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Foreword / Avant-Propos

I am pleased that we have three articles from three different countries in this issue. This international flavour should stimulate Canadian contributors in both of our official languages. Please keep the manuscripts and news items flowing.

Alec H. Paul
Editor

Impact Of Climatic Warming on Residential Consumption of Natural Gas in Canada

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ABSTRACT

Natural gas, an increasingly popular fuel for residential space heating in southern Canada, is foreseen to undergo demand changes over the next half-century as a result of climatic and population changes. "Greenhouse effect" climatic changes ought to reduce national per capita use for winter fuel, but bulk regional requirements are projected to increase in western Canada as a result of net population increases. These forecasts are necessarily qualified by a number of simplifying assumptions regarding markets and technology.

RÉSUMÉ

Le gaz naturel est un combustible qui devient de plus en plus populaire pour le chauffage résidentiel au Canada méridional. Pendant le prochain demi-siècle, on prévoit des changements de demande suite aux changements climatiques et démographiques. Les changements climatiques causés par «l'effet de serre» devraient réduire l'utilisation nationale per capita des combustibles hivernaux; cependant, on prévoit que les besoins régionaux bruts augmenteront dans l'Ouest canadien proportionellement à la croissance nette de la population. A cause de certaines hypothèses simplificatrices concernant les marchés et la technologie, les prévisions sont établies sous réserve.

INTRODUCTION

"Greenhouse effect" climatic warming is a popular scientific question currently enjoying broad support (Schneider, 1984, World Climate Programme, 1985, Bolin et al 1986). It is expected that global temperatures will increase by 1.5-4.5°C or more within the next century as a result of growing levels of radiatively-active gases in the atmosphere (CO_2, O_3, N_2O, NH_3, CH_4, etc.), which absorb or reflect the Earth's radiation of heat to space.

Measurements indicate that atmospheric CO_2 has increased 10 per cent since 1957, and some of the other gases seem to be increasing faster (Environment Canada, 1987). The main sources of these gases are from combustion of fossil fuels and deforestation, but other natural emissions from areas like marine wetlands may play a role. The oceans have been absorbing about half of the atmospheric increase, but this effect is expected to decrease very soon. The forecasted temperature rise is based on a doubling of present CO_2 levels which is believed to be possible by 2030 AD and highly probable by 2050 AD. Temperatures are expected to be warmer than the global averages at high latitudes and during winter (Environment Canada, 1987). Such a change could engender profound socio-economic effects, which would be important to Canada. Canada's geographical location presently exacts an annual economic burden, that of the space heating of buildings over winter. Warmer temperatures could have substantial alleviating effects, although these might be offset by higher fuel costs, population growth and energy expenditures for air conditioning. The impact of technological change is also a factor very difficult to estimate.

Here, we make a projection of residential natural gas consumption over the next fifty years, using available information on use patterns, population growth and forecasts of climatic warming. It is a simple projection, not incorporating all factors, but may have strategic value for long-term energy and economic planning. For this paper we made a conscious decision not to speculate on future energy conservation, as there are many opinions, and the necessary details of argument could detract from the main themes presented here. A second major simplification introduced is that the proportion of population using natural gas for home-heating will remain constant. Intuitively, we sense that the ratio will increase, but how much? Projected future fuel mixes remain controversial. We do expect, however, that use will continue over several decades despite longer-term concern over fossil fuel supplies (Bach, 1984).

USE OF NATURAL GAS FOR SPACE HEATING

Over the past quarter-century an extensive pipeline network has developed over much of southern Canada outside of the Atlantic Provinces, in order to transport natural gas from principal source regions in the West. The fuel has several advantages over others for future use which include: direct connection with customers, effectiveness in small, efficient furnaces, additional use for water heating, cooking and refrigeration, and government subsidies for household conversions. In each province, indigenous distribution agencies have been formed, creating problems of data standardization for a national study such as this one. For the present forecast, data were selected from six major cities and their respective provinces. There is generally a 10-year record for residential gas consumption (Table 1).

TABLE 1: Cities, Gas Delivery Agencies and Periods of Record

Agency	City	Record
Gaz Métropolitain	Montreal	1975-84
Consumers' Gas	Toronto	1975-84
Greater Winnipeg Gas Co.	Winnipeg	1975-84
Saskatchewan Power Corp.	Regina	1975-84
Northwestern Utilities	Edmonton	1979-84
British Columbia Hydro	Vancouver	1981-84
Statistics Canada	Provincial Totals	1975-84

As well, gas consumption is mostly for space heating, compared with electricity where user billing does not distinguish between lighting, appliance operations and heating.

POPULATION GROWTH

While world population is expected to exceed six billion by the turn of the century, the forecasted growth for Canada is much less spectacular, being 0.1-0.4 per cent cumulatively from 1983 to 2006. Provincial estimates are available from Statistics Canada until 2006, while from 2007 to 2031 national projections have been used. The greatest relative growth, at least until 2006, is foreseen to be in the western provinces. (Statistics Canada, various years) (Figure 1)

These rates are considered to be "medium growth" by Statistics Canada. Such population data give an estimate of future customers for natural gas within a set of assumptions regarding market size. Although it may be desirable to input an energy conservation factor, or attempt to estimate future fuel mixes, we consider that these would be highly speculative and have chosen to assume consumption per-customer/per heating-degree day to be constant. The estimated populations for the years 2006 and 2031 are shown in Figure 1.

RELATIONS WITH CLIMATE

In 1927 the American Gas Association demonstrated a quantitative relationship between ambient air temperature and heating load from which the heating-degree day concept was developed. In general, the heating season is assumed to begin when the mean daily temperature falls below 18° C.

The threshold is selected by statistically relating the quantity of heating fuel necessary to keep the indoor temperature steady at a comfortable level to the negative departure of temperature below the base. Houses with good insulation can make use of lower bases in the calculation. While heating

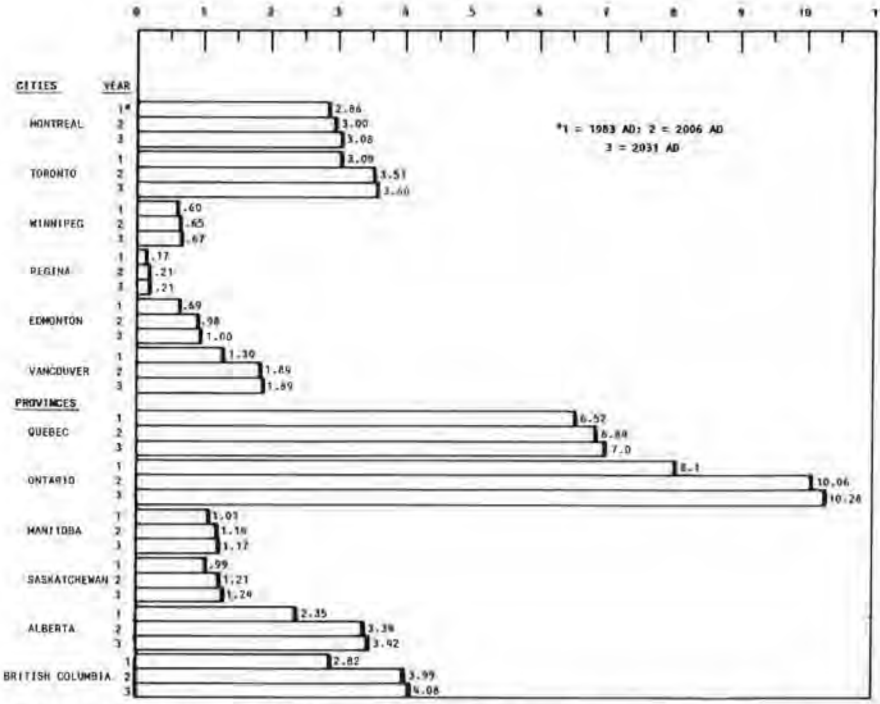

FIGURE 1. Population Projections 1983-2031 AD; Estimated Population (in millions)

degree-days are empirically derived and lack theoretical foundation, they serve many practical purposes (Gullett and Phillips 1986).

The following climatological expressions were examined in relation to gas consumption:

- Heating-degree days for year: bases 18, 15, 13 and 10°C;
- Mean monthly temperature calculated two ways:
  - (a) mean daily max.+ mean daily min. ÷ 2, averaged for the month;
  - (b) mean daily temperature computed from hourly values ÷ 24, and averaged for the month.

These were examined by linear regression for a 10-year record at six cities and for their respective provinces. The coefficients of determination (r^2) shown in Table 2, suggest that no particular expression has an advantage, and therefore, the mean monthly temperature computed from the daily maximum and minimum values was selected. This was because of its broad application to ordinary climatological stations, and its ease of comparison to climatic change scenario temperatures, as will be discussed below. Monthly temperatures higher than, say 18°C, will correspond to a very minimal use of gas, and therefore play a negligible role in defining the terms of the equations, which are presented in Table 3. Table 2 confirms the continued

TABLE 2: Coefficients of Determination (r^2) for Correlations Between Gas Consumption and Climate Heat Load Expressions

Temperature Variable	Heating-Degree Day Bases (°C)				Mean Monthly Temperature	
	10	13	15	18	Method (a)	Method (b)
Montreal	.77	.78	.79	.78	.76	.76
Toronto	.86	.88	.89	.88	.86	.86
Winnipeg	.89	.90	.90	.90	.89	.88
Regina	.74	.76	.77	.76	.75	.74
Edmonton	.80	.82	.83	.83	.83	.83
Vancouver	.42	.51	.54	.55	.55	.55
Quebec	.81	.84	.85	.85	.84	.84
Ontario	.91	.93	.93	.93	.91	.90
Manitoba	.89	.90	.90	.90	.89	.88
Saskatchewan	.92	.93	.94	.94	.93	.93
Alberta	.86	.88	.89	.89	.89	.88
B.C.	.80	.87	.88	.87	.85	.86

TABLE 3: Relations of Residential Natural Gas Consumption to Monthly Heating Requirements

	Equations for Cities and Provinces	Coefficient of Determination (r^2)
Montreal	Y = -15.3X + 374.1	.78
Toronto	Y = -20.7X + 477.2	.88
Winnipeg	Y = -22.0X + 391.8	.90
Regina	Y = -15.5X + 380.0	.76
Edmonton	Y = -20.5X + 476.6	.83
Vancouver	Y = -24.5X + 557.4	.55
Quebec	Y = -16.2X + 378.6	.85
Ontario	Y = -21.0X + 476.4	.93
Manitoba	Y = -17.4X + 390.7	.90
Saskatchewan	Y = -17.9X + 411.4	.94
Alberta	Y = -21.9X + 535.1	.89
B.C.	Y = -26.5X + 538.4	.87

The equations are of the form:

$$Y = mX + b$$

where

Y is the estimated per customer natural gas consumption (m^3)
X is the mean monthly temperature (°C)

validity of the 18°C or 15°C thresholds. Home energy conservation across Canada may allow lower thresholds in future. The lower r^2 values for Vancouver in Tables 2 and 3 are likely related to the shorter period of record for gas consumption (Table 1), and the information should be used with greater caution.

