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# An Effect of Finite Differences on the Estimation of Predictability

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[Manuscript received 2 October 1972]

ABSTRACT
It is shown that the use of finite differences tends to underestimate the growth of small errors, but that the underestimation is not serious provided the resolution is sufficient.

## 1 Introduction

Recently, Lorenz (1972) discussed the instability of Rossby wave motion with reference to the doubling time of small errors. He found that under certain conditions the doubling time was about 33 hours. Further he stated that since this doubling time was about half that obtained by Smagorinsky (1969) that one might conclude that numerical methods tend to underestimate the growth rate. It is the purpose of this paper to show that this is indeed the case, but the underestimation is not significant as long as we have sufficient resolution.

## 2 The equations

The basic approach is the following. We imagine that we treat exactly the same problem as Lorenz, but that we do it using finite differences. Further we suppose that since we are interested in the stability of the Rossby wave, that the basic equation we will integrate is that given by Lorenz as equation (5), namely

$$\frac{\partial \zeta'}{\partial t} = -\left[\frac{\beta}{k_0^2}\frac{\partial}{\partial x} + k_0 A \cos(k_0 x)\frac{\partial}{\partial y}\right](\zeta' + k_0^2 \psi') \tag{1}$$

where $\psi'$ is the perturbation stream function, $\zeta'$ is the perturbation vorticity, $\beta$ is the Rossby parameter, $k_0$ the wave number of the basic Rossby wave whose amplitude is $A$, and $x$ is a coordinate which moves with the Rossby wave at a speed

$$c = U - \beta/k_0^2. \tag{2}$$

Lorenz eventually solves this equation (1) for a disturbance of zonal wave number 6; i.e., $N = 6$. To solve this equation using finite differences we shall define a set of grid points $x_p$ such that

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$$x_p = pd, \quad p = 1, 2, \ldots P \tag{3}$$

where $Pd = 2\pi/N$. We suppose that we have the same grid length in the north-south ($y$) direction, and further, we specify that the flow is doubly periodic in $x$ and $y$ of period $2\pi D$, so that for the basic flow to satisfy the same condition, $k_0 D = N$.

If we now suppose that $P = 2K + 1$, then it follows we can express the values of $\psi_p'$ as a trigonometric polynomial

$$\psi_p'(y, t) = \psi'(x_p, y, t) = \sum_{|k| \leq K} A_k(y, t)\, e^{ikpd(N/D)} \tag{4}$$

where $k = 0, \pm 1, \pm 2, \ldots \pm K$. By assuming the form (4) we are in effect neglecting any possible solutions of (1) which have longer $x$ wavelengths than $2\pi D/N$, as did Lorenz.

We further define the finite-difference operators $L_1$ and $L_2$ as

$$L_1 = \left\{ (\ )_{p+1} - (\ )_{p-1} \right\} \frac{1}{2d}, \tag{5}$$

$$L_2 = \left\{ (\ )_{p+1} + (\ )_{p-1} - 2(\ )_p \right\} \frac{1}{d^2}. \tag{6}$$

Operator $L_2$ approximates $\partial^2/\partial x^2$ and $\partial^2/\partial y^2$, while $L_1$ approximates $\partial/\partial x$ and $\partial/\partial y$, depending on which direction we take the differences.

Following Lorenz, we choose to measure variables such that $k_0 = 1$ and $A = 1$. Thus equation (1) becomes

$$\frac{\partial \zeta'}{\partial t} = -\left(\beta \frac{\partial}{\partial x} + \cos x \frac{\partial}{\partial y}\right)(\zeta' + \psi') \tag{7}$$

whose finite-difference version is

$$\frac{\partial}{\partial t}(L_2^x + L_2^y)\psi' = -(\beta L_1^x + \cos x L_1^y)(L_2^x + L_2^y + 1)\psi', \tag{8}$$

where superscripts $x$ or $y$ on the operators indicate that they are to be applied in the $x$ or $y$ directions, respectively. Since $k_0 = 1$, it follows that $D = N$ in these units, and thus if we consider the simplest possible modal solutions of (8) we have

$$\psi_p'(y, t) = \sum_{|k| \leq K} X_k\, e^{ikpd}\, e^{i(ly + \lambda t)} \tag{9}$$

where $l$ will be treated as a parameter, and $\lambda$ is the eigenvalue of the system (8). In view of the required periodicity the possible values of $l$ are multiples of $1/N$.

If we now substitute the expression (9) into equation (8) and denote the response functions of operators $L_1$ and $L_2$ by $R_1$ and $R_2$, respectively, we obtain a set of $2K + 1$ homogeneous algebraic equations to solve, namely

$$lR_1(l)a_k^* Y_{k-1} + 2(\beta k a_k^* R_1(k) + \lambda) Y_k + lR_1(l) a_k^* Y_{k+1} = 0 \tag{10}$$

for $k = -K$ to $+K$, and with $Y_{-K-1} = Y_{K+1} = 0$. In the above expressions we have defined

$$a_k^* = \frac{k^2R_2(k) + l^2R_2(l) - 1}{k^2R_2(k) + l^2R_2(l)} \tag{11}$$

$$Y_k = (1 - k^2R_2(k) - l^2R_2(l))X_k, \tag{12}$$

while the response functions are defined as follows

$$R_1(s) = \sin 2\theta/2\theta, \quad R_2(s) = (\sin \theta/\theta)^2, \tag{13}$$

where $\theta = sd/2$. We note that as $d \to 0$, the response functions approach 1, and thus equation (10) is identical to that obtained by Lorenz.

## 3 Parameters, grid lengths and results

We solve the eigenvalue problem (13) in the same manner as Lorenz using the same parameter values; that is, we choose $N = 6$, and a value of (dimensional) $A$ which corresponds to an rms northward velocity of 12 m $s^{-1}$. In this case the space and time scales are approximately 750 km and 12 h, respectively. We choose to compare the finite-difference results to the most rapidly growing mode considered by Lorenz, that is, for $l = 2/3$. In equation (13), the $K$th approximation corresponds to having $2K + 1$ grid points in the fundamental domain $x = 0$ to $2\pi D/N$ and thus the grid length corresponds to $2\pi D/N(2K+1)$. The first approximation will then have a grid length of approximately 1600 km, the second, about 1000 km, and the $K$th, approximately $4800/(2K+1)$ km.

TABLE 1 Eigenvalues $|\lambda|$ for successively higher approximations for both second-order finite-difference method and spectral method. The $K$th approximation has $2K + 1$ grid points per fundamental wavelength and $2K + 1$ spectral components.

| $K$ | $\lvert\lambda\rvert_{GRID}$ | % Difference | $\lvert\lambda\rvert_{SPECTRAL}$ | % Difference |
|---|---|---|---|---|
| 1 | 0.101602 | 61.1 | 0.248599 | 4.8 |
| 2 | 0.209554 | 23.2 | 0.261118 | 0.3 |
| 3 | 0.232910 | 10.8 | 0.261072 | 0.1 |
| 4 | 0.246852 | 5.4 | 0.261050 | 0.0 |
| 5 | 0.252819 | 3.2 | 0.261049 | 0.0 |
| 6 | 0.255695 | 2.1 | 0.261049 | 0.0 |
| 7 | 0.257264 | 1.5 | 0.261049 | 0.0 |
| 8 | 0.258212 | 1.1 | 0.261049 | 0.0 |
| 9 | 0.258835 | 0.9 | 0.261049 | 0.0 |
| 10 | 0.259268 | 0.7 | 0.261049 | 0.0 |

In Table 1 we present the eigenvalues for successive approximations, and their percentage differences from the true eigenvalue which is $|\lambda| = 0.261049$ to six decimals. The column labelled $|\lambda|_{SPECTRAL}$ corresponds to the eigenvalue obtained if we use the spectral method of integration. We note that the grid-point method underestimates the growth rates, but that if we have more than 9 grid points per wavelength, the underestimation is less than 5 percent. On the other hand, this particular mode has the majority of its variance in a zonal flow, which will have a minimum truncation error. Since most of the variance is concentrated in one component, the spectral method converges extremely rapidly, whereas we notice the grid-point method converges relatively slowly.

