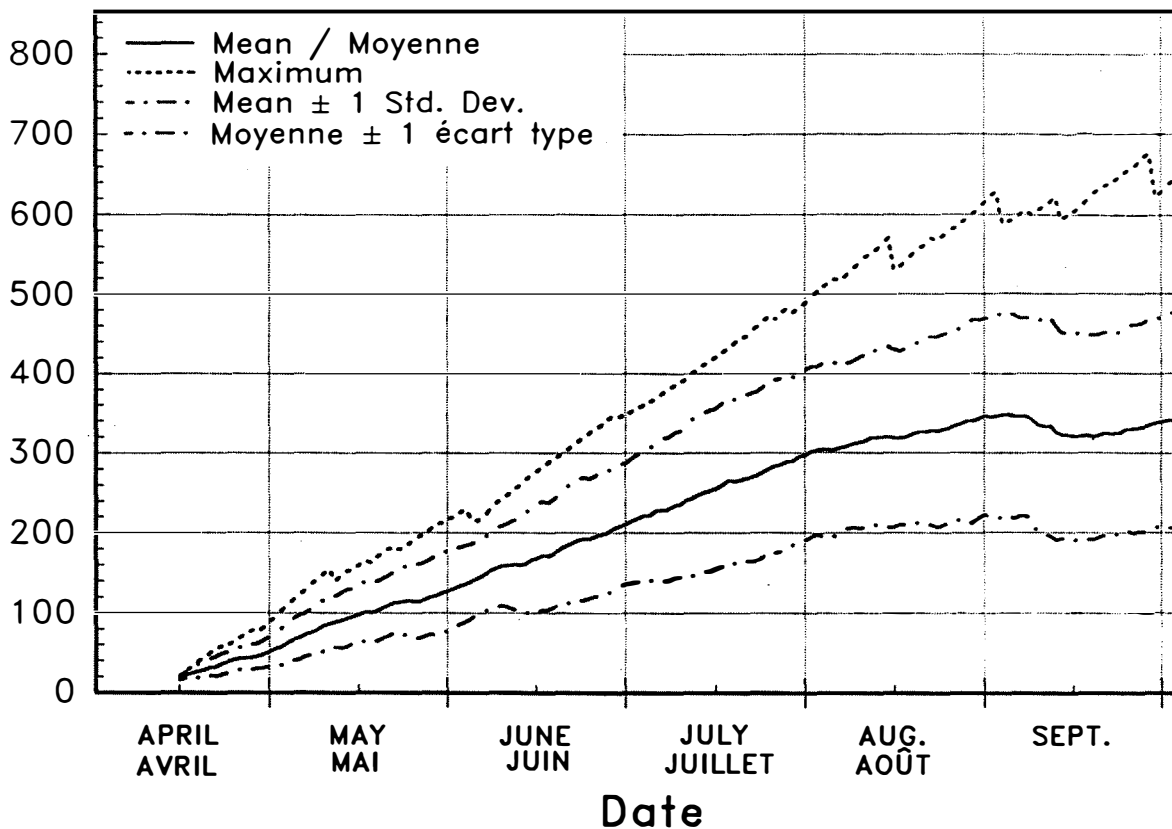


Smithers



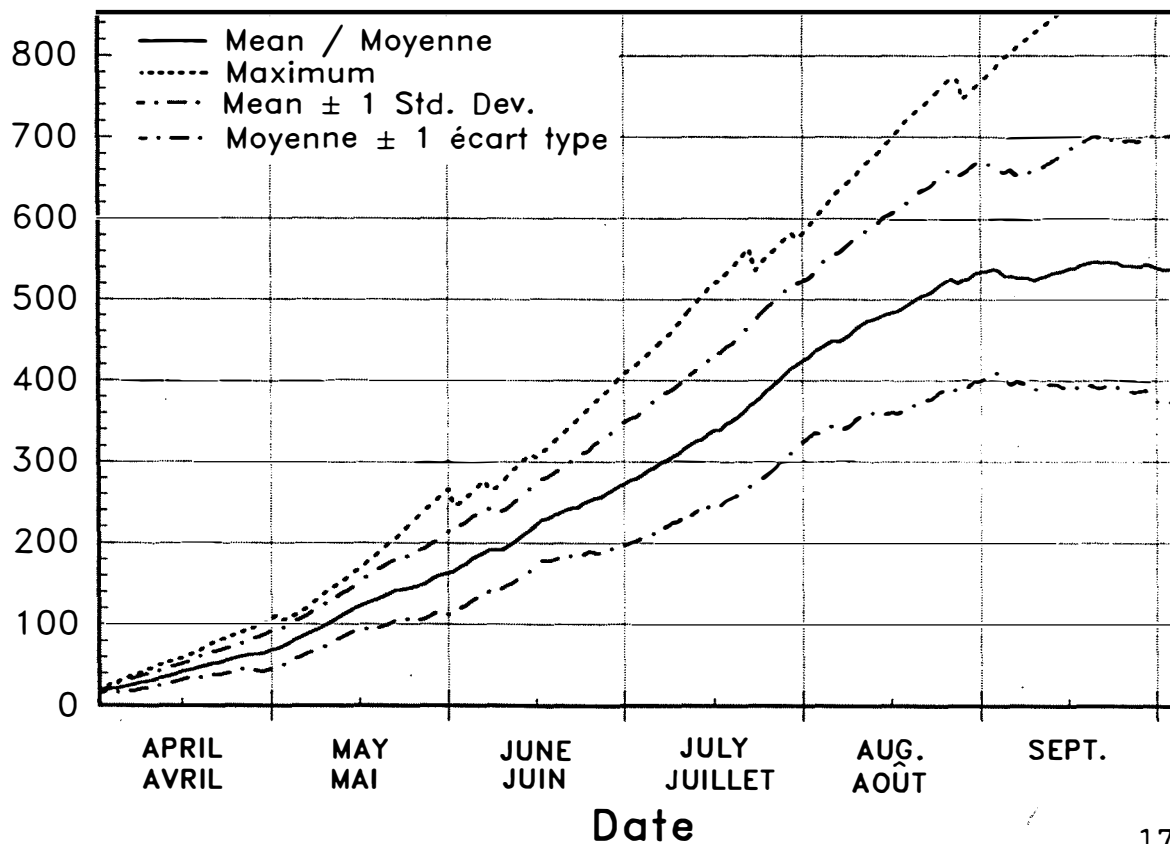
Drought Code / Indice de sécheresse

Fort Nelson

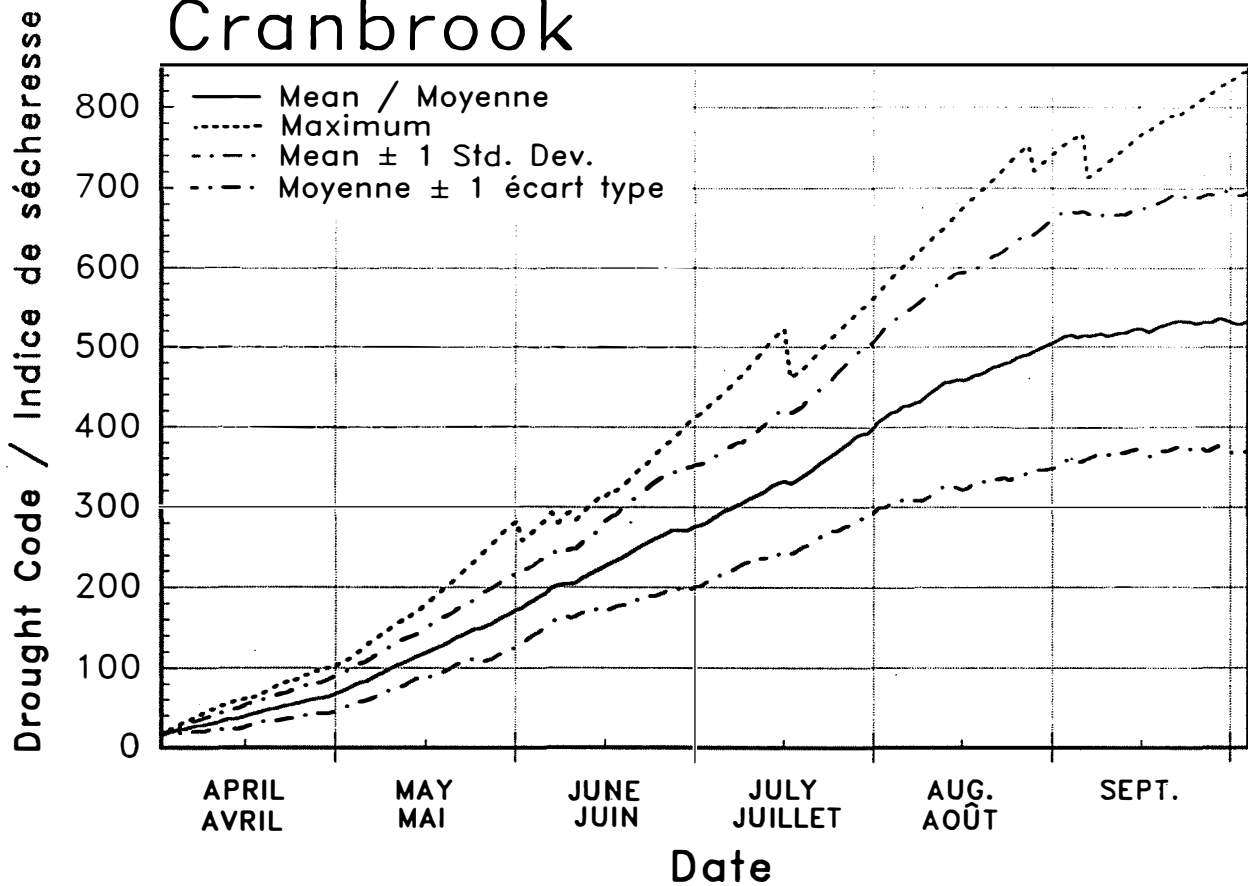


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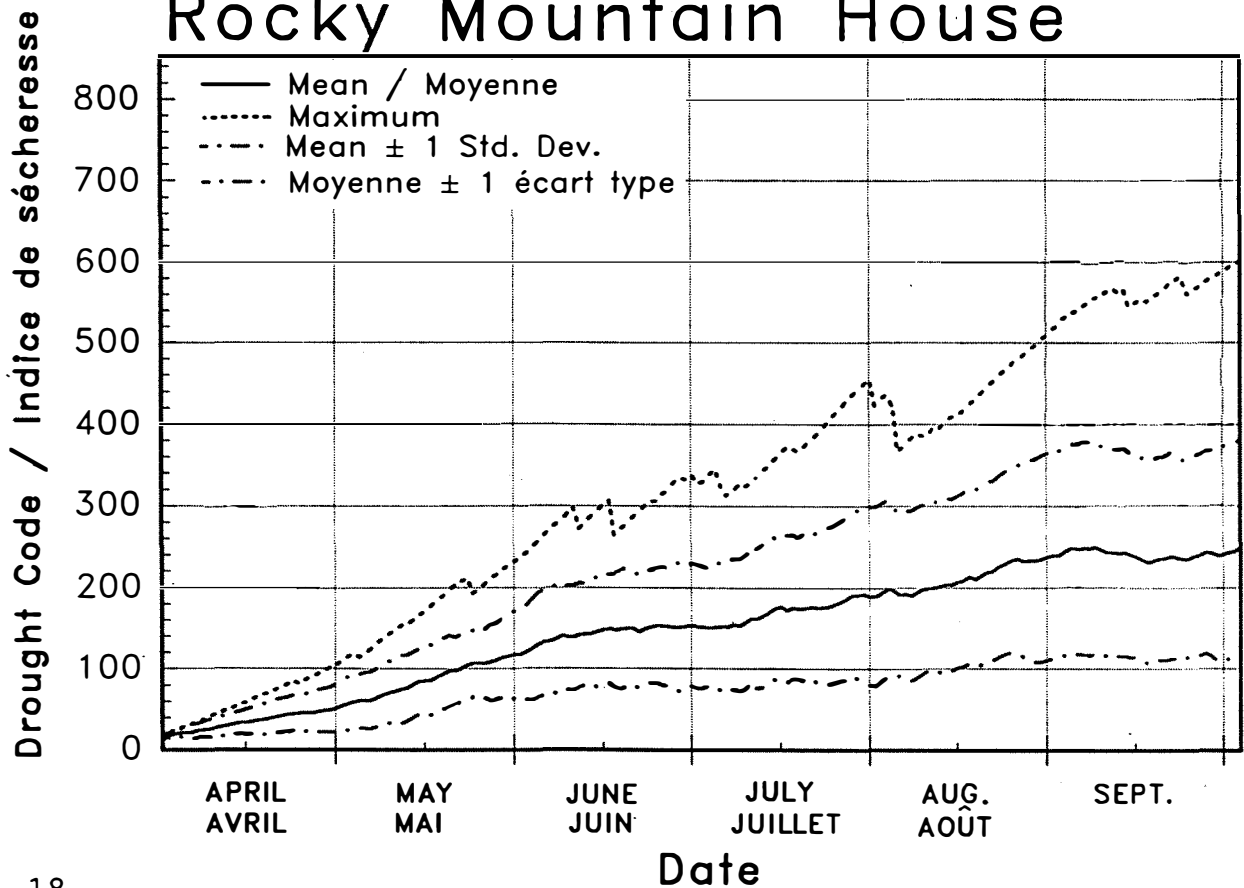
Williams Lake



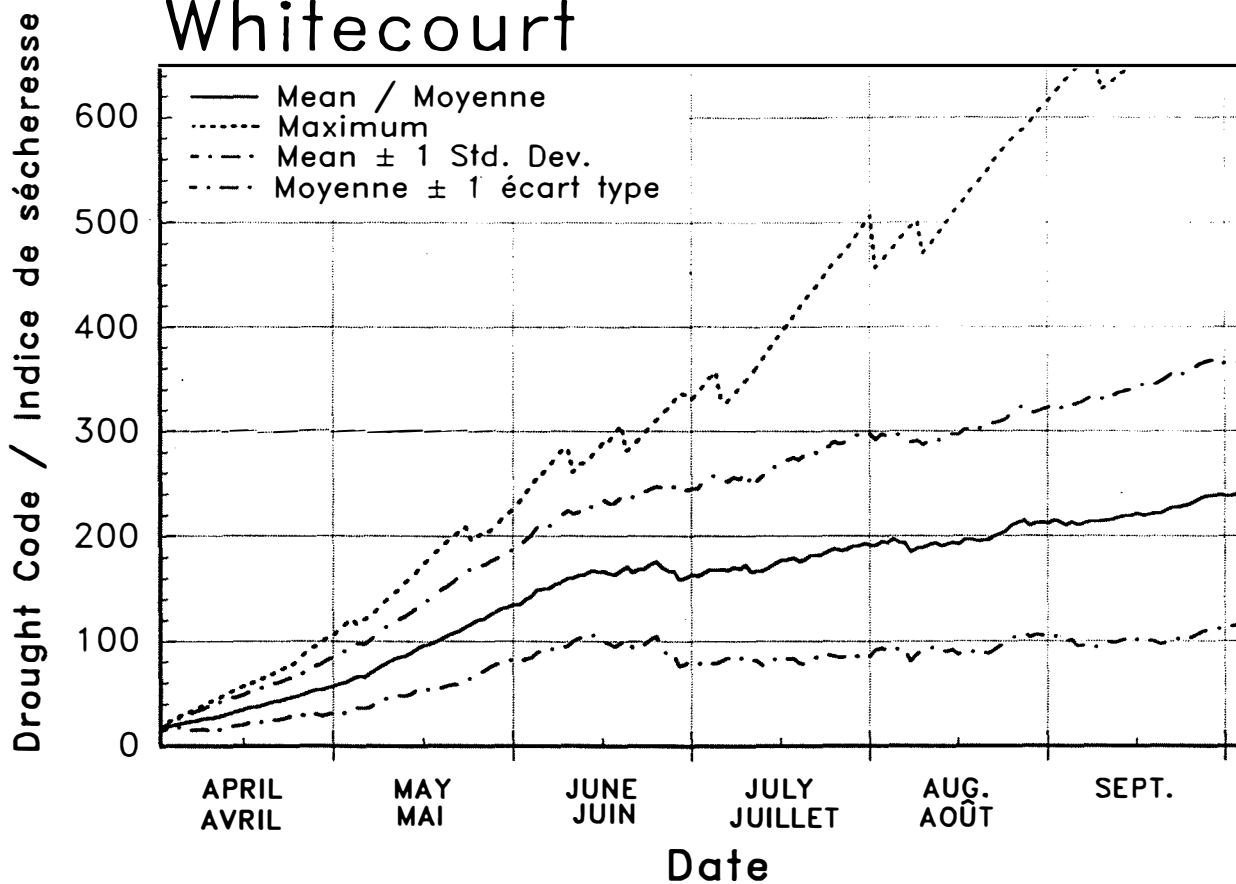
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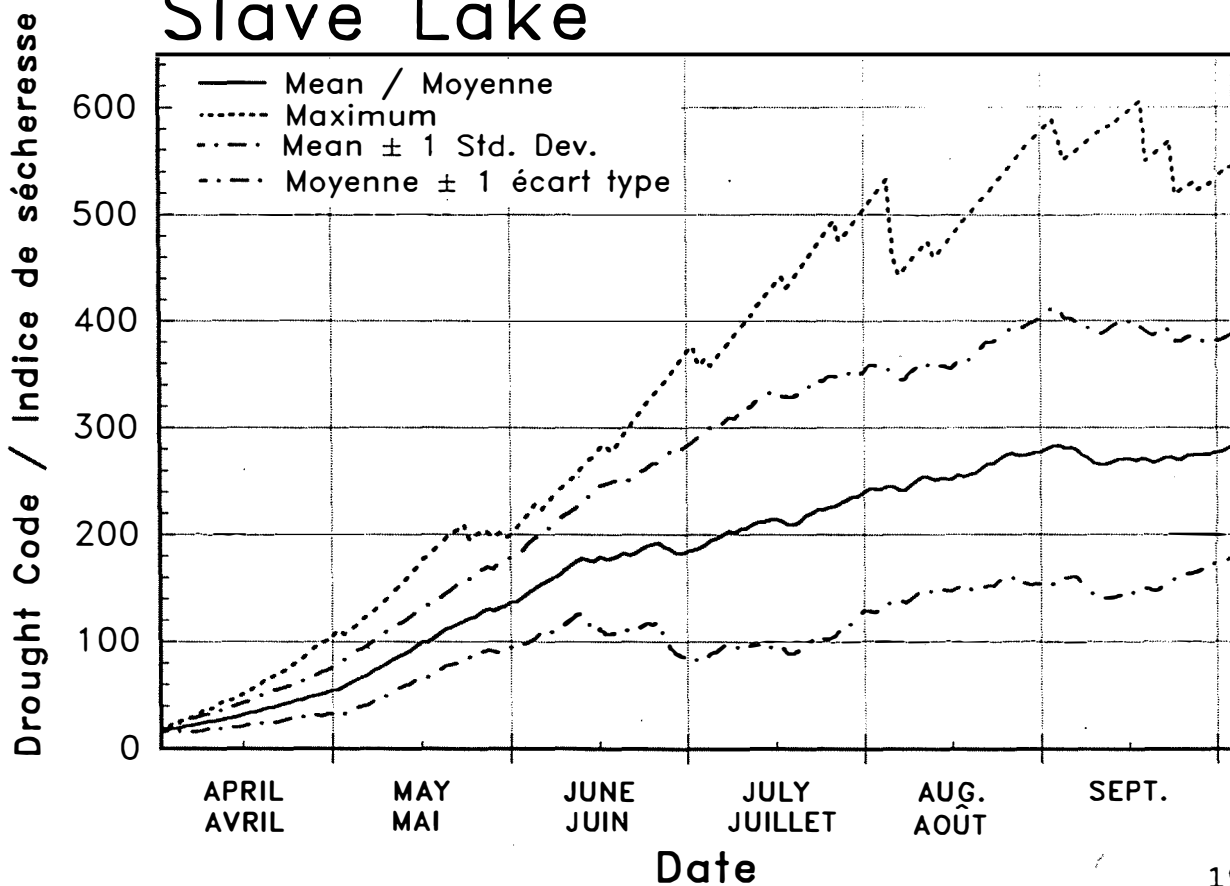
Rocky Mountain House