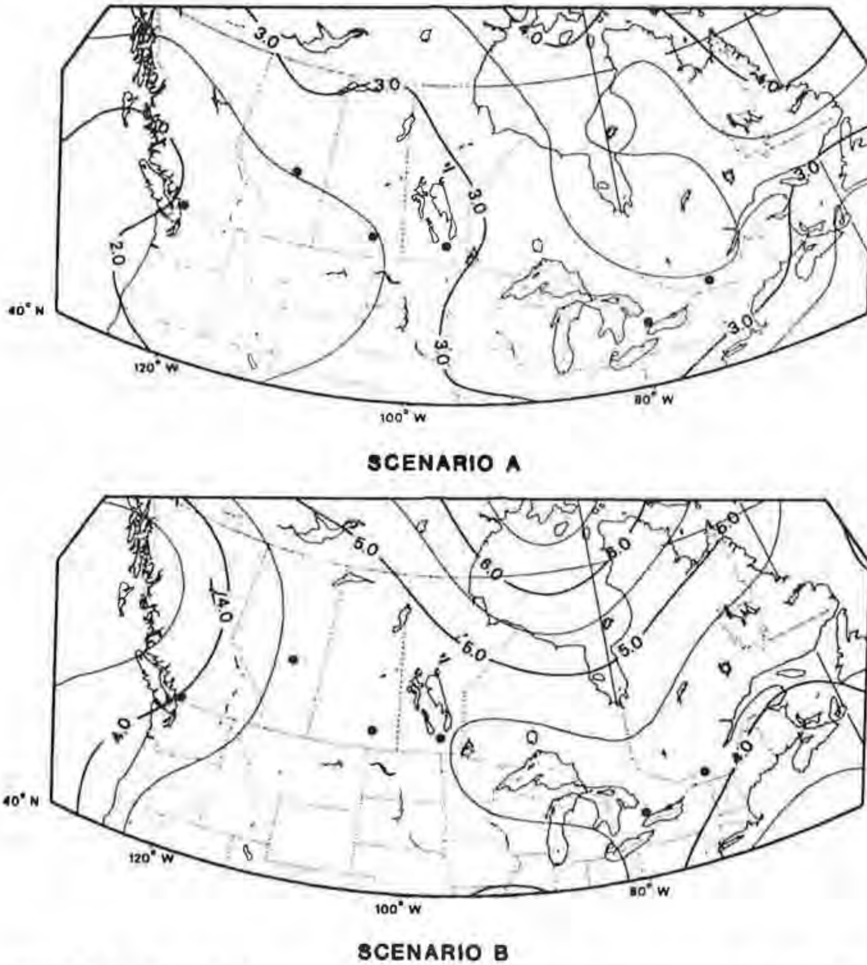

FIGURE 2. Generalized annual air temperature increment from present with double CO_2 atmosphere according to Scenarios A (top) and B (below) (°C)

To estimate the possible magnitude of regional temperature changes resulting from a doubling of CO_2 concentration, recourse was made to output from two general circulation models (GCM's). These are modified versions of the Goddard Institute for Space Studies (GISS) and The General Fluid Dynamics Laboratory, Princeton University (GFDL) models which are elaborate simulations based on the atmospheric laws of energy, moisture and momentum. They are costly to operate because of computer time needed to perform the many calculations, and so many factors are parameterized. Their intent is for hemispheric analyses, but output is available for grid points providing information at a regional scale. A recent paper by Cohen (1986) summarized the applicability of such models for regional studies. The two models he uses are those utilized here and referred to as Scenario A and Scenario B. A and B have somewhat different grid sizes and point values in many instances, but the signs and magnitudes have broad similarities. The grid-point values were interpolated to the six cities studied here (Table 5). Figure 2 is a generalized map of the incremental temperature warming according to the two scenarios.

Both scenarios support the general view that the southern interior of the country from the Great Lakes through to the prairies will be drier as well as warmer than at present, while the Arctic will be considerably warmer and wetter, enabling places like Fort Simpson to grow crops now being cultivated at Edmonton. Some of the increased population forecasted for the west may well come to reside in the northwest.

SUMMARY OF METHOD

Temperature/gas consumption relations were developed from linear regression, and Pearson product moment correlations indicated a significance at the 95 per cent level. For the years 1975-84 a ratio of customers to population was computed for each city and the mean value was adjusted to the projected 2031 AD population. Then the scenario temperatures were substituted in the equation. The output is summarized in Tables 4, 5, 6. Table 4 projects population and gas customer data for the six cities and provinces. Table 5 shows yearly per customer consumption under climate scenarios A and B, and finally Table 6 provides estimates for reduced per customer consumption across the country (except the Atlantic and northern areas) once major climatic warming has set in.

TABLE 4: Population and Residential Customers for Natural Gas (thousands)

	Mean Number of Customers	Mean Population (1975-84)	Ratio of Customers/ Population (1975-84)	Projected Population 2031	Projected Number of Customers 2031
Montreal	151	2821	.05	3078	154
Toronto	267	2941	.09	3599	324
Winnipeg	135	586	.23	670	154
Regina	50	161	.31	212	66
Edmonton	136	621	.22	1004	221
Vancouver	64	1232	.05	1885	94
Quebec	165	6369	.03	7003	210
Ontario	1105	8541	.13	10282	1337
Manitoba	160	1031	.16	1173	188
Saskatchewan	194	957	.20	1242	248
Alberta	491	2095	.23	3423	787
British Columbia	369	2642	.14	4082	571

TABLE 5: Estimated Annual Consumption with Scenarios A and B

	Mean Annual Gas Consumption			% Change from Present to Scenario A	% Change from Present to Scenario B	Mean Annual Temperature (°C)		
	1975-1984 ($10^6 m^3$)	Scenario A ($10^6 m^3$)	Scenario B ($10^6 m^3$)			1951-80	Scenario A	Scenario B
Montreal	510.5	426.7	448.6	-16.4	-12.1	6.2	9.4	8.6
Toronto	1064.2	1114.5	975.4	+4.6	-8.3	7.3	9.2	10.9
Winnipeg	702.2	767.3	650.3	+9.3	-7.4	2.2	3.5	6.4
Regina	197.6	242.1	205.3	+22.6	+3.9	2.2	4.7	7.7
Edmonton	646.8	1015.2	958.5	+57.0	+48.2	1.6	4.5	5.5
Vancouver	245.6	329.1	322.2	+34.0	+31.2	9.8	10.9	11.1
Quebec	553.5	572.6	604.3	+3.5	+9.2			
Ontario	4386.3	4543.0	3970.4	+3.6	-9.5			
Manitoba	664.3	743.2	630.5	+11.9	-5.1			
Saskatchewan	836.3	975.2	814.3	+16.6	-2.6			
Alberta	2649.3	4122.2	3908.4	+55.6	+47.5			
British Columbia	1205.3	1715.7	1697.0	+42.4	+40.8			
Provincial Total	10295.0	12672.0	11625.0	+23.1	+12.9			

TABLE 6: Actual and Forecasted Annual Gas Consumption Per Customer

	Mean Annual Per Customer Use (m^3)	Annual Per Customer Use with Scenario A (m^3)	Annual Per Customer Use with Scenario B (m^3)	Per cent Decrease in Consumption from Present to Scenario A	Per cent Decrease in Consumption from Present to Scenario B
		(thousands)			
Montreal	3.4	2.8	2.9	18.1	13.9
Toronto	4.0	3.4	3.0	14.0	24.7
Winnipeg	5.2	5.0	4.2	5.0	19.5
Regina	4.0	3.7	3.1	9.0	22.9
Edmonton	4.7	4.6	4.3	3.2	8.6
Vancouver	3.6	3.5	3.4	3.7	5.7
Quebec	3.4	2.7	2.9	19.2	14.8
Ontario	4.0	3.4	3.0	14.2	25.0
Manitoba	4.2	4.0	3.4	5.0	19.4
Saskatchewan	4.3	3.9	3.3	9.7	24.6
Alberta	5.4	5.2	5.0	2.6	7.6
British Columbia	3.3	3.0	3.0	9.0	10.0
Total Provincial	24.5	27.2	20.4	9.3	16.7

DISCUSSION

While Ontario is foreseen to receive the most people, the greatest relative population growth over the next half-century is projected to occur in the western provinces. With high customer to population ratios (Table 4), overall consumption of gas would be expected to trend upwards without considering climatic warming. In Table 5 increases in gross consumption are seen to be projected over most of the country, particularly in Alberta and British Columbia. However, as Table 6 indicates there is a per customer decrease in consumption which is particularly marked in Quebec and Ontario. An overall national reduction of one-tenth to one-fifth of present use seems apparent by the year 2031.

Many factors must be considered when analysing regional patterns. The A and B scenario temperatures differ, with Scenario B being warmer (mean annual temperature) for all cities except Montreal. However, the Montreal case is seen to be locally anomalous, arising from the interpolation of grid-point values, and this is not identified in the broad-scale analysis (Figure 2).

CONCLUSION

This projection of future Canadian natural gas use indicates an average 10-20 per cent decrease in use by individual residential consumers by 2031.

However, the climatic warming does not offset an overall increase in consumption which results from population growth. It must be emphasized that this is a simple projection which assumes situations regarding markets and technology which may not remain true. These assumptions and generalizations are, in summary:

- technology does not advance and develop better efficiency and conservation.
- the proportion of the population using natural gas remains constant.
- the climatic warming occurs by 2030. A recent paper (Bolin *et al* 1986) confirms that the combined effect of all radiatively active gases could well produce such a temperature rise.
- temperature scenarios interpolated from grid points to urban centres are also used provincially.
- population projections after 2006 are national. These have been divided provincially using the proportions established for 1983-2006. The projection is for a "medium growth" scenario.

A further limitation is that the GCM results are "noisy", reflecting the different parameterizations of the two models and the simplifications necessary to drive both. Scenario A temperatures are generally lower than those of B. Any interpretation of these projections must be made with caution. They pertain to broad areas and the numbers are approximate. However, general conclusions such as these are well above guesswork and can shape the contingency allowances for long-term strategic planning of energy supply. An alternative approach which avoids using GCM results on regional scales would be to examine the sensitivity of gas consumption to hypothetical temperature changes. This would enable the development of strategies to respond to a range of possibilities and ought to be considered in a future study.

ACKNOWLEDGEMENTS

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Seasonal Snowfall Totals in Northern New England: Recent Trends and Variability

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ABSTRACT

Long-term trends and seasonal variability in snowfall totals for ten northern New England sites were studied for the 37 winter seasons from 1949-50 through 1985-86. Utilizing ten-year moving averages to depict trends, many of the sites experienced distinct increases in snowfall totals from the beginning of the study period to the late 1960s and 1970s. Thereafter, a majority of sites showed a significant decline in the seasonal snowfall trend into the 1980s. It is suggested that the late 1960s through 1970s peak was the more exceptional period. Analysis of extreme snowfall seasons utilizing a snowfall variability index indicated a higher frequency of unusual years for the latter half of the study period.