### 4 Final remarks

By a simple analysis we have shown that the grid-point method underestimates the growth rates in the case of the instability of Rossby wave motion. We have further shown that in this particular case the underestimate is not serious as long as we have more than 9 grid points per fundamental wavelength.

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## BOOK REVIEW

CLIMATE: PRESENT, PAST AND FUTURE. Vol. 1. *Fundamentals and Climate Now*. By H. H. Lamb. Methuen and Co. Ltd., London, 1972, 613 pp., $39.90.

Perhaps the most fitting word to describe this book is pragmatic. The nature of the material presented is of the variety most useful in fields of study related to the topic of climatic change. Climatologists are always being asked questions with regard to the meteorological possibility, or otherwise, of specific events. This book provides one of the few sources of material with practical application from which answers can be given. When the Palynologist asks whether southwest winds would have been prevalent at point $X$, at a date $Y$ years ago, it is all very well to quote advances in quantitative theories of climate but, despite their elegance their practicality has yet to be proven. It is in this sense that the reviewer sees the volume as pragmatic.

The book covers almost every sub-branch of climatology. Chapter one provides the reader with a glossary of useful meteorological terms; but the book really begins with the second chapter which is a good statement of physical climatology well oriented to the topic of climatic change. Chapter three presents a clear picture of dynamic climatology and ends with a useful summary of major climatic features resulting from the dynamic factors. There follows a straightforward account of mainly observational material on seasonal changes, and the major features of the general circulation are related to the principal controlling factors. Consideration is given to the seasonal shifts of long planetary waves and circulation patterns and the resulting effects at the surface. Chapter five, on the stratosphere, sets out with good intent but is hampered by the lack of observational and theoretical material on the subject. An interesting and well balanced account of quasi-periodic and cyclic phenomena is then presented, and the review of knowledge on the southern

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# The Relation Between the North Pacific Sea Surface Temperature Anomaly During the Sixties and Hail Damage in Alberta

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ABSTRACT
Coincident with anomalously warm sea surface temperature in the North Pacific during the period 1962–67 was a period of low hail damage in the Province of Alberta. Investigation of thirty-three years of hail insurance records reveals a reduction in hail damage during this period. Analysis of monthly mean upper air data indicates a significant change in the summer upper air circulation over Alberta. The mean jet stream is found to be farther south and much stronger than for the period 1950–61. Some evidence is found to support the claim that the hail damage shifted southward with the jet stream.

## 1 Introduction

In the past decade, considerable attention has been focussed on teleconnection, the effect of large-scale air-sea interactions on the climate of distant areas. Drought in the northeastern United States during the period 1962–65 was accounted for by Namias (1966). The reason proposed was the interaction of anomalously cold water along the Continental Shelf with the overlying atmosphere. Bjerknes (1969) established a connection between equatorial sea-surface temperature in the central Pacific Ocean and the strength of the extra-tropical westerlies. The problem of teleconnection was attacked from a longitudinal point of view by Namias (1969). He showed that the anomalously warm sea surface temperature regime that existed over one-third to one-half of the North Pacific Ocean from the fall of 1961 to the winter of 1967–68 led to more severe winters over the eastern two-thirds of the United States. The present study examines the relation between the sea surface temperature anomaly documented by Namias and hail damage in Alberta which occurred during the same period of time.

## 2 The anomalous regime

### a *Initiation*

Namias showed that in the fall of 1961 an anomalously strong North Pacific high pressure system developed, centred near 135°W and 35°N. Departures from normal sea level pressure were in excess of two standard deviations. This

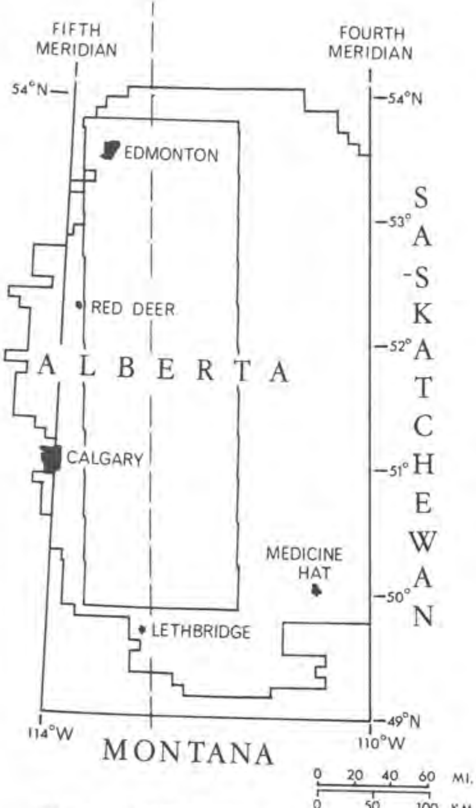


Fig. 1 Analysis areas used in the study.

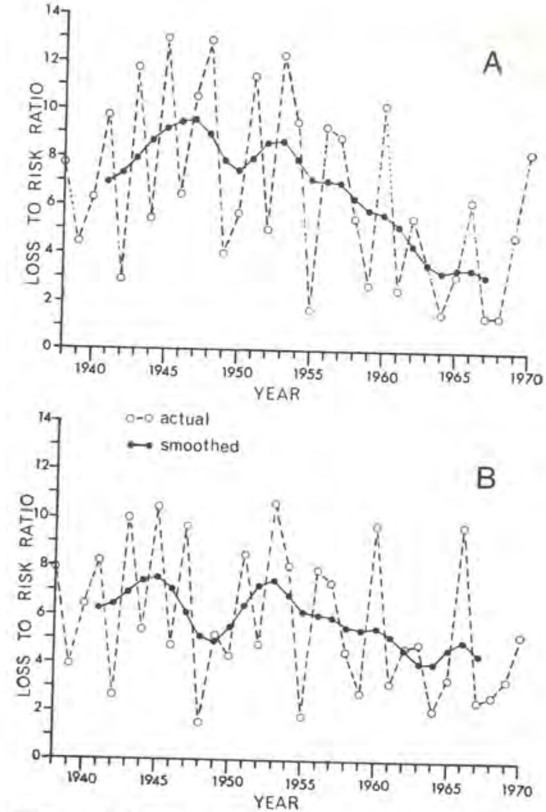


Fig. 2 Variation of loss-to-risk ratio for the period 1938–70 for the small area (A) and the large area (B). Circles represent actual annual loss-to-risk ratios, and dots the smoothed values.

pressure system was responsible for the warming of the North Pacific sea surface as a result of three co-operating factors:

1) the location and intensity of the high were favourable for Ekman layer advection[1] of warm water from the south;

2) persistent warm and moist air advection from the south prevented normal seasonal cooling by loss of heat from the water to the overlying airmasses;

3) the lack of cyclonic activity resulted in considerably less wind stirring of the surface layers of the ocean than normal, allowing this stable regime of warm water over cold to build.