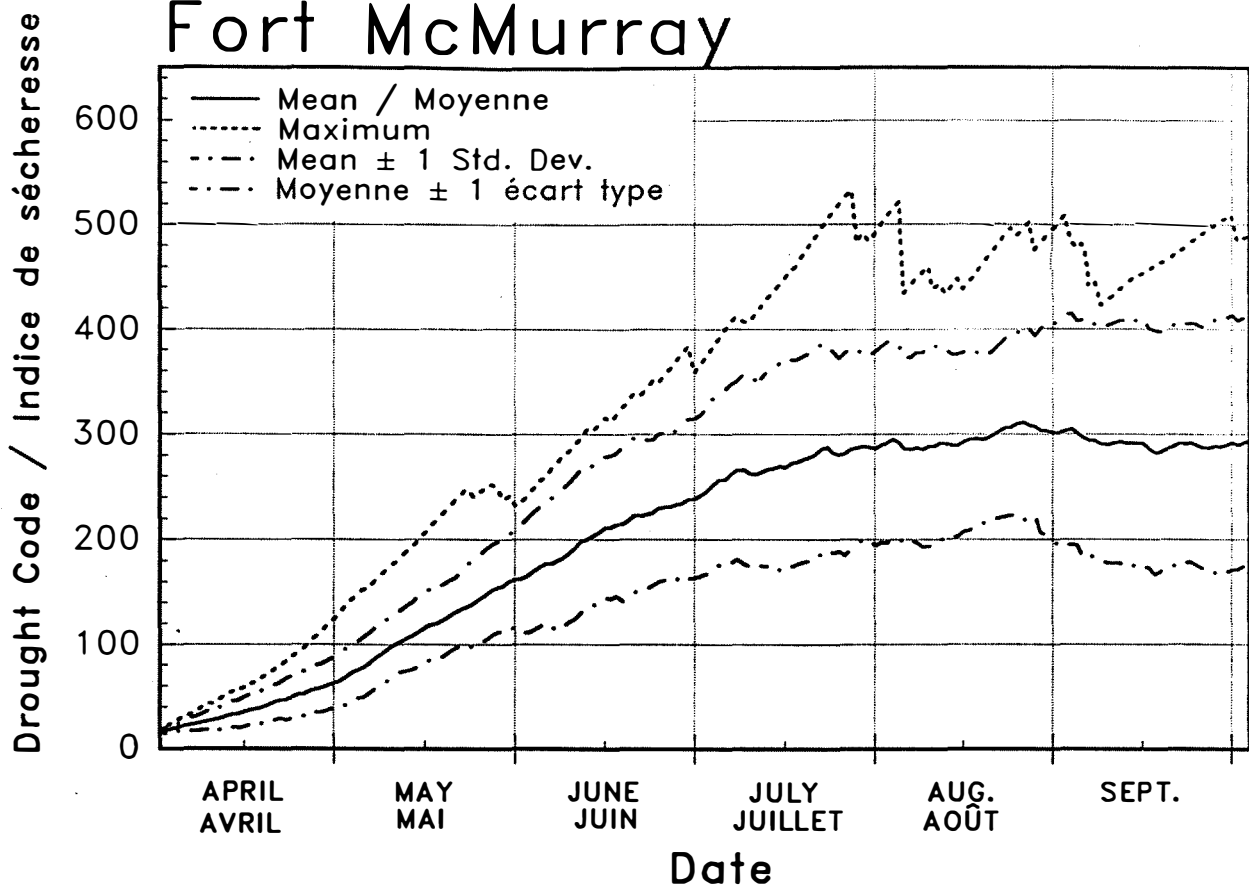
Whitecourt



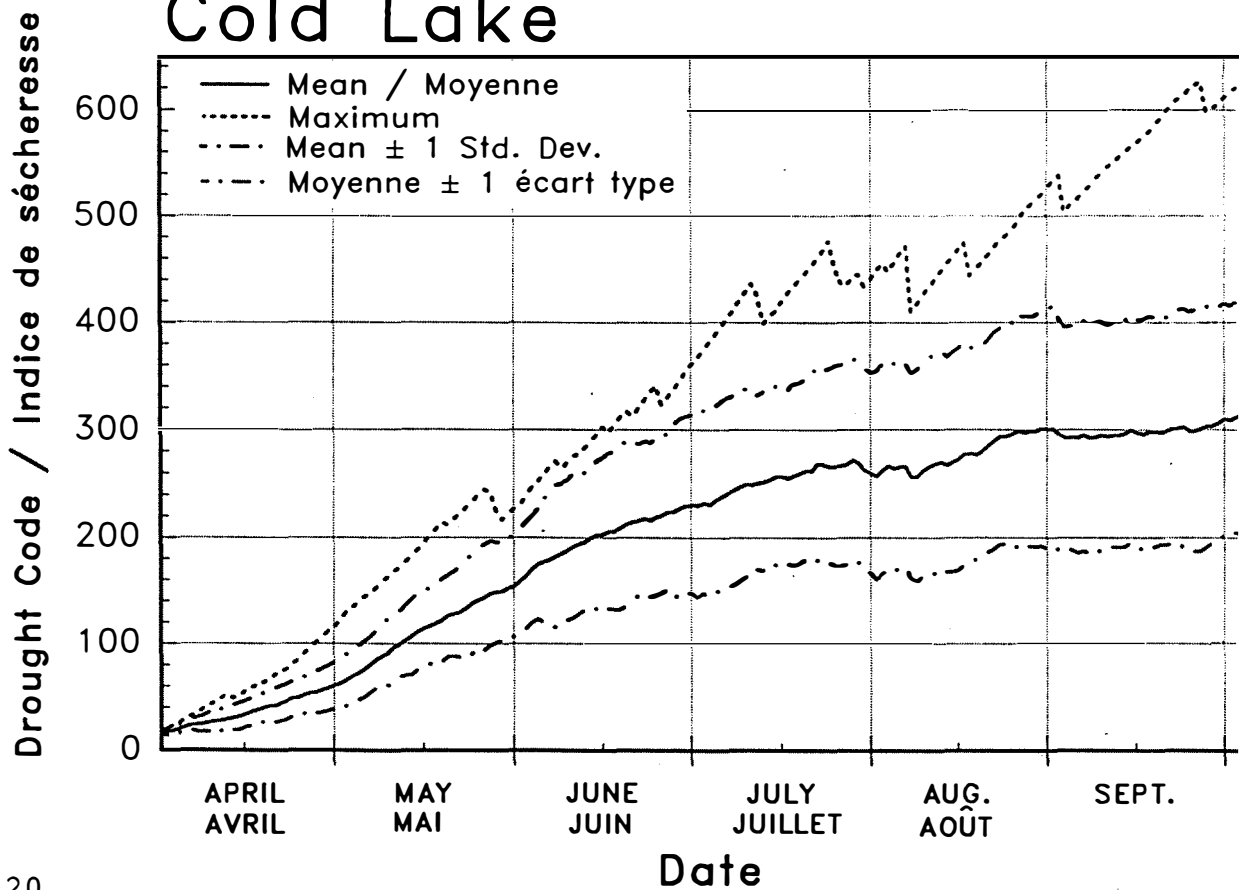
Slave Lake

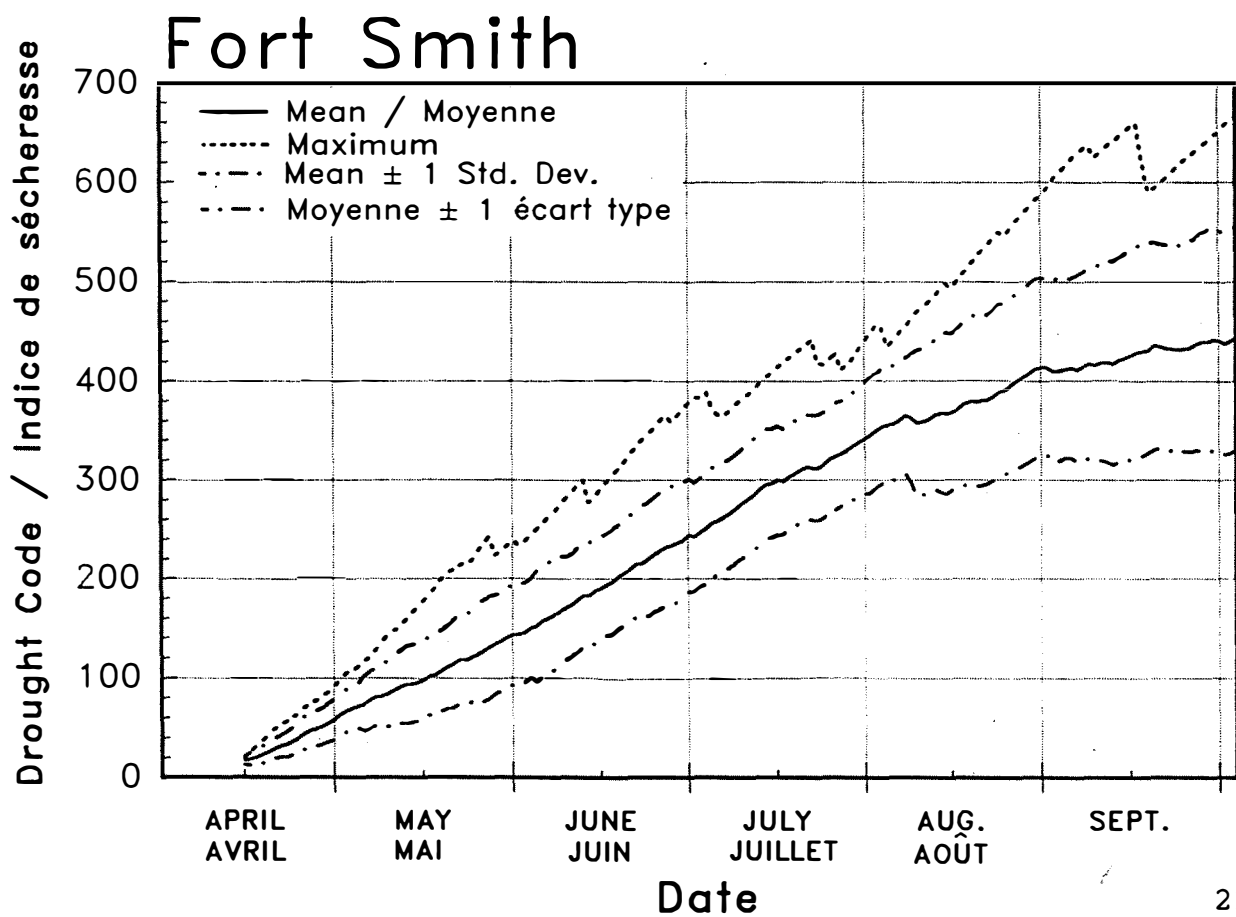
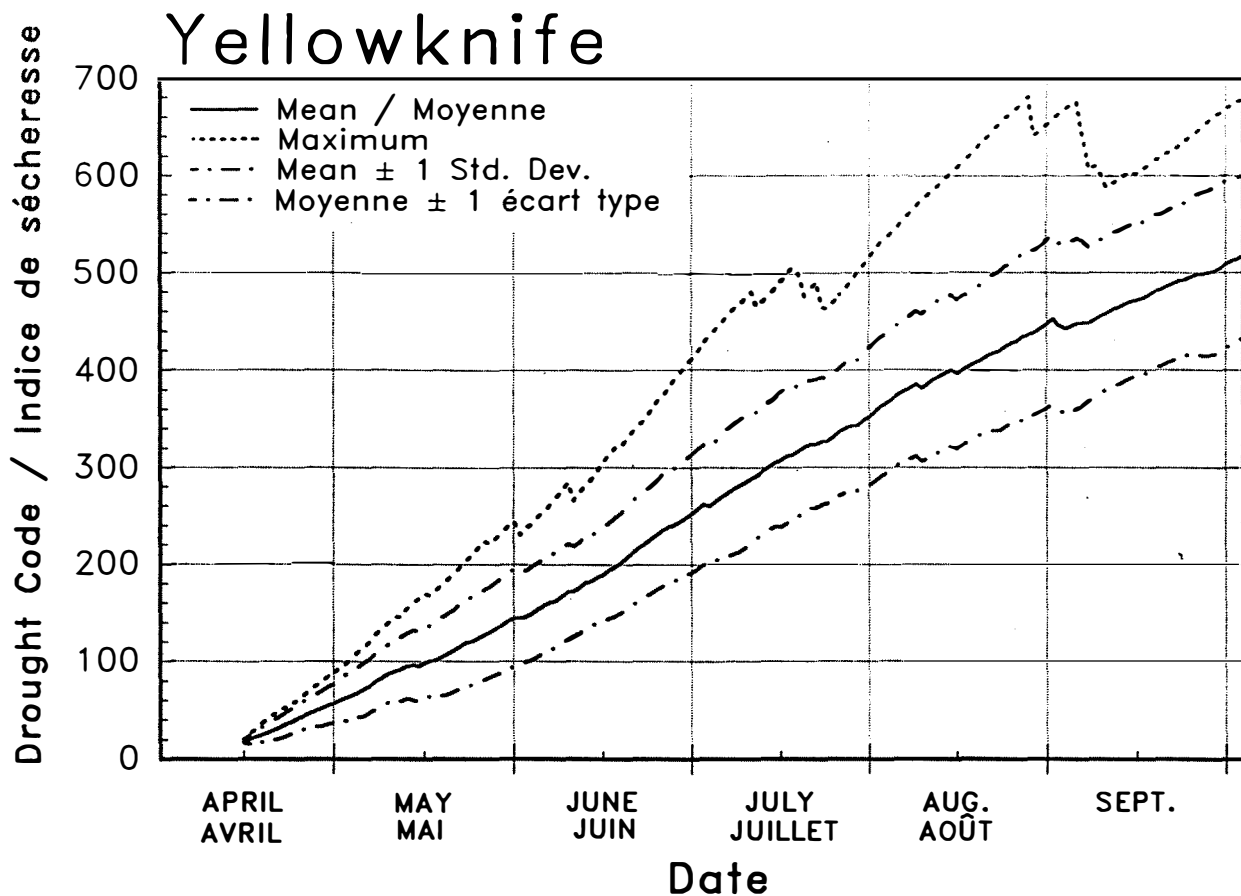


Fort McMurray

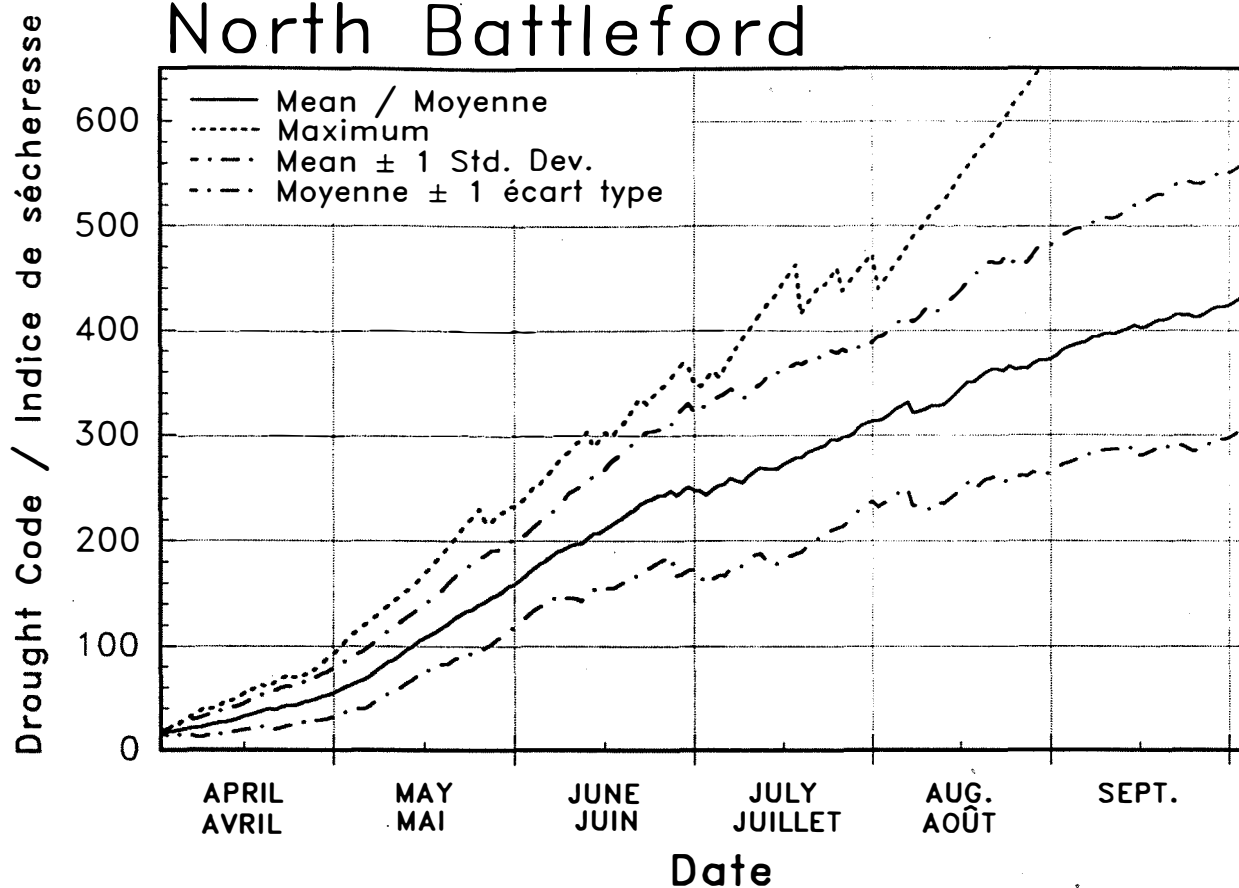


Cold Lake

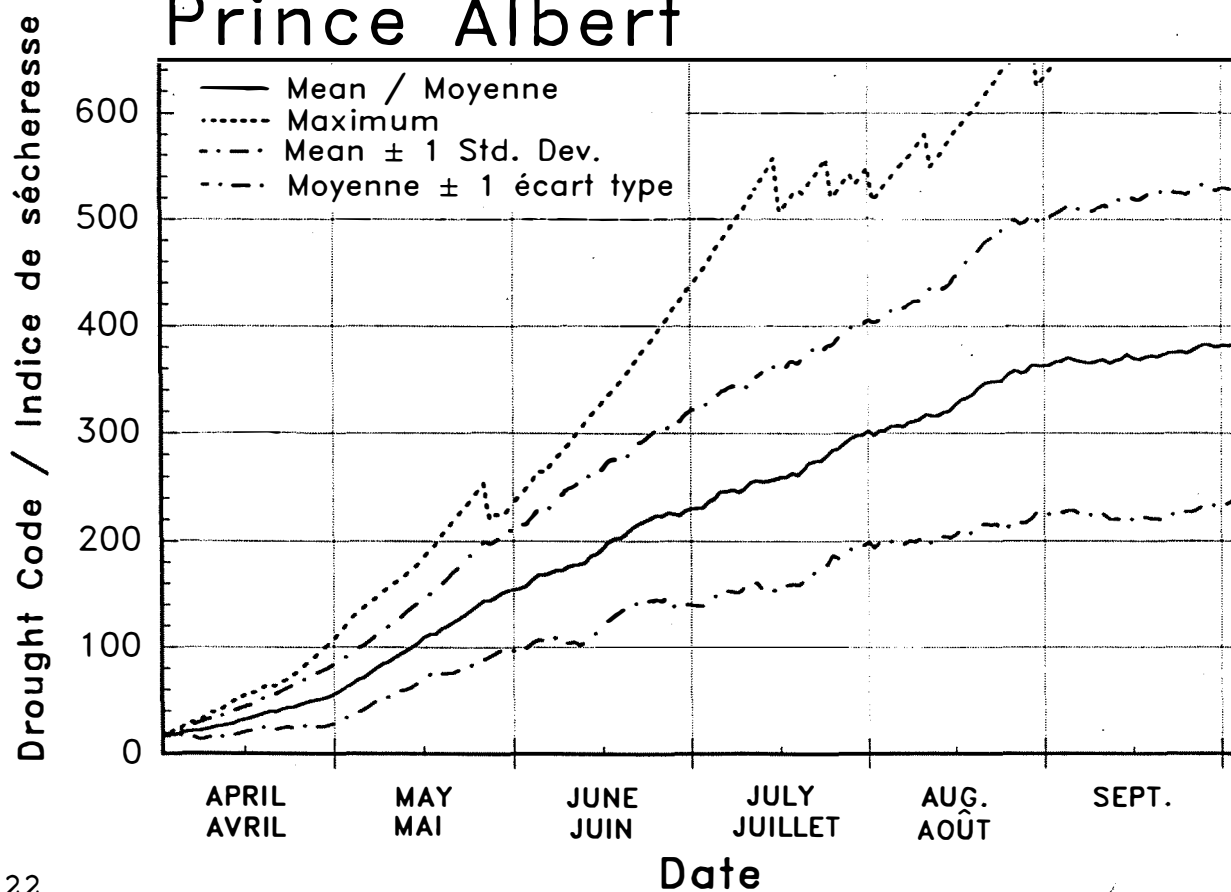




North Battleford

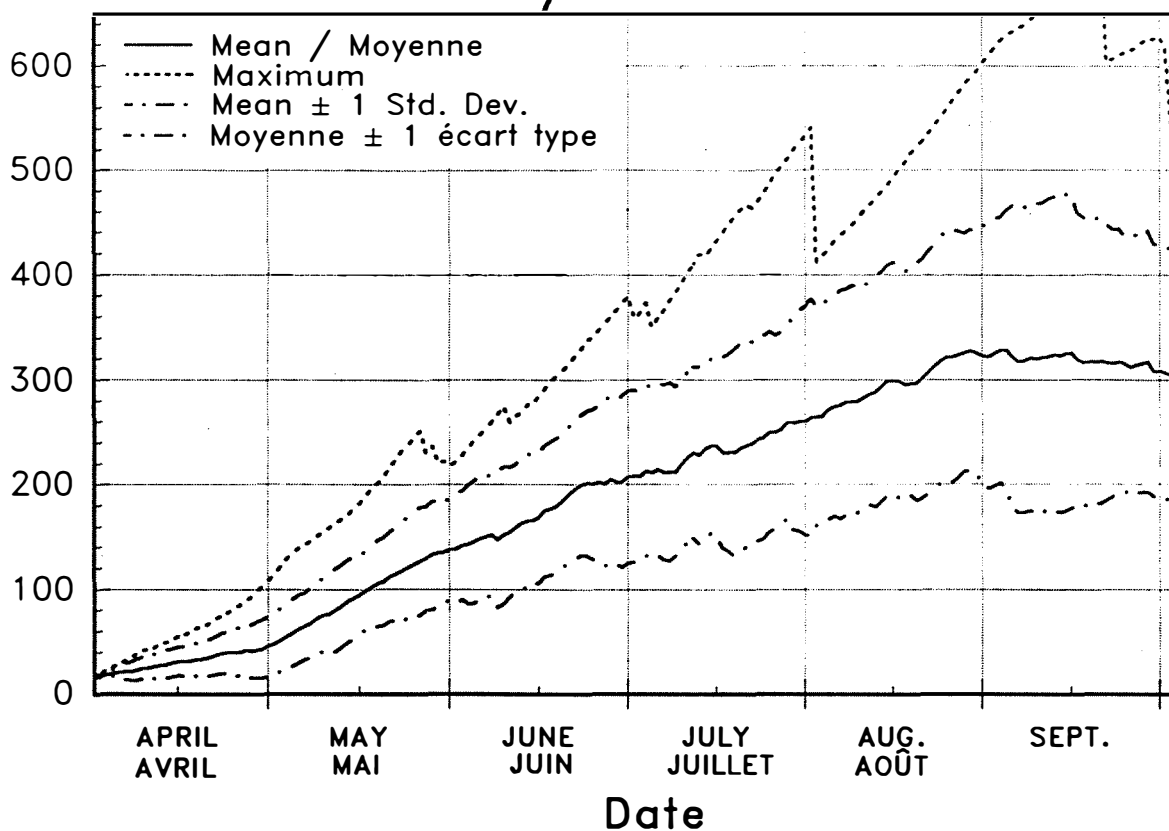


Prince Albert



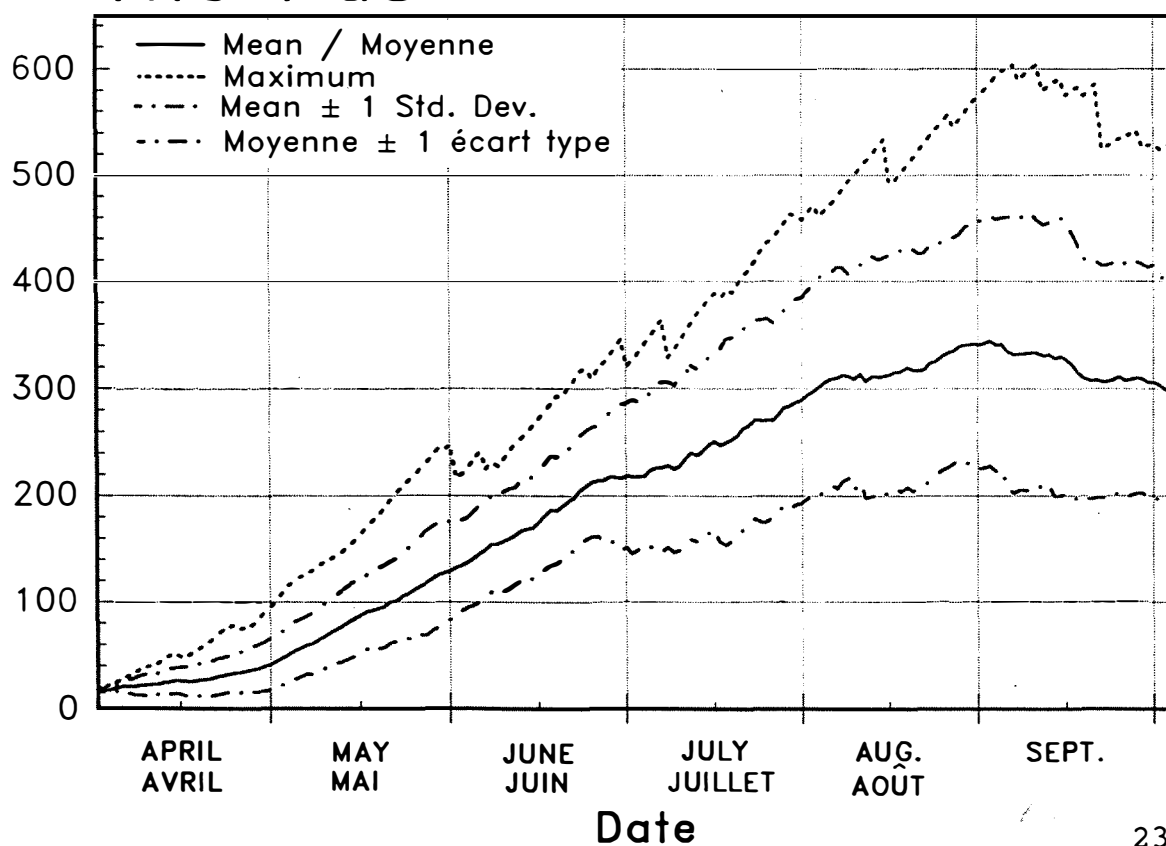
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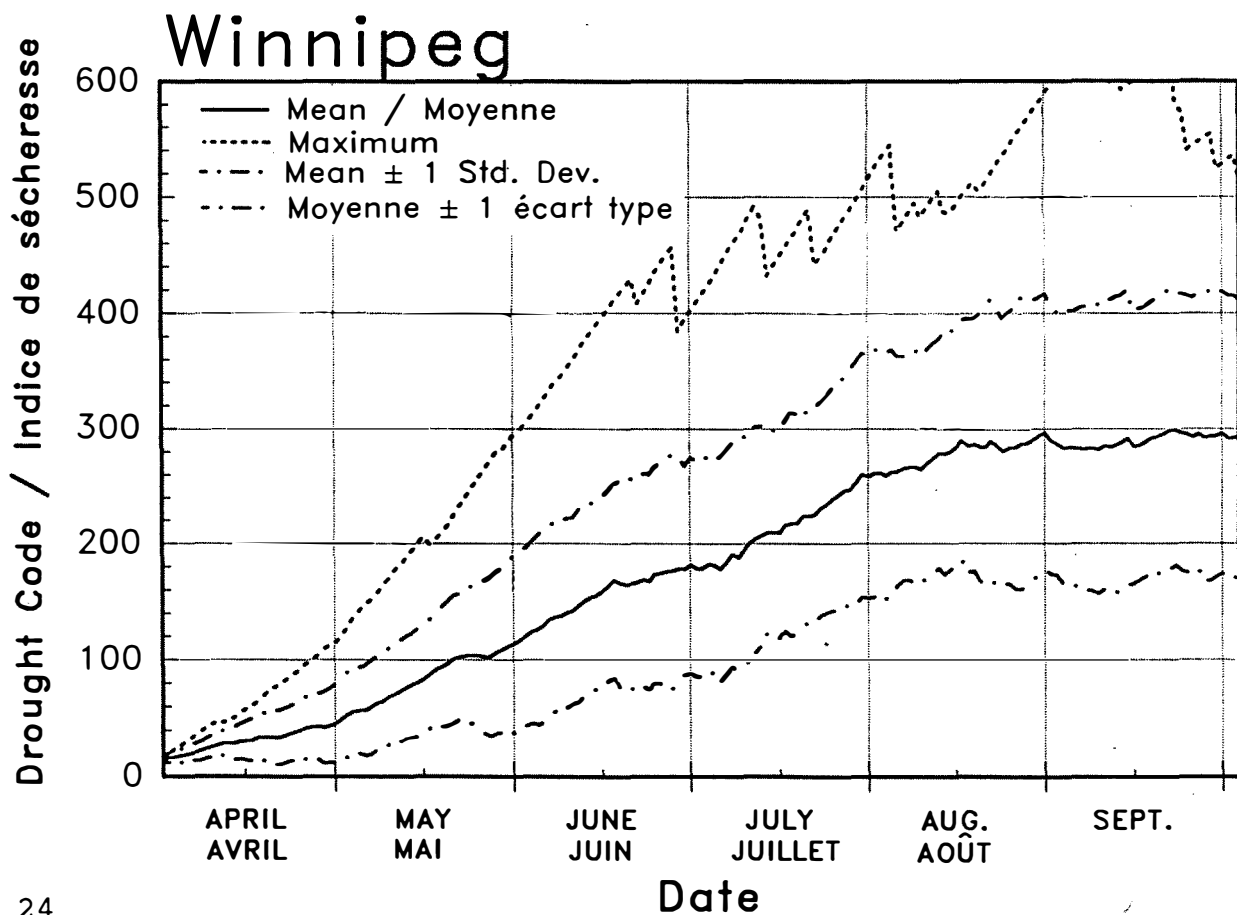
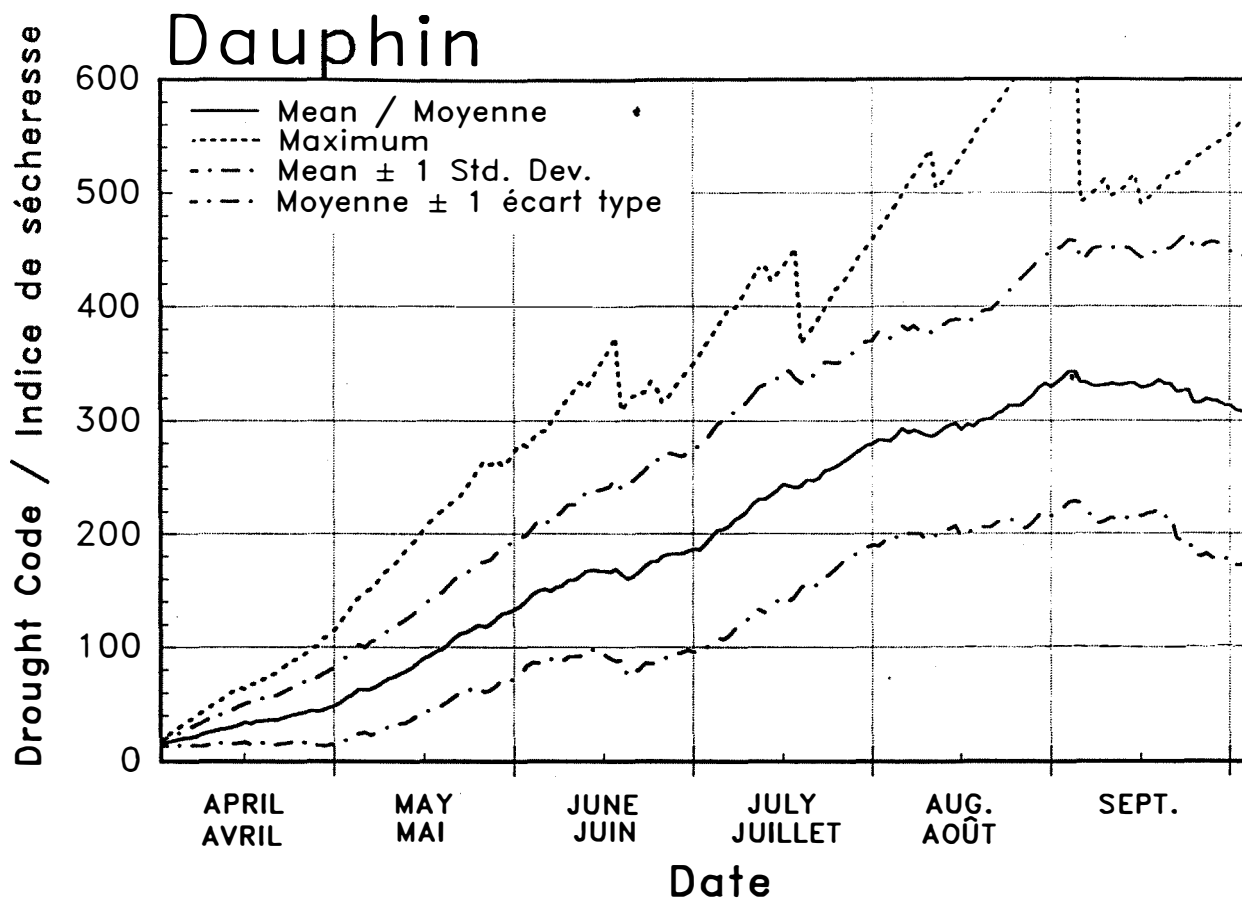
Hudson Bay