RÉSUMÉ

Les tendances à long-terme et la variabilité des totales de neige à dix stations de la Nouvelle-Angleterre du nord ont été étudiées. La période d'étude comprend trente-sept saisons hivernales, de 1949-50 jusqu'à 1985-86. En décrivant les tendances par les moyennes mouvantes de dix ans, on trouve que la plupart des stations présente une augmentation distincte de totale de neige du début de la période d'étude jusqu'à la fin des années 1960 et durant les années 1970. Ensuite une majorité des stations a enregistré une tendance significative de déclin de la neige saisonnière. On suggère que la pointe de la fin des années 1960 au travers des années 1970 a été la période la plus exceptionnelle. Une analyse des saisons de neige extrême, suivant un indice de variabilité de neige, a indiqué une fréquence plus élevée d'années exceptionnelles pendant la dernière moitié de la période d'étude.

1. INTRODUCTION

Snowfall in mid-latitude climates is of considerable importance with respect to impacts upon water resources (e.g., Hendrick and DeAngelis, 1976), transportation (e.g., DeFreitas, 1975; Cohen, 1981), and other economic activities (Oliver, 1981). Lynch et al. (1981) and Dubreuil (1981) have documented the economic impacts of the unusually light snowfall for the 1979-80 season in Ontario and southern Quebec. Ski resort operators felt a large negative economic impact due to the lack of snow during the season, thus providing one illustration of the importance of snowfall variability. An assessment of temporal trends and interannual variability of snowfall can be useful in planning appropriate preparations or actions in response to such climatic variations.

Northern New England is a region with an important recreational ski industry. The objective of this study is to investigate the temporal trends of seasonal snowfall totals during recent decades for northern New England and to assess the interannual variability of snowfall, i.e. whether extreme seasons (either with unusually high or low totals) have become more or less frequent in recent years.

2. DATA

Snowfall records for 37 seasons from the winters of 1949-50 through 1985-86 were obtained from the *Climatological Data* publications of the National Climatic Data Center for ten sites in Vermont, New Hampshire and western Maine (Figure 1). Comments in Table 1 document any data problems including substitutions of data from nearby sites to facilitate a complete record with no missing data. The most elaborate substitutions of estimated values occurred for Rumford, Maine. Five of the sites had complete records necessitating no estimations from nearby sites. Mean seasonal snowfall totals and standard deviations for the entire period are given in Table 2. Considerable variation in mean snowfall receipt exists across the study area. Also presented in Table 2 are Chi-square values for a test of whether seasonal snowfall totals are normally distributed (Panofsky and Brier, 1958). Results indicate that snowfall amounts are indeed normally distributed for all sites.

3. ANALYSIS AND DISCUSSION

To assess long-term trends in total seasonal snowfall, 10-year running means were calculated for each site (Figure 2). Snowfall seasons are labelled according to the calendar year for the January of the winter season (i.e., winter of 1949-50 is referred to as 1950). Ten-year means were used following the suggestions of Dixon and Shulman (1984) who have shown that running means of 10-30 years in length perform better than shorter averaging periods for predictive purposes. To illustrate the significance of any difference between the most recent 10-year average and those of previous periods, t-statistic values (Panofsky and Brier, 1958) were calculated comparing the mean snowfall totals for the ten-year period 1977 through 1986 to all other

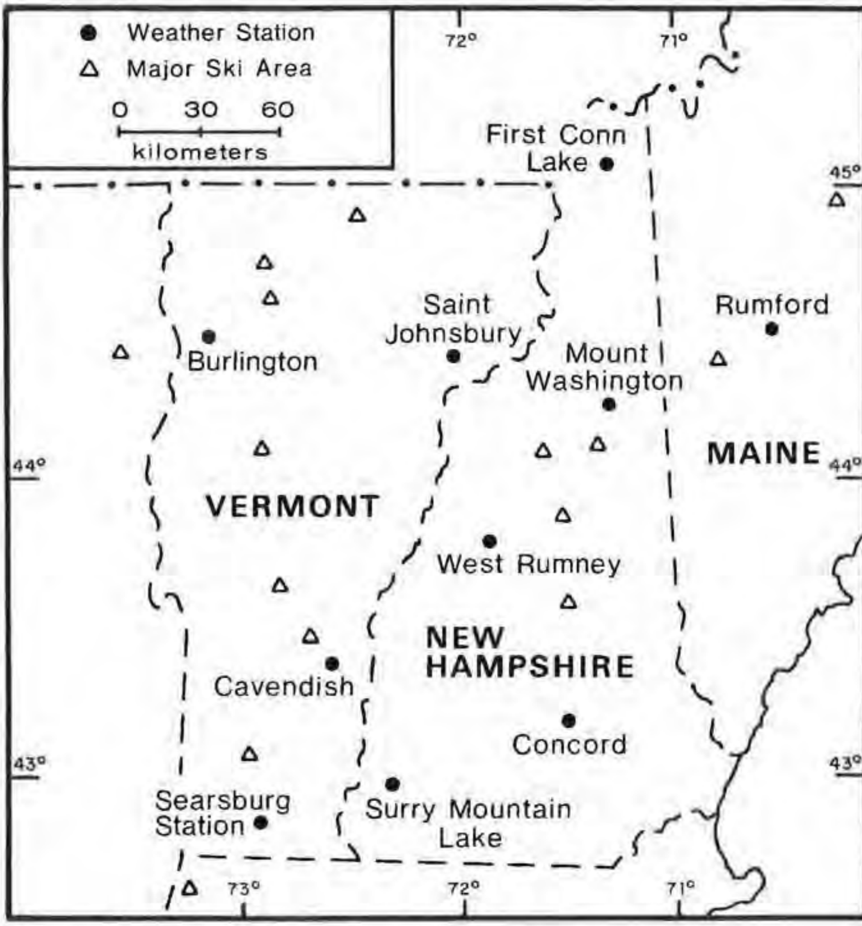

FIGURE 1. Location map of weather station sites used in study.

TABLE 1: Relevant information on weather stations used in this study.

Site	Latitude, Longitude	Altitude (m)	Comments on Data Record
Rumford 1SSE, ME	44° 32' N 70° 32' W	192	For 1983-84, 1985-86 seasons, used West Paris. Prior to 1971, several monthly and seasonal values were derived from other Rumford sites (Rumford 1S, Rumford 3SW, Rumford Power Plant) at slightly different locations and elevations.
Concord, NH	43° 12' N 71° 30' W	105	Record complete
First Conn Lake, NH	45° 05' N 71° 17' W	506	Record complete
Mount Washington, NH	44° 16' N 71° 18' W	1909	Substituted Pinkham Notch for 1 missing month during 1981-82.
Surry Mtn. Lake, NH	43° 00' N 72° 19' W	168	Record complete
West Rumney, NH	43° 48' N 71° 51' W	171	Substituted Woodstock for 1 missing month in each of 1950-51, 1956-57, 1958-59, 1959-60
Burlington, VT	44° 28' N 73° 09' W	101	Record complete
Cavendish, VT	43° 23' N 72° 36' W	244	Record complete
Saint Johnsbury, VT	44° 25' N 72° 01' W	213	Substituted Monroe, NH for a few months in each of 1959-60, 1974-75, 1975-76. Substituted Gilman for a month in 1961-62. Substituted W. Danville for a month in 1952-53.
Searsburg Station, VT	42° 52' N 72° 55' W	475	Substituted Readsboro for 1 missing month in each of 1968-69, 1971-72. Substituted Searsburg Mountain for entire seasons of 1952-53, 1955-56 and 1 month in 1961-62.

TABLE 2: Mean seasonal snowfall totals (based on 37 seasons) with standard deviation values and Chi-square values for test of normal distribution.

Site	Mean (cm)	Standard Deviation (cm)	Chi-square*
Northern Portion of Study Area:			
Mount Washington, NH	723.1	265.2	7.43
First Conn Lake, NH	422.0	81.1	2.68
Rumford, ME	234.3	71.2	5.24
Saint Johnsbury, VT	219.0	58.1	7.72
Burlington, VT	205.7	52.1	6.68
Southern Portion of Study Area:			
Searsburg Station, VT	293.8	68.7	5.03
West Rumney, NH	247.7	65.4	6.57
Cavendish, VT	240.6	67.4	7.63
Surry Mountain Lake, NH	173.0	54.7	6.93
Concord, NH	163.3	50.1	10.00

* To reject the hypothesis of a normal distribution, Chi-square needs to exceed 13.36 (0.10 significance level) or 20.09 (0.01 significance level). Therefore, all sites had normally distributed seasonal snowfall totals.

10-year averages. Portions of the trend lines in Figure 2 found to be significantly different from the 1977-1986 period at the 0.05 and 0.10 significance levels are plotted with thick and thin solid lines, respectively, while the dashed portions represent periods when 10-year means were not significantly different from the 1977-1986 average.

The curves in Figure 2 illustrate that for 8 of the 10 sites the 1977-1986 decadal snowfall average is significantly lower than for earlier periods, especially compared to the mid-1960s through the 1970s. For several of the sites, recent snowfall totals are at the lowest level for the entire study period. By contrast, no significant trends are evident for Saint Johnsbury and Concord. Mount Washington experienced its lowest average totals during the 1950s, although the most recent decadal value is significantly lower than that experienced during the mid 1960s through 1970s.

Several of the sites experienced a rise in the snowfall trend line depicted in Figure 2 during the first portion of the study period, from the 1950s to the 1970s. This corresponds to the observations of Jones and Jiusto (1980) in New York State. Severe winters during the 1970s brought exceptionally high snowfall amounts to much of the United States including New England (Diaz and Quayle, 1980), resulting in a much greater extent of snowcover by the late 1970s (Heim and Dewey, 1984). However, the trend was distinctly reversed with the advent of much lower snowfall amounts in more recent years, as in the 1980-81 season across North America (Foster and Rango, 1982).

Although Figure 2 illustrates a significant downward trend in recent years for most of the northern New England sites, it should be noted that such lower snowfall totals may not be unprecedented. In a study for the northeastern United States from 1929 through 1959, using a more limited data set including only two of the northern New England sites in the present study, Namias (1960) found that several winters during the 1950s ranked among the highest snowfall amounts for his study period; they also included the two highest (1955-56, 1957-58). Although Namias' results were dominated by exceptionally high snowfalls in New York, Pennsylvania and eastern Ohio, they nevertheless suggest that the northeastern United States experienced distinctly lower average snowfalls in decades prior to the 1950s. Thus, the generally low snowfall totals experienced in recent years in northern New England may not be unusual. On the contrary, the exceptionally high totals for the late 1960s through 1970s may be the more unusual phenomenon.

The rapid drop in the trend lines for recent years depicted in Fig. 2 for most sites is partially the function of some extreme anomalous winters. In a study of the whole United States for the winters of 1949-50 through 1980-81, Walsh et al. (1982) noted that the extreme cases for snow cover totals occurred during the more recent years: most snow during 1977-78 and 1978-79, and least snow during 1980-81. Diaz and Quayle (1980) also noted the importance of the extreme winters of the late 1970s in terms of increased variability.