The development of the anomalously high pressure system is attributed by Namias to the development of a very extensive pool of cold water over the east-central Pacific during the winter of 1960–61. The cold pool persisted through the summer of 1961 and caused low level cooling of the airmasses in the fall of 1961. The resulting vertical stabilization of the atmosphere allowed the formation of a high strong enough to dominate over the Aleutian low, causing the latter to be displaced northward.

**b** *Magnitude of the Anomaly*

Averaged over the period 1961–67, the sea surface temperature anomaly had a maximum value slightly in excess of two Fahrenheit degrees (1.1°C) near 35°N and 165°W. For the summers of this period, the highest average anomaly was not as marked, but had a value slightly in excess of 1.5 Fahrenheit degrees (0.83°C.). The size of the anomaly hardly seems significant, but when one considers its areal extent (one-third to one-half of the North Pacific Ocean), it represents a very large additional input of energy into the "atmospheric engine."

## 3 Hail insurance data

Thirty-three years of hail insurance records were used to examine whether there exists a relation between the sea-surface temperature anomaly and hail damage in Alberta. The hail insurance data are organized by townships, each six miles square and numbered northward from the forty-ninth parallel, with its range numbered westward from a designated meridian.

In the jargon of the insurance business, the *risk* is the amount for which an item is insured, and the *loss* is the amount paid out as a result of a claim. The *loss-to-risk* ratio is used as an index of the severity of the hail damage in any given year. Quoting the *loss-to-risk* ratio in per cent is common practice, and will be followed in this study. The hail insurance data were obtained from the Alberta Hail & Crop Insurance Corporation, and were checked for accuracy by Alberta Hail Studies staff.

After examination of the completeness of the insurance coverage, two areas for analysis were chosen, as shown in Fig. 1. The first is the quasi-rectangular

[1]In the Northern Hemisphere, wind stresses on the surface of the ocean set up a mean transport at right angles to the wind direction (von Arx, 1962). Therefore, the circulation to the south and west of the high resulted in the northward transport of warm surface water.

area bounded by the southern and northern edges of townships eleven and forty-five (in the south and north), respectively, and by the eastern and western edges of ranges 13 and 26 (in the east and west), respectively. This area, which will be designated as A, the small area, covers 58,040 km$^2$. The second and larger area, B, outlined by the irregular heavy line, will be designated as the large area, and covers approximately 133,000 km$^2$.

The western boundary of B demarcates (for all intents and purposes) the western extremity of the cultivated land in southern Alberta. To the west of this boundary are forested areas and the foothills of the Rockies. In an attempt to use as much of the hail insurance data as possible, some areas with very little or no insurance coverage were included in B. For example, B includes the dry lands in the vicinity of Hanna and the Suffield Defence Research Establishment (both north-northwest of Medicine Hat).

## 4 Time series analysis of hail insurance data

Attempts to determine trends in hail damage by examining the loss-to-risk ratios for small areas were not very successful. To obtain an overall view, the losses and risks for the individual townships were summed separately for each year for both analysis areas. From these totals, the average annual loss-to-risk ratios were obtained. The resulting time series are shown in Fig. 2.

One would expect the plot of loss-to-risk ratio versus time to exhibit a fair degree of randomness. However, the plots for both areas of analysis show a periodicity of close to four years. No explanation has been found for this result.

Because of the very large variation in the average loss-to-risk ratio, the time series was smoothed using the seven-point approximation to a Gaussian filter given by Holloway's formula 5.1 (1958):

$$\bar{r}_t = 0.016\, r_{t-3} + 0.094\, r_{t-2} + 0.234\, r_{t-1} + 0.312\, r_t + 0.234\, r_{t+1} + 0.094\, r_{t+2} + 0.016\, r_{t+3}$$

where

$r_t$ = loss-to-risk ratio at time $t$,
$\bar{r}_t$ = smoothed loss-to-risk ratio at time $t$.

The smoothed time series for each area shows a maximum centred at about 1945, followed by a minimum in 1949. The loss-to-risk ratios increased again to a maximum in 1953, followed by a slow decrease. In the Sixties, the decrease becomes more marked. In fact, the smoothed series reach their lowest points at this time.

The anomalous sea surface temperature regime lasted from the fall of 1961 to the winter of 1967–68. From the point of view of hail production, the anomalous period was therefore from the summer of 1962 to the summer of 1967. Listed in Table 1 are the mean loss-to-risk ratios for both areas for six-year periods beginning in1938. The reduction is seen to be a unique event in the period 1938–67. Since 1967, the loss-to-risk ratios have increased.

TABLE 1. Comparison of loss-to-risk ratios (in %) for six-year periods beginning in 1938.

| Period | Area B | Area A |
|---|---|---|
| 1938–43 | 6.52 | 7.10 |
| 1944–49 | 6.14 | 6.78 |
| 1950–55 | 6.34 | 7.60 |
| 1956–61 | 5.92 | 6.53 |
| 1962–67 | 4.55 | 3.59 |

A long-term downward trend in the loss-to-risk ratios can be seen as well. The change toward larger, more economically viable farms may be responsible for this trend. The resultant increased insurance coverage into areas less susceptible to hail damage may account for the gradual reduction in the loss-to-risk ratios in the two analysis areas. Summers (1966) mentions other possible causes. Changes to crops more resistant to hail damage may be responsible for the decrease. Long-term climatic changes may have occurred as a result of a change in the large-scale weather patterns in western Canada, or the changes brought about by man's increased interference in nature by farming, forestry, mining and manufacturing. The amount of risk written possibly could influence the loss-to-risk ratio as well.

Even if this long-term trend is removed, it can still be stated that, at the time of the anomalous sea surface temperature regime, a marked reduction in hail damage in Alberta occurred. Significance testing of the data is not possible because the condition that the distribution of loss-to-risk ratios be normal is not met.

## 5 Shift in hail damage

To determine whether any latitudinal shift in hail damage occurred during the anomalous period, the large analysis area was divided into six latitudinal strips, each nine townships wide. For each strip, the annual loss-to-risk ratio was determined. The time series obtained were smoothed, using the Gaussian filter. The resulting series are shown in Fig. 3, plotted on a common time axis. From the point of view of teleconnection, the most significant feature is the high loss-to-risk ratios for townships 4 to 12. This strip is the only one for which the loss-to-risk ratio is above normal for the period 1962–67, suggesting that a southward shift in hail damage occurred. Confirmation of this shift would require examination of the hail insurance records for Montana.