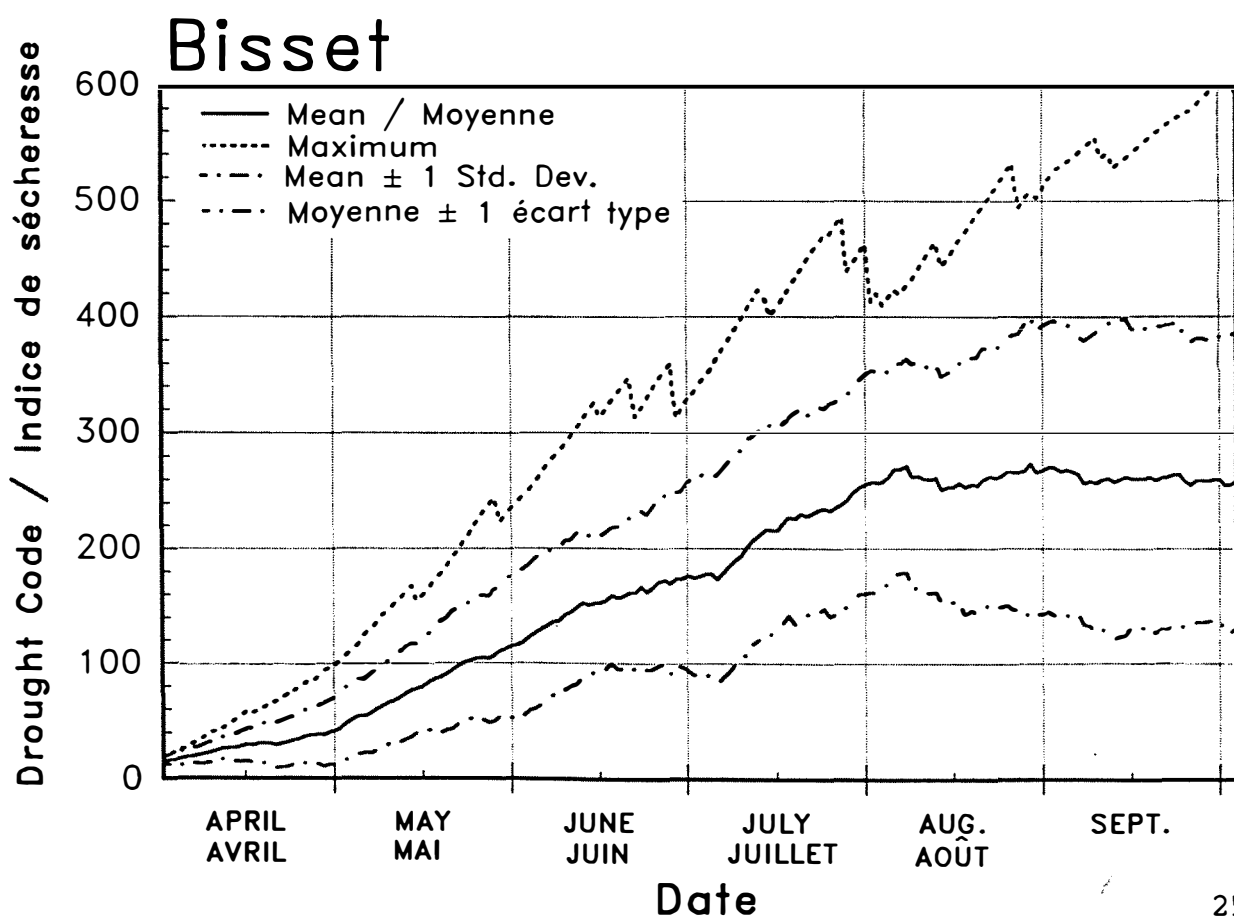
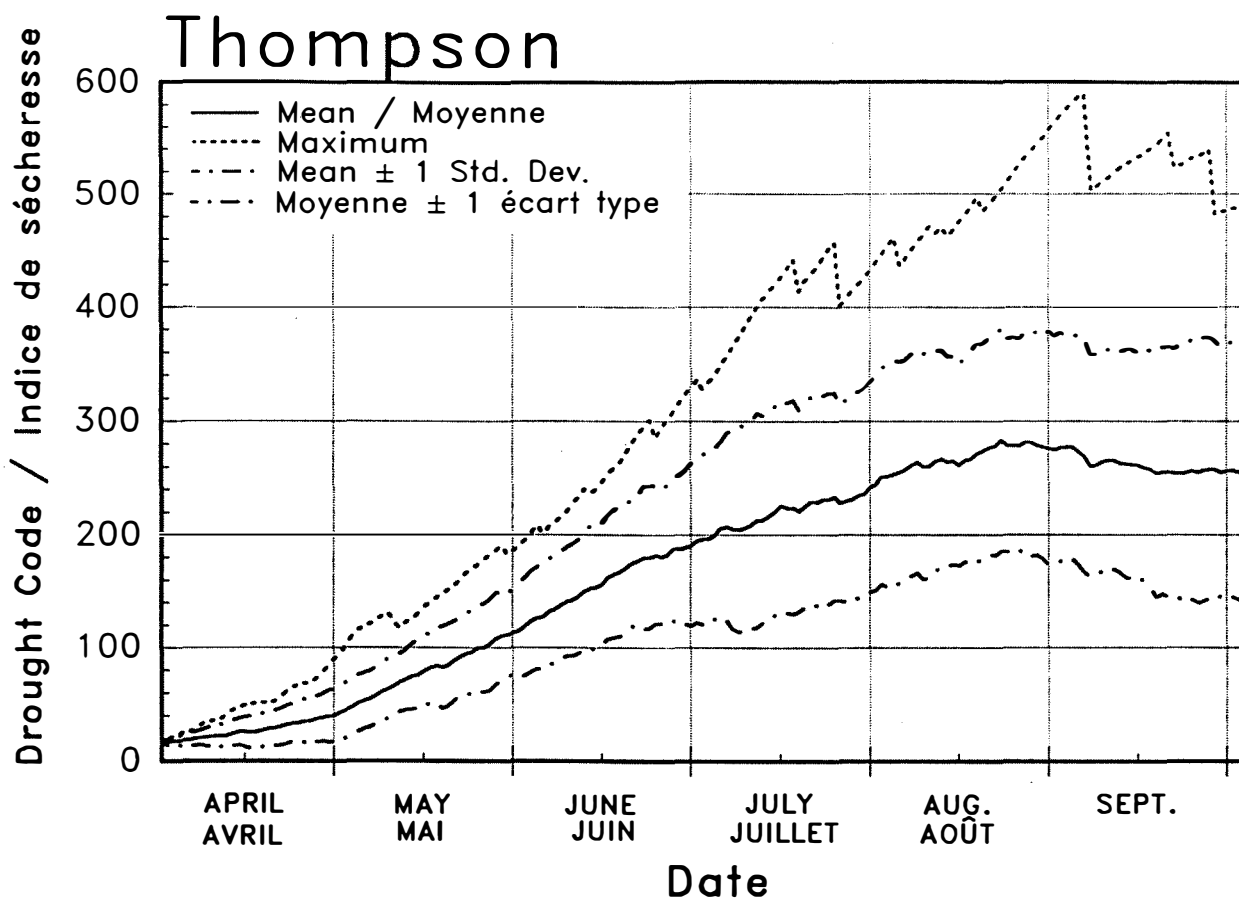


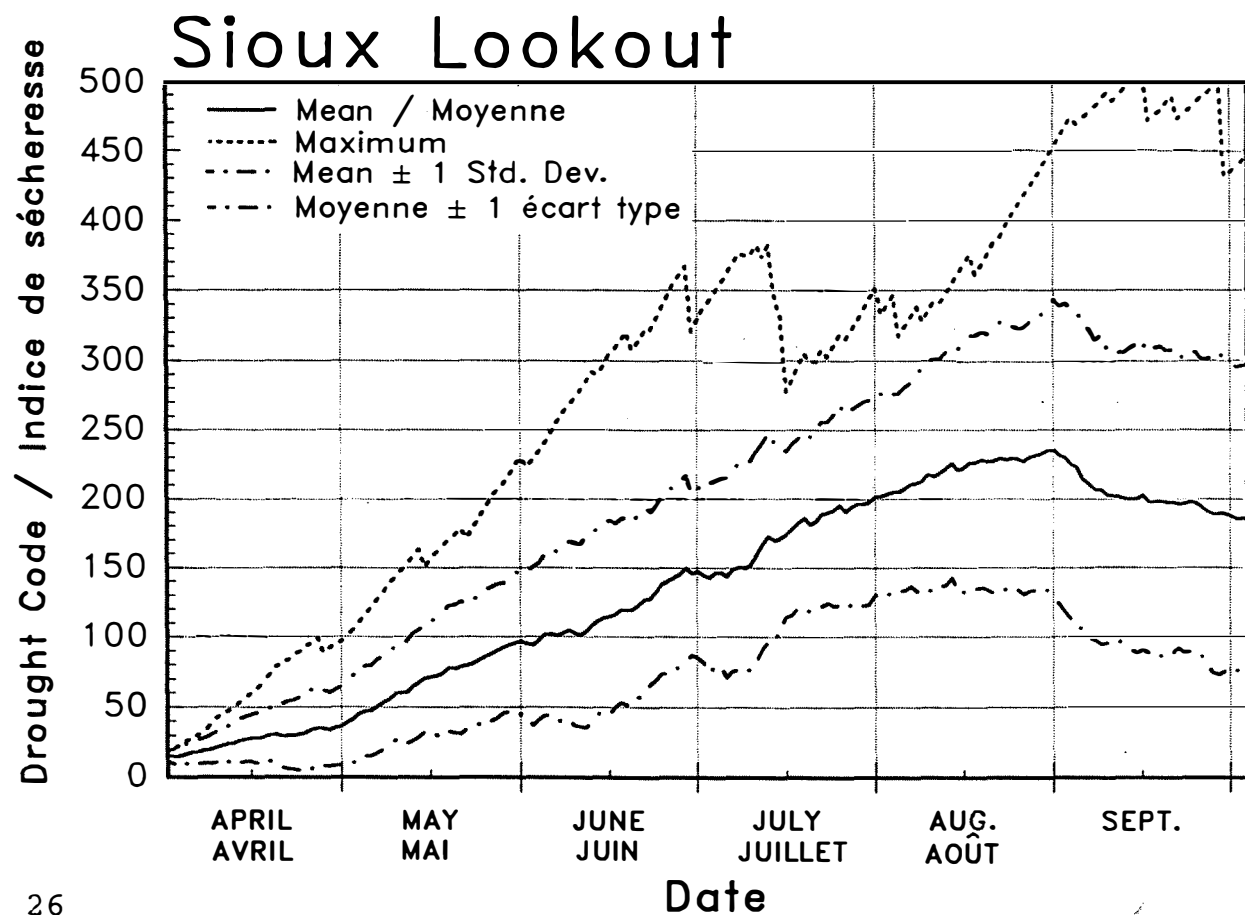
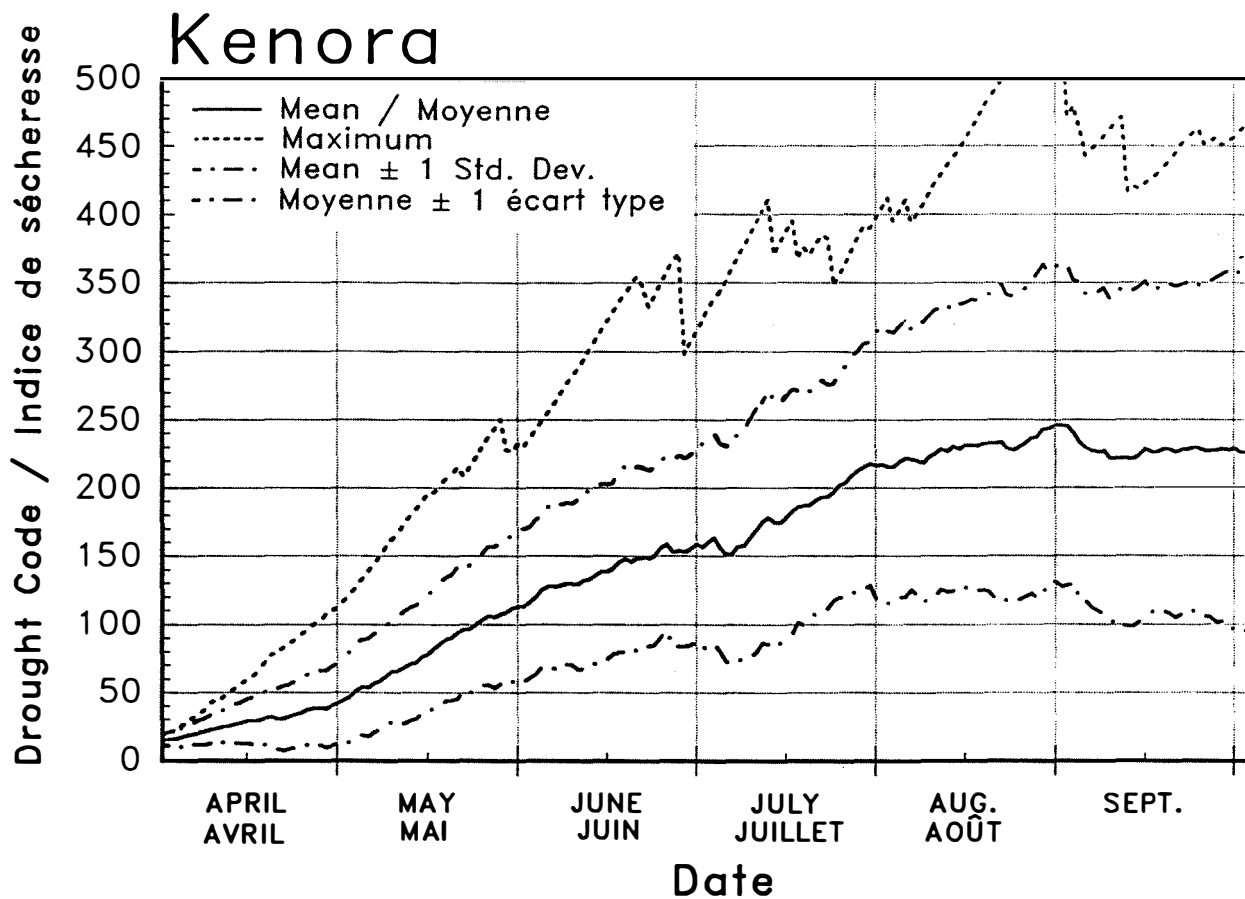
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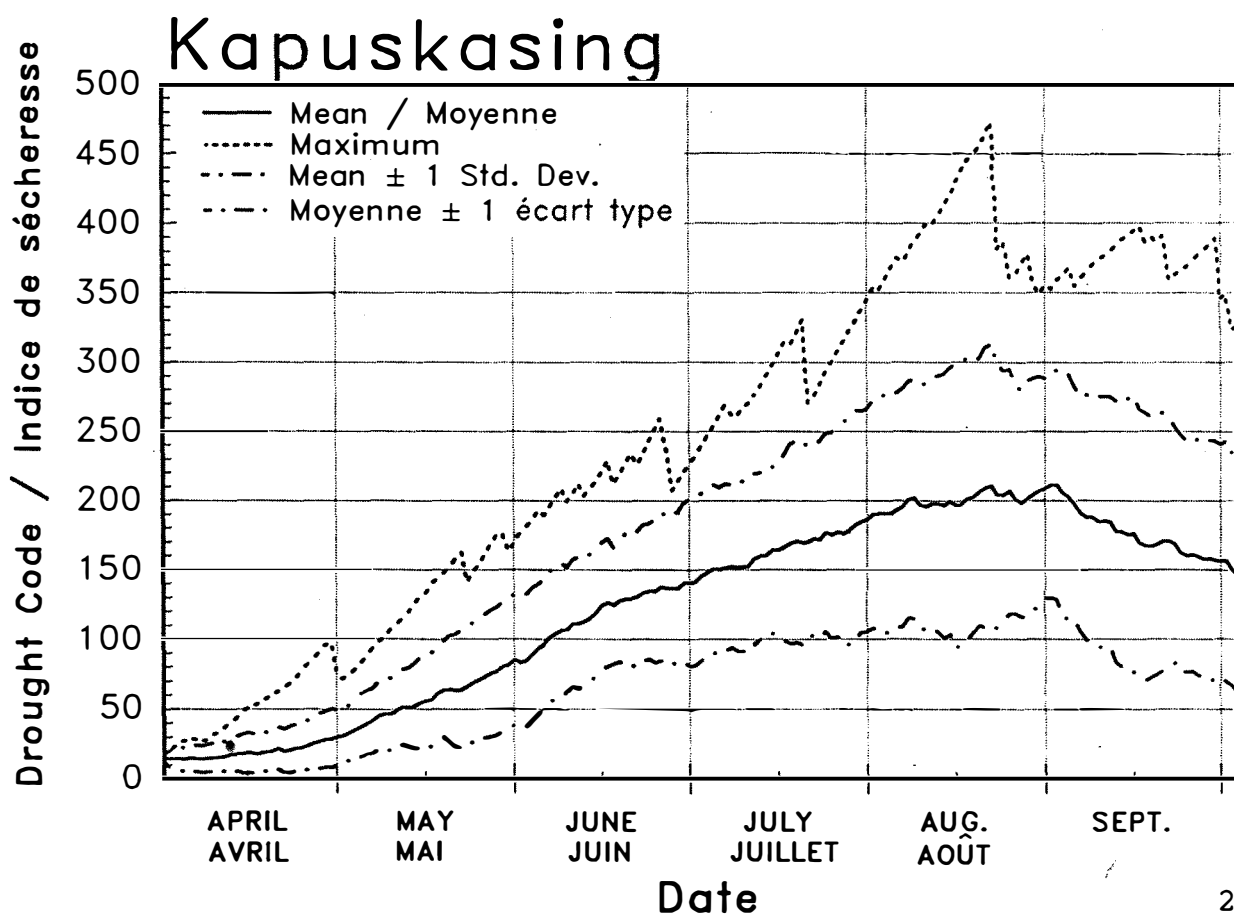
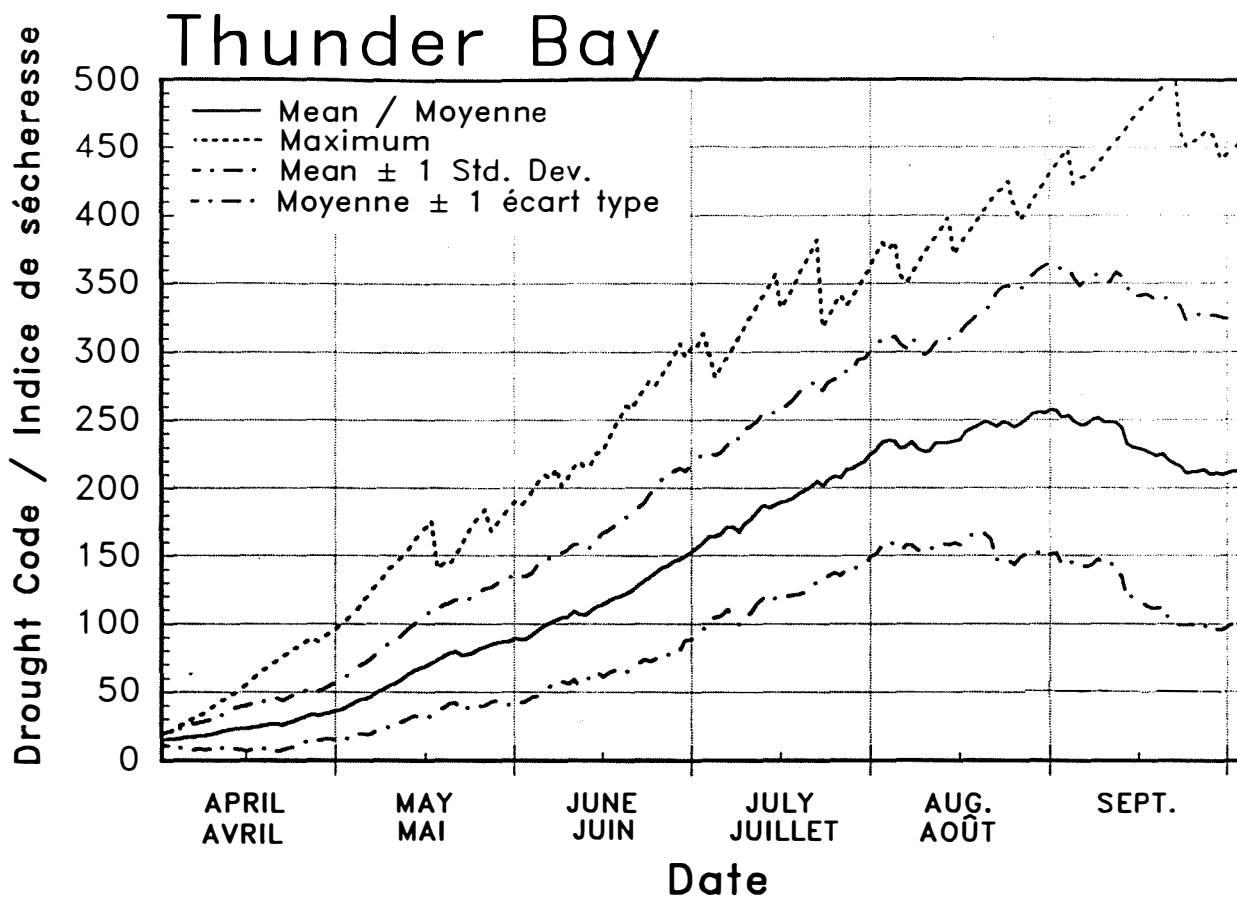
The Pas

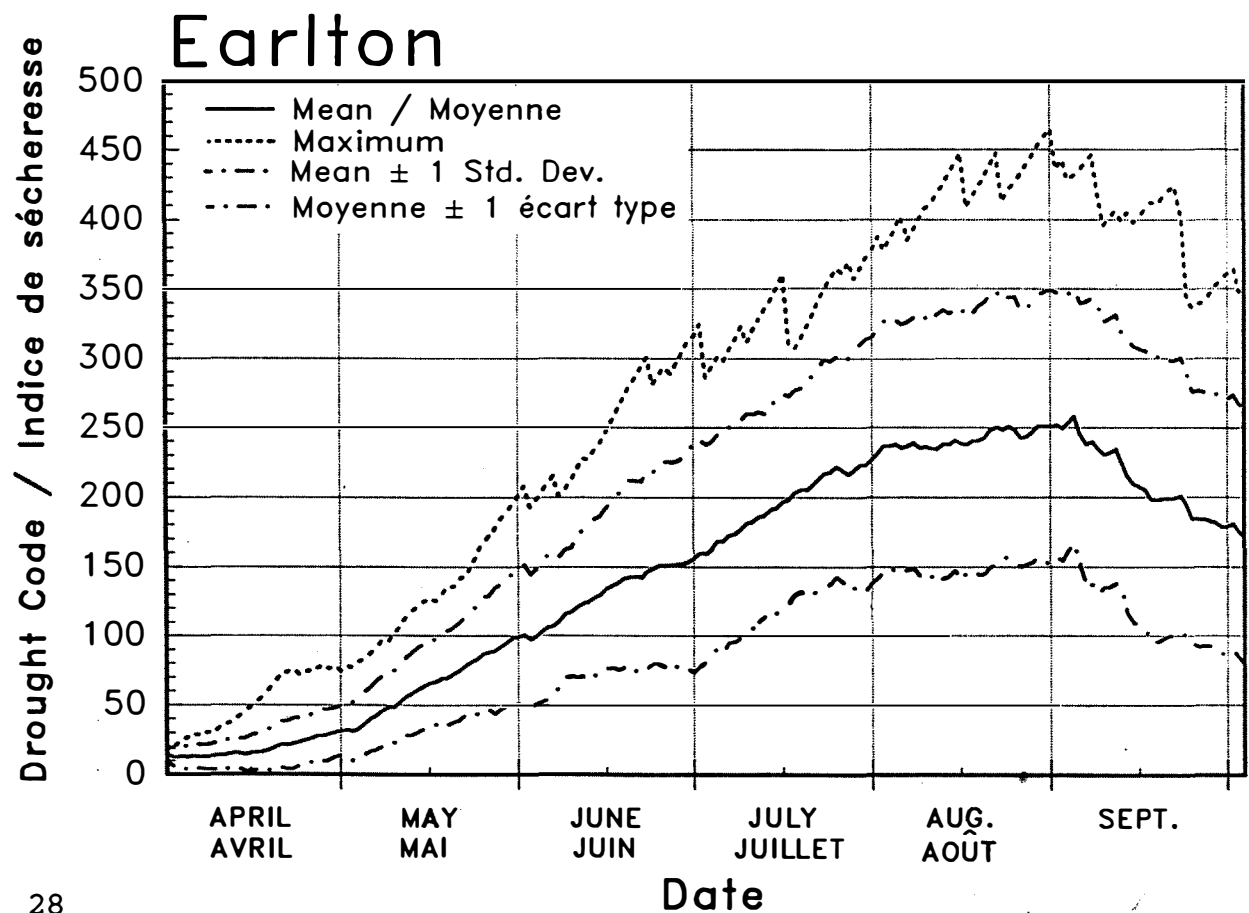
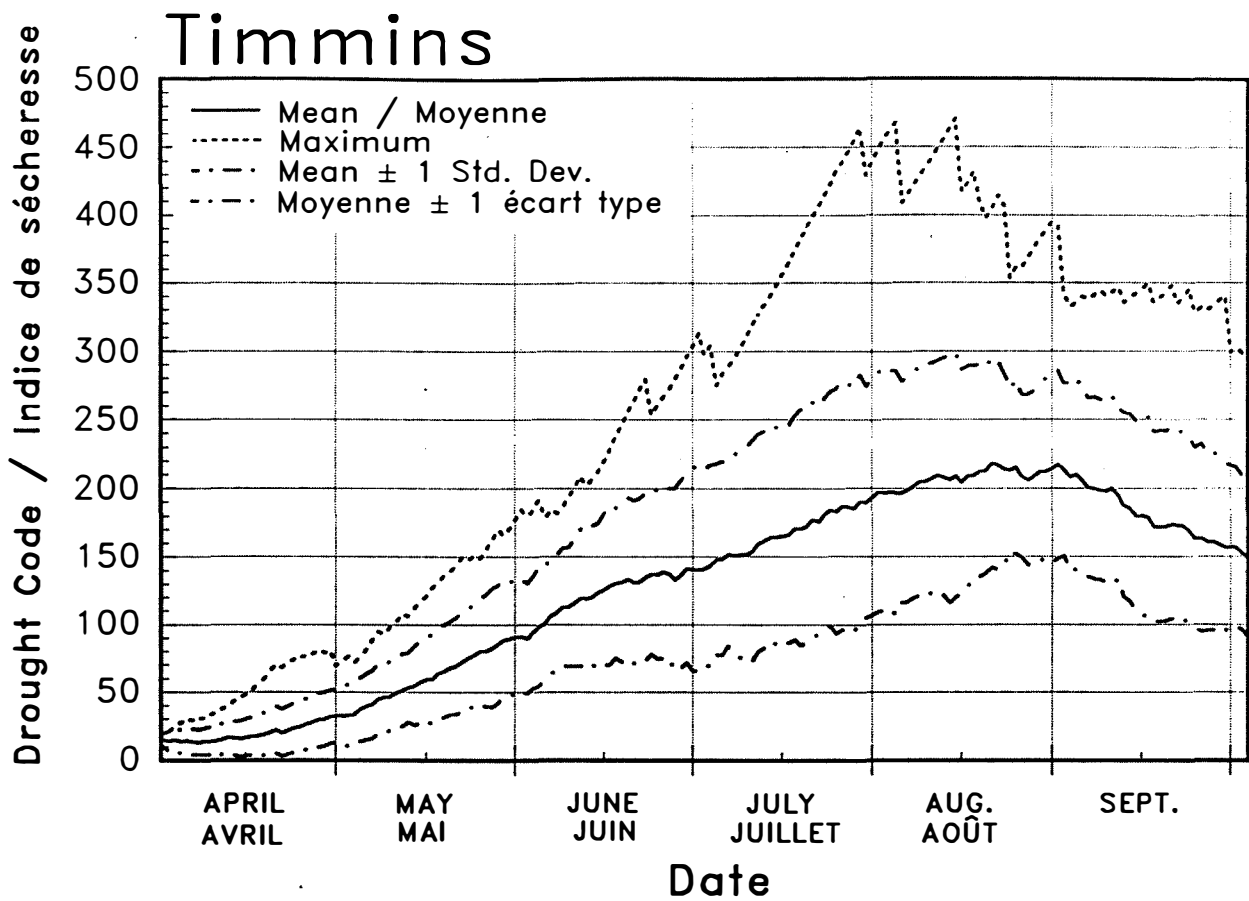