To assess whether there has been an increase in the frequency of extreme winter snowfalls in recent years for northern New England (i.e., large departures from the long-term average regardless of whether the departures are positive or negative), the climatic variability index of Tavakol and Jones (reported in Lamb, 1982, p. 256 and subsequently used in studies of temperature departures by Suckling, 1984, 1985 and Higuchi et al., 1986) was modified for use in the present study. The original index formulation was:

$$\text{Climatic Variability Index} = \frac{1}{n} \sum_{i=1}^{n} \frac{|x_i - \bar{x}_i|}{\sigma_i} \qquad (1)$$

where $\bar{x}$ is the average of the entity under study for the entire period for site i, x_i is the value for site i for the specific year for which the index is being calculated, σ_i is the standard deviation of x for site i, and n is the number of sites.

Essentially such an index attempts to determine how well, or how poorly, the standardized values of x for a year fit the normal pattern. Hence, as demonstrated by Suckling (1987), a more appropriate expression for closeness of fit is a least-squares approach where:

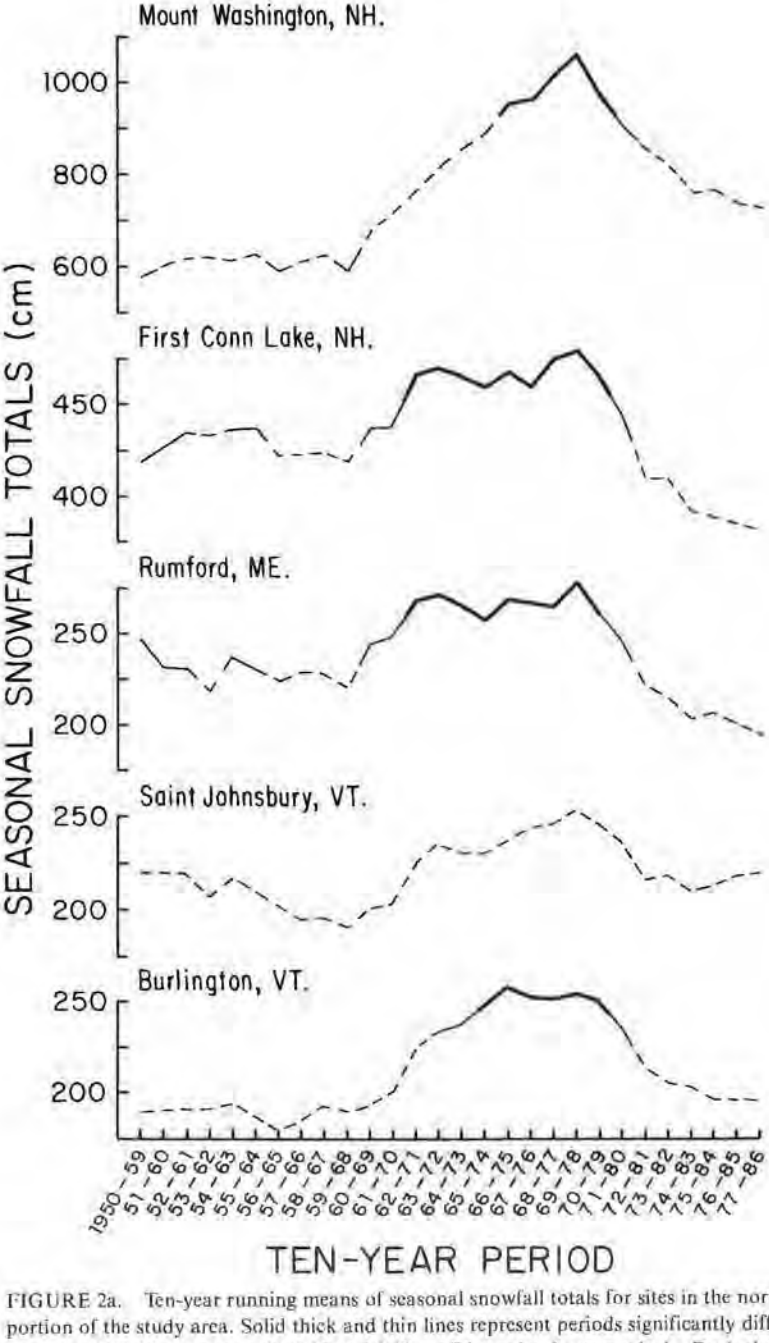

FIGURE 2a. Ten-year running means of seasonal snowfall totals for sites in the northern portion of the study area. Solid thick and thin lines represent periods significantly different from the 1977-86 average at the 0.05 and 0.10 confidence levels, respectively. Dashed portions of the lines represent periods not significantly different from the 1977-86 average.

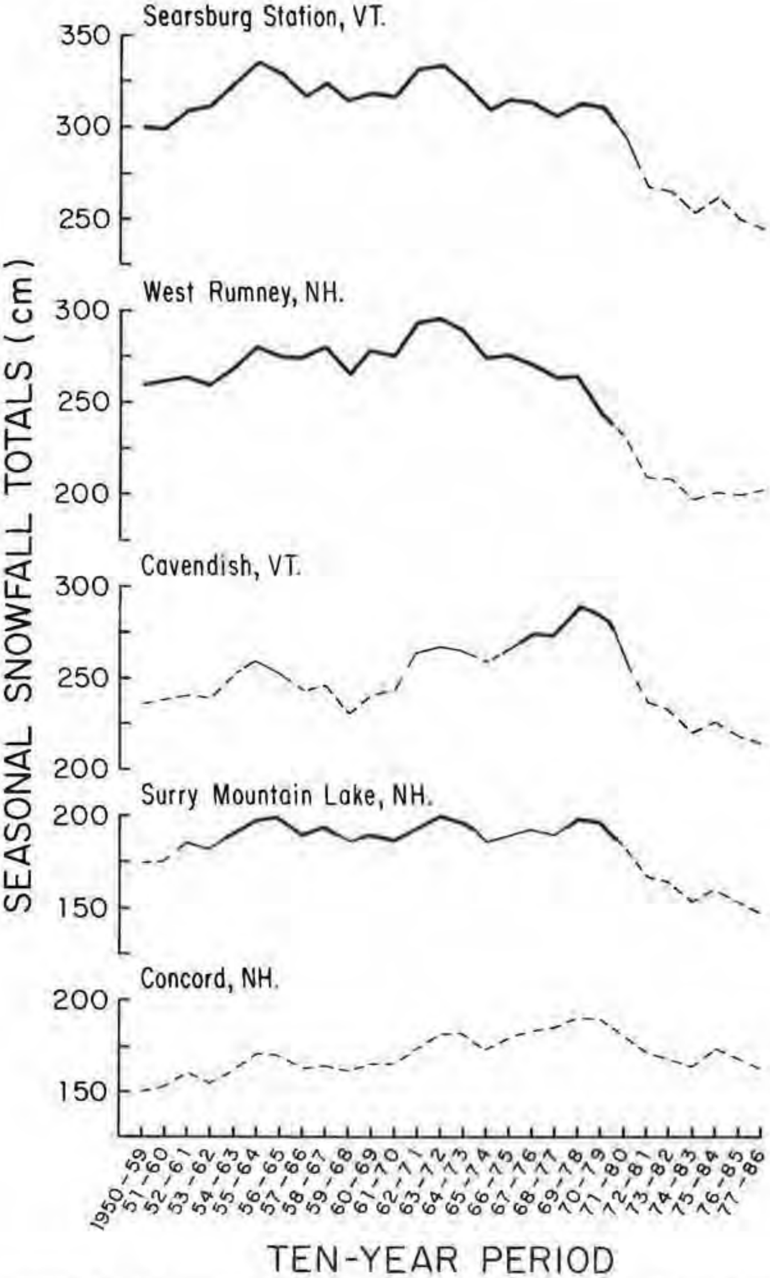

FIGURE 2b. Same as Fig. 2a except for sites in the southern portion of the study area.

$$\text{Snowfall Variability Index} = \left[\frac{1}{n} \sum_{i=1}^{n} \frac{(x_i - \bar{x}_i)^2}{\sigma_i^{\,2}} \right]^{0.5} \qquad (2)$$

and x refers to seasonal snowfall totals in the present study.

The median index value obtained utilizing the formulation in Equation 2 is about 0.8. Relatively low index values represent seasons with snowfall amounts close to "normal" for the region, whereas high index values indicate extreme cases with values either much higher or much lower than average. Calculated index values are plotted for individual snowfall seasons (again referred to by the calendar year for the January of the winter season) in Figure 3. High index values (above 0.95) are highlighted by large solid dots for exceptionally high snowfall seasons and large open dots for unusually low snowfall years. It should be noted that the extreme years identified in Figure 3 using the snowfall variability index formulation from Equation 2 are identical to those found in a test run using the formulation given in Equation 1.

The single highest index value in Figure 3 occurred for the 1970-71 season during which many weather stations reported the highest December

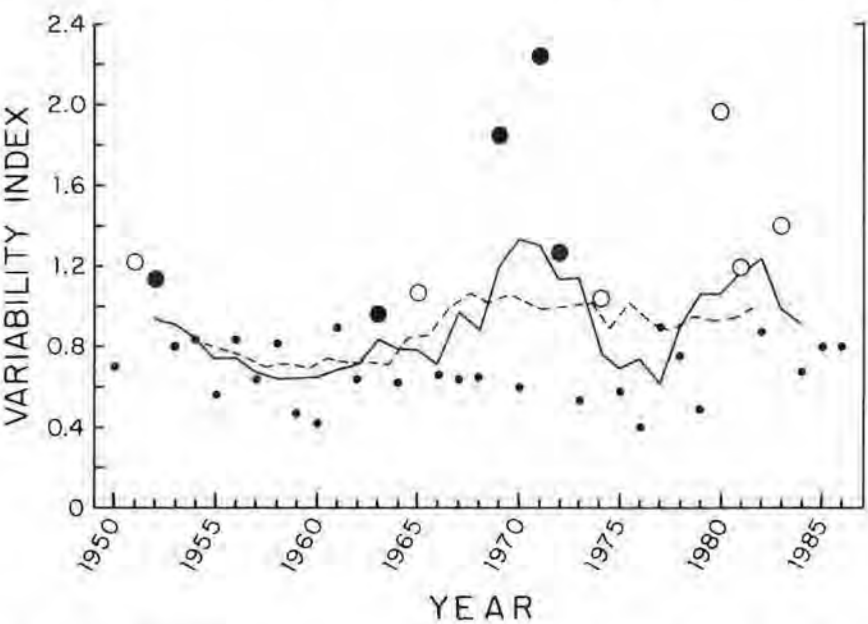

FIGURE 3. Snowfall variability index values. Large solid dots represent exceptionally high snowfall seasons while large open dots represent exceptionally low snowfall seasons. Solid and dashed lines represent 5- and 10-year running means of the index values, respectively.

snowfall totals on record (Ludlum, 1972). For the present study, 6 of the 10 sites had the heaviest snowfalls of the study period during this season. The second highest index value depicted in Figure 3 corresponds to the exceptionally low snowfall totals recorded during 1979-80. All but one site recorded the lowest seasonal total of the study period during this season (second lowest at First Connecticut Lake). Note that this corresponds to the same exceptional season for Ontario and Quebec reported by Lynch et al. (1981) and Dubreuil (1981).