## 6 Objective analysis of the summer upper air circulation over Alberta

To examine the relation between hail damage and the mean upper wind fields, analyses of monthly mean data for the 700-, 500-, 400-, 300- and 200-mb levels for the years 1950 to 1970, inclusive, were performed using an objective technique. The analyses were performed on an $8 \times 9$ grid (eight columns, nine rows), shown in Fig. 4, which has the 381-km grid length used at the National

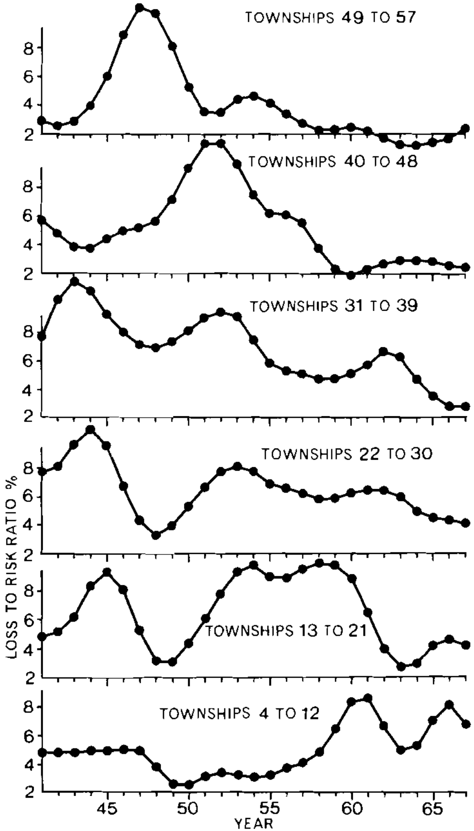


Fig. 3 Smoothed time series of loss-to-risk ratios for six strips, each nine townships wide, in the large analysis area.

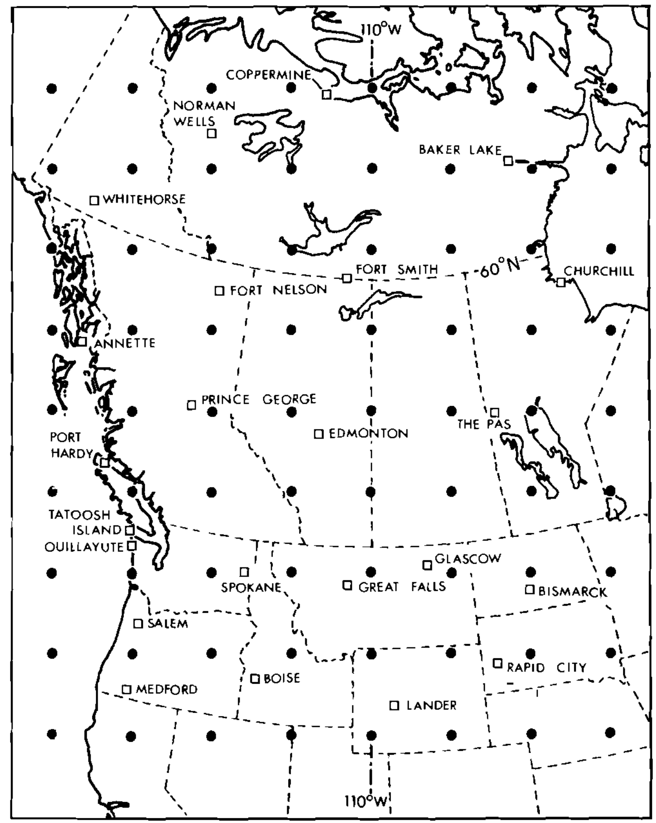


Fig. 4 The objective analysis grid (dots) and the upper air stations (squares) used in the analysis.

Meterological Center of the United States (referred to henceforth as NMC). The grid is oriented parallel to 110°W instead of 80°W for the standard NMC grid.

Summers and Paul (1967) showed that the bulk of the hail insurance claims are made for storms occurring in July and August, and therefore the objective analyses were performed for those two months only.

The analysis method used is basically that described by Cressman (1959) and used by NMC. The program used was that of Linton *et al.* (1971), which is essentially a revised and improved version of the Glahn and Hollenbach (1959) program. Results of the objective analysis were compared with basic analyses and with maps published in the *National Summary of Climatological Data* of the United States. The comparisons indicated that the objective analysis produced a very good height field in the area of interest.

Prior to 1956 in the United States, and 1959 in Canada, monthly vector mean winds were not available. Therefore, the effect of missing wind data was tested. After performing an analysis on data which included vector mean wind speed and direction, the wind data were removed and the analysis was repeated. The two results were in good agreement. The removal of wind data resulted in an average decrease in height of 2.5 gpm over Alberta, and the gradients and their directions differed by no more than six gpm per grid interval and eight degrees, respectively.

## 7 Analysis of the circulation

Columns four and five of the 8 × 9 output height field were used to calculate the geostrophic wind components at grid centres for the five levels analyzed, using the following finite-difference equations:

$$u_i = -\frac{gm}{fd}(z_{i,j} - z_{i+1,j} + z_{i,j+1} - z_{i+1,j+1})$$
$$v_i = \frac{gm}{fd}(z_{i,j+1} - z_{i,j} + z_{i+1,j+1} - z_{i+1,j}) \qquad (1)$$

where

$u_i$ = the eastward wind component
$v_i$ = the northward wind component
$z_{i,j}$ = the geopotential height at grid point $i, j$
$f$ = the Coriolis parameter
$g$ = the acceleration due to gravity
$d$ = the grid interval (381 km)
$m$ = $1.866/(1 + \sin \phi)$ is the map factor for a polar stereographic projection, secant at 60°N
$\phi$ = the latitude.

The geostrophic winds at grid centres were then obtained, using:

$$V_i = (u_i^2 + v_i^2)^{\frac{1}{2}}$$
$$\theta_i = 270 - \arctan(u_i/v_i) \qquad (2)$$

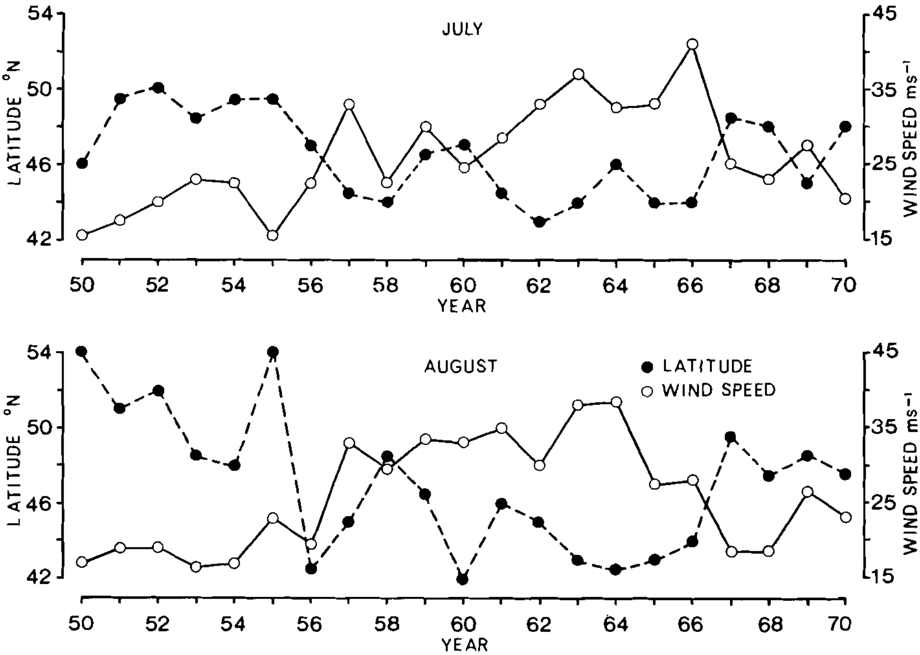


Fig. 5 Strengths and positions of the monthly mean jet maxima for July and August for the years 1950–70.

where

$$V_i = \text{the wind speed}$$
$$\theta_i = \text{the wind direction (deg).}$$

These winds were used to construct monthly mean cross-sections one-half grid interval west of 110°W, approximately through the middle of both analysis areas. The 381-km grid interval introduces some smoothing to the wind field. The actual vector mean winds at the southern stations are higher than the computed mean winds. However, the method used allows us to compare winds over a longer time span, as upper-air winds were not routinely observed prior to 1959 in most of the area analyzed.