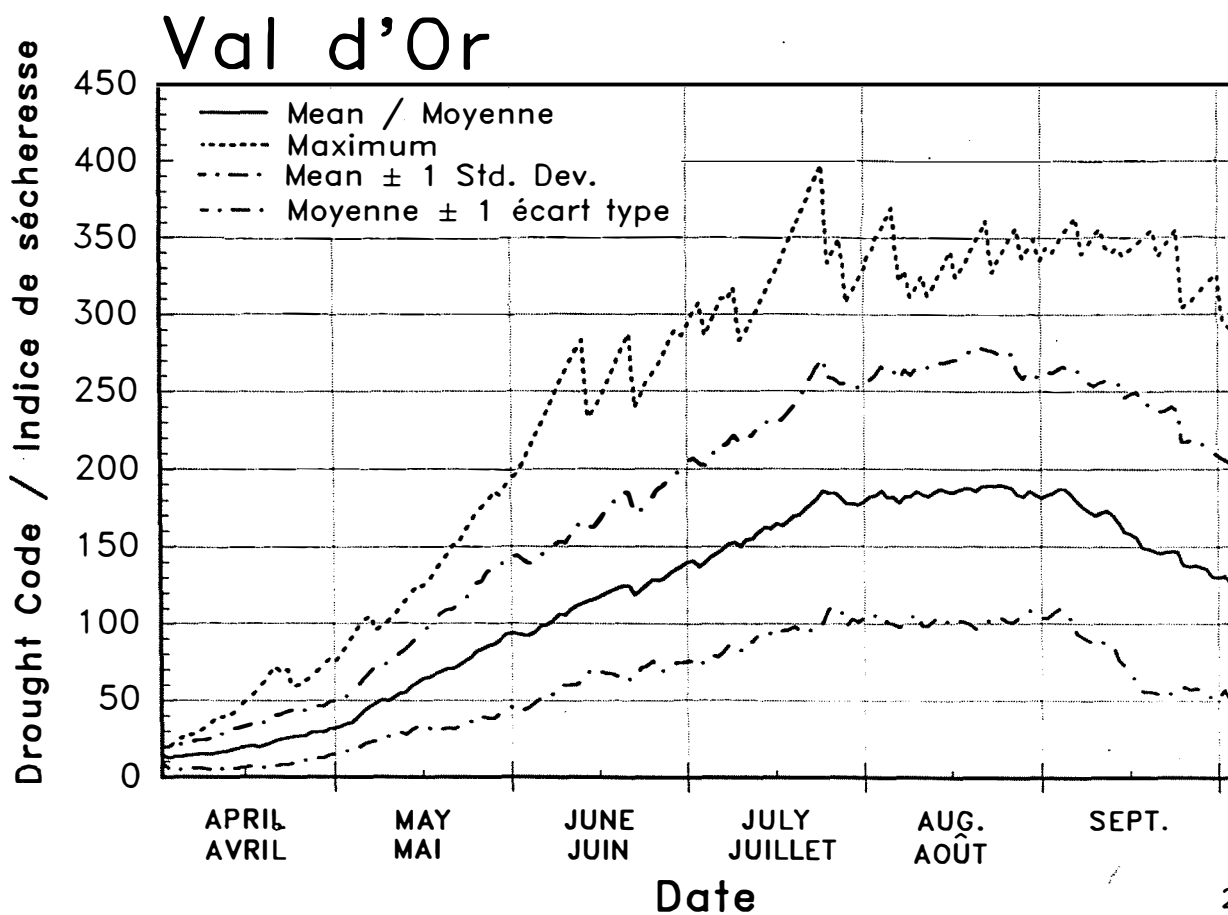
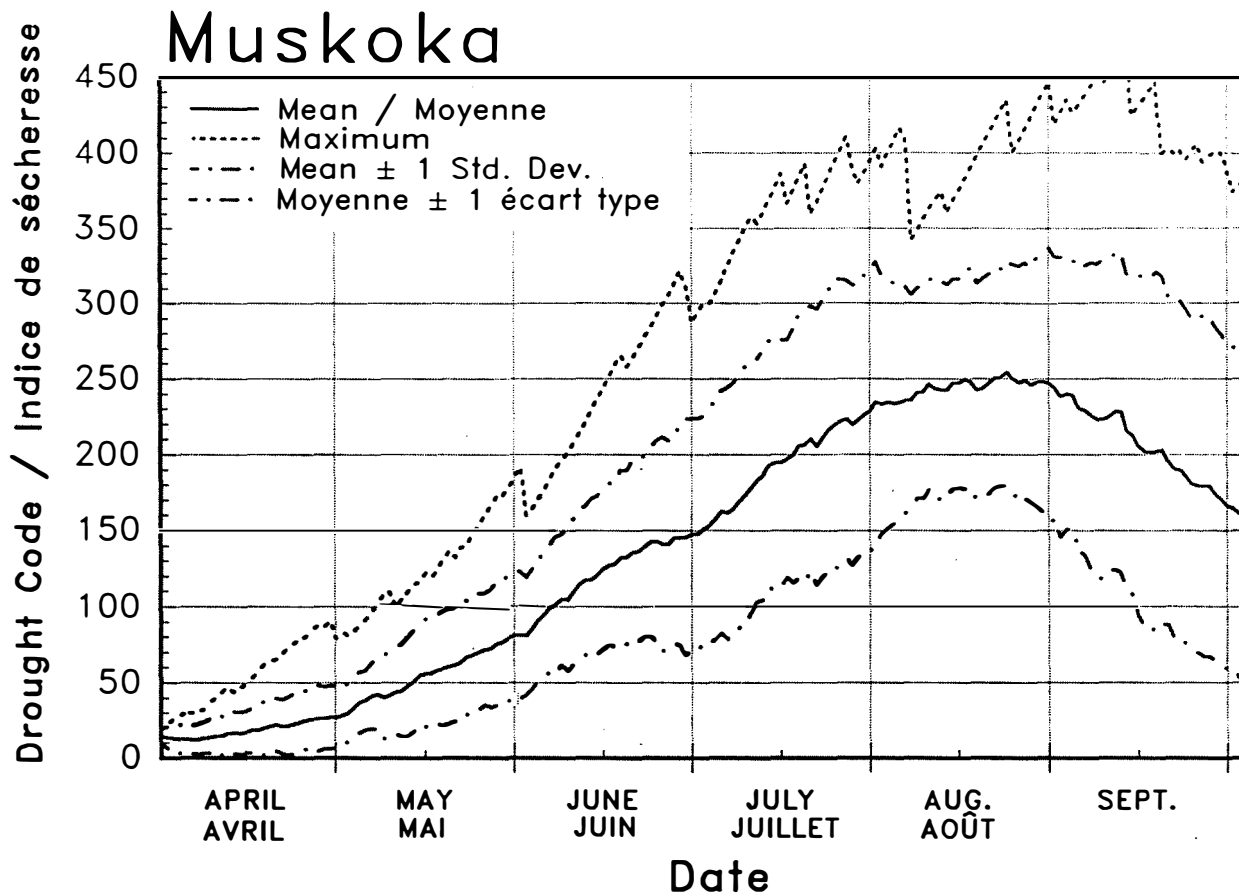




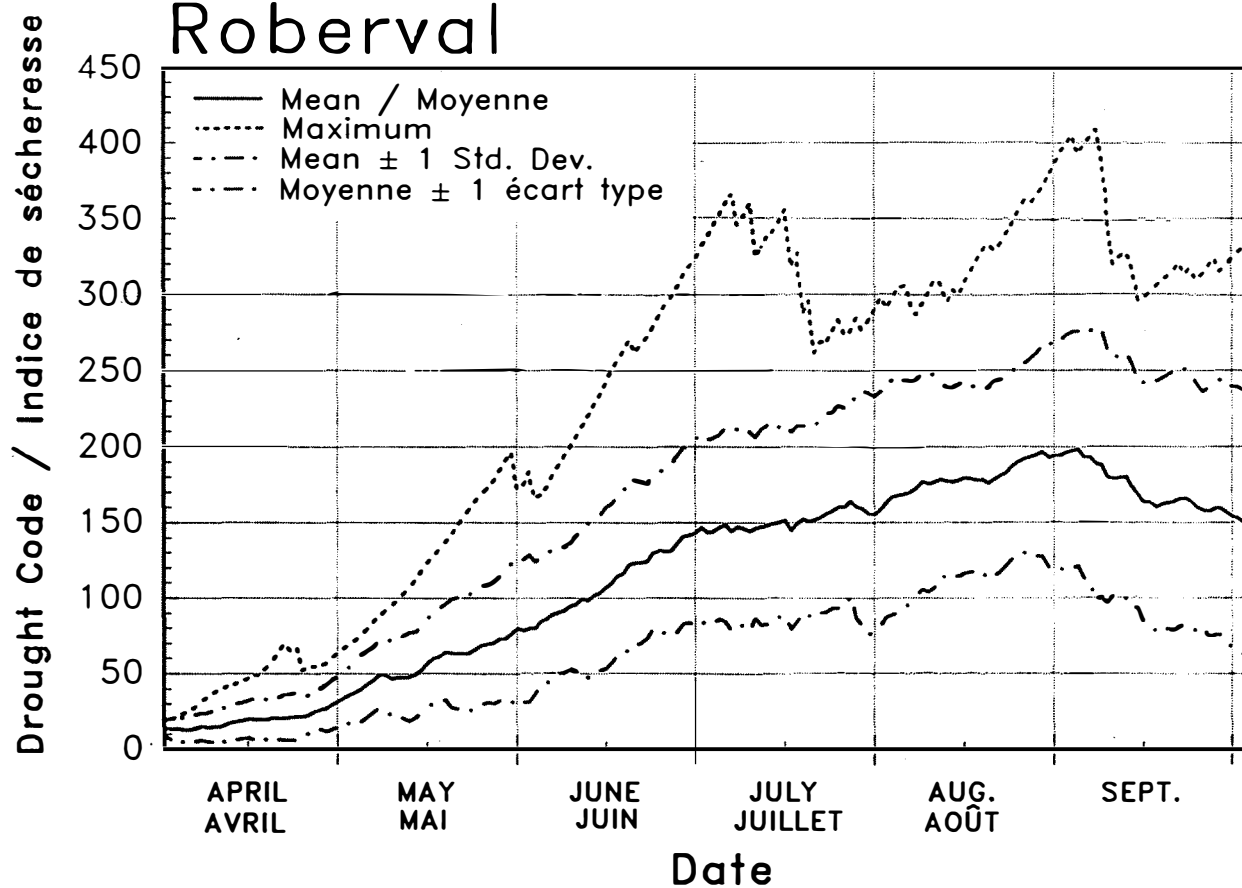




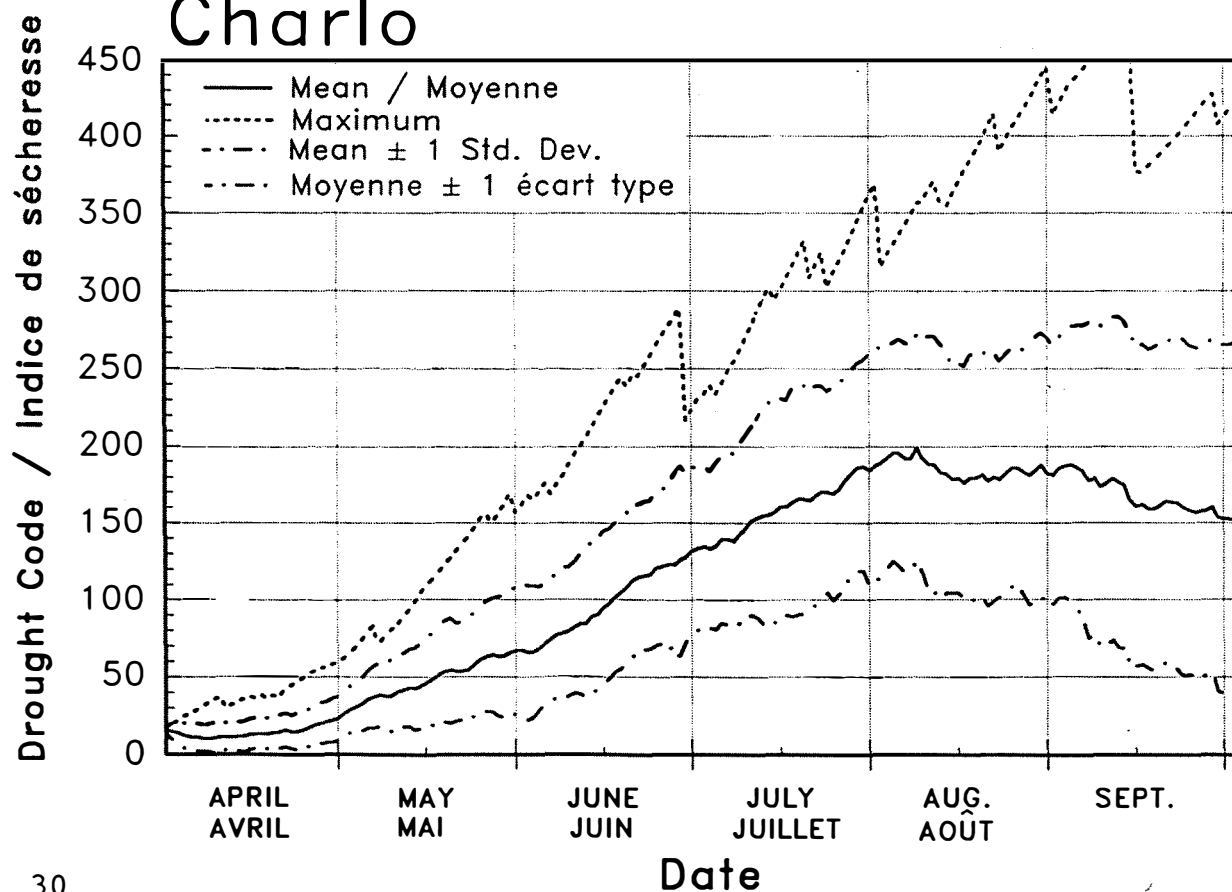




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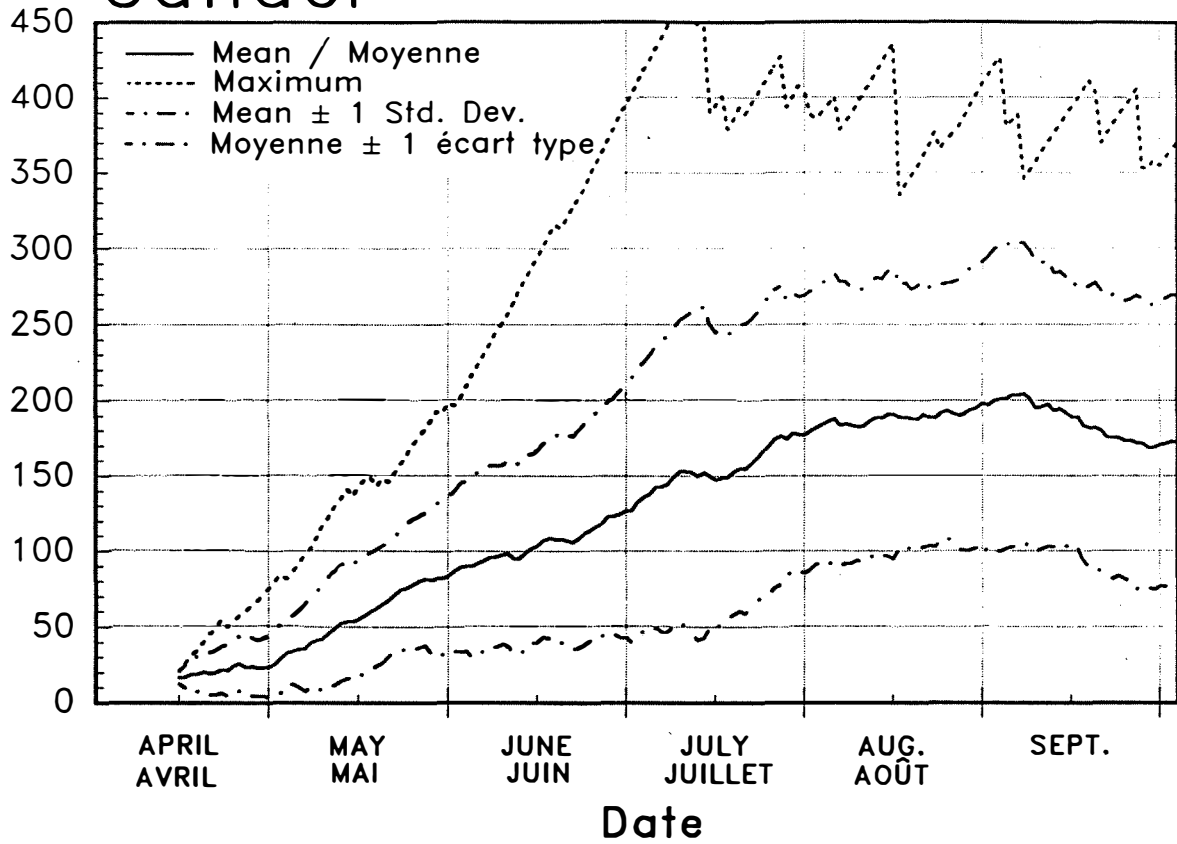