To illustrate the temporal trend for the variability index, 5- and 10-year running means of the index values are also plotted in Figure 3. From the 5-year running mean curve, periods of high variability are evident during the late 1960s and early 1970s and again during the early 1980s. The first of these periods is dominated by three winters with unusually high snowfall (1968-69, 1970-71, 1971-72) and one with low snowfall (1973-74). The exceptional winters of the late 1970s documented for the whole of the United States by Diaz and Quayle (1980) and Walsh et al. (1982) do not emerge as significant extreme years for northern New England. The second period of high index values in Figure 3 (the early 1980s) is dominated by three exceptional winters with low snowfall totals (1979-80, 1980-81, 1982-83). The low snowfalls for these three winters are the main cause for the rapid drop in the trend lines depicted in Figure 2.

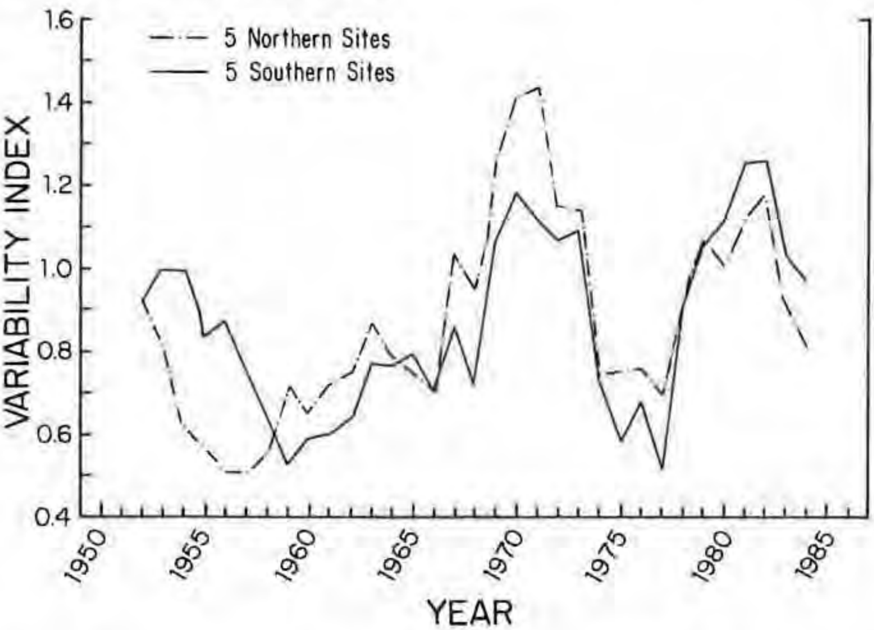

FIGURE 4. Five-year running means of snowfall variability index values for the northern and southern subregions of the study area.

The 10-year running mean curve in Figure 3 illustrates that variability index values are generally higher for the second half of the study period. This suggests that a larger frequency of unusual snowfall seasons has occurred in recent years.

Visual comparison of Figure 2a and Figure 2b suggests that snowfall trends may differ to an important extent between the northern and southern sites. Snowfall variability index values were calculated for stratified samples of the 5 northern and the 5 southern sites. A simple correlation of the index values for the two subregions yielded $r = 0.68$. Plots of 5-year running means of the index values (Figure 4) illustrate no apparent difference between the trends for the two subregions; also, results in Fig. 4 are similar to those depicted in Figure 3.

4. CONCLUSION

This study has illustrated that during recent decades seasonal snowfall totals in northern New England have varied significantly at the majority of study sites. The trend has been to lower average seasonal snowfall amounts for the most recent years, following peak 10-year averages encompassing the late 1960s and 1970s. However, evidence from some sites and within the literature suggests that the most recent decadal snowfall averages may not be unusually low compared to those of decades earlier in the century. On the contrary, the high snowfall averages of the late 1960s through 1970s may represent the more exceptional period, albeit a short aberration.

Analysis of extreme snowfall seasons utilizing a snowfall departure index suggests that a higher frequency of unusual years has occurred during the latter half of the 37-year study period. This was a consequence of some extreme high snowfall seasons in the late 1960s and early 1970s followed by extreme low snowfall seasons especially during the 1980s.

An increase in seasonal variability is an important aspect of the region's snowfall climatology. Recreational skiing as well as other economic activities may require operational and budgetary strategies that take into consideration greater variations in annual snowfall amounts.

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ERRATA

Dr.Olajire J. Olaniran of the University of Ilorin, Nigeria has drawn our attention to the fact that the captions to Figures 4 and 5 in his article "The July-August Rainfall Anomaly in Nigeria" (Climatological Bulletin, Vol. 22, No. 2, 1988, pp. 26–38) were reversed. Our apologies to him and to the readership for this unfortunate error.

The July-August Rainfall Anomaly in Nigeria

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[Original manuscript received 15 July 1986; in revised form 15 February 1988]

ABSTRACT

The July-August period is considered to be an anomaly in the rainfall climatology of Nigeria because rainfall is reduced over southern Nigeria despite the great depth and humidity of the tropical maritime air near the coast. In this study the number of dry-spell days and the length and frequency of dry spells during the July-August period in Nigeria were analysed quantitatively in order to illustrate this phenomenon. The inter-annual variability was also analysed. The climatological structure of the rainfall anomaly varies significantly for southern and northern Nigeria according to the weather zone that prevails over each area. Latitudinal and elevational features of the spatial pattern were identified here in addition to the longitudinal variation reported by other researchers.

RÉSUMÉ

La période de juillet-août est considérée comme anomalie dans la climatologie des pluies du Nigéria, car les précipitations sont réduites au sud du pays malgré la profondeur et l'humidité bien élevée de l'air maritime tropicale vers le littoral. L'article analyse le nombre de jours des périodes sèches, également la durée et la fréquence de telles périodes, pendant juillet-août en Nigéria, ainsi que la variabilité annuelle. La structure climatologique de l'anomalie des pluies diffère significativement du sud au nord selon le système de temps qui prévaut dans chaque région. Les caractéristiques de la distribution concernant la latitude et l'altitude sont identifiées ici, ainsi que celles selon la longitude rapportées déjà par d'autres chercheurs.

INTRODUCTION

The July-August period is important in the rainfall climatology of Nigeria. In the south it is a time of reduced rainfall separating two main rainy seasons, and can last up to six weeks (Ojo, 1977). Such terms as 'little dry season' (Ireland, 1962), 'July-August break' or 'intermonsoon period rainfall' (Davies et al., 1985) have been applied to this period. Ojo (1977) regards it as part of the 'rainfall anomaly' of the West African region, because this break in the rainy season is experienced near the coast of southern Nigeria at a time of year when the very humid tropical maritime (mT) air mass is deepest there.

Bar graphs showing mean monthly rainfall amount (Ireland, 1962; Griffiths, 1972a; and Oguntoyinbo, 1982) or rain-days (Ireland, 1962 and Griffiths, 1972a) have been used to illustrate the 'little dry season' phenomenon in Nigeria. On these charts, stations which experience the 'July-August break' exhibit the double rainfall maximum with peaks about May/June and September/October, while other Nigerian stations show a single rainy season with a maximum about August. By rainfall amount and number of rain-days, the double peak extends from the coast to about Bida (9° N) in western Nigeria but is barely evident even at 4° N in the east (Griffiths, 1972a). Ireland (1962) also noted that for southern Nigeria the intensity of the 'little dry season' decreases progressively eastward; it is not recognizable beyond longitude 5° E when illustrated by rain-days.

This considerable spatial variation in the rainfall anomaly cannot be adequately illustrated by bar graphs of either rainfall amount or rain-days, or by monthly averages of rainfall amount or rain-days (Ireland, 1962). This paper therefore uses daily data to analyze the dry spell component of the reduced rainfall of the inter-monsoon period. These data include number of dry days per year, and the duration and frequency of occurrence of dry spells. First, however, in order to provide an understanding of the climatological basis of the 'little dry season', the systems producing rainfall over Nigeria will be discussed.

SYSTEMS PRODUCING RAINFALL OVER NIGERIA

During the rainy season, Nigeria receives moisture from the tropical Atlantic via low-level southwesterly flow across her southern coast. At the surface, this moist southwesterly airstream can penetrate beyond the country as far as the southern fringes of the Sahara Desert near 20° N. Figure 1 shows that this southwest monsoon flow decreases in thickness northward from the Gulf of Guinea. It is overlain by a hotter and drier northeasterly airstream emanating from above the Sahara. The discontinuity between these two contrasting air masses, known as the inter-tropical discontinuity (ITD), is steepest near the surface and fades out at about the 700 mb (3 km) level. Figure 1 also subdivides Nigeria on the basis of weather zones which fluctuate seasonally with the ITD.

Zone A, north of the ITD, marks the farthest penetration southward of the dry harmattan air at the surface. This zone is characterized by rainless cirrus clouds at great heights. Apart from this cirrus and suspended dust, skies are clear.

The ITD reaches the surface at the north edge of Zone B, which extends southward for 240-320 km. Cloud development is generally limited to

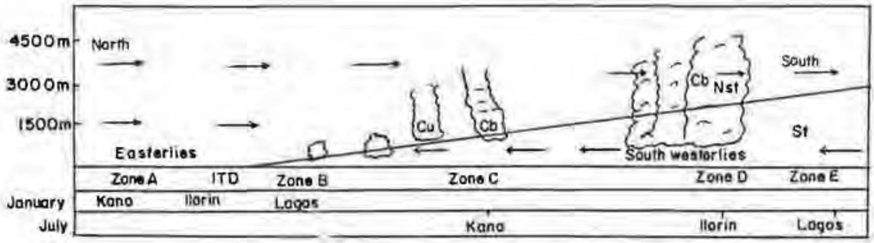


FIGURE 1. The ITD and the weather zones in an idealized atmospheric cross-section from South to North over Nigeria (From Ojo, 1977)

slight cumulus activity by day, but on 1-5 days per month, isolated thunderstorms break out in the afternoon or evening.

Zone C extends southwards for 600-800 km. It is periodically traversed, generally from east to west, by 'disturbance lines' ranging from well-defined line squalls to belts of heavy cloud without rain.

Zone D covers an average width of about 320 km. Its weather is characterized by clouds of great vertical development; days with rain are the rule rather than the exception, and rainfall tends to be more prolonged and less intense than in Zone C. It may last up to 12 hours and produce substantial amounts, particularly on the coast.