Isotachs and isogons were drawn by hand, and the monthly mean jet maxima and positions were estimated to the nearest metre per second and half degree latitude, respectively. The results, plotted in Fig. 5, show that on the average, for the period 1962–67, the jet maxima were stronger and displaced southward.

The extent of the change in the circulation over Alberta during the anomalous period is shown in the averaged cross-sections, Figs. 6 a, b, c and d, which were constructed using the vector mean winds at each grid centre for the periods 1950–61 and 1962–67. The average increase in the jet maximum for the period 1962–67 was approximately 11 m $s^{-1}$ for July, and 7 m $s^{-1}$ for August, and the southward shift for both months was at least one grid length. A more

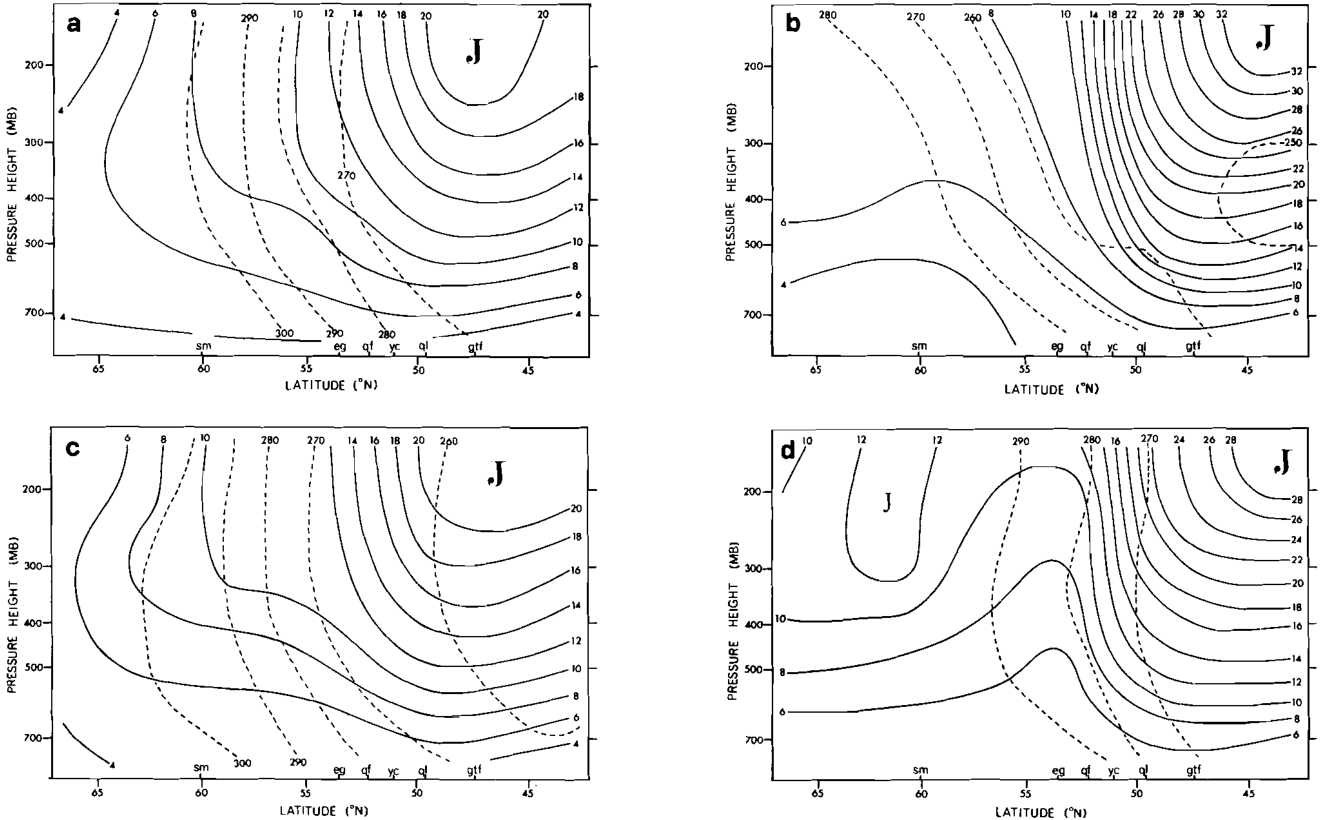


Fig. 6 Averaged cross-sections for: (a) July 1950–61, (b) July 1962–67, (c) August 1950–61, (d) August 1962–67. Solid lines are isotachs (m $s^{-1}$) and dashed lines are isogons (deg true). Location identifiers: *sm* Fort Smith, N.W.T., *eg* Edmonton, *qf* Penhold, *yc* Calgary, *ql* Lethbridge, *gtf* Great Falls, Mont.

precise estimate of the southward shift is not possible as the cross-sections do not extend south far enough. The jet-stream structure during the anomalous period is also characterized by much stronger horizontal wind shears on the north side of the jet. After 1967 the upper wind structure reverted to a pattern more like that prior to 1962.

## 8 Questions concerning the anomalous sea surface temperature regime

Fig. 5 shows that quite a strong monthly mean jet occurred as early as 1957, and that as far as the strength of the mean jet is concerned, the anomalous regime appears to be well established by 1959. The southward displacement is not completely established until 1962. This leads to the question as to which was responsible for the anomalous sea surface temperature regime:

the formation of the cold pool in the east-central Pacific, which eventually led to the formation of the very strong high in the fall of 1961, or

the upper air circulation responding to influences elsewhere and resulting in the production of the cold pool.

It does not seem logical that the cold pool would lead to the same atmospheric response as the warm pool, i.e., an increase in the strength of the summer upper air circulation. Namias (1969) admits that questions such as these are usually unanswerable, and that his evidence for the claim that the anomalous regime was initiated in the fall of 1961 is circumstantial.

In view of the fact that time constants for oceanic changes are very large compared with time constants for atmospheric changes, it seems reasonable to conclude that the anomalous sea surface temperature regime of the Sixties may have occurred in response to atmospheric changes beginning as early as 1957.

The July and August monthly mean jet structures for 1967 were considerably weaker than for the previous five years. Again the atmospheric circulation changed before the sea surface temperature regime did. If a more satisfactory mechanism for the initiation of the anomalous regime is proposed in the future, it seems likely that the role of the atmospheric circulation will be emphasized.

## 9 Conclusions

Concurrent with the North Pacific sea surface temperature anomaly from the fall of 1961 to the winter of 1967–68 was a marked reduction in hail damage in Alberta for the summers of 1962 through 1967. Neglecting any effects which have not been considered, this suggests that either the sea surface temperature anomaly was responsible for the reduction, or that the mechanism responsible for the anomaly also caused the reduction in hail damage.