Charlo



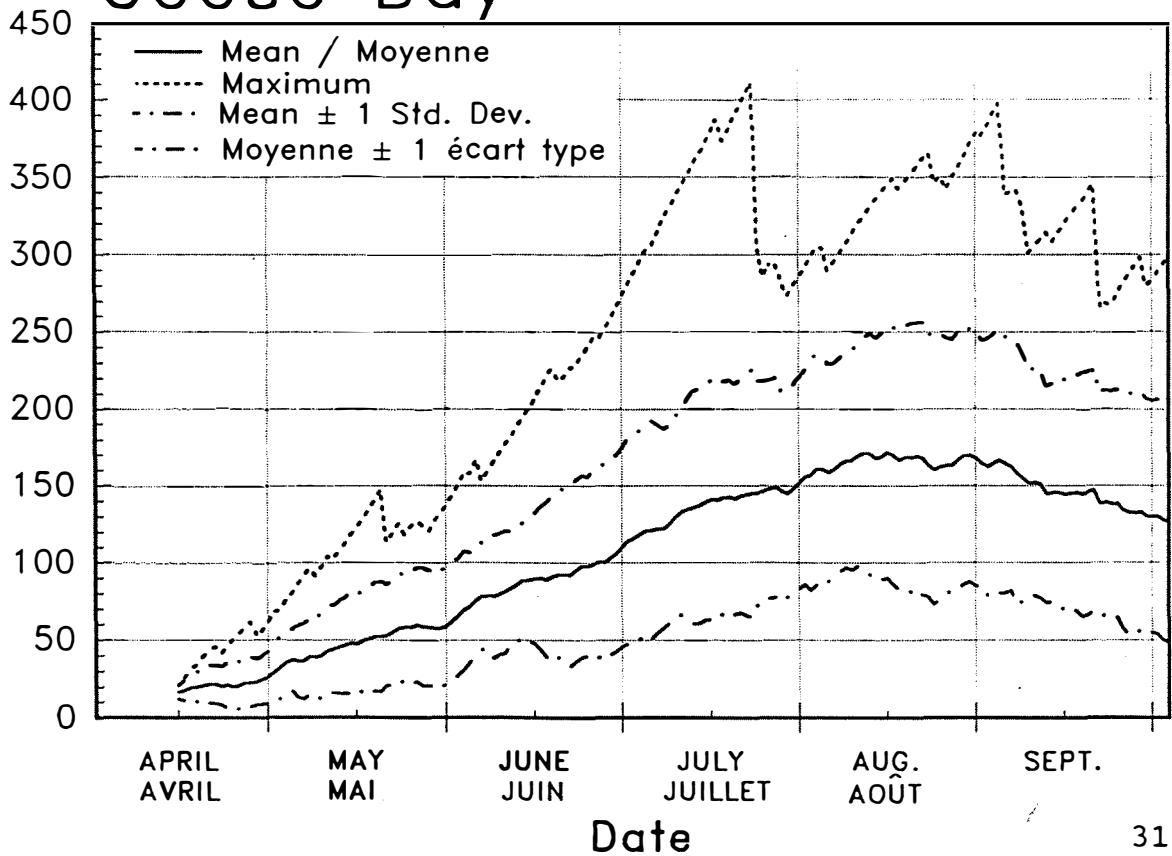
Drought Code / Indice de sécheresse

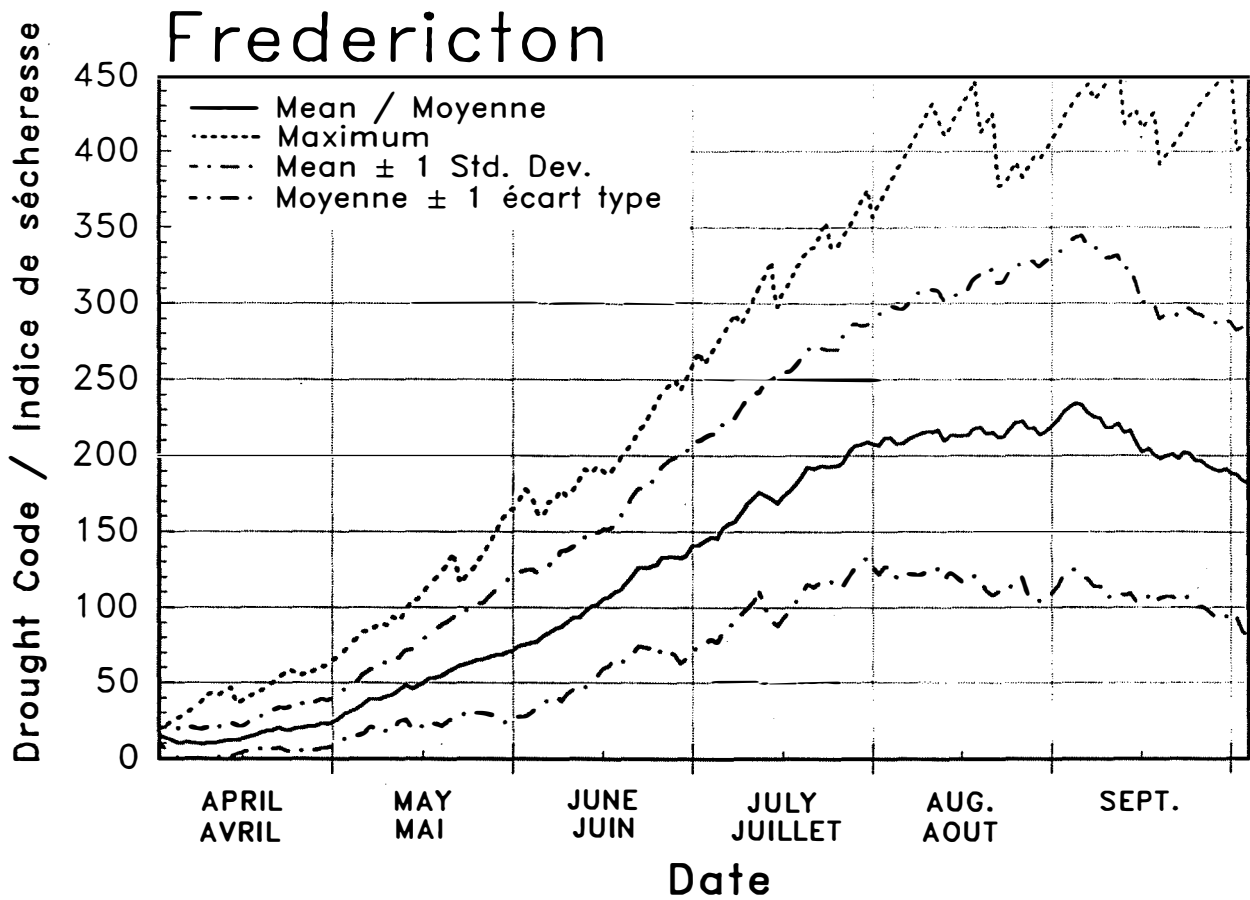
Gander



Drought Code / Indice de sécheresse

Goose Bay

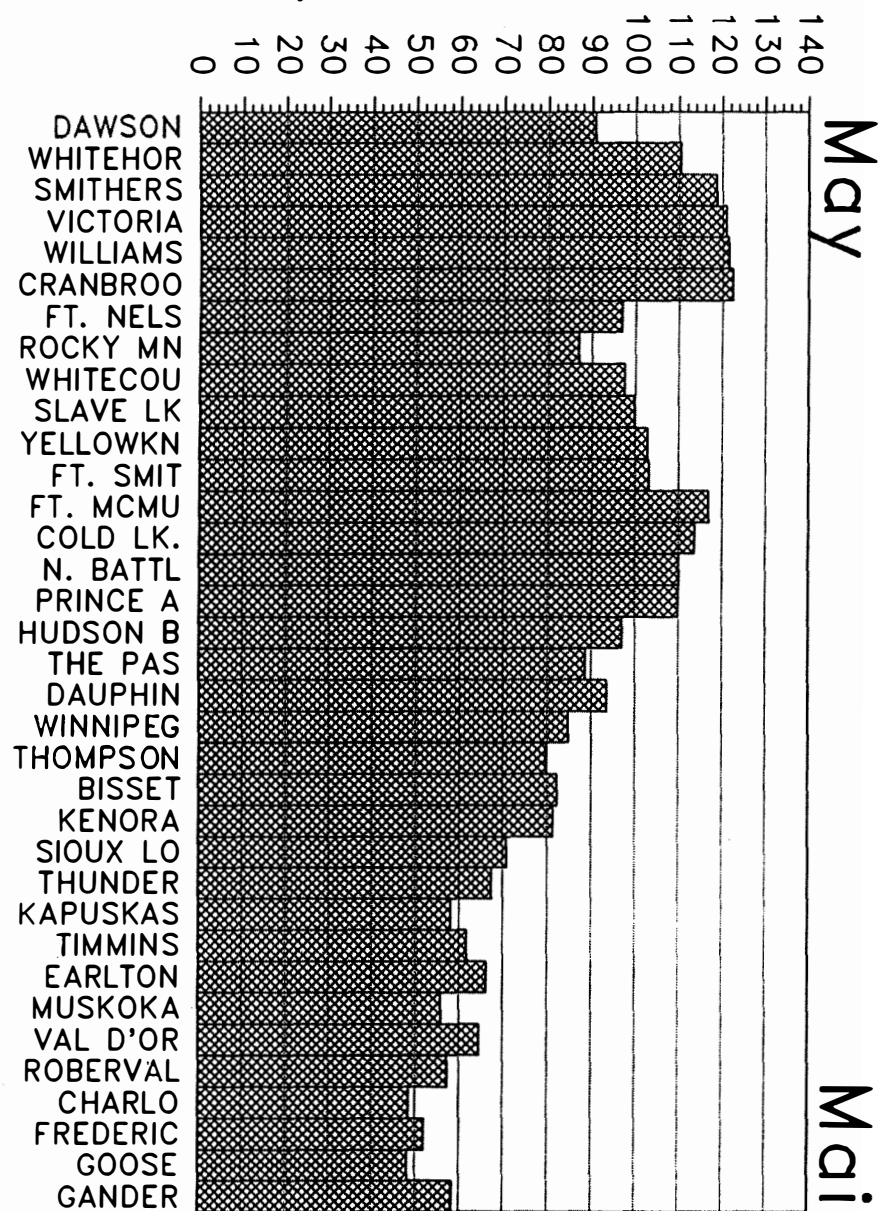




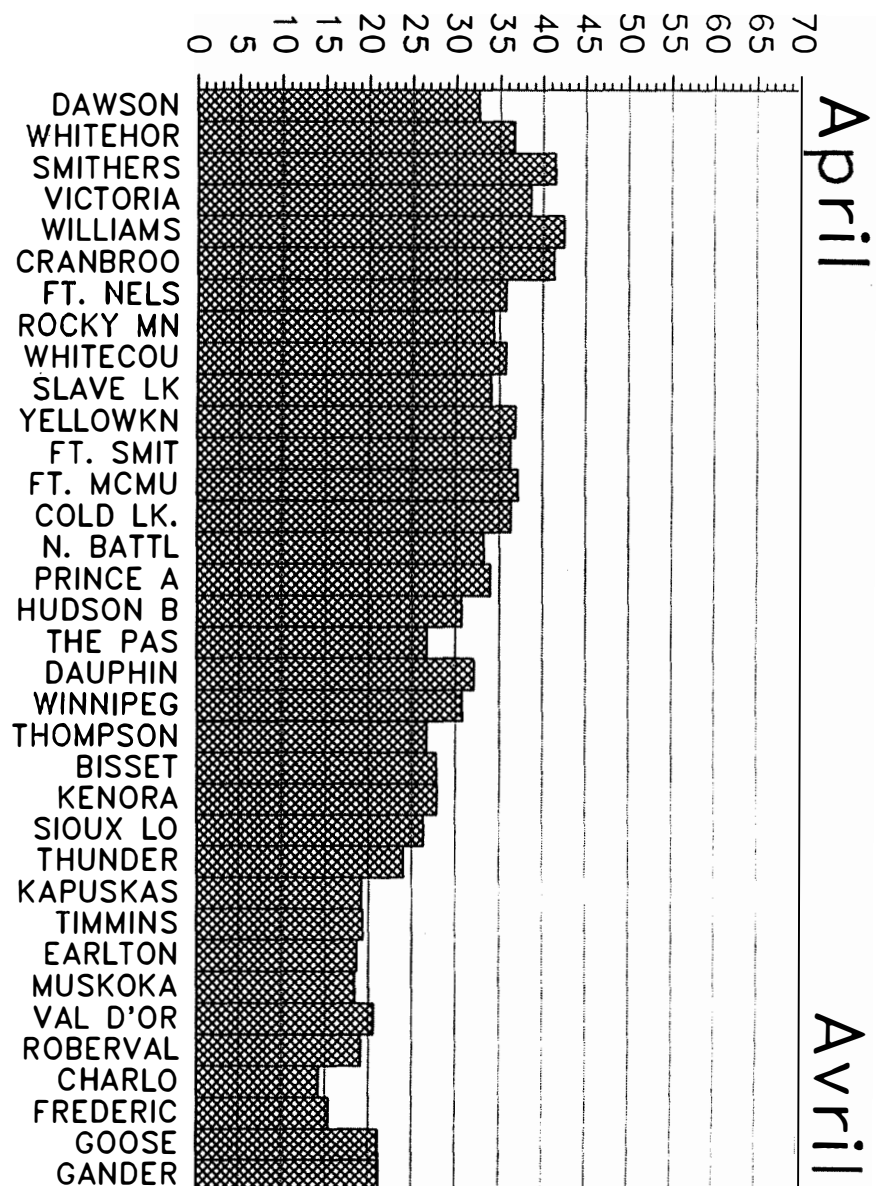
Appendix C

Mean monthly DC values for all stations by month

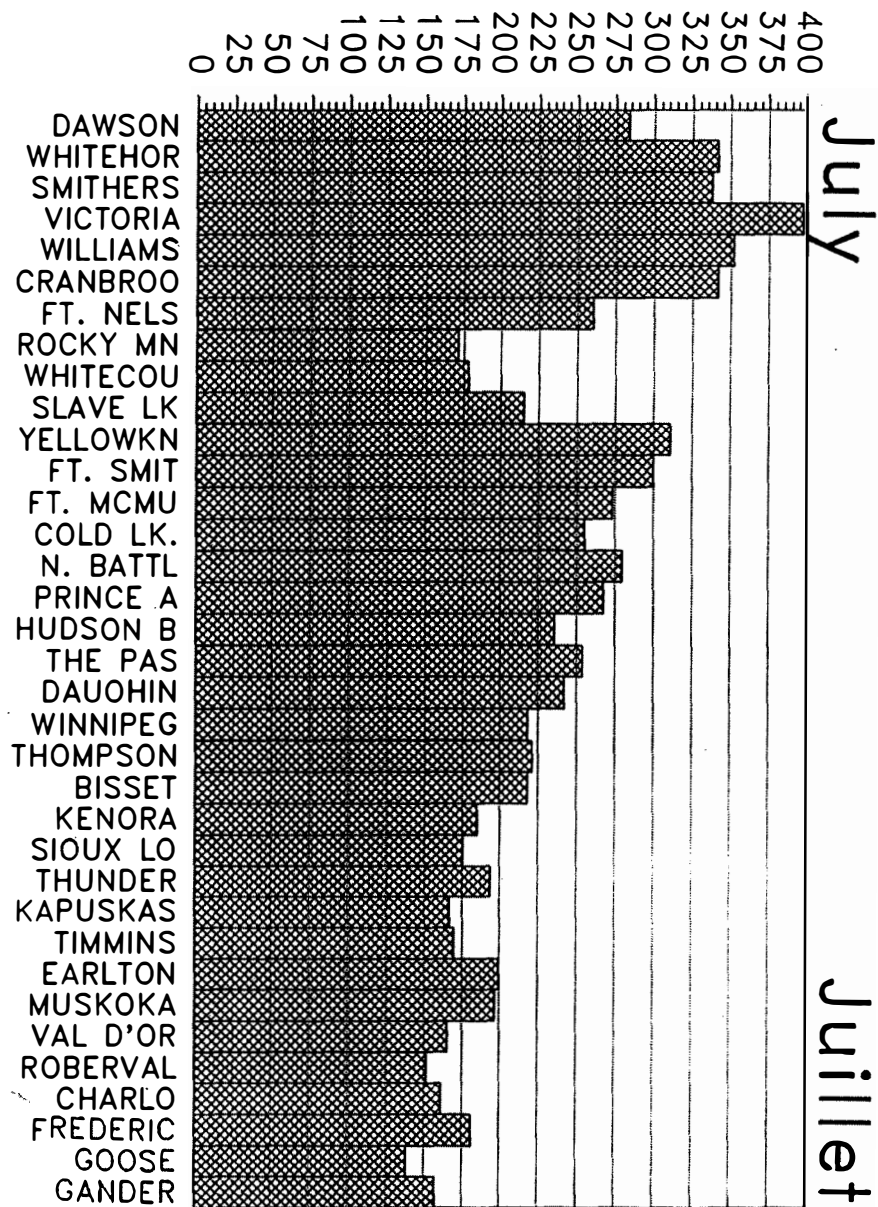
Mean Monthly DC
Moyenne mensuelle de l'IS



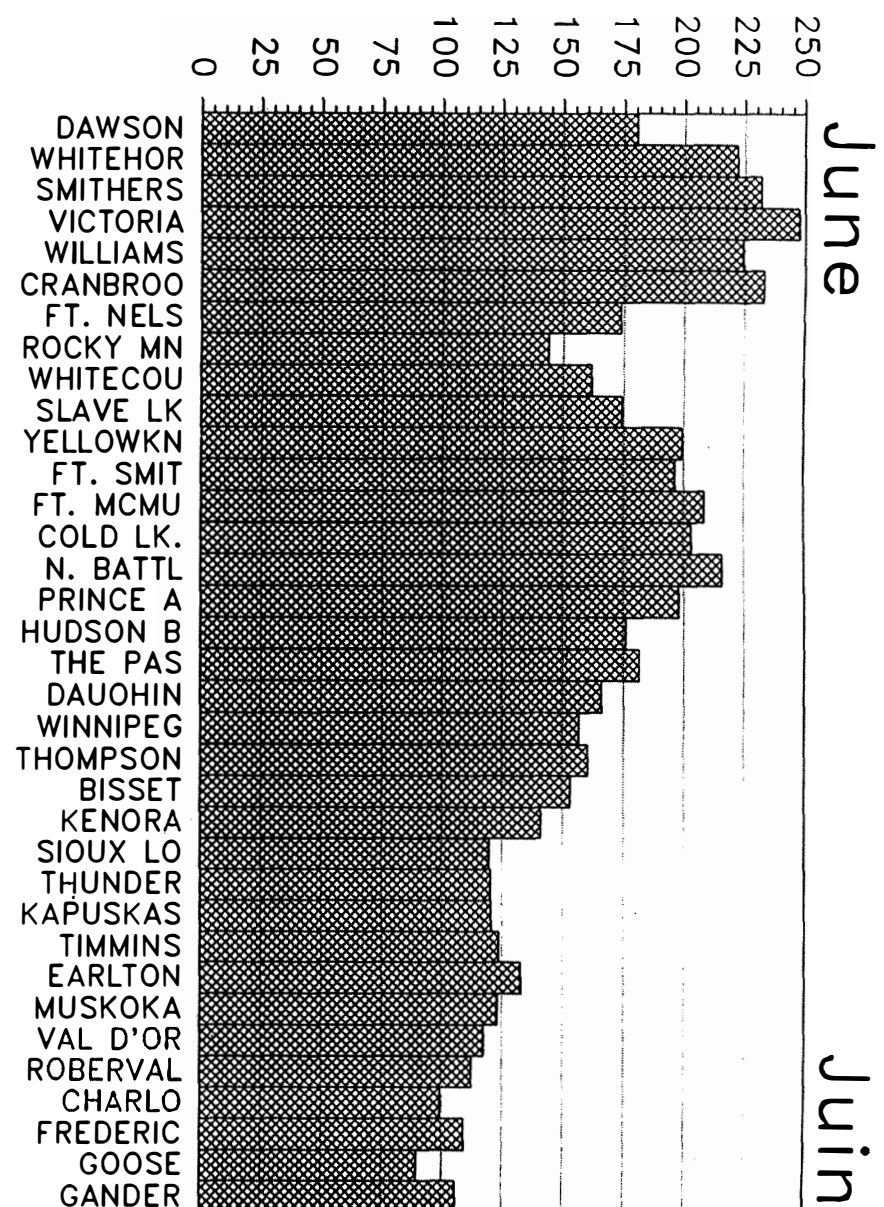
Mean Monthly DC
Moyenne mensuelle de l'IS



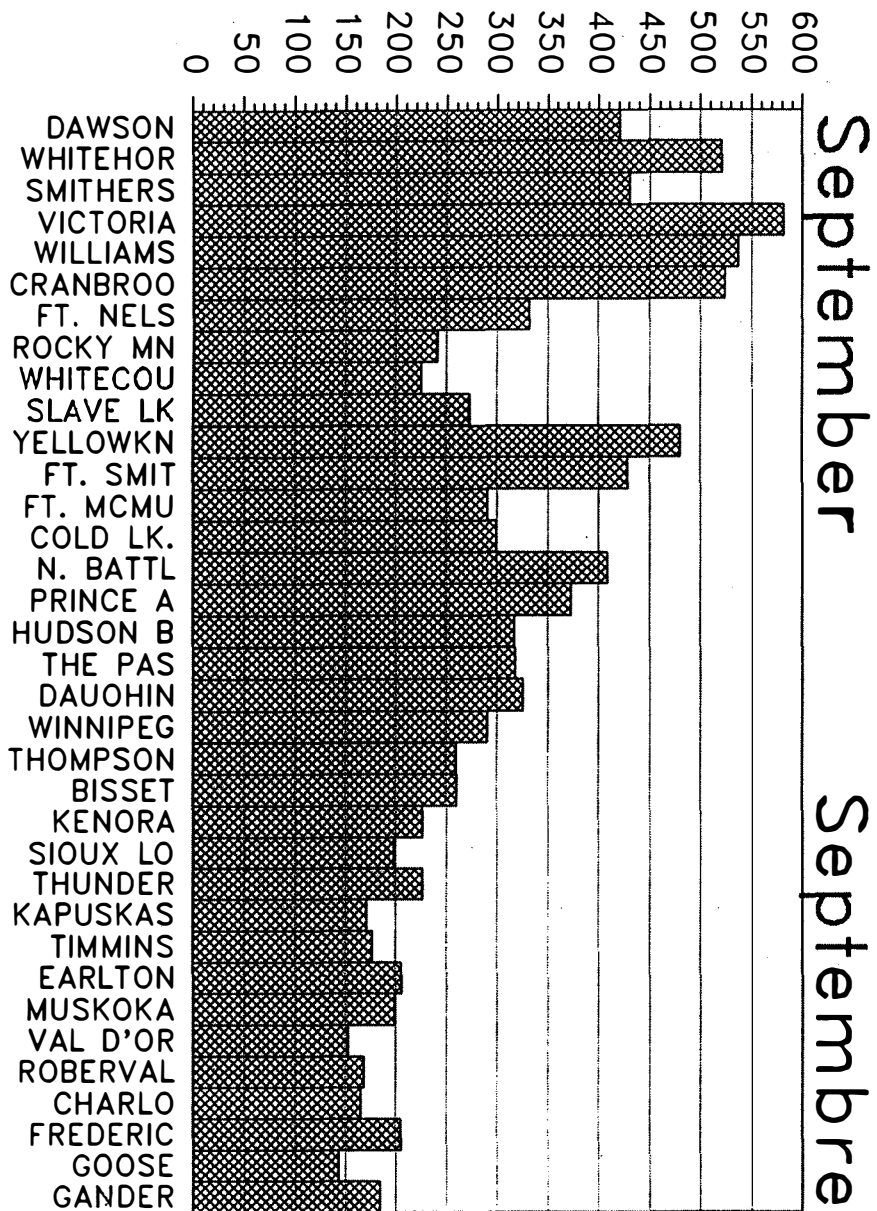
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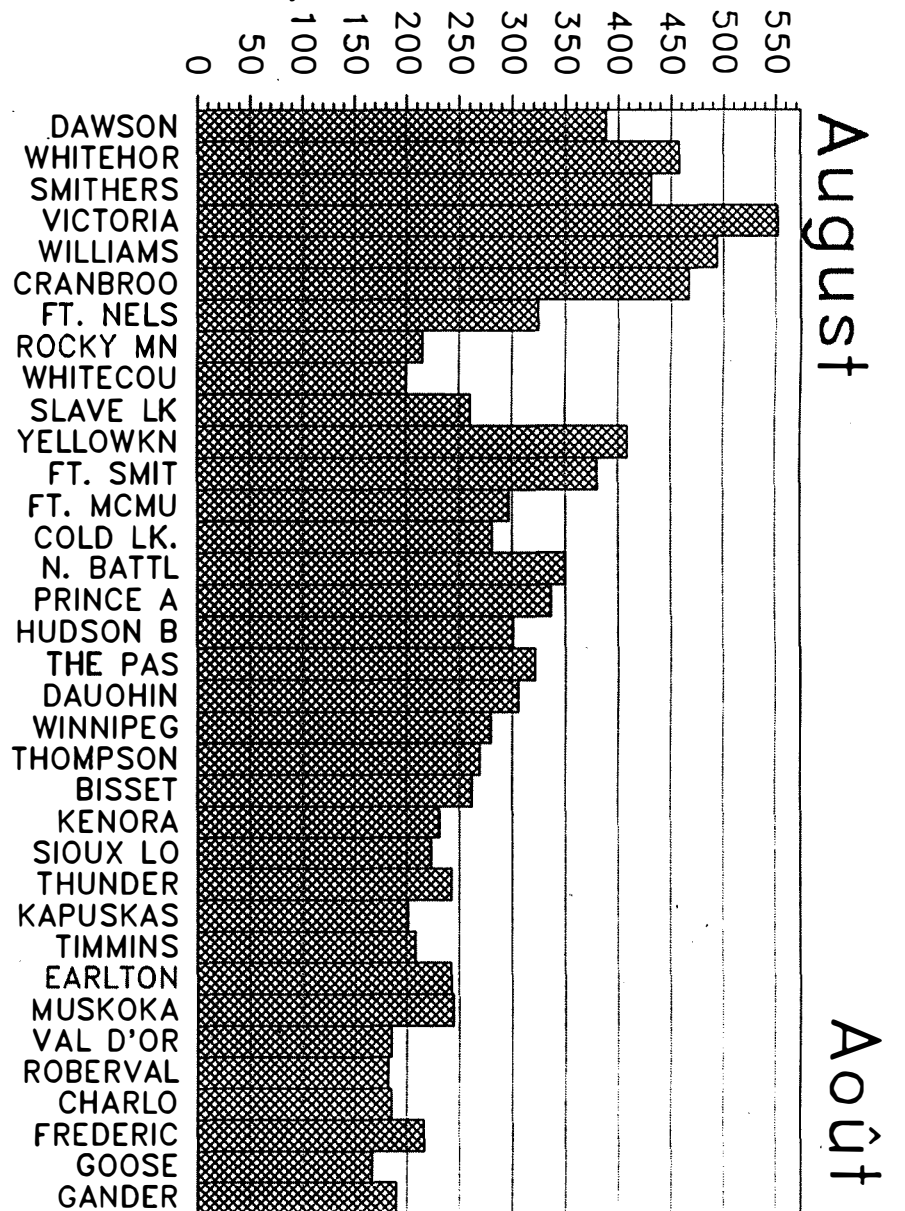
Mean Monthly DC
Moyenne mensuelle de l'IS



Mean Monthly DC
Moyenne mensuelle de l'IS



Mean Monthly DC
Moyenne mensuelle de l'IS



Août

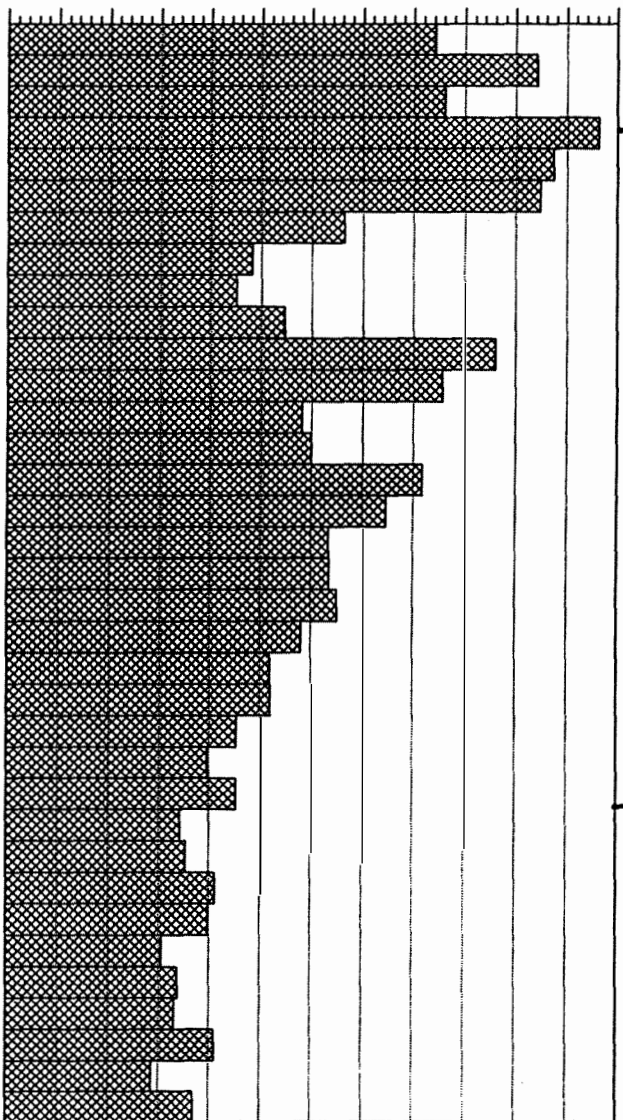
Mean Monthly DC
Moyenne mensuelle de l'IS

0 50 100 150 200 250 300 350 400 450 500 550 600

September

Septembre

DAWSON
WHITEHOR
SMITHERS
VICTORIA
WILLIAMS
CRANBROO
FT. NELS
ROCKY MN
WHITECOU
SLAVE LK
YELLOWKN
FT. SMIT
FT. MCMU
COLD LK.
N. BATTL
PRINCE A
HUDSON B
THE PAS
DAUOHIN
WINNIPEG
THOMPSON
BISSET
KENORA
SIOUX LO
THUNDER
KAPUSKAS
TIMMINS
EARLTON
MUSKOKA
VAL D'OR
ROBERVAL
CHARLO
FREDERIC
GOOSE
GANDER



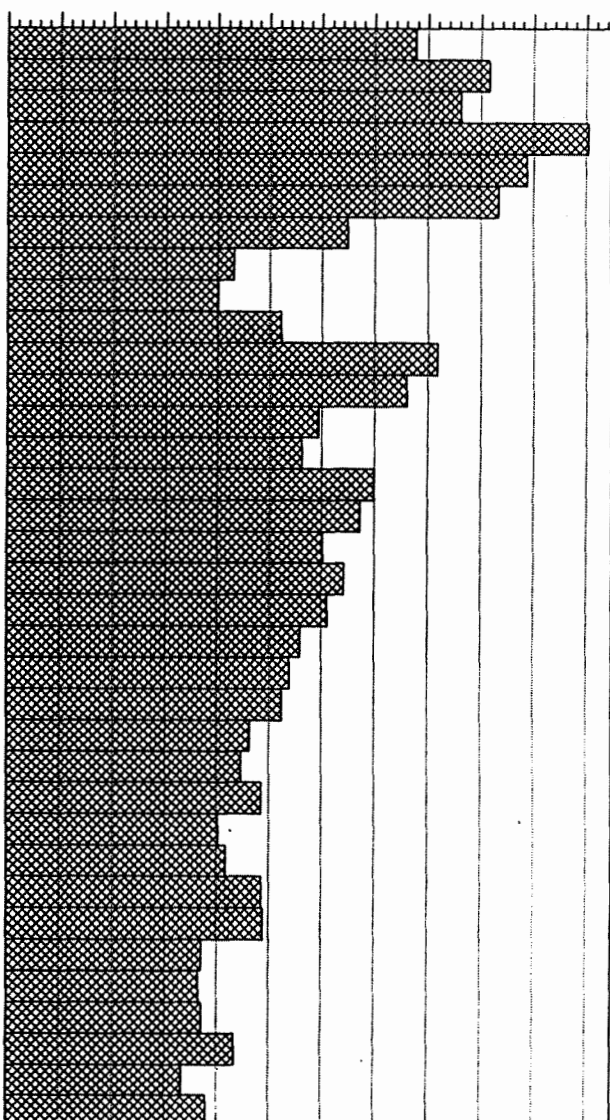
Mean Monthly DC
Moyenne mensuelle de l'IS

0 50 100 150 200 250 300 350 400 450 500 550

August

Août

DAWSON
WHITEHOR
SMITHERS
VICTORIA
WILLIAMS
CRANBROO
FT. NELS
ROCKY MN
WHITECOU
SLAVE LK
YELLOWKN
FT. SMIT
FT. MCMU
COLD LK.
N. BATTL
PRINCE A
HUDSON B
THE PAS
DAUOHIN
WINNIPEG
THOMPSON
BISSET
KENORA
SIOUX LO
THUNDER
KAPUSKAS
TIMMINS
EARLTON
MUSKOKA
VAL D'OR
ROBERVAL
CHARLO
FREDERIC
GOOSE
GANDER



MID-LEVEL STABILITY AND MOISTURE INDEX: LIKELIHOOD OF EXTREME FIRE BEHAVIOR¹

by

R.L. Raddatz², G. Kluth³, and K.G. Hirsch⁴

Introduction

Most fires that burn large areas do so as a result of major fire runs or "blow-ups" on only a few days within their lifetime. This extreme fire behavior is usually the result of severe fire weather conditions that combine with fuel and topographic characteristics to produce rapid rates of spread and sudden increases in fire intensity. The purpose of this paper is to describe a technique for predicting when such extreme fire behavior may occur in Manitoba.