Zone E, the most southerly, penetrates only a relatively short distance inland in July and August when the ITD has been displaced north beyond Nigeria. Stratus with a base of only 200-300 m is common, with little sunshine. Relatively stable conditions, sometimes with a temperature inversion, are prevalent above this level, inhibiting upward movement and consequently rainfall occurrence.

The descriptions presented above refer to weather conditions during the northward movement of the ITD. During the southward movement, Zones C and D are difficult to separate. Figure 1 also shows the position of three cities in relation to the ITD in January and July respectively.

It appears that Zone E weather is responsible for the short dry season over southern Nigeria in July-August. But dry conditions of short duration can still occur over northern Nigeria, especially if Zone D weather does not cover this area completely. Bar graphs of monthly average rainfall or rain-days will tend to mask such short-term features of rainfall distribution for northern Nigeria.

Ireland (1962) and Ojo (1977) have considered physical causes of reduced rainfall during July-August other than Zone E weather over the south. They suggest that the main rain-bearing systems, the southwesterlies, become deflected into westerlies which, according to Nieuwolt (1977), exhibit only scattered areas of weak convergence. Thus, rainfall occurrence will increase eastwards over southern Nigeria as the westerlies weaken in that direction.

Another hypothesis regarding the 'little dry season' invokes stabilization of the lower atmosphere by the coolness of the sea in the Gulf of Guinea. This may be a result of the northward extension of the cold Benguela current or an upwelling of cold water.

Ireland (1962) hypothesized that the 'little dry season' is a northward extension of the main dry season of the southern hemisphere. Southern Africa comes under the influence of the subtropical high pressure belt in July. This effect may reach the coast of southern Nigeria, thereby producing a stable southwest airstream.

The role of topography in the occurrence of the 'little dry season' over southern Nigeria has not been evaluated. However, according to Davies *et al* (1985), anabatic winds generated in highland areas interact with the trades to favour instability and consequently rainfall occurrence. Griffiths (1972b) noted a similar situation in the highlands of Kenya.

In the absence of actual meteorological observations, it is difficult to evaluate these several hypotheses. Possibly the various forces reinforce one another in reducing rainfall during the July-August period in Nigeria. Longitudinal, latitudinal and perhaps altitudinal differences appear to be significant, and are therefore studied in relation to number of dry days, frequency and duration of dry spells in this paper. Southern and northern Nigeria are treated separately.

METHODS OF STUDY

(a) *The Data Base*

Daily rainfall data for July and August 1971-80 were collected for the 46 stations shown in Figure 2. Complete daily rainfall records are available for this decade. Stations south of 9° N represent southern Nigeria, and the remainder northern Nigeria. According to Adejokun (1966), the ITD has its mean annual surface location over Nigeria at latitude 9° N, with a fluctuation of ± 0° 30'.

In addition to the map of the data collection stations, in Figure 3 the relief and schematic physical regions of the country are shown.

(b) *The Definition of a Dry Spell*

A 'dry spell' refers to a series of consecutive days, none of which is a rain-day. In this study a value of 2 mm was adopted to define a rain-day because, according to Nieuwolt (1977), daily rainfalls of less than 2 mm are insignificant to agriculture or water supply because in warm climates such small amounts largely evaporate before infiltrating the soil. A dry spell is defined here as a period of 5 or more days, each with less than 2 mm of rainfall.

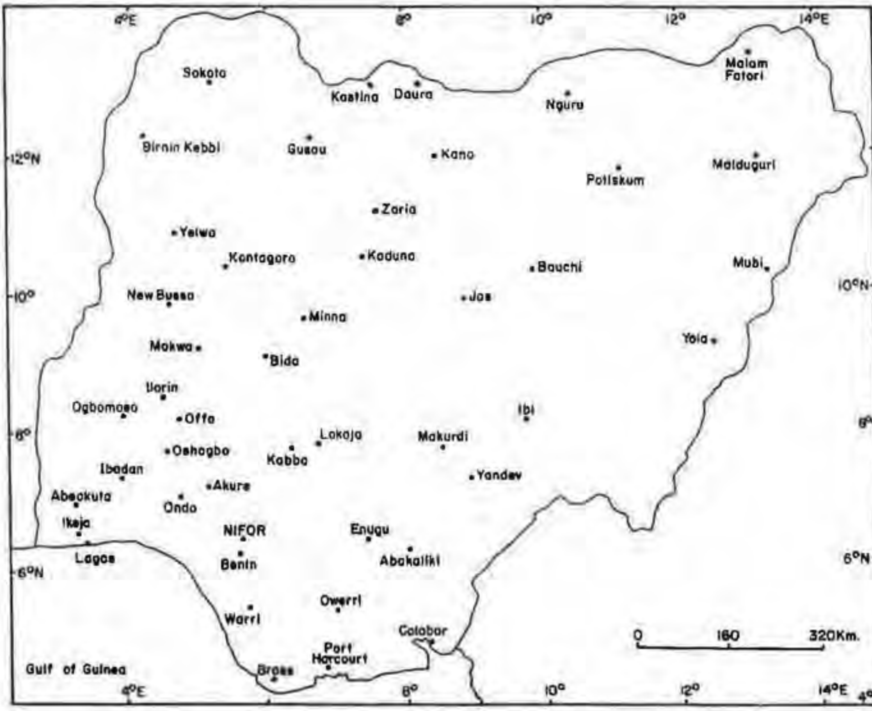


FIGURE 2. Map of Nigeria showing the data collection stations.

(c) *The Characteristics of Dry Spells*

This study analysed number of dry-spell days, and frequency and duration of dry spells, at each station in July and August. The annual average number of dry-spell days was taken to be the total number of days involved in dry spells divided by the number of years in which dry spells occurred. The mean length of dry spells was taken as the total number of days involved in dry spells divided by the total number of dry-spell occurrences. The frequency of occurrence of dry spells was taken as the number of dry spells of various lengths divided by the number of years used in data analysis.

(d) *Statistical Analysis of Results*

The three aspects of dry-spell occurrence described above were each related to latitude, longitude, and elevation using the multiple regression technique. Results of the simple linear correlation and the multiple regression analysis are shown in Tables 1 and 2 and maps are presented in Figure 4. To gain some idea of the inter-annual variability, the coefficient of variation of the yearly values was computed for each station for each aspect of dry-spell occurrence, and mapped (Figure 5).

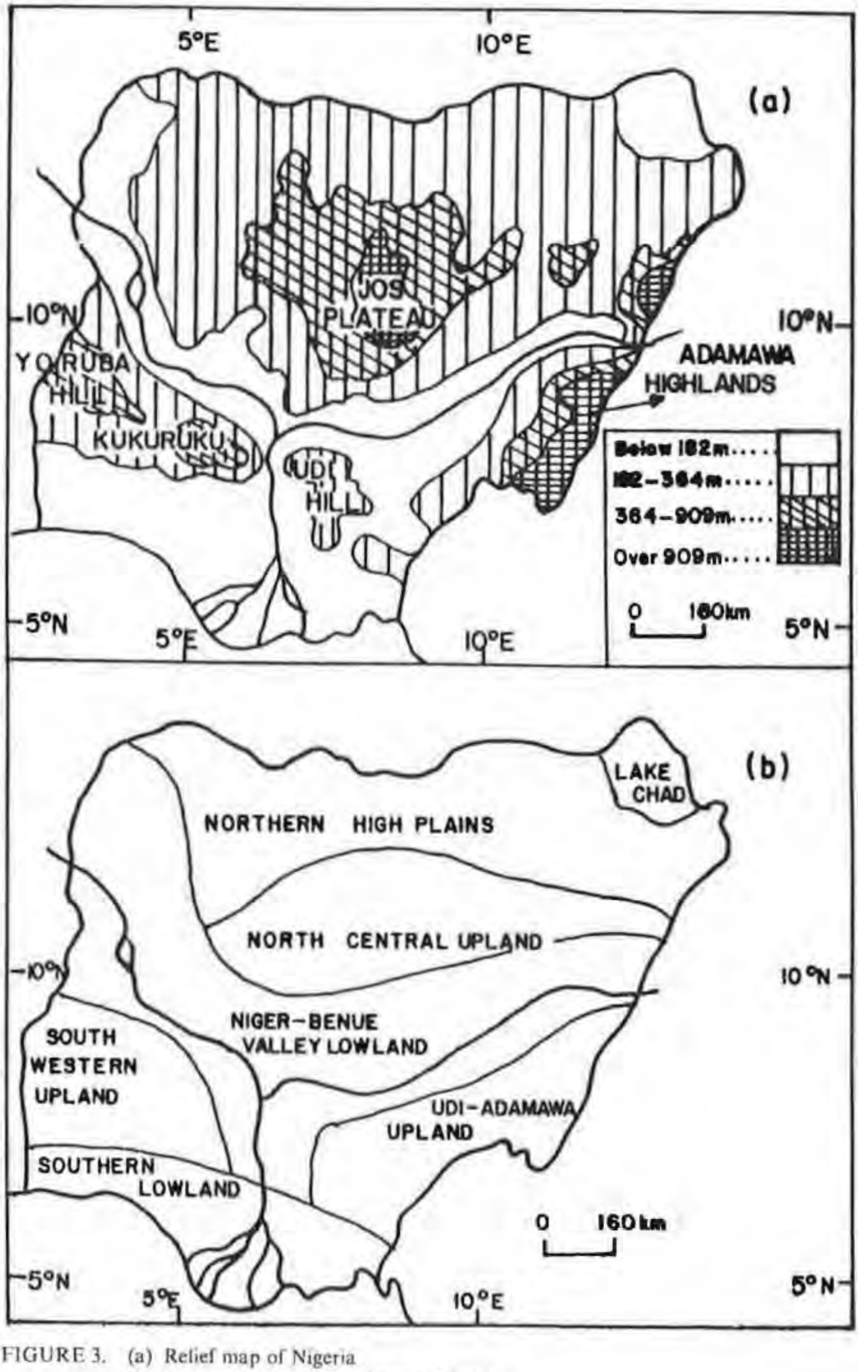


FIGURE 3. (a) Relief map of Nigeria
(b) Schematic physical regions of Nigeria

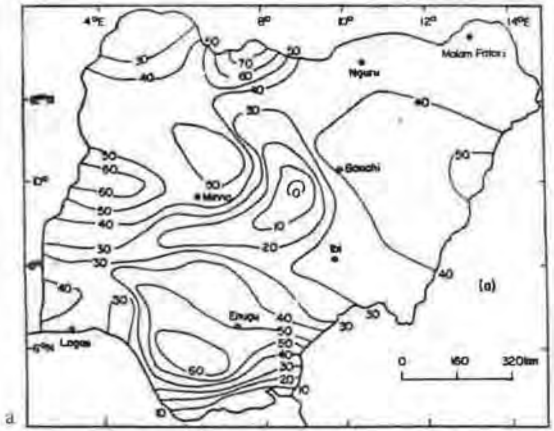
TABLE 1: Simple correlation between different aspects of dry spell occurrence during the July-August period in Nigeria and geographical factors

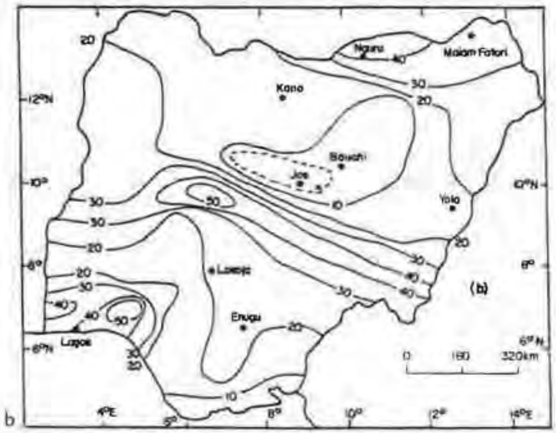
	Latitudinal Factor	Longitudinal Factor	Elevational Factor
(a) Southern Nigeria (<9° N)			
Number of dry-spell days	0.582*	-0.550*	0.293
Mean length of dry spells	0.227	-0.603*	-0.073
Mean frequency of dry spells	0.849*	-0.263	0.532*
(b) Northern Nigeria (>9° N)			
Number of dry-spell days	0.398	0.323	-0.418
Mean length of dry spells	0.205	0.263	-0.478*
Mean frequency of dry spells	0.422	0.213	-0.561*
(c) Southern and Northern Stations Combined			
Number of dry-spell days	-0.138	-0.200	-0.329*
Mean length of dry spells	-0.173	-0.268	-0.363*
Mean frequency of dry-spells	-0.049	-0.137	-0.338*

*Statistically significant at 95% probability level.