The effect on the summer upper-air circulation over Alberta was a southward shift of at least one grid interval (381 km) and a marked intensification of the jet maximum. Some evidence was found to support the hypothesis that the hail damage moved southward with the jet maximum.

**Acknowledgements**

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*Book Review continued from page 40*

oscillation is most useful. In chapter seven there is a detailed discussion of anomalous patterns in the general circulation. The subject matter here is possibly of more interest to researchers in one geographical area, than to the general reader. There follows a brief account of the principles of oceanography that even the most critical reviewer must welcome since this important subject is so often totally omitted from climatological texts. The discussion of climatically sensitive points in the ocean is particularly interesting, although one would have hoped for more detail on the question of long-term variation of sea level. Details on the hydrologic cycle are then given and, although not always directly related to climatic change, are necessary in a work of this kind. Finally, some observed causes of climatic variation are treated. In this final section we have: 1) detailed consideration given to the complexities of ocean-atmosphere interactions on different, relatively short, time scales; 2) a valuable summary of Professor Lamb's comprehensive and important work on volcanic activity and climatic change; and 3) a review of the development of theories of the relation of sunspots and other solar disturbances to changes of climate.

Overall, the book is easy to read and provides an extremely valuable source of relevant information in the increasingly important field of climatic change. It is hoped that we do not have to wait too long for the companion volume.

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# Seasonal and Annual Precipitation Efficiency in Canada

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[Manuscript received in final form 27 March 1973]

ABSTRACT
Precipitation efficiency is the percentage of the total water vapor over an area that falls to the surface as measurable precipitation on an average day. This variable focuses attention on the dynamic mechanisms that produce different precipitation patterns in different areas. The concept of precipitation efficiency is discussed and its seasonal and annual values are mapped for several Canadian stations. Maximum seasonal values occur in winter for all of the country. National highs are found on the West Coast and along the St. Lawrence Lowland, a result of the cyclonic activity in these regions.

## 1 Introduction

The quantity of precipitation received by a station is controlled by three factors: 1) the amount of available water vapor in the air; 2) the initial degree of saturation represented by this vapor; and 3) the presence of dynamic mechanisms which provide the cooling necessary to produce saturation and cause the water vapor to condense and form droplets large enough to fall to the earth's surface. These three variables have been listed as important considerations in forecasting the quantity and location of precipitation as well as areas of large-scale overcast (Jenrette 1961; Ferguson, 1962).

Precipitable water vapor is a measure of the total water vapor content of the air. It is the depth of liquid that would result if all the vapor above a particular point were condensed into a layer on the surface. Expressed as a depth this measure of atmospheric moisture may be readily compared with measured amounts of precipitation. Precipitable water vapor, like other measures of humidity, is controlled primarily by air temperature, elevation and effective distance from sources of evaporative moisture. The amount of available water vapor sets an upper limit on the amount of possible precipitation. Latent heat of condensation is a prime source of energy for storms and the amount of water vapor in the air provides one measure of the energy available for their development or maintenance.

Although it has been used to help determine the maximum possible amount of precipitation in an area, in most cases total precipitable water vapor is only poorly correlated with actual recorded precipitation (e.g., Semonin, 1960). Bruce (1964) in a study of this relationship for the Canadian Prairies found a significant relationship only during the summer season. The limits on which a column of air can rise means that all the precipitable water above a station could never be precipitated. For periods greater than a few hours the continual flow of moisture into an area can support rainfall totals exceeding the amount of moisture above the area at any given time. For regions of similar elevation and exposure to advected moisture precipitable water vapor is a rather stable property over wide areas when averaged over any one season (see for example: Reitan, 1960b, Bruce, 1964, pp. 139–141; Hay, 1970). Precipitation, however, is highly variable. Most regional differences in precipitation are caused by variations in the initial degree of saturation of the air mass and the vertical motions needed to transform water vapor into measurable precipitation. Jenrette (1961) presented a method of forecasting large-scale areas of cloud formation and precipitation based on these two parameters. Bruce (1964) suggests that the efficiency of storm mechanisms in the fall, winter and spring are largely independent of atmospheric water vapor content leading to poor correlations between precipitable water and recorded precipitation over the Prairies. Dynamic mechanisms that initiate precipitation can vary widely in scale, from a large cyclone to a small convective storm. On a national scale they often appear to be strongly localized such as the orographic effects along the Coast Range or the preferred route of cyclonic storms along the St. Lawrence. The distribution of precipitable water vapor is much more uniform.

In summary, the precipitation received by a station is the result of a combination of factors. The quantity of available moisture is the enabling factor, dynamic mechanisms provide the causal process, and the degree of saturation controls how active these mechanisms must be to be effective.

## 2 Precipitation efficiency

Precipitation efficiency is the measure of the effectiveness of dynamic mechanisms in releasing the moisture in the air. It is defined as the percentage of the average precipitable water vapor that is released and falls to the surface as measurable precipitation on an average day:

$$P_{eff}\,(\%) = \frac{\text{average precipitation per day}}{\text{average precipitable water vapor}} \times 100.$$

Precipitation efficiency is usually averaged over a monthly or annual time period. Maps of this parameter reveal the areal patterns of the effects caused by dynamic mechanisms and degree of saturation on the recorded precipitation. Monthly and annual maps of precipitable water vapor for Canada have been published by Hay (1971) and Tuller (1972). Figs. 1–3 show the winter, summer and annual mean patterns determined by Tuller from upper air sounding data for a ten-year period.

Saturated precipitable water shows a distribution pattern very similar to that of actual precipitable water vapor. The precipitable water relative humidity (W.R.H., degree of saturation of the total depth of the atmosphere involved in precipitation processes) showed only a small variation over the country for any one month when available upper-air data were used. This is especially truc

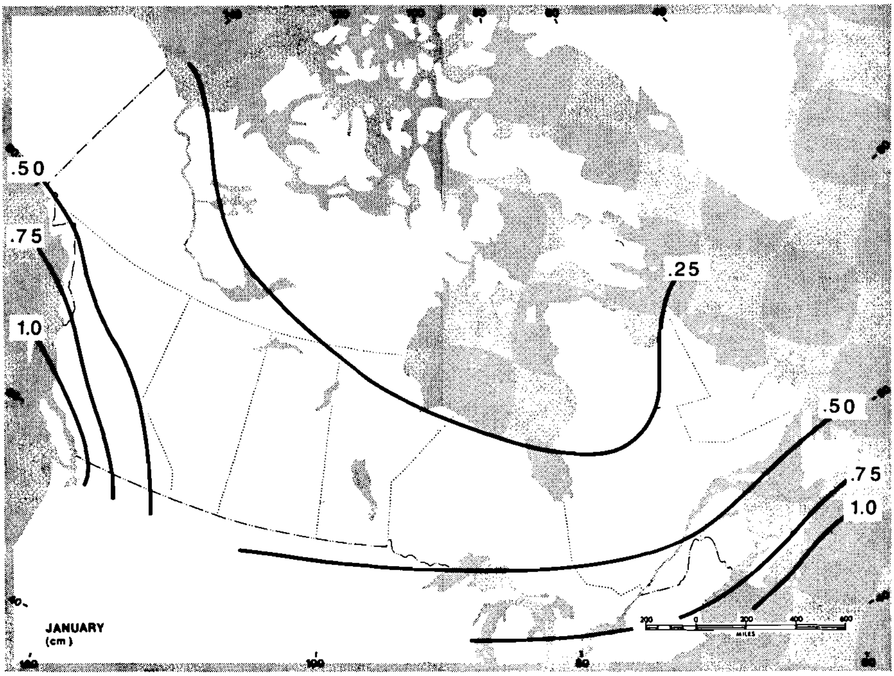

Fig. 1 Mean precipitable water vapor (cm) over Canada, January.