A number of researchers have analyzed individual wildfires and related extreme fire behavior to various weather conditions (Alexander 1985). Brotak (1977), in an extensive study, examined the weather associated with 98 major fires in the United States and determined that:

- 1) nearly 90% of all runs on major fires were associated with regions of strong pressure gradients near frontal zones,
- 2) nearly 90% of all runs were associated with the eastern portion of a clearly discernable trough at 500 mb,
- 3) over 90% of all runs occurred when moisture advection at 850 mb was insufficient to produce precipitation, and
- 4) fire runs were associated with steep atmospheric lapse rates (i.e., air mass instability); 92% occurred when the temperature difference between 950-850 mb was 6°C or more,

¹ Summary of a presentation at the Seventh Central Region Fire Weather Committee Scientific and Technical Seminar, April 4, 1990, Winnipeg, Manitoba.

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76% occurred when the temperature difference between 850-700 mb was 10°C or more and 70% occurred when the temperature difference between 850-500 mb was 26°C or more.

In addition, other factors such as low-level jets and various wind profiles may contribute to fire runs or blow-ups.

Stability and Moisture Indices

Haines (1988), building on the stability and moisture relationships delineated by Brotak (1977), investigated 0000 GMT upper-air soundings in the vicinity of 74 major fires in the United States - 29 in the west and 45 in the east. Low, middle and high level atmospheric indices were developed which indicate the relative potential for extreme fire behavior. These indices represent the stability and moisture of an air mass resulting from synoptic-scale processes. The particular index that is applicable to a given region is dictated by the area's overall elevation. The level chosen is the lowest index level that is still high enough above the surface to avoid significant diurnal variation.

Haines' mid-level index will be described here since it is the most applicable to Manitoba. The mid-level stability and moisture index was calculated by determining the temperature difference between the 850 and 700 mb levels and the atmospheric moisture content at the 850 mb level. A numerical value was assigned to each factor as follows:

| <u>850 mb T - 700 mb T</u> | <u>Factor (A)</u> |
|-----------------------------|-------------------|
| Less than 6°C | 1 |
| 6-11°C | 2 |
| Greater than/equal to 11°C | 3 |
| <u>850 mb T - 850 mb Td</u> | <u>Factor (B)</u> |
| Less than 6°C | 1 |
| 6-13°C | 2 |
| Greater than/equal to 13°C | 3 |

where T is temperature and Td is dewpoint temperature. The two factors were then added together to obtain an index of the likelihood of extreme fire behavior for the day.

| <u>Index = Factors (A + B)</u> | <u>Class of Day (Likelihood of Extreme Fire Behavior)</u> |
|--------------------------------|---|
| 2 or 3 | Very low |
| 4 | Low |
| 5 | Moderate |
| 6 | High |

In this study, Haines (1988) found that 6% of the major fires occurred when the mid-level index was very low while 58% of the days in the baseline fire season (1981) were in that class; 16% occurred under a low classification while 25% of the days fit that category; 78% of the major fires burned under a moderate to high index while only 17% of the baseline fire season's days were in that class. These results indicate that the mid-level index is a useful indicator of days when extreme fire behavior may occur. However, some major fire runs did occur on low and very low index days. This implies that the index only represents part of the overall fire weather picture. Therefore, it should be used in conjunction with other meteorological⁵ and fire danger indicators to estimate the potential for extreme fire behavior.

Operational Mid-Level Stability and Moisture Index: Prairie Weather Centre

A procedure for calculating a mid-level stability and moisture index (MLI-Dex) has been developed at the Prairie Weather Centre (PRWC). The technique uses grid-point data at the standard atmospheric levels for a "prairie window". These data are received twice daily (1630 and 0430 GMT) from the Canadian Meteorological Centre for forecast-model times of $t = 0, 6, 12, 18, 24, 30,$ and 36 hours. The fields transmitted include heights, temperatures and dewpoint depressions at the 1000, 850, 700 and 500 mb levels. At the PRWC, the data are automatically decoded and stored in a computer disk-file. A data access routine and Bessel interpolation (Haltiner 1971) are used to provide upper-air data over specified locations at selected forecast times (Raddatz and Atkinson 1982). Actual and forecast MLI-Dex values for specified locations are calculated from the interpolated grid-point data in the manner indicated by Haines (1988). However, in this operational application, Factor (B) is determined from relative humidity (RH) values rather than dewpoint temperatures.

That is,

| <u>850 mb RH</u> | <u>Factor (B)</u> |
|---------------------------|-------------------|
| Greater than/equal to 70% | 1 |
| 45-70% | 2 |
| Less than 45% | 3 |

⁵ To obtain a more complete picture of the weather conditions, the mid-level index, which classifies a day's extreme fire potential according to air mass stability and moisture, should be used in conjunction with indicators of wind speed and direction such as pressure gradients and fronts.

MLI-Dex Verification for Manitoba and Conclusions

The mid-level stability and moisture index was calculated from $t = 0$ hour (0000 GMT) grid-point data interpolated to either The Pas (YQD) or International Falls (INL) for nineteen (19) major wildfire runs which were documented in or near Manitoba from 1986-89⁶. The index was also calculated for the entire 1988 fire season (April 1 - August 31) for INL and the entire 1989 season for YQD to provide baseline information on the relative frequencies of the various index classes. These two locations were used for the Manitoba verification since historical interpolated grid-point data had only been saved for radiosonde sites. In all cases either INL or YQD was the radiosonde station closest to the wildfire being investigated. In addition, only 0 hour (i.e., actual) grid-point data was considered to avoid any uncertainty introduced by the forecast process.

Verifications (Tables 1, 2, and 3) were comparable to the results obtained by Haines (1988). Therefore it was concluded that the MLI-Dex is applicable to Manitoba. Furthermore, it was assumed that the mid-level index, calculated from 12, 24 and 36 hour forecasts for 0000 GMT, will be a useful indicator of the potential for extreme fire behavior provided that the additional uncertainty introduced by the forecast process is not overlooked.

⁶ Other undocumented fire runs may have occurred.

Table 1. Days of major wildfire runs in Manitoba during 1986-89.

| Documented wildfire run days | | Mid-level index | |
|------------------------------|---|-----------------|-----|
| Date | Fire name/location | INL | YQD |
| May 21, 1986 | Red Lake #7 | M | |
| 28 | Red Lake #7 | H | |
| 29 | Red Lake #7 | H | |
| June 3 | Red Lake #7 | VL | |
| May 5, 1987 | Wallace Lake | M | |
| 8 | Woodridge, Wallace Lake | M | |
| May 1, 1988 | Breton Lake, Gull Lake, and Kenora #14 | H | |
| 2 | Kenora #14 | M | |
| 3 | Kenora #14 | H | |
| May 11, 1989 | Gowan, Ashern Sandy R. | | M |
| 12 | Gowan, Ashern Sandy R. | | L |
| 13 | Gowan, Ashern Sandy R. | | L |
| 14 | Gowan, Ashern Sandy R. | | M |
| 15 | Gowan, Ashern Sandy R. | | M |
| 16 | Gowan, Ashern Sandy R. | | L |
| JULY 21, 1989 | Northern Manitoba | | H |
| 22 | Northern Manitoba | | H |
| 23 | Northern Manitoba | | H |
| August 1, 1989 | Northern Manitoba | | M |

Table 2. Summary of major wildfire run days and Mid-level index in Manitoba during 1986-89.

| Mid-level index | Wildfire run days (19) | |
|-----------------|------------------------|----|
| | # | % |
| Very low | 1 | 5 |
| Low | 3 | 16 |
| Moderate/High | 15 | 79 |

Table 3. Summary of major wildfire run days and fire season days in relation to the mid-level index during the 1988 and 1989 fire seasons (April 1 - August 31).

| Mid-level index | Wildfire Run Days (13) | | Fire season days (301) | |
|-----------------|------------------------|----|------------------------|----|
| | # | % | # | % |
| Very low | 0 | 0 | 76 | 25 |
| Low | 3 | 23 | 107 | 36 |
| Moderate/High | 10 | 77 | 118 | 39 |

References

- Alexander, M.E. 1985. Bibliography of wildfire case histories and studies. Environ. Can., Can. For. Serv., North. For. Cent., Edmonton, Alberta. Study NOR-5-191. File Report No. 4.
- Brotak, E.A. 1977. Meteorological conditions associated with major wildfires. Ph.D. Dissertation, Yale University, New Haven. Conn. 183 pp.
- Haines, D.A. 1988. A lower atmosphere severity index for wildlife fires. National Weather Digest 13(2): 23-27.
- Haltiner, G.J. 1971. Numerical weather prediction. John Wiley and Sons, Toronto. 252 pp.
- Raddatz, R.L.; Atkinson, G.B. 1982. Automated weather element input to forest fire severity forecasting. Tech. Mem., TEC-877. Atmos. Environ. Serv., Environ. Can. 16 pp.

THE INTELLIGENT FIRE MANAGEMENT INFORMATION SYSTEM: AN OVERVIEW¹

by

K.R. Anderson and B.S. Lee²

Abstract

The Intelligent Fire Management Information System (IFMIS) is a microcomputer based decision support system developed primarily for forest fire preparedness planning and for dispatching initial attack resources to wildfires. The IFMIS program integrates weather, terrain, and forest inventory databases to produce maps of potential fire behavior. For fire detections, IFMIS provides reports outlining interpolated weather conditions, predicted fire growth, and available fire suppression resources. This paper describes IFMIS and its applications to fire management with an emphasis on its meteorological aspects.

Introduction

In recent years, Canadian fire protection agencies have become more dependent on decision support systems for planning and real-time decision making. In western Canada, a number of fire protection agencies have adopted forest fire preparedness planning approaches to determine daily initial attack resource requirements (Gray and Janz 1985; Lanoville and Mawdsley 1990; De Groot 1991; Hirsch 1991). Forest fire preparedness planning is the process of ensuring that adequate suppression resources are available to cope with daily anticipated fire events. Until recently, preparedness planning was strictly weather based and did not incorporate fuels or topography. The Intelligent Fire Management Information System (IFMIS) offers a new approach by integrating weather, fuels, and topography into a spatially based procedure for preparedness planning. The spatial approaches used by IFMIS also improve real-time decision support for dispatching fire suppression resources to wildfires by providing better estimates of fire weather and fire behavior potential.

¹ A presentation made at the Seventh Central Region Fire Weather Committee scientific and technical seminar, April 4, 1990, Winnipeg, Manitoba.

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Background

The Intelligent Fire Management Information System (IFMIS) is a decision support system developed at Forestry Canada's Northern Forestry Centre in Edmonton (Lee 1990; Lee and Anderson 1989). The system has been under development since 1987 and was first demonstrated to the Alberta Forest Service at Whitecourt Forest, Alberta, Canada, in September 1988. Since then, a total of six Canadian and one U.S. agency have either adopted IFMIS or are evaluating its application within their organizations. The first operational trials of IFMIS were conducted in 1989. In that year, four installations were tested in the Canadian provinces of Alberta and Saskatchewan. In 1990, six installations were added including four forests in Alberta, the State of Alaska, and Kootenay National Park. At least five more installations are being planned for the 1991 fire season.

Description

The IFMIS program is a microcomputer based fire management system. The system integrates a number of advanced technologies including relational databases, mathematical modeling, geographic information display, and expert systems. Lee (1990) described the conceptual basis and structure of IFMIS software since the 1988 fire season.

Relational Databases

The fire environment is complex and to predict fire danger, a large number of factors must be considered. To approach the problem, IFMIS manages a variety of databases. These include forest inventory, terrain, daily weather, fire suppression resources, and others.

The term relational database describes how the databases interact. Databases are often designed to reduce redundancy by storing common information in a separate, but related database. For example, a database containing airtanker deployment information may contain aircraft types associated with a deployed airtanker group, but specific information on the aircraft type, such as cruising speed and maximum range, are stored in a separate database of aircraft specifications.

The central IFMIS database is the forest inventory database. This database consists of geographically referenced cells containing forest fuel type (e.g., black spruce, jack pine, etc.). The cell size depends on available data, with most IFMIS installations using cell sizes varying from 25 to 100 hectares.

Topography can be incorporated into the forest inventory database. Terrain information, such as slope, aspect, and

elevation, can be stored for each cell transforming this database into a forest environment database.

Weather, another critical feature of the fire environment, is managed on a daily basis. Lookout towers and ranger stations typically take daily weather measurements at 1200 Local Standard Time (LST). This weather is stored in the weather database and is used to model the fuel moisture conditions at potential fire sites. Regional forecasts can be entered into IFMIS, which is a very useful planning tool.

The activation and deployment of fire suppression resources, such as airtankers and helicopter-carried (initial attack) ground crews, are managed by IFMIS. Resource deployment information is used to assess coverage efficiency for planning purposes, and to decide on resource dispatching when actual fires are reported.

Mathematical Modeling

Using information stored in the databases, IFMIS uses mathematical models to predict important factors in the fire environment. These include fire weather conditions, potential fire behavior, and resource dispatching.

The IFMIS program uses the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987) as a basis for modelling and interpreting fire weather. The FWI System estimates forest fuel moisture conditions using empirical models driven by daily 1200 LST weather readings. These weather readings include temperature, relative humidity, 10 metre wind speed, and 24 hour precipitation. Outputs from the system include three fuel moisture codes and three fire behavior indices.

The IFMIS program interpolates both weather and FWI System values between stations using a weighted moving average shown in the following equation,

$$x' = \frac{\sum x_i / d_i^2}{\sum 1 / d_i^2}$$

where x' is the interpolated weather value at a location x_i , and d_i is the distance from the location to the weather station.

The interim edition of the Canadian Forest Fire Behavior Prediction (FBP) System has been in use in Canada since 1984 (Lawson et al. 1985). The FBP System estimates the forward rate of spread (ROS) of a fire for 14 defined fuel classes using input FWI values. Additional FBP outputs in the upcoming release include the head fire intensity (HFI), the crown fraction burned (CFB), and the total fuel consumed (TFC).

Using the FBP System with the forest inventory database and interpolated FWI values, IFMIS can predict potential fire behavior such as ROS, HFI, CFB, and TFC. This integration of interpolated weather with fuels and topography to produce quantitative estimates of potential fire behavior has greatly improved the ability of fire management agencies to respond to daily fire management planning issues.

Resource deployment information allows IFMIS to estimate the attack times to fire sites using alertness levels for getaway times and great circle routes and cruising speeds for travel times. Future modeling will be centered around line building capabilities and fire containment. Linear programming approaches are also being developed to determine optimal resource deployment with the goals of maximizing coverage while minimizing required resources.

An example of IFMIS's modeling is illustrated by the detection assessment report shown in Figure 1. When a fire is reported by a lookout tower, the location is radioed into the dispatch office. Entering only the location, date, and estimated time of ignition, the dispatcher receives a complete report in seconds from IFMIS, with estimates of weather conditions, forest inventory data, predicted fire behavior, and closest fire suppression resources.

Geographic Information Displays

The IFMIS program is capable of presenting database and modeling information in a variety of formats. These include the familiar seasonal histograms of weather (Fig. 2) and fire intensity rank charts (Fig. 3), adapted from Alexander and De Groot (1988). The program can also display spatial information with maps.

Using the available database, IFMIS can produce a number of maps. Information can be plotted directly from a database, such as fuel type or crew locations, or from models to predict the fire danger within a region. This approach can provide the forest fire manager with daily or hourly maps and reports depicting fire weather (Fig. 4), fire behavior (Fig. 5 and 6), and resource utilization effectiveness (Figure 7) in a matter of minutes.

The mapping feature of IFMIS has proved to be a valuable preparedness planning tool. Lee and Anderson (1989) described a spatial approach to forest fire preparedness planning that incorporated weather, fuels, and topography to suboptimally determine the daily allocation of suppression resources. Fire management planning in western Canada is based upon the philosophy of early detection of forest fires and rapid initial attack. In order to meet this goal, all fires must receive initial attack before they reach a critical size. This criteria is called the initial attack size objective. Using such a policy, IFMIS can assess the efficiency of prepositioned resources within a forest region on a daily or hourly basis.

Smoke Detection Report

Location: Zone 13 431425 m E 6022642 m N
 Date: JUL 14, 1989
 Ignition time: 1600 LDT

Actual Weather Conditions at 12:00 LST:

| Temp | RH | Wind | Dir | Rain | FFMC | DMC | DC | ISI | BUI | FWI | DSR |
|------|----|------|-----|------|------|------|-----|-----|------|-----|------|
| 24.7 | 50 | 8.1 | 360 | 0.0 | 86.6 | 14.4 | 345 | 4.0 | 26.1 | 7.5 | 0.97 |

FBP Fuel Types:

| Species | FBP Fuel | % Cover |
|---------|----------|---------|
| JP | C3 | 58 % |
| TA | D1 | 18 % |
| TM | C2 | 15 % |
| GR | O1 | 10 % |

FBP Projections:

| Elapsed Time (hh:mm) | LDT | FFMC | ISI | ROS (m/min) | CFB % | HFI (kW/m) | TFC (t/ha) | Dist (km) | Area (ha) | Perim (m) |
|-------------------------|------|------|-----|----------------|----------|---------------|---------------|--------------|--------------|--------------|
| 0:00 | 1600 | 85.6 | 3.4 | 0.0 | 0 | 199 | 0.60 | 0.0 | 0.0 | 0.0 |
| 0:15 | 1615 | 86.0 | 3.6 | 0.9 | 0 | 216 | 0.60 | 0.0 | 0.0 | 33.5 |
| 0:30 | 1630 | 86.4 | 3.9 | 1.1 | 0 | 234 | 0.60 | 0.0 | 0.1 | 96.8 |
| 0:45 | 1645 | 86.8 | 4.1 | 1.3 | 0 | 255 | 0.60 | 0.0 | 0.2 | 170.6 |
| 1:00 | 1700 | 86.6 | 4.0 | 1.2 | 0 | 244 | 0.60 | 0.1 | 0.5 | 242.5 |
| 2:00 | 1800 | 86.1 | 3.7 | 1.1 | 0 | 220 | 0.60 | 0.1 | 2.0 | 503.2 |
| 3:00 | 1900 | 85.6 | 3.4 | 1.0 | 0 | 199 | 0.60 | 0.2 | 4.3 | 739.8 |
| 4:00 | 2000 | 84.6 | 3.0 | 0.8 | 0 | 163 | 0.60 | 0.2 | 6.9 | 935.9 |
| 5:00 | 2100 | 83.6 | 2.6 | 0.7 | 0 | 135 | 0.60 | 0.3 | 9.6 | 1100.3 |
| 6:00 | 2200 | 83.6 | 2.6 | 0.7 | 0 | 135 | 0.60 | 0.3 | 12.6 | 1264.7 |

L/B Ratio: 1.153

Available Crews:

| ID | Base Name | Aircraft | Status | Dist (km) | Bear | ETA (hh:mm) |
|---------|-------------------|----------|------------|--------------|------|----------------|
| IAC P07 | THUNDER MOUNTAIN | 206B | 15 Minutes | 31.5 | 161 | 0:13 |
| IAC P02 | LOWER FISHING LAK | 206B | 15 Minutes | 98.9 | 291 | 0:34 |
| IAC P05 | ENGLISH CABIN | 206B | 15 Minutes | 146.2 | 327 | 0:48 |

Available Airtankers:

| ID | Base Name | Aircraft | Status | Dist (km) | Bear | ETA (hh:mm) |
|------|-----------------|----------|----------|--------------|------|----------------|
| 2 LR | LA RONGE | DC-6B | On Base | 102.4 | 210 | 0:29 |
| 4 BN | BUFFALO NARROWS | B25J | On Base | 214.0 | 78 | 0:49 |
| 3 ML | MEADOW LAKE | C52F | One Hour | 161.7 | 80 | 1:33 |

Figure 1. A detection assessment report for a simulated fire occurring at 1600 LDT, July 14, 1989 at UTM location 431425 m E, 6022642 m N, Zone 13.

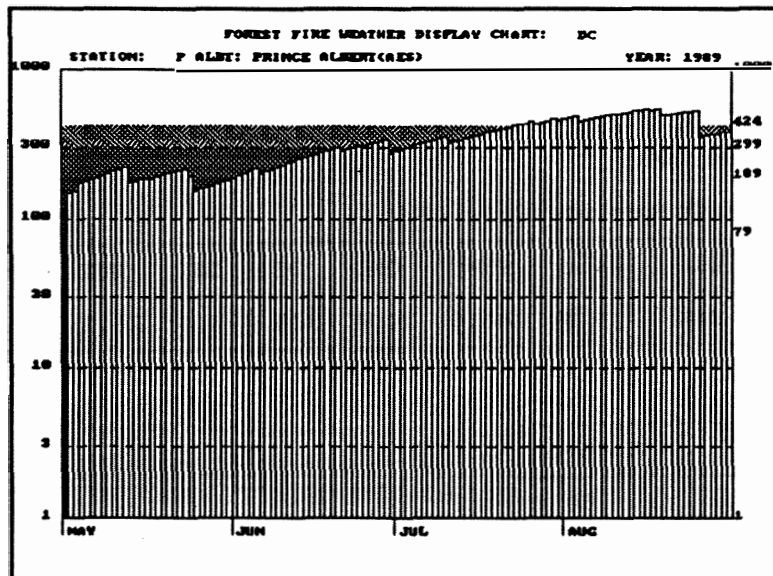


Figure 2. A Forest Fire Weather Display Chart produced by IFMIS showing, in histogram form, the daily Drought Code (DC) values for Prince Albert over the 1989 fire season.

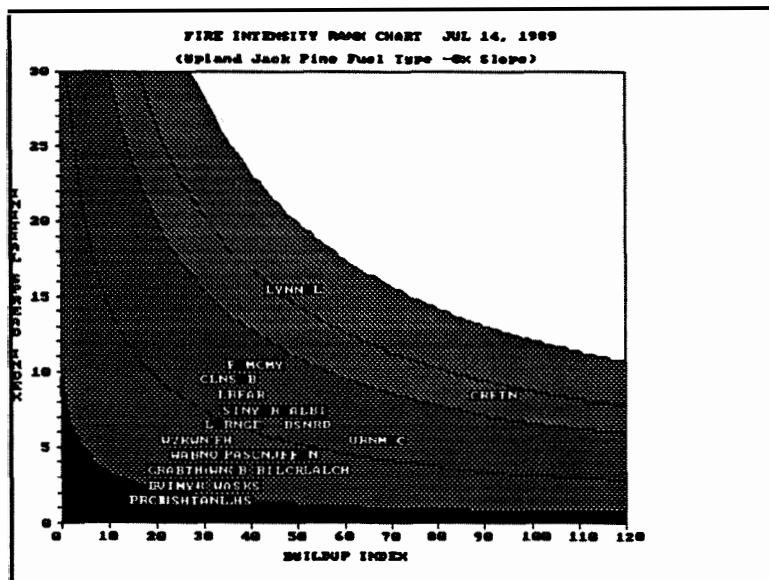


Figure 3. A Fire Intensity Rank Chart produced by IFMIS showing the relative predicted fire intensity, delineated by grey scales, at weather station locations throughout Saskatchewan.

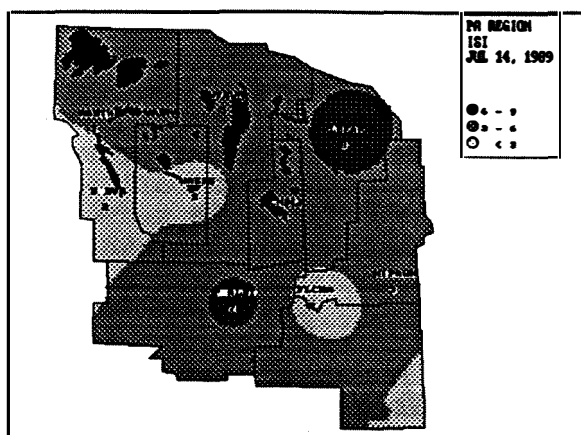


Figure 4. Initial spread index (ISI) map for the Prince Albert region, July 14, 1989.

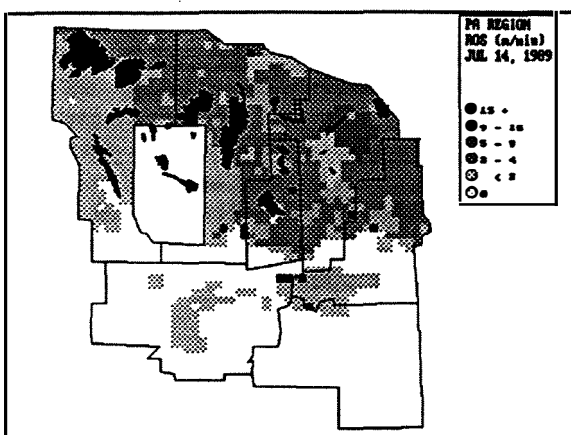


Figure 5. Rate of spread (ROS) map for the Prince Albert region, July 14, 1989.

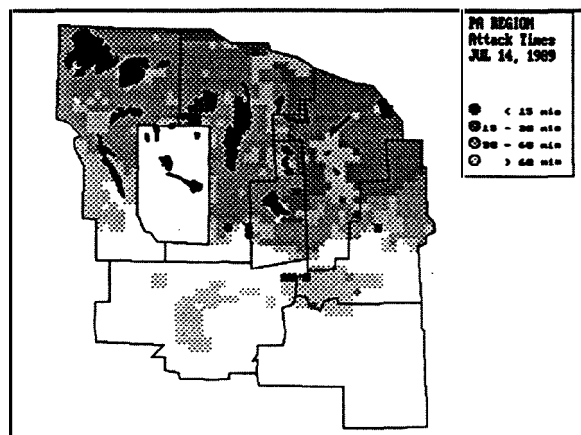


Figure 6. Attack times map for the Prince Albert region, July 14, 1989.

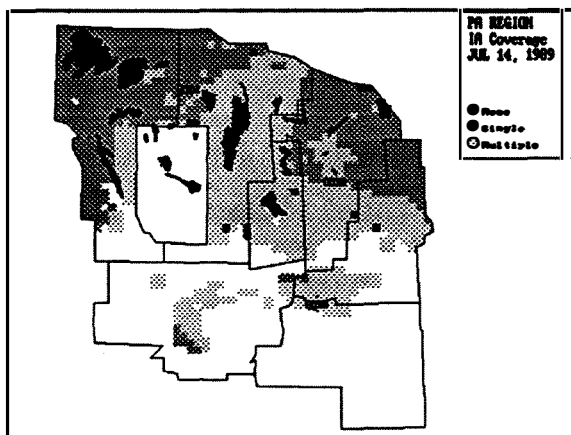


Figure 7. Coverage map for the Prince Albert region, July 14, 1989, using three initial attack crews.