TABLE 2: Percentage of variation of different aspects of dry spell occurrence during the July-August period in Nigeria explained by different geographical factors

	Latitudinal Factor	Longitudinal Factor	Elevational Factor	All Factors Combined
(a) Southern Nigeria (<9° N)				
Number of dry-spell days	33.9	23.1	6.6	63.6
Mean length of dry spells	17.4	36.4	4.9	58.7
Mean frequency of dry spells	72.1	2.5	1.2	75.8
(b) Northern Nigeria (>9° N)				
Number of dry-spell days	15.8	14.7	17.5	48.0
Mean length of dry spells	2.2	15.5	22.8	40.5
Mean frequency of dry spells	17.6	6.7	31.5	55.8
(c) Southern and Northern Stations Combined				
Number of dry-spell days	0.5	0.9	10.8	12.2
Mean length of dry spells	0.5	2.4	13.2	16.1
Mean frequency of dry spells	2.6	0.1	11.8	14.1





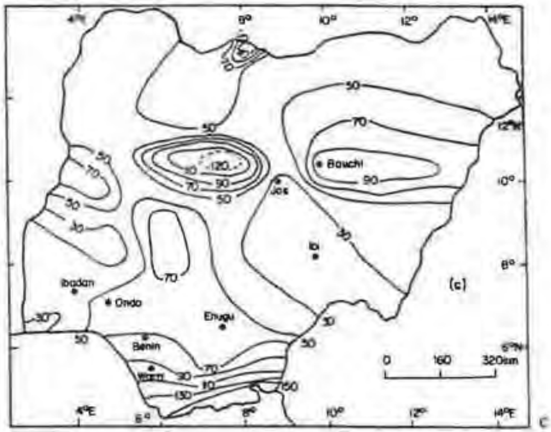


FIGURE 4. The occurrence of dry spells during the period of rainfall anomaly in Nigeria
(a) average number of dry days.
(b) mean length of a dry spell (days).
(c) mean frequency of dry spells.

Figure 4a shows the spatial variation of the average number of dry-spell days over Nigeria during the July-August period. Only around Ikeja (extreme southwest) and on the top of the southwestern upland does this number approach 40 days. Over southern Nigeria the average number of dry-spell days during the 'little dry season' shows the greatest variation according to latitude (Tables 1a and 2a). Figure 4a shows that this variation is most noticeable east of about longitude 5° E. The depth of the mT air mass associated with Zone E weather decreases inland from the coast causing an increase in dry-spell days with latitude (Figure 4a and Table 1) over southern Nigeria. Up to longitude 5° E, the average number of dry days decreases eastwards in southern Nigeria as the westerlies weaken. These two features cause the average number of dry days per year during the little dry season to exhibit strong latitudinal and longitudinal variations over southern Nigeria. The results of the multiple regression analysis in Table 2a confirm this.

Over northern Nigeria (north of about 9° N), the average number of dry-spell days varies randomly, with about 14-26 days in the northeast and 14-17 days in the northwest; over the north-central upland area the number decreases gradually with elevation (Figures 3 and 4a). The lack of significant correlations in Table 1b clearly attests to the randomness. When Zone C weather which is capable of causing dry spells over northern Nigeria is in residence, the associated belt of heavy cloud without rain moves in almost any direction. This leads to a random occurrence of dry spells.

The high numbers of dry-spell days in the northeast and the northwest (Figure 4a) confirm the view of Ireland (1962) that it is difficult to detect dry conditions of short duration from monthly averages of rainfall amount and rain-days, which depict July-August as a period of peak rainfall for northern Nigeria.

Figure 4b shows the spatial variation of the mean length of July-August dry spells. For southern Nigeria there is a strong west-east reduction in mean length (Fig. 4b and Table 1a), reflecting the pattern of operation of the westerlies over the region.

For northern Nigeria the results in Table 1b show that the mean length of dry spells decreases significantly with increasing elevation. Over much of northern Nigeria, particularly over the north-central highland, Zone D weather is in residence during the July-August period, and days with rain are the rule rather than the exception. However, the north-central upland may further enhance the rainfall, as suggested by the results in Table 1b.

Figure 4c shows the spatial variation of the mean frequency of July-August dry spells. This frequency is found to vary strongly according to latitude for southern Nigeria (south of 9° N). The increase in the frequency of dry spells with latitude is more apparent for stations east of 5° E (Fig. 4c) and this is due to the decreasing depth inland of the mT air mass associated with

Zone E weather. In spite of the general relationship with latitude, however, it can be seen from Figure 4c that the frequency of occurrence of dry spells is comparatively higher for the southwestern part than for the eastern section of southern Nigeria. The higher values are caused by the westerlies which are stronger in the west than in the east of the region.

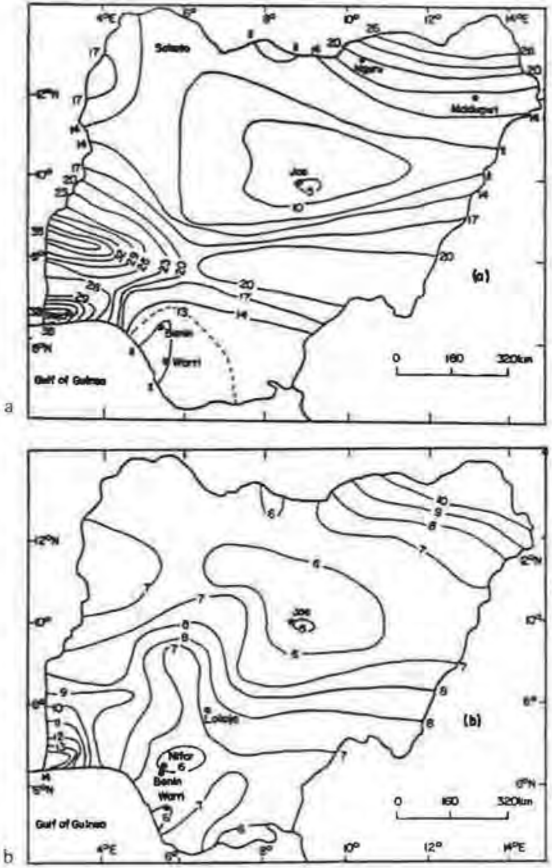
The results in Table 1a also show that over southern Nigeria the higher the elevation the greater the frequency of dry-spell occurrence. Elevation tends to increase with latitude, however, and latitude appears to be the more important factor. The results of the multiple regression analysis (Table 2a) show that 72.1% of the variation in dry-spell frequency is associated with latitude and only 1.2% with elevation.

Two points emerge. First, the climatological structure of rainfall anomaly during the July-August period differs significantly between the southern and northern parts of Nigeria. For example, the percentage of the variation in number of dry days associated with the variations in latitude, longitude, and elevation is 63.6 for southern Nigeria, and 48.0 for northern Nigeria, but only 12.2 for the whole country (Table 2). Thus, the physical causes of dry spells during the July-August period do not reinforce one another for the whole country. Over southern Nigeria Zone E weather reinforced by the westerlies is responsible for the occurrence of dry spells during the July-August period. Over the north-central upland the prevalence of Zone D weather prevents the occurrence of dry spells, while over the poleward end of the northern plain, Zone C weather encourages the occurrence of dry spells.

A second general observation is that analysis of dry-spell characteristics gives a better spatial perspective of July-August rainfall anomaly over Nigeria than does analysis of monthly averages of rainfall or rain-days. Over southern Nigeria, for example, the average number of dry-spell days was found to exhibit both latitudinal and longitudinal variations, the mean length of dry spells was found to exhibit a strong west-east variation and the frequency of occurrence of dry spells was found to increase inland from the coast. For northern Nigeria, the average number of dry-spell days had an irregular spatial pattern while the duration and frequency of dry spells were each found to decrease significantly with elevation. In contrast, only the west-east variation has been apparent when the 'little dry season' has been illustrated with monthly averages of rainfall amount or rain-days for southern Nigeria (see Ireland, 1962 and Griffiths, 1972a).

INTER-ANNUAL VARIABILITY

To gain some idea of the year-to-year variation of the occurrence of rainfall anomaly, the coefficient of variation of the yearly values was computed and mapped (Figure 5) for each aspect of dry-spell occurrence during the July-August period in Nigeria.



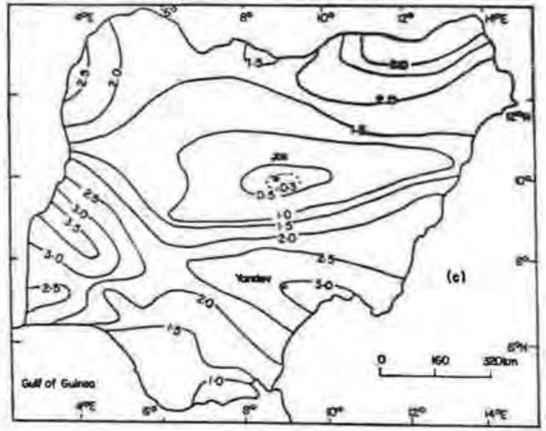


FIGURE 5. The inter-annual variability of the occurrence of different aspects of dry spells during the period of rainfall anomaly in Nigeria (%).

(a) Total number of dry days.
(b) mean length of individual dry spells (days)
(c) frequency of dry spells.