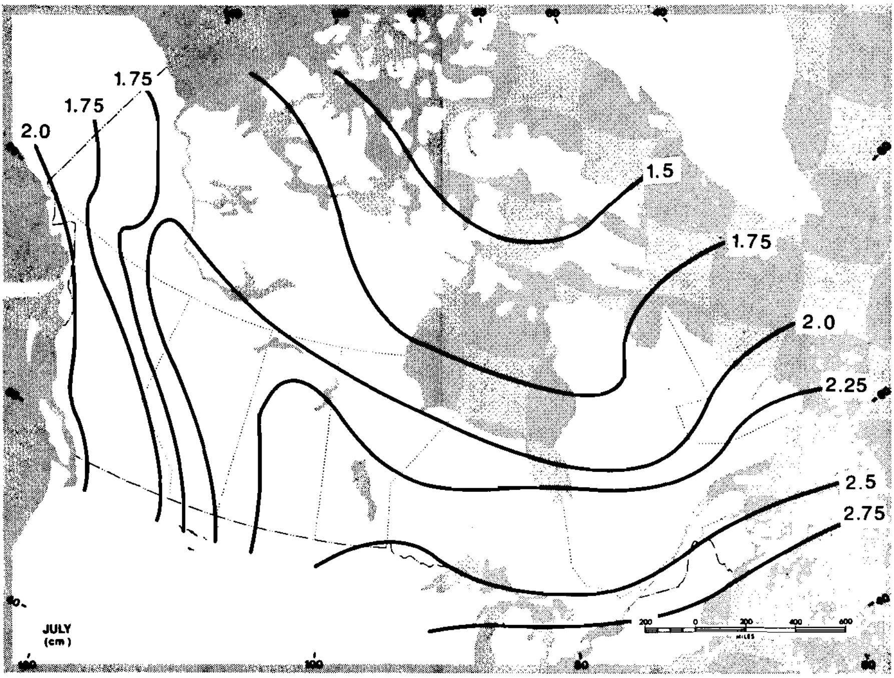

Fig. 2 Mean precipitable water vapor (cm) over Canada, July.

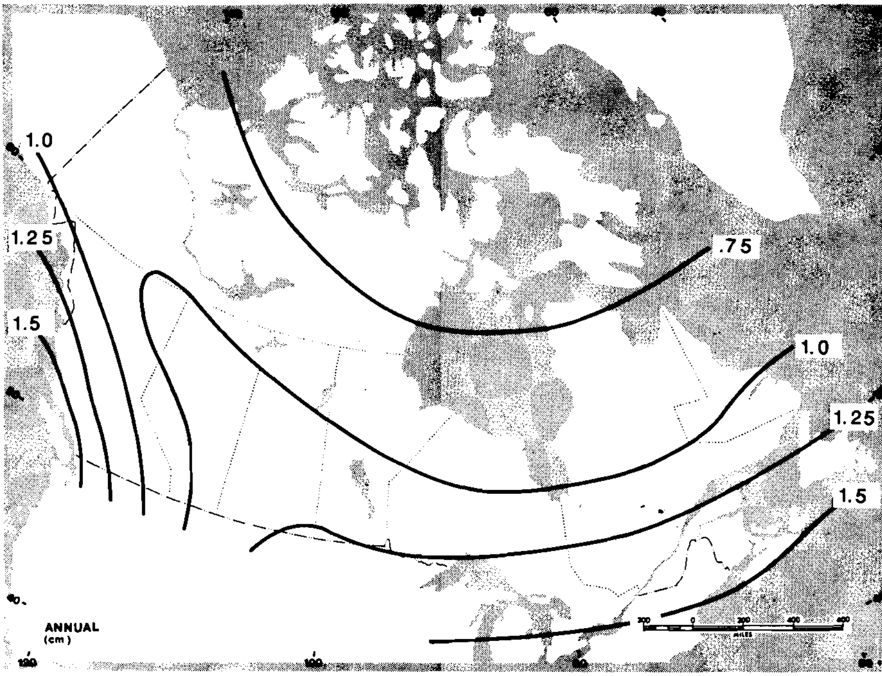


Fig. 3 Mean precipitable water vapor (cm) over Canada, Annual.

of the winter season (January) when values for 20 stations ranged from 59% to 67% and had an average of 63%. The spring and fall seasons had the greatest variations, the range reaching 15%. Some regional variations were seen, however, and these will be discussed here briefly to present the basis for the later discussion of precipitation efficiency. The yearly patterns of W.R.H. for four stations, representative of different regions of the country, are shown in Fig. 4.

Most stations in Canada have a minimum W.R.H. in the spring with the exception of stations along the east coast (e.g., Stephenville) where W.R.H. is highly variable throughout the year. The West has a bimodal pattern with another pronounced low in the fall and maxima in summer and winter. Stations in the East (such as Trout Lake) and the North have a fall maximum. During the summer, W.R.H. values are higher in the northeastern portions of Canada and are lowest in the southwest where the drying influence of the Pacific sub-tropical high pressure cell is evident. During the winter the Pacific Coast has the highest relative humidities and the north-central interior regions form a pocket of somewhat lower values. In most cases, however, the gradients and variations in W.R.H. are not large, although exceptions are quite possible over the western mountain areas where data are not available.

The regional variations in the long-term mean monthly relative saturation of the air are small enough that the distribution pattern of $P_{eff}$ can be thought of as resulting primarily from the relative effectiveness of dynamic mechanisms.

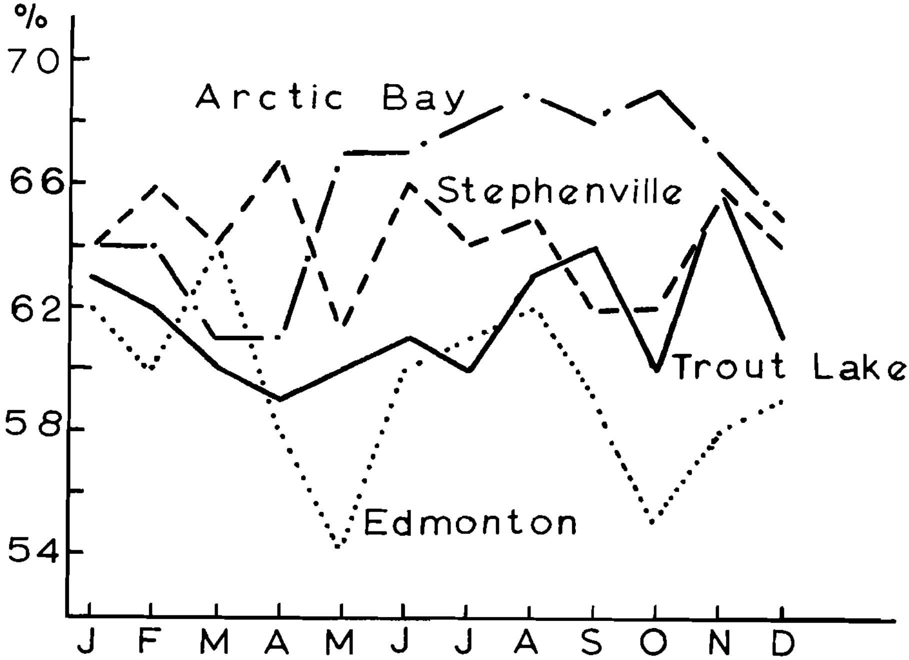


Fig. 4 Seasonal trends of precipitable water relative humidity at selected stations.