For each cell, IFMIS computes the time it would take a potential fire to reach the initial attack size objective. This elapsed time criteria, referred to as the attack time, can be displayed in map form (Fig. 6). With this type of information, the forest fire manager can use IFMIS to determine how many resources can reach the cell within this time from predetermined bases. This elapsed time includes both the getaway time and travel time to a cell. By selectively activating and deactivating initial attack bases, a coverage assessment map (Fig. 7) can be produced. Coverage for a cell is often classified as none, single, or multiple meaning that zero, one, or more than one initial attack resource can reach the cell within the attack time required. Those cells classified as no coverage are considered to have a higher probability for an escaped wildfire to occur given a potential ignition source.

Expert Systems

Expert systems are computer programs that undertake the solution of complex tasks or problems using knowledge rather than data which mimic the solution methods of human experts. The knowledge embodied in an expert system may be that of one or more experts within a narrow field of endeavor. Expert systems are well suited to problems that are too imprecise to be defined in terms of mathematical models, although mathematical models may be used to derive facts for use in the knowledge base.

Current research and development work with expert systems is centered around encoding agency policies and human expertise into knowledge processing activities such as preparedness planning and recommending an appropriate suppression response for new fire starts. A presuppression planning advisory system has been developed for Kootenay National Park which makes recommendations on how to deploy fire crews, when to charter or release rotary wing aircraft, and appropriate detection and prevention activities. In addition, an appropriate suppression response expert system has been demonstrated that recommends resources to be dispatched to new fire starts as well as the appropriate tactics to be used.

Conclusions

The Intelligent Fire Management Information System was originally developed to be a cost effective decision support system for initial attack dispatching. Since its inception in 1987, it has gradually matured to a full featured fire management information system that has been adopted by seven fire management agencies in Canada and the United States.

Acknowledgements

The authors are indebted to T. Van Nest, Fire Behavior Officer with the Alberta Forest Service, Edmonton, Canada, for his advice during the design and development of IFMIS. The authors would also like to thank R.M. Smith, Fire Research Technician for his help in preparing the figures for this paper.

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References

Alexander, M.E.; De Groot, W.J. 1988. Fire behavior in jack pine stands as related to the Canadian Forest Fire Weather Index (FWI) System. Can. For. Serv., North. For. Cent., Edmonton, Alberta. Poster with text.

- De Groot, W.J. 1991. Development of Saskatchewan's Fire Suppression Preparedness System. Pages 23-49 in Proc. 6th Central Region Fire Weather Committee Scientific and Technical Seminar, Winnipeg, Manitoba, April 6, 1989. For. Can., North. For. Cent., Edmonton, Alberta.
- Gray, H.W.; Janz, B. 1985. Initial attack initiatives in Alberta: a response to the 1980s. Pages 25-35 in Proc. of the Intermountain Fire Council 1983 Fire Management Workshop, Banff, Alberta. For. Can., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-271.
- Hirsch, K.G. 1991. Development of an initial attack preparedness system for Manitoba. Pages 81-89 in Proc. 11th Conf. Fire and Forest Meteorology, Missoula, MT, April 16-19, 1991. Soc. Am. For., Bethesda, MD. SAF Publ. 91-04.
- Lanoville, R.A; Mawdsley, W.M. 1990. Systematic assessment of daily fire preparedness requirements. Pages 253-261 In Alexander, M.E. and Bisgrove, G.F. 1990. The art and science of fire management. Proc. of the First Interior West Fire Council Annual Meeting and Workshop, Kananaskis Village, Alberta, Oct. 24-27, 1988. For. Can., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-309.
- Lawson, B.D.; Stocks, B.J; Alexander, M.E.; Van Wagner, C.E. 1985. A system for predicting fire behavior in Canadian Forests. Pages 6-16 in Proc. 8th Conf. on Fire and Forest Meteorology, Detroit, MI, April 29-May 2, 1985. Soc. Am. For., Bethesda, MD. SAF Publ. 85-04.
- Lee, B.S. 1990. Use of advanced concepts in dispatching fire control resources. Pages 137-147 in Alexander, M.E. and Bisgrove, G.F. 1990. The art and science of fire management. Proc. of the First Interior West Fire Council Annual Meeting and Workshop, Kananaskis Village, Alberta, Oct. 24-27, 1988. For. Can., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-309.
- Lee, B.S.; Anderson, K.R. 1989. A spatial analysis approach for forest fire preparedness planning. Pages 339-345 in Proc. 10th Conf. on Fire and Forest Meteorology, Ottawa, Canada, April 17-21, 1989. Environ. Can., Atmos. Environ. Serv., Downsview, Ont.
- Van Wagner, C.E. 1987. Development and structure of the Canadian Forest Fire Weather Index System. Can. For. Serv., Ottawa, Ontario. For. Tech. Rep. 35.

Meteorological and Fire Behavior Characteristics of the 1989 Fire Season in Manitoba, Canada^{1,2}

by

K.G. Hirsch³ and M.D. Flannigan⁴

Abstract

During the 1989 fire season, a record number of fires (1147) and area burned (3.28 million ha) occurred in the Province of Manitoba, Canada. These fires consumed over 9% of the provincial forested land base, forced the evacuation of 24,500 people from 32 different communities and cost \$55 million (US) to suppress. The majority of the fire activity occurred during two distinct periods; the first in mid-May resulting from an outbreak of human-caused fires, and the second in mid to late July due primarily to lightning-caused fires. In both situations the synoptic weather pattern consisted of a 500 hPa blocking ridge centered over Manitoba that produced maximum temperatures of 30°C to 35°C, and minimum relative humidity values of 15% to 25%. As these ridges weakened wind speeds averaging 25 km/h to 35 km/h produced numerous high intensity crown fires in stands consisting primarily of black spruce and jack pine. Seven major wildfire runs were documented with headfire rates of spread ranging from 16.7 m/min (1 km/h) to 44.4 m/min (2.7 km/h) and head fire intensities estimated at between 18000 kW/m to 40000 kW/m. A probability analysis estimating the return period of such an extraordinary fire season projected that this type of event could be expected in Manitoba only once every 400 years.

Introduction

The Province of Manitoba is located near the geographical centre of Canada (latitude 49° N - 60° N; longitude 90° W - 102° W).

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Approximately 50% of the province's 650,000 km² land base is classified as forested and 23% is considered productive forest land (Manitoba Natural Resources 1986). The majority of the province is located within the Boreal Forest Region of Canada (Figure 1) as classified by Rowe (1972). The dominant tree species within this area include *Picea glauca* (Moench) Voss (white spruce), *Picea mariana* (Mill.) B.S.P. (black spruce), *Pinus banksiana* Lamb. (jack pine) and *Populus tremuloides* Michx. (trembling aspen).

Fire is widely acknowledged as a natural component of the boreal forest ecosystem (Wein and MacLean 1983). The fire cycle can vary between 40 and 250 years depending on the conditions of the local fire environment (Chandler et al. 1983). The fire behavior is generally characterized by high intensity, stand replacing crown fires which cover large areas. Records dating back to 1918 indicate that within Manitoba, prior to 1989, an average of 394 fires per year have produced an annual area burned of 128,600 ha (Hirsch 1990).

During the 1989 fire season, a record number of fires (1147) and area burned (3.28 million ha) occurred in Manitoba (Figure 2). These fires consumed over 9% of the province's forested area, burned an area six times larger than the 1988 Yellowstone National Park fires, and exceeded the province's total area burned for the previous 25 years combined. The fires also forced the evacuation of 24,500 people from 32 different communities and cost in excess of \$55 million (US) to suppress. The Manitoba fires accounted for 43% of the 7.51 million ha burned in Canada in 1989 (Canadian Committee on Forest Fire Management 1990), which was also a 71-year record high value (Van Wagner 1988).

The majority of the area that burned in Manitoba in 1989 occurred during two distinct periods. The first was the result of an outbreak of human-caused fires in the central regions of the province in mid-May. The second took place in mid to late July due primarily to lightning-caused fires in northern Manitoba. The purpose of this paper is to provide a retrospective analysis of the fire weather and fire behavior that occurred during these two key periods. Where possible, documented wildfire runs have been used to substantiate the linkages between the extreme fire behavior and the severity of the fire weather and fire danger conditions. A short discussion on the historical perspective of the 1989 fire season is also presented.

Antecedent Weather

The climate of Manitoba is classified as cool continental. Total precipitation averages from 400-600 mm per year (based on data for 1951-80) with most of the precipitation falling in the summer (Environment Canada 1982a). Mean annual daily temperatures for the 1951-80 period averaged between -7°C in the northern areas of the province to +3°C in the south (Environment Canada 1982b).

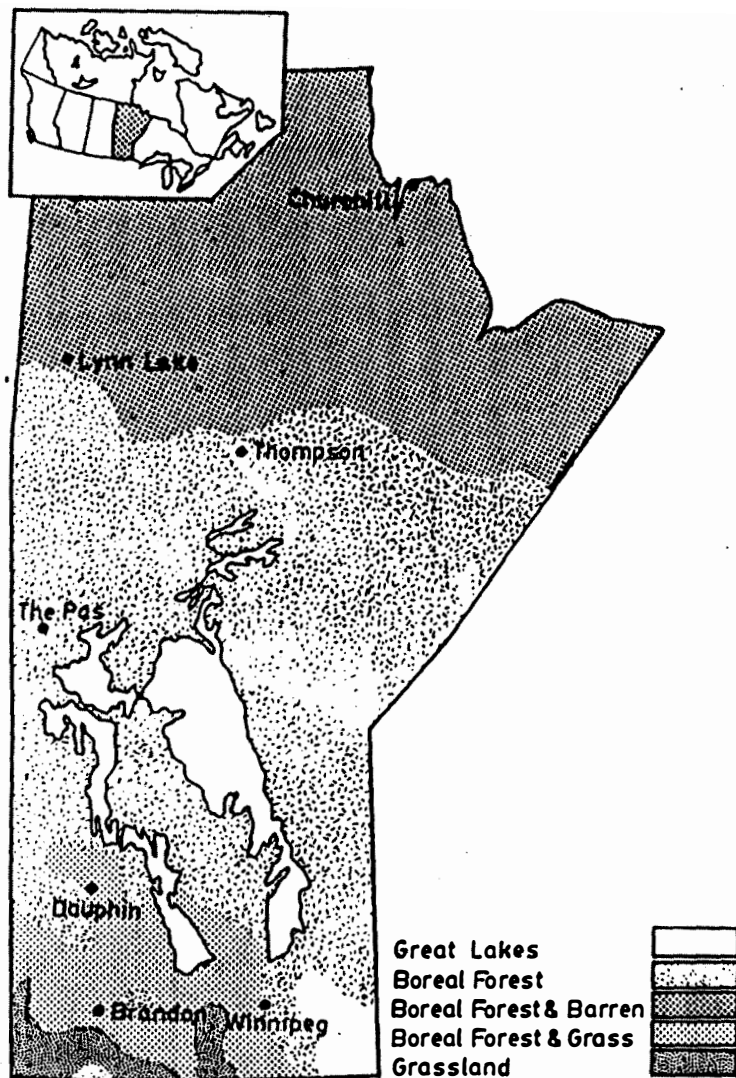


Figure 1. Forest regions of Manitoba (based on Rowe 1972).

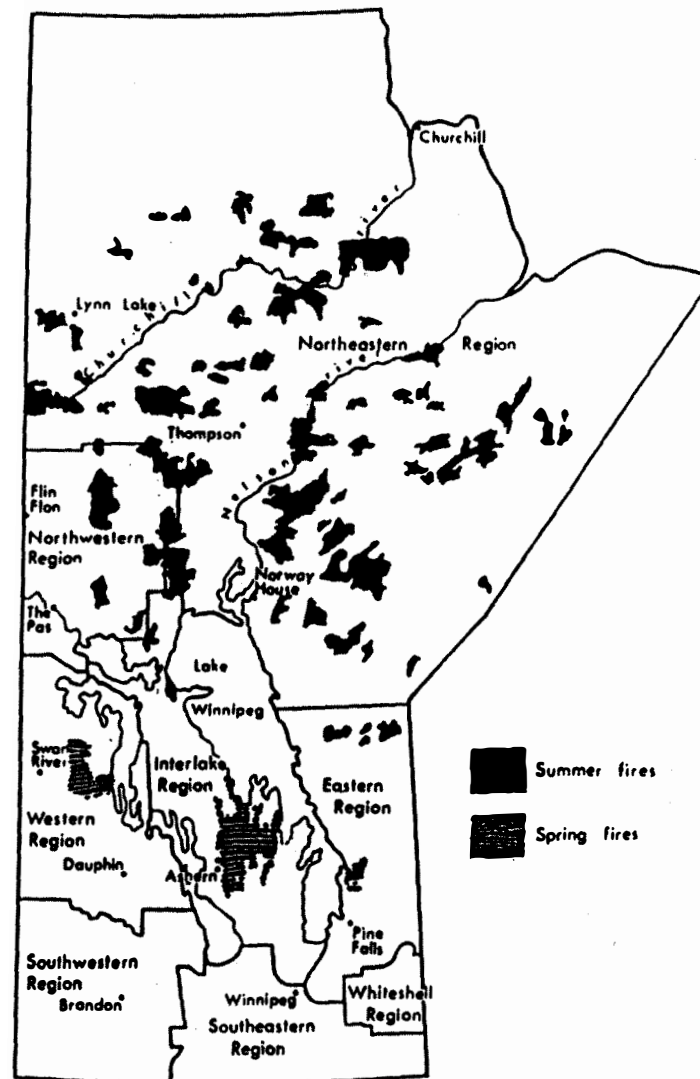


Figure 2. Area burned in Manitoba during 1989 by fires greater than 5000 ha in size.

The winter of 1988-89 (November 1, 1988 - March 31, 1989) was characterized as milder and drier than normal. Figure 3 shows that precipitation, as a percentage of normal for the winter period, was above average in the northwest and the extreme southwest sections of the province. Remaining portions of the province had below normal precipitation with most stations receiving around 75% of normal. In April 1989, southern areas experienced a normal spring snowmelt however precipitation was only 25-50% of normal while in the north precipitation was, for the most part, above normal (Figure 4).

Synoptic Weather Conditions Associated with the Active Fire Periods

Meteorological data for the two periods of major fire activity were obtained from the Canadian Atmospheric Environment Service (AES) in Winnipeg and the Manitoba Natural Resources (MNR) department. These data included mean sea level pressure analysis and surface data such as: temperature, atmospheric moisture (dewpoint temperature or relative humidity), wind speed and direction, and precipitation. Upper air data and analysis, also obtained from AES, included 850 hectopascal⁵ (hPa) analysis, 500 hPa analysis, 250 hPa analysis and tephigrams⁶ from The Pas, Shilo (near Brandon), and Churchill, Manitoba and Big Trout Lake, Ontario.

May 11-17, 1989

The weather in May prior to the 11th was warm and dry with very little or no precipitation across much of central Manitoba. During the entire period of intense fire activity a "blocking ridge" at 500 hPa was dominant. Blocking ridges in the upper atmosphere generally provide sunny and warm conditions at the surface and shunt any precipitation-bearing systems away from the region under the ridge. Temperatures were generally in the mid to upper twenties (°C) but did exceed 30°C on occasion with minimum relative humidity (RH) values as low as 15% and wind speeds on the critical days averaging 20-35 km/h.

Figure 5 shows the 500 hPa analysis for May 11, 1989 0700 Central Daylight Time (CDT). A 500 hPa ridge extends from the central United States to Manitoba and northwestern Ontario and then continues northwestward to the Northwest Territories while a major trough extends southward from British Columbia. The upper ridge remained anchored over Manitoba between May 11 and May 17 before moving eastward to Ontario. The surface analysis for May 11, 1989 1300 CDT (Figure 6) shows a low pressure system moving over northern Saskatchewan with a trough and frontal system south to Wyoming. A strong southerly gradient in the pressure pattern was

⁵ 1 hectopascal (hPa) = 1 millibar = .1 kilopascal

⁶ Tephigram - a thermodynamic diagram with temperature and logarithm of potential temperature as coordinates.

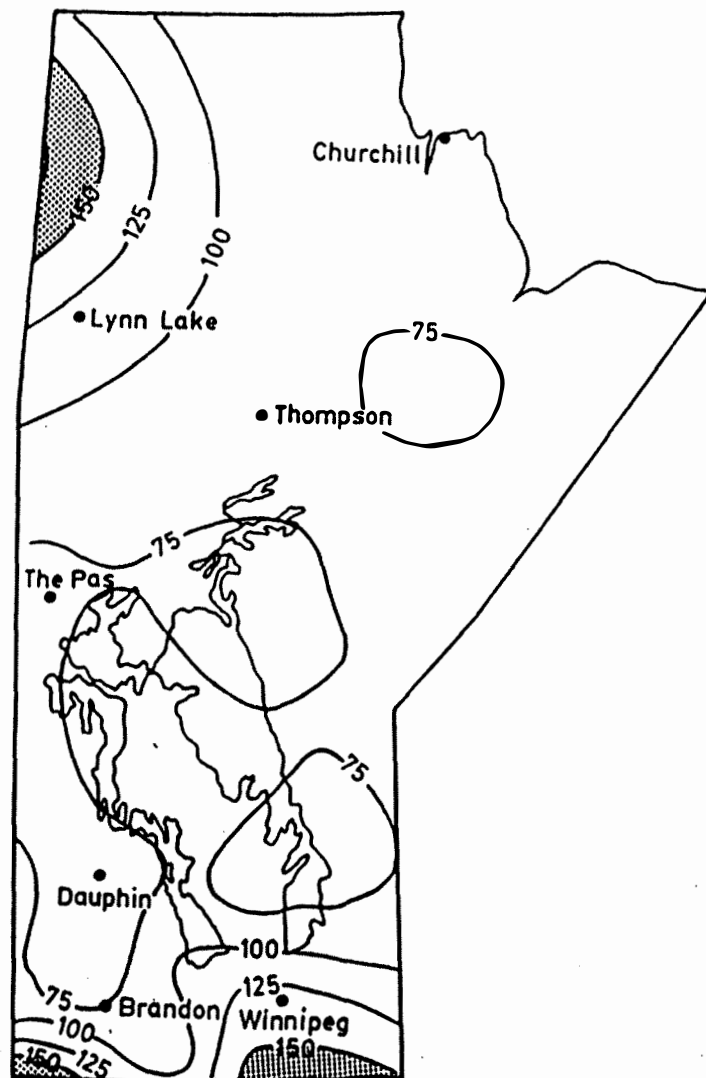


Figure 3. Precipitation as a percentage of normal for Manitoba, Nov. 1, 1988 - March 31, 1989 (percentages above 150% and below 50% are shaded).

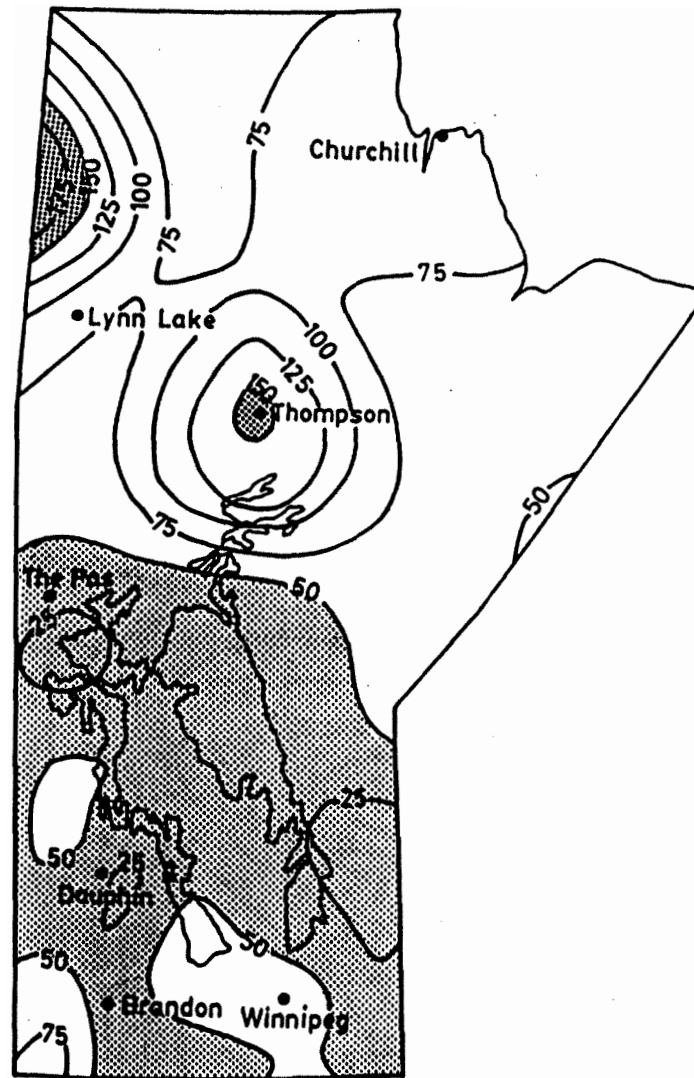


Figure 4. Precipitation as a percentage of normal for Manitoba, April 1 - 30, 1989 (percentages above 150% and below 50% are shaded).

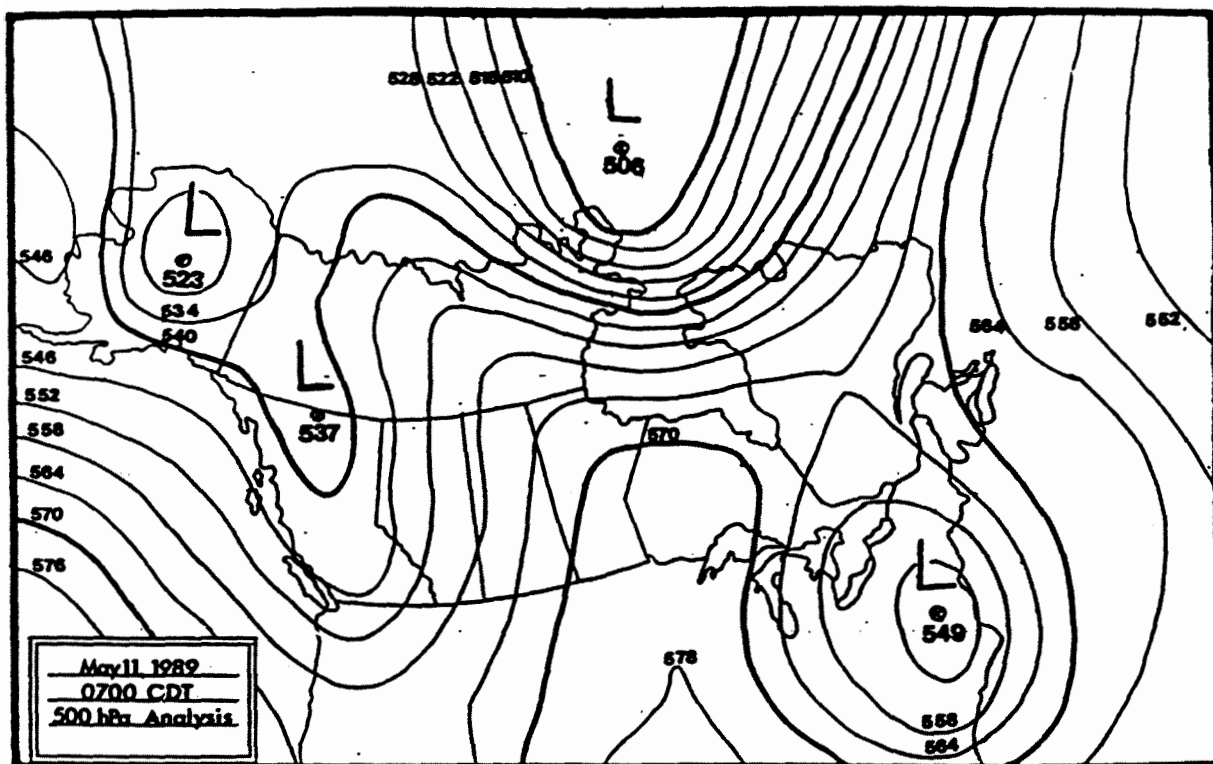


Figure 5. 500 hPa analysis valid for May 11, 1989, 0700 CDT (note: heights are in decameters).

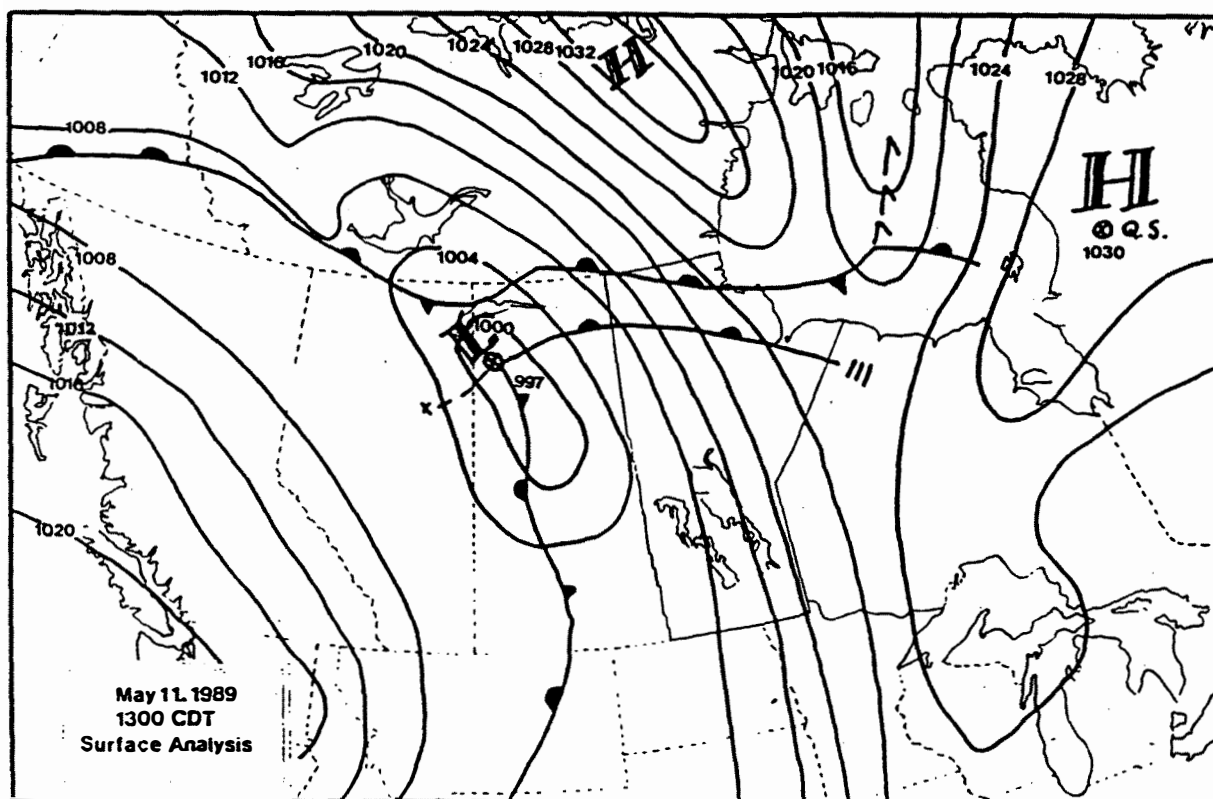


Figure 6. Surface analysis valid for May 11, 1989, 1300 CDT (note: isolines are in hectopascals).

pulling warm and dry air from the south-central United States. Windy, warm and dry conditions associated with this weather pattern are conducive to rapid fire spread. Wind speeds dropped as the surface pressure gradient slackened by May 13 but the pressure gradient intensified once again on May 16 causing moderate wind speeds. By May 18 the extreme fire activity subsided as cooler, showery weather moved into the province.