Year-to-year variation will be high when the physical causes of rainfall anomaly over an area change from season to season. Thus, for southern Nigeria east of longitude 5° E the yearly variability of the total number of dry-spell days is high except in the coastal belt (Figure 5a). In some years the westerlies will reach further eastward than in others thereby causing high variability of occurrence of dry spells. Also, for the area between the southern boundary of Zone D weather and the northern boundary of Zone E weather (between about 8° 30' and 9° 30'N) the variability of the length of dry spells is high (Figure 5b). Zone E weather may penetrate as far inland as 9° 30'N in some years but may not reach 8° 30'N in others.

If the physical causes of July-August rainfall anomaly (discussed in the section on systems producing rainfall over Nigeria) reinforce themselves in some years but not in others over an area, there will also be high variability in the pattern of occurrence of dry spells. Thus, over the extreme southwestern corner of southern Nigeria, the duration of dry spells changes considerably from year to year (Figure 5b). The situation may arise that, due to atmospheric changes over southern Africa, the influence of the subtropical high pressure belt is carried equatorwards thereby stabilizing the southwesterlies at the coast of West Africa. This may reinforce Zone E weather and lead to prolonged dry spells in some years, contributing to high variability in the duration of dry spells from year to year over the region.

It has been hypothesized above that over the coastal area of Nigeria the air can become stabilized in the lower parts of the atmosphere during the July-August period due to coolness of the sea in the Gulf of Guinea. This may result from the northward extension of the cold Benguela current or from an upwelling of cold water. Zone E weather reinforced by such a stabilized air mass will lead to a high occurrence of dry spells at the coast in some years. This may contribute to the higher variability of the frequency of dry spells over the coastal than over the inland areas of southern Nigeria (Figure 5c).

Over northern Nigeria the inter-annual variability of the different aspects of dry-spell occurrence is more random (Figure 5). The basis of the irregularity in the pattern of occurrence of dry spells over the region has been explained above.

CONCLUSION

Previous studies of the July-August rainfall anomaly, namely those of Ireland (1962), Griffiths (1972a) and Oguntoyinbo (1982), were descriptive and were based on monthly averages of rainfall or rain-days. They found that the rainfall anomaly of southern Nigeria exhibits a predominantly longitudinal pattern of variation. In this study, however, different aspects of dry-spell occurrence, namely the total number of dry-spell days, length and frequency of occurrence of dry spells, were subjected to quantitative analysis for southern and northern Nigeria. The year-to-year variation was also analyzed.

It was found that the climatological structure of rainfall anomaly during the July-August period differs significantly between southern and northern Nigeria according to the weather zone which prevails over each area. The rainfall anomaly for southern Nigeria was found to vary according to both latitude and longitude when illustrated by the total number of dry-spell days, in the west-east direction when illustrated by the duration of dry spells, but according to latitude when the frequency of dry-spell occurrence was analyzed. For northern Nigeria, the rainfall anomaly had an irregular spatial pattern when illustrated by the total number of dry-spell days, but a significant decrease with elevation when illustrated with both the duration and frequency of occurrence of dry spells. This analysis gives a better spatial perspective of the occurrence of rainfall anomaly over Nigeria during the July-August period than does analysis of monthly averages of rainfall or rain-days. It provides a basis for further research into the phenomenon.

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CLIMATOLOGY GOES TO COURT

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The term forensic climatology was coined in the United States during the 1960's to label the role of climatology in connection with legal matters in general and criminology in particular. In Ontario, the development of forensic climatology began in 1973 when David Murdoch, climate services specialist for the Ontario Climate Centre of Environment Canada, became involved in a successfully prosecuted murder trial. Subsequently Toronto area police forces began to turn more frequently to past weather information as an aid in their investigations. Then, in 1976 Murdoch was invited by the Ontario Provincial Police to attend 'The First Conference of Forensic Meteorology' in New Orleans, Louisiana.

This truly opened the door to a growing involvement of the Ontario Climate Centre with the Ontario judicial system—a system that includes as many as 1400 courtrooms in the Oshawa-Toronto-Oakville area. During the past ten years, Ontario Climate Centre staff have testified in over five hundred trials. In fact, in the early 1980's when the demand on Climate Centre personnel for court appearances was particularly high (111 court appearances in 1981), the Climate Centre arranged for the regional weather offices to handle local cases and most recently has begun to refer clients to the private sector in hopes of establishing a forensic expertise there as well. A continuing demand for lectures and seminars on forensic climatology has also evolved. Classes are regularly held at police training colleges at Brampton and Aylmer, educating special automobile accident and criminal investigation teams on using past weather details in crime solving. Also the lecture circuit inspires requests from conventions of fire marshals, insurance adjusters and others, all interested in the fascinating relationship between weather, climate and crime.

In general, forensic climatology is based upon the presentation of certified past weather facts and statistics. Opinions on the weather are extremely speculative as anyone who has seen 'rain on one side of the street and not on the other' can attest. As an expert witness, the climatologist is often asked to give opinion evidence on matters which he has investigated in his professional capacity. This ability to give opinion is a privilege not given to most witnesses, and it often weighs heavily on the outcome of the case.

The three main reasons for having a climatologist attend court are:

1) to discredit or refute another witness's testimony
2) to corroborate another witness's testimony or evidence
3) to assist the court in understanding the relevance of certain technical facts.

The climatologist is usually accredited or qualified as an expert through a series of questions based on his curriculum vitae. If the court accepts these qualifications, the questioning begins in earnest - questioning and cross-examination that can be very demanding. Since few lawyers are versed in the field of meteorology themselves, the age-old practice "if you can't attack the evidence attack the credibility of the witness" is often employed. Accordingly, it is often the manner in which the weather facts are presented that separates the forensic expert from the 'amateur'; demeanour and preparation are all-important in imparting credibility to the testimony. Also important is the discipline to stay within one's bounds of expertise and to refuse to ramble into speculation and embellishment despite attempts by questioning lawyers to lead the witness down the proverbial garden path.

The forensic climatologist requires a thorough knowledge of weather observing practices as well as a complete understanding of the codes, inspection, quality control and instrumentation involved in the collection of weather data. In addition, the climatologist needs to know the theories of his trade in a special way. Like a teacher, the forensic climatologist requires an ability to express in lay terms to a judge or jury the weather processes (adiabatic lift, lake effect, radiational cooling in the formation of ground fog, etc) that lie behind his evidence.

Furthermore, although the climatologist has not taken the weather observations himself (i.e. the climatologist is reading from certified documents completed by a trained weather observer), the expert should know that he is allowed to present such data to the court under *The Canada Evidence Act*, Section 30, Subsection 1 which states that "where oral evidence would be admissible, then in lieu of such information, a record made in the course of business or procedure is acceptable".

Testimony on the weather presented by a climatologist who was not at the scene of the crime is classed as circumstantial evidence, in that it is not first-person testimony based on facts perceived by the five senses. Television lawyers have given circumstantial evidence a 'bad name', but it is often the weight of this type of evidence that sways the case.

In a discussion regarding which weather elements are used as evidence in court and how those elements are applicable, Table 1 should prove useful.

TABLE 1: Meteorological elements and their forensic applications

Observed/Derived Weather Element	Forensic Applications (example)	Type of Proceeding
Dry bulb temperature Wind chill	condition of roads (icy or not) body cooling after death	- motor vehicle accidents - criminal - inquests
Wind velocity (surface, upper)	- insurance claims, structural damage - voices, gunshots heard downwind - movement of smoke, odours pollution	- civil - criminal - environment offences
Visibility (restrictions to vision such as fog, snow)	- identification of suspects white-outs	- criminal accidents
Precipitation	heavy snowfalls (roof collapse) - heavy rain, flooding - wet roads - footprints, wet soil - slippery sidewalks	- civil - civil - accidents - criminal slip/fall - civil
Cloud cover	lighting levels identification (full moon)	criminal
Snow on ground	- footprints - frost penetration	criminal - civil
Dewpoint, relative humidity	dew formation, wet shoes	- criminal
Humidex	discomfort levels	- labour boards

The past few years have again held their share of fascinating "front-page" trials in which climatology has contributed a piece towards the solution of a legal puzzle. Following are two actual cases in which the Ontario Climate Centre has been deeply involved.

1. Inquest of Erica Daigler, September 1986, Toronto

On August 15, 1986, an archway fell at the Canadian National Exhibition grounds, fatally injuring a young New York State girl. At the subsequent inquest, a climatologist was called to testify as to the nature of the winds on that afternoon. Following a study of the CNE terrain and the associated weather conditions, he was able to state clearly that the highest gale-force winds related to the thunderstorms of that August afternoon did not occur until after the sign/archway fell. As a result, the conclusion was that lesser winds had blown the archway down, and negligence was assigned in the inadequate archway construction. Although this was an inquest, the results were crucial as the opportunity for civil liability action was now clearly open to the girl's family. Media coverage included both Canadian and American TV stations, in one of the highest-profile inquests in which the Climate Centre has ever been involved.

2. First-degree Murder, December 1986, Simcoe, Ontario

The victim died as a result of a fire in his cottage on a farm near Simcoe. The prosecution contended that the victim was involved in an extra-marital relationship with one of the female farm workers, and that his wife had set fire to the cottage in revenge. The charge against the wife was murder. The defence's position was that a thunderstorm on the night in question had produced a lightning strike that ignited the building. At the trial, the climatologist showed conclusive evidence that no thunderstorm activity existed in the area on the night in question, much to the surprise of the defence lawyer who had not counted on expert testimony to refute his client's sworn defence.

Accordingly, these two examples illustrate some of the important applications of climate data in a forensic setting. However, in order to keep the true nature of forensic climatology in perspective, note that for every high-profile case there are perhaps 20 less dramatic cases. Included in this latter category are civil law suits involving disputed insurance claims, contractual disputes, slip and falls, and offences under the *Highway Traffic Act*.

In the United States, the forensic climatologist tends to be in business for himself. The National Oceanic and Atmospheric Administration, the American equivalent of Canada's Atmospheric Environment Service, has basically assumed the role in forensic matters as a provider of certified documents, referring all demands for court appearances (unless the federal government is involved) to the private sector. A look through the American Meteorological Society Bulletin shows advertisements for numerous private firms eager to sell their climatological expertise. In Canada, the forensic climatologist is most likely a public servant. However, given the current governmental interest in promoting private enterprise, a greater move towards encouraging a viable private sector expertise could be realized in Canada as well. In this regard, the Ontario Climate Centre as part of the Scientific Services Division, Environment Canada is considering a workshop in forensic climatology in the coming year. Perhaps the Climate Centre could remain the main provider of climatological data, while the private sector could assume an expanded role providing consultation and expert court opinion.

The field of forensic climatology is an expanding one. Without benefit of any formal advertising, the Ontario Climate Centre contends with a very demanding workload. Clearly there is a market for more forensic service, and an opportunity exists for those interested in this fascinating blend of science and law.

NOTE: Special thanks are due to Mr David Murdoch for his advice regarding this article. Further information can be obtained from the author, at the Ontario Climate Centre, Room 301, 25 St. Clair Avenue East, Toronto, Ontario, M4T 1M2.

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