July 21 - August 2, 1989

The weather in late May and throughout June was generally cool and wet across the province. In July, prior to July 21, the weather had been hot and dry in most of north-central Manitoba. On the evening of July 17 widespread lightning activity, accompanied by only spotty precipitation, occurred across north-central Manitoba contributing significantly to the 195 fire ignitions that were reported between July 18 and July 20. Once again an upper ridge played a major role during the active fire period. Figure 7 depicts a 500 hPa ridge extending from the southwestern United States to central Manitoba at 0700 CDT on July 21, 1989. This ridge held its position until July 24 when it was eroded by a disturbance from British Columbia. By July 28 another ridge located over the centre of the continent was influencing Manitoba. This ridge was eventually replaced by a moist, vigorous "Pacific" system on August 3.

At the surface, warm, dry and windy weather prevailed over Manitoba between July 21 and July 23. Figure 8, the surface analysis valid for 1300 CDT on July 21, 1989, shows a broad low over the Northwest Territories with a frontal trough from the low southwards through Saskatchewan to the United States. A moderate south to southwest flow of hot air prevailed over Manitoba. Temperatures ranging from 30°C to 36°C were associated with this weather pattern. A disturbance from the west coast moved through northern Manitoba on July 25 and 26 bringing cooler temperatures and showery weather. Conditions were dry from July 27 until August 3 when a low pressure system brought widespread rains to northern Manitoba.

The persistence of a blocking ridge in the upper atmosphere was common to both periods of intense forest fire activity. This feature would intuitively be associated with forest fire activity since the persistent warm, dry weather is conducive to the drying of the forest fuels, resulting in an increased potential for ignition, greater fire spread and higher fire intensity. Newark (1975) showed a relationship between forest fire occurrence and the 500 hPa upper atmospheric ridging in northwestern Ontario. Stocks and Street (1983) found that these well entrenched ridges were a common denominator in critical fire periods in northwestern Ontario during 1974-80. Other authors (Flannigan and Harrington 1988; Nimchuk 1983; Schroeder et al. 1964) have also found relationships between upper atmospheric ridging and severe fire weather. The link between blocking ridges and extreme fire behavior has been documented and appears to have been operative during the 1989 fire season in Manitoba.

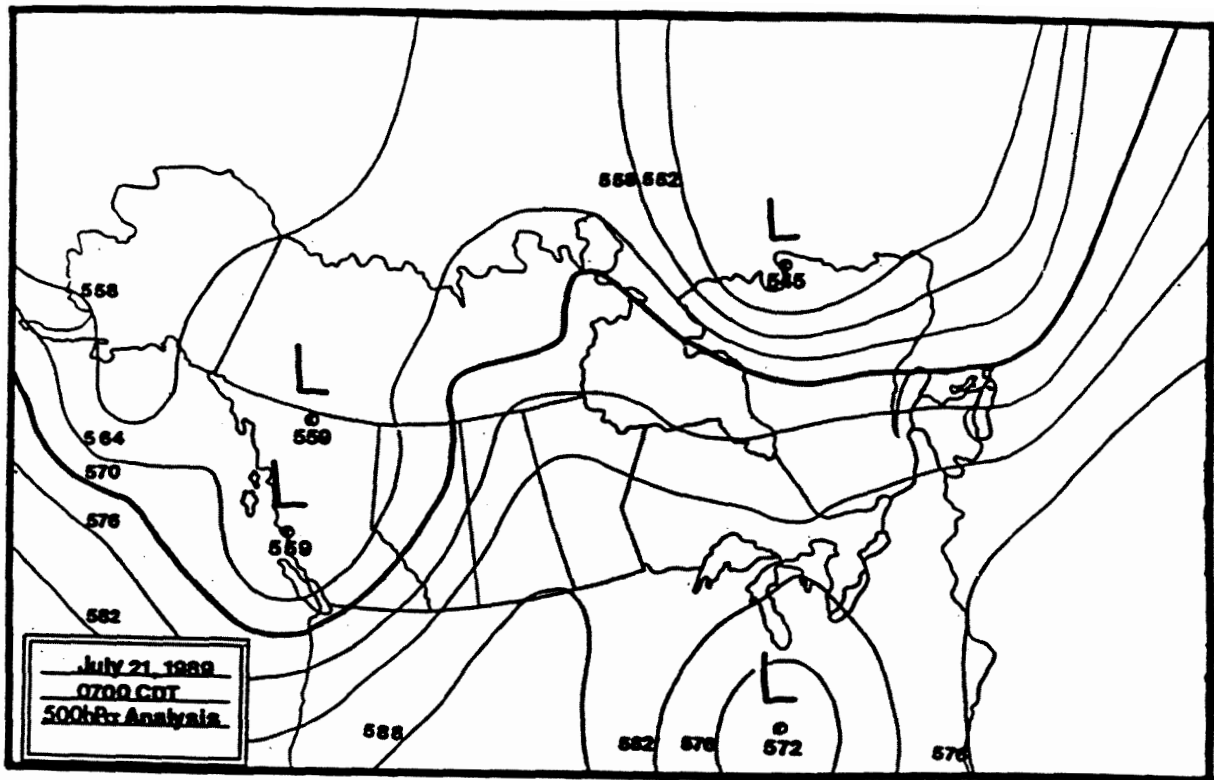


Figure 7. 500 hPa analysis valid for July 21, 1989, 0700 CDT (note: heights are in decameters).

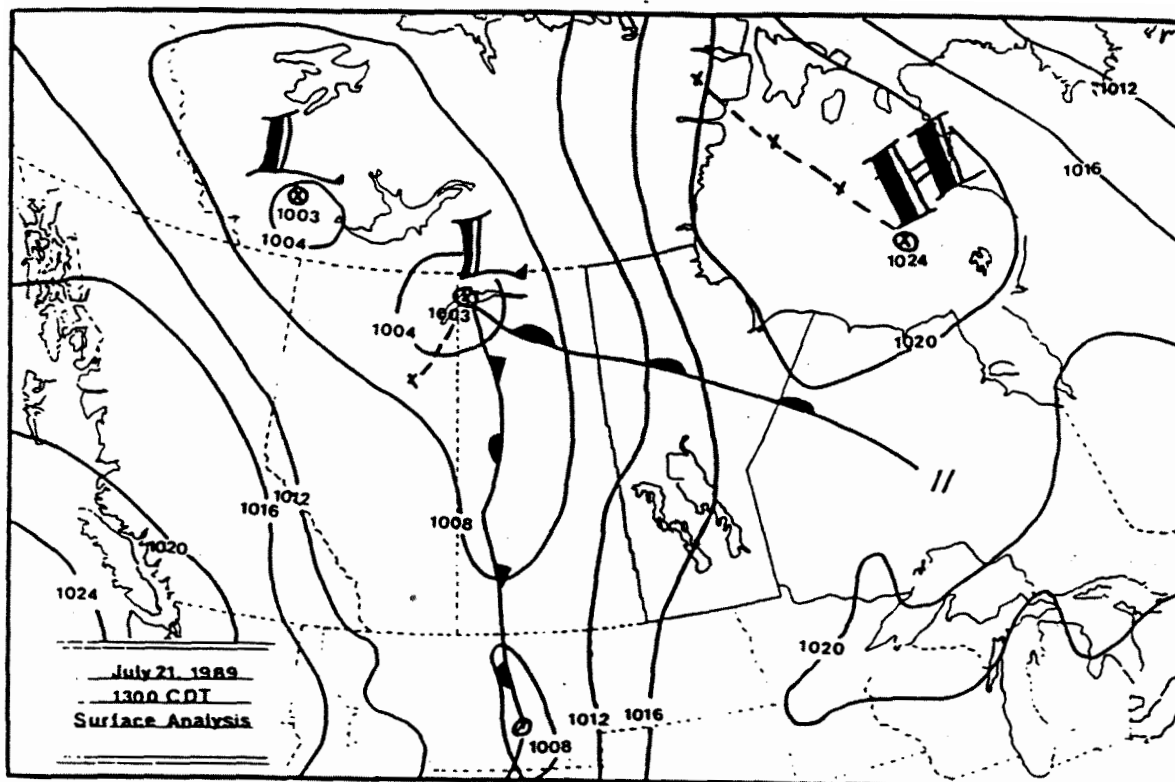


Figure 8. Surface analysis valid for July 21, 1989, 1300 CDT (note: isolines are in hectopascals).

Fire Danger and Fire Behavior

The wide spread fire activity that transpired in Manitoba during the 1989 fire season was unprecedented in the province's recorded history. Numerous high intensity, continuous crown fires were the result of multiple fire ignitions occurring during periods of extreme fire weather. Many of the 75 fires that exceeded 5,000 ha in size (see Figure 2) experienced the majority of their fire growth as a result of major fire runs on just one or two days. Random observations by a number of MNR fire suppression staff have provided valuable descriptions of the fire behavior characteristics as well as headfire rate of spread data on seven of these conflagrations. This type of data, though not overly detailed, has been quite adequate for other recent case-studies of wildfires in this area of Canada (Alexander et al. 1983; Alexander and Lanoville 1987; Stocks and Flannigan 1987; Hirsch 1989).

Valuable insights concerning the extreme fire danger conditions and the associated fire behavior can be gained by examining the components of the Canadian Forest Fire Danger Rating System or CFFDRS (Stocks et al. 1989). The CFFDRS is used by all of the fire management agencies in Canada to indicate the potential for wildfire ignition, behavior and impacts. The two primary modules of the CFFDRS are the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987; Van Wagner and Pickett 1985) and the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). The FWI System consists of six components that provide "numerical ratings of relative fire potential in a standard fuel type (i.e., a mature pine stand) on level terrain" whereas the FBP System provides "quantitative outputs of selected fire behavior characteristics for certain major Canadian fuel types and topographic situations" (Merrill and Alexander 1987).

Table 1 lists the 1300 Central Daylight Time (CDT) fire weather observations and the values of the FWI System components⁷ on the day of each of the well-documented wildfire runs. The indices reveal a number of key points. First, during all of the fire runs the moisture content of the surface litter and the top 5-10 cm of the duff layer was extremely low. Samples taken near Fire #64 showed the upper duff layers to have a moisture content between 30% and 50%. Second, the deeper duff layers (10-25 cm) were moist in May but were very dry during the July fires and contributed

⁷ The FWI System is comprised of three fuel moisture codes and three fire behavior indexes. The three moisture codes represent the moisture content of the fine fuels (Fine Fuel Moisture Code - FFMC), loosely compacted decomposing organic matter (Duff Moisture Code - DMC), and the deep layer of compact organic matter (Drought Code - DC). The three fire behavior indexes, which are derived from the moisture codes and the surface wind, indicate the rate of initial fire spread (Initial Spread Index - ISI), total available fuel (Buildup Index - BUI), and the intensity of a spreading fire (Fire Weather Index - FWI).

Table 1. Fire weather observations and fire danger indexes at 1300 CDT on the days of seven major wildfire runs in Manitoba during the 1989 fire season.

| Fire Name | Location | | Date (1989) | Temp. (°C) | RH (%) | 10-m wind | | FWI System components | | | | | |
|--------------|--------------|---------------|----------------|---------------|-----------|-----------------|-------------|-----------------------|-----|-----|------|-----|-----|
| | Lat. (°N) | Long. (°W) | | | | speed (km/h) | dir. (°) | FFMC | DMC | DC | ISI | BUI | FWI |
| Sandy River | 51°05' | 96°20' | May 11 | 25.3 | 23 | 37.0 | 180 | 93.5 | 40 | 82 | 40.6 | 40 | 51 |
| | | | May 15 | 29.5 | 24 | 6.8 | 270 | 94.2 | 61 | 110 | 10.8 | 61 | 26 |
| Cowan | 52°05' | 100°30' | May 13 | 27.0 | 20 | 10.0 | 180 | 94.3 | 46 | 220 | 12.8 | 61 | 29 |
| Sherridon | 55°00' | 101°00' | July 21 | 36.0 | 24 | 33.0 | 205 | 93.1 | 75 | 575 | 34.6 | 113 | 73 |
| Snow Lake | 54°20' | 99°50' | July 21 | 36.0 | 24 | 33.0 | 205 | 93.1 | 75 | 575 | 34.6 | 113 | 73 |
| Norway House | 53°55' | 97°50' | July 22 | 30.9 | 40 | 24.0 | 190 | 92.6 | 94 | 516 | 20.5 | 129 | 55 |
| Fire #64 | 54°15' | 99°55' | July 25-26 | 23.0 | 56 | 15.5 | 225 | 89.1 | 91 | 610 | 8.2 | 133 | 31 |

significantly to the amount of available fuel. Third, though the potential rate of fire spread varied substantially on days with major fire runs the potential fire intensity was consistently at a high or extreme level.

Table 2 provides specific fire behavior information on each of the well-documented wildfire runs. Undoubtedly a larger number of runs took place however, the necessary observations and weather data were only available for these seven fires. The average headfire rate of spread (ROS) over the period of the documented fire runs ranged from 16.7 m/min (1.0 km/h) to 44.4 m/min (2.7 km/h). These values are not unusually high for boreal forest fuel types however the overall length of some of the runs and the large number that were occurring simultaneously made the situation unique.

The overstory fuel consumed during the fire runs was a mixture of tree species with black spruce being the most dominant. Forestry Canada Fire Danger Group (1992) describes this as the Boreal Spruce (C-2) fuel type. The only exception to this was the Cowan Fire where the area was covered almost entirely with 25-30 year old jack pine (FBP System fuel type: C-4 Immature Pine). Topography in all of Manitoba's forested area could be considered gently undulating with very few steep slopes. Therefore, slope was not seen as an influential factor on the headfire ROS.

The fuel consumption data given in Table 2 are estimated values derived from the FBP System (Forestry Canada Fire Danger Group 1992) rather than actual field measurements. Clearly, the May fires did not produce the same level of fuel consumption as the July fires due to the differences in the moisture content of the deeper duff layers and the heavier woody fuels. Visual, post-fire inspections at some of the July fires showed complete consumption of all of the duff layers above mineral soil which in the Boreal Spruce (C-2) fuel type could be as deep as 30 - 50 cm.

Table 2 also provides headfire intensity values calculated according to Byram (1959) using an average low heat of combustion of 18,000 kJ/kg. The fire intensity levels during all of the fire runs greatly exceeded the point where suppression efforts would have been effective or even safe. Alexander and DeGroot (1988) state that when a fire's intensity is greater than 4000 kW/m the effectiveness of suppression (even with the use of airtankers, or backburning) is minimal. Therefore, when many of the fire runs were taking place suppression staff focused their efforts on evacuating residents of endangered communities. In total, 2000 people from 7 communities were forced to leave their homes in May and another 22,500 people from 25 communities were evacuated in July (Hirsch 1990).

Each major wildfire could in itself be an individual case-study of extreme fire behavior however, discussion has been limited to a few examples of highly unusual fire behavior. During the May fires, for instance, swamps and sloughs that are normally filled with water and serve as natural fuel breaks, were completely dry

9
Table 2. Fire behavior characteristics of seven major wildfire runs in Manitoba during 1989.

| Fire name | Calender date (1989) | Local time (CDT ⁶) | FBP System fuel type | Average wind speed ² (km/h) | Average rate of spread (m/min) | Spread distance (km) | Fuel consumption ¹ | | | Headfire intensity ⁵ (kW/m) |
|--------------|----------------------|--------------------------------|----------------------|--|--------------------------------|----------------------|-------------------------------|---|-------|--|
| | | | | | | | Surface ³ | Crown ⁴ (kg/m ²) | Total | |
| Sandy River | May 11 | 1140-1840 | Boreal Spruce | 29.8 | 22.8 | 9.6 | 1.84 | 0.80 | 2.64 | 18058 |
| | May 15 | 1300-1530 | Boreal Spruce | 12.0 | 24.9 | 4.3 | 2.55 | 0.76 | 3.31 | 24726 |
| Cowan | May 13 | 1700-2000 | Immature Pine | 20.0 | 44.4 | 8.0 | 1.82 | 1.20 | 3.02 | 40226 |
| Sherridon | July 21 | 1230-2130 | Boreal Spruce | 24.6 | 27.8 | 15.0 | 3.64 | 0.80 | 4.44 | 37030 |
| Snow Lake | July 21 | 1120-2143 | Boreal Spruce | 23.7 | 20.1 | 12.5 | 3.64 | 0.80 | 4.44 | 26773 |
| Norway House | July 22 | 1500-2000 | Boreal Spruce | 29.8 | 16.7 | 5.0 | 3.87 | 0.80 | 4.67 | 23397 |
| Fire #64 | July 25-26 | 1400-0100 | Boreal Spruce | 21.0 | 19.4 | 12.8 | 3.92 | 0.69 | 4.61 | 26830 |

¹ Estimated values derived from the FBP System (Forestry Canada Fire Danger Group 1990).

² Wind speed observations (i.e., a 2 or 10 minute average of the 10-m open wind speed) were taken each hour during the fire run and averaged.

³ Includes forest floor and woody fuel consumption.

⁴ Includes only foliage (no woody material).

⁵ Calculated according to Byram (1959) using a low heat of combustion of 18,000 kJ/kg. e.g. (22.8 m/min x 1 min/60 sec) x 2.64 kg/m² x 18000 kJ/kg = 18058 kW/m.

⁶ Central Daylight Time.

and burned rapidly throughout the night. Also, the Sandy River Fire, located next to Lake Winnipeg (the 5th largest lake in Canada) was influenced significantly by shifting winds (45°-90°) due to a "lake breeze" effect. This phenomena is rarely experienced in Manitoba and made the development and implementation of suppression plans very difficult.

The summer fire behavior was unusual primarily because of the high levels of fuel consumption and the volatility of the fine fuels. Fire #64 was the best documented example of a major fire run occurring under relatively moderate fire weather conditions. A possible reason for this type of fire behavior was the consumption of a large amount of available fuel on a day with good convective lift. Other examples of uncharacteristic fire behavior included indrafts being observed as far as 5 km ahead of major convection columns and significant crowning occurring at 3:00 a.m. with a humidity of 80%. This type of fire behavior rendered traditional suppression techniques ineffective leaving backburning by aerial ignition as the most utilized and effective suppression tool.

The 1989 Fire Season in Perspective

As stated previously, the 1989 fire season resulted in the highest area burned since records began in 1918. Was 1989 an anomaly or was it just part of the natural variability within the fire environment? The answer to this question is unknown. The large area burned may simply have been the result of multiple fire ignitions coinciding randomly with periods of below normal precipitation and short-term extreme fire weather. On the other hand, some individuals may wish to connect the severity of the 1989 fire season to greenhouse warming. This however cannot be stated with any certainty but, one should be aware that if significant climate warming does take place the events of 1989 could be a foreshadowing of things to come.

How unusual was the fire season climate of 1989 in Manitoba? Quite, in terms of temperatures for July. The mean July temperature in 1989 was the highest ever recorded for five stations in northern Manitoba. The new record July temperatures at these stations exceeded the previous records by an amazing 1.2°C-2.3°C. Otherwise, the climate during the remainder of the fire season was not that unusual except for a greater frequency of dry periods associated with the blocking ridge episodes. Precipitation for the entire fire season was near normal however, it appears that the timing of the precipitation and not the amount was most important in these critical fire weather situations.

How often could a fire season like 1989 (in terms of area burned) be expected in Manitoba? Depending on the analysis, it could be expected once every 400-770 years. This return period was calculated using the non-normal distribution of annual area burned in Manitoba for 1918-1989. The data was transformed to a normal distribution and the probability of a year like 1989 was determined to be 0.0025, producing a return period of 400 years (i.e., return

period = $1/0.0025 = 400$ years). The range of the return period is influenced significantly by one extreme year. In this case if 1989 is excluded from the distribution data the probability of a year in which 3.28 million ha is burned would be 0.0013 which yields a return period of about 770 years.

Summary

The 1989 fire season will long be remembered as one of the most severe in Manitoba's history. The record number of fires (1147) and area burned (3.28 million ha) had a significant impact on the province's natural resources and its people. The majority of the fire activity occurred between May 11 - 19 in the central regions of the province and from July 21 - August 2 in northern Manitoba. The dominant weather feature during both situations was a blocking ridge in the upper atmosphere. These blocking ridges resulted in prolonged periods of warm, dry weather which significantly raised the fire danger conditions by lowering the moisture content of the forest fuels. Multiple ignitions of human-caused and lightning-caused fires during these periods overwhelmed suppression efforts and when the upper ridges began to weaken, strong winds produced numerous major fire runs. Many examples of extreme fire behavior were observed and a total of seven wildfire runs were documented. Observed headfire rates of spread and estimated headfire intensities ranged from 16.7 m/min (1.0 km/h) to 44.4 m/min (2.7 km/h) and 18057 kW/m - 40226 kW/m, respectively. A return period analysis based on area burned information showed that Manitoba can expect an extraordinary fire season like 1989 only once every 400 years.

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References

Alexander, M.E., and DeGroot, W.J. 1988. Fire behavior in jack pine stands as related to the Canadian Forest Fire Weather Index (FWI) System. Canadian Forestry Service, Northern Forestry Centre, Edmonton, AB. Poster (with text).

- Alexander, M.E., and Lanoville R.A. 1987. Wildfires as a source of fire behavior data: a case study from the Northwest Territories, Canada. Pages 86-93 in Postprint volume, ninth conference on fire and forest meteorology. American Meteorological Society, Boston, MA.
- Alexander, M.E., Janz, B. and Quintillio, D. 1983. Analysis of extreme wildfire behavior in east-central Alberta: a case study. Pages 38-46 in Preprint volume, seventh conference on fire and forest meteorology. American Meteorological Society, Boston, MA.
- Byram, G.M. 1959. Combustion of forest fuels. In Forest fire: control and use. K.P. Davis, Ed. McGraw-Hill, NY. p. 61-89.
- Canadian Committee on Forest Fire Management 1990. Reports tabled at 1990 annual meeting, Sault Ste. Marie, ON., January 23-25, 1990. Nat. Res. Coun. Can., Ottawa, ON.
- Chandler, C., Cheney, C. Thomas, P., Traubaud, L., and Williams, D. 1983. Fire in forestry (volume I): forest fire behavior and effects. John Wiley and Sons, Inc. p. 298-307.
- Environment Canada 1982a. Canadian Climate normals 1951-80. Vol. 3. Precipitation. Environ. Can., Atmos. Environ. Serv., Downsview, ON., 602 p.
- Environment Canada 1982b. Canadian Climate normals 1951-80. Vol. 2. Temperature. Environ. Can., Atmos. Environ. Serv., Downsview, ON., 306 p.
- Flannigan, M.D., and Harrington, J.B. 1988. A study of the relation of meteorological variables to monthly provincial area burned by wildfire in Canada (1953-80). Jour. of Appl. Meteor., 27: 441-452.
- Forestry Canada Fire Danger Group. 1992. Development and structure of the Canadian Forest Fire Behavior Prediction System. Forestry Canada, Ottawa, ON., For. Tech. Rep. [in prep].
- Hirsch, K.G. 1989. Analysis of the fire behavior associated with three 1988 spring wildfires in central Canada. Pages 416-425 in Proceedings of the 10th Conference on Fire and Forest Meteorology, April 17-21, 1989, Ottawa, ON.
- Hirsch, K.G. 1991. A chronological overview of the 1989 fire season in Manitoba. Forestry Chronicle 67(4): 358-365.
- Manitoba Natural Resources 1986. Five-year report on the status of forestry. Volume 1. Manitoba Natural Resources, For. Br., Winnipeg, MB. 40 p.

- Merrill, D.F., and Alexander, M.E. (eds) 1987. Glossary of forest fire management terms. Fourth edition. Natl. Res. Counc. Can., Can. Comm. For. Fire Manage., Ottawa, ON. Publ. NRCC No. 26516. 91 p.
- Newark, M.J. 1975. The relationship between forest fire occurrence and 500 mb longwave ridging. Atmosphere 13:26-33.
- Nimchuk, N. 1983. Wildfire behavior associated with upper ridge breakdown. Alberta Energy and Nat. Resour., For. Serv., Edmonton, AB. ENR Rep. No. T/50. 45 p.
- Rowe, J.S. 1972. Forest regions of Canada. Can. For. Serv., Ottawa, ON. Publ. No. 1300, 172 p.
- Schroeder, M.J., Golvinsky, M., et al. 1964. Synoptic weather types associated with critical fire weather. U.S. Dept. Agric., For. Serv., Pac. SW. For. Exp. Stn., Berkley, CA.
- Stocks, B.J., and Flannigan, M.D. 1987. Analysis of the behavior and associated weather for a 1986 northwestern Ontario wildfire: Red Lake #7. Pages 9-12 in Postprint volume, ninth conference on forest and fire meteorology. American Meteorological Society, Boston, MA.
- Stocks, B.J., and Street, R.B. 1983. Forest fire weather and wildfire occurrence in the boreal forest of northwestern Ontario. Pages 249-265 in R.W. Wein et al. (eds). Resources and Dynamics of the Boreal Zone. Assn. Cdn. Univ. North. Studies.
- Stocks, B.J., Lawson, B.D., Alexander, M.E., Van Wagner, C.E., McAlpine, R.S., Lynham, T.J., and Dube, D.E. 1989. The Canadian Forest Fire Danger Rating System: an overview. Forestry Chronicle 65(6): 450-457.
- Van Wagner, C.E. 1987. Development and structure of the Canadian Forest Fire Weather Index System. Can. For. Serv., For. Tech. Rep. 35.
- Van Wagner, C.E. 1988. Historical pattern of area burned in Canada. Forestry Chronicle 64(3): 182-185.
- Van Wagner, C.E., and Pickett, T.L. 1985. Equations and Fortran program for the Canadian Forest Fire Weather Index System. Can. For. Serv., For. Tech. Rep. 33.
- Wein, R.W., and MacLean, D.A. (eds) 1983. The role of fire in northern circumpolar ecosystems. John Wiley and Sons Inc. Toronto. 322 p.

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