A major value of the index of $P_{eff}$ is that it helps focus attention on the factors responsible for creating a particular precipitation regime throughout an area. Regions of low total precipitation and high efficiency are limited in their total precipitation by a shortage of available water vapor even though the mechanisms are present to facilitate its release. Areas with low totals and low efficiency are more limited by the ineffectiveness or absence of the dynamic mechanisms. High precipitation totals and high efficiency mean that the dynamic mechanisms are active in releasing the abundant vapor in the air. High totals and low efficiency emphasize that even though precipitation is abundant there is a great deal of moisture in the air that is not being utilized.

The use of $P_{eff}$ in conjunction with the usual precipitation totals helps provide a better understanding of the processes involved in producing the observed precipitation distributions. Since the patterns of seasonal and annual precipitation in Canada are well known this report presents the corresponding patterns of $P_{eff}$. "Seasonal" and annual maps are included and a brief discussion of each pattern is given in simplified terms.

## 3 Methodology

Monthly and annual precipitation efficiencies were computed for 73 stations in Canada using Eq. (1). Precipitation data were obtained from the Meteorological Branch (1967). Mean monthly and annual values of precipitable water

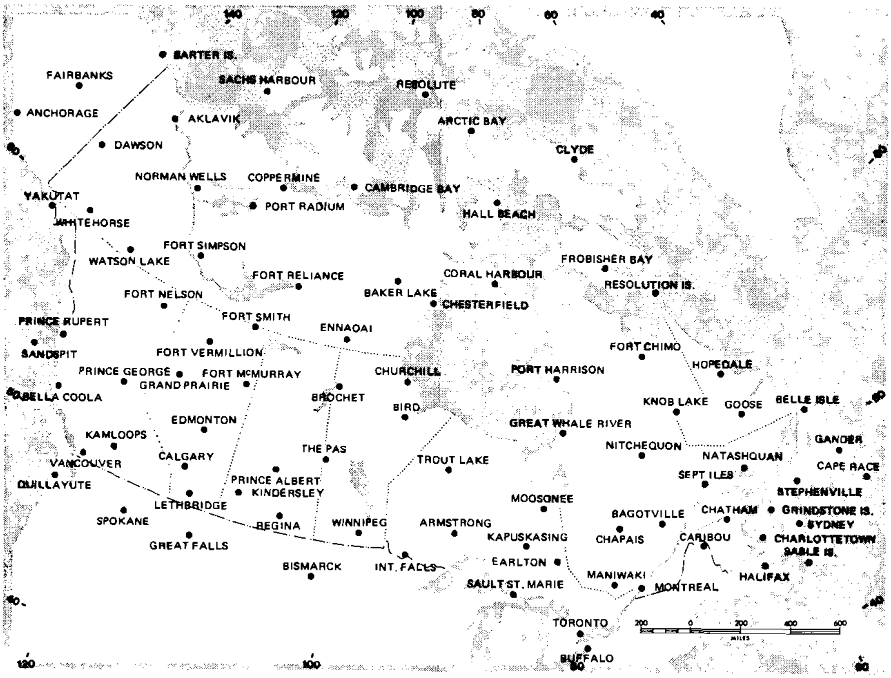


Fig. 5 Station locations.

vapor were taken from a study by Tuller (1972). In addition, precipitable water data published by Reitan (1960a) for 10 U.S. stations near the Canadian border were used. One station, Barter Island, Alaska, was incorporated using Tuller's (1972) precipitable water data, and data for another, Yakutat, was taken from an earlier study by Tuller (1971). Station locations are shown in Fig. 5.

Precipitation is an element that can vary greatly from station to station as a result of local siting and exposure factors. Although efforts are made to the contrary, the reported precipitation is often strictly representative only of a very small local area. This is especially true in the mountainous West. For this reason a dot pattern was used to represent $P_{eff}$ at each station rather than attempt to draw isolines through areas of pronounced climatic discontinuities. A graduated scale of dot size was employed with larger dots representing greater precipitation efficiency. The resulting pattern is sufficient to illustrate the regional variations and relative values of the index without creating an unwarranted impression of accuracy. To interpret this index the problems involved in the accurate measurement of precipitation itself should be kept in mind. Any errors in the published precipitation data will carry over into the $P_{eff}$ index. Likewise the short period of record for the upper air data used in computing precipitable water vapor may produce some variation in these results.

Seven categories of $P_{eff}$ are used: 0–4%, 5–9%, 10–14%, 15–24%, 25–44%, 45–74%, and over75%. These are sufficient to emphasize the areas of high and low efficiency and illustrate the regional differences between the majority of stations clustered at the low end of the scale.

## 4 Results

Figures 6, 8, 10 and 12 present the seasonal march of the pattern of $P_{eff}$ in Canada. In general, the efficiency decreases from south to north and from the coasts toward the interior of the continent.

### a *Winter*

Precipitation efficiency reaches its seasonal peak in the winter when cyclonic storms dominate the weather patterns. January (Fig. 6) represents the winter months, December, January and February. Fig. 7 shows a compilation of winter storm tracks taken from Klein (1957), the interquartile range of the position of the Arctic front in January (Barry, 1967) and zones of confluence determined from streamline analysis by Bryson (1966). Frontal zones and storm tracks are widely spread over the country and well developed during the winter season producing rather high efficiency indices throughout Canada with the exception of the high Arctic.

Two areas of maximum efficiency are dominant in the winter. Along the Pacific Coast orographic effects and the proximity to a consistent source of moisture contribute to the high values. The Gulf of St. Lawrence, lies along the preferred track of cyclonic storms through eastern Canada.

Lowest values in the southern part of the country are found in Saskatchewan. The distinct dry zone in the southern Prairies was formally recognized as long ago as the late 1850's in the reports of John Palliser. A more recent examination of this "Canadian Dry Belt" by Villimow (1956) reduced the areal extent of the actual dry belt to a region in southwestern Saskatchewan and southeastern Alberta. The dry zone experiences considerably fewer cyclonic storm passages than areas north or south, and is a region of subsidence and horizontal divergence. Although the station network in the current study is not dense enough to reveal the outlines of Villimow's dry belt the lack of dynamic mechanisms is corroborated by the low values of precipitation efficiency for Kindersley, Saskatchewan, during all seasons of the year.

### b *Spring*

In the spring (March–May) $P_{eff}$ values decline throughout the country (Fig. 8), especially along the West Coast and in the St. Lawrence region accompanying the slow northward movement of the Pacific sub-tropical high pressure cell and the decrease in cyclonic activity, respectively. These two regions, however, still maintain the highest efficiencies in Canada. Frontal zones, particularly the Arctic front, move northward (Fig. 9). The interior valleys of British Columbia have particularly low efficiencies in this season. Late spring is also the time of the annual low for most stations in the North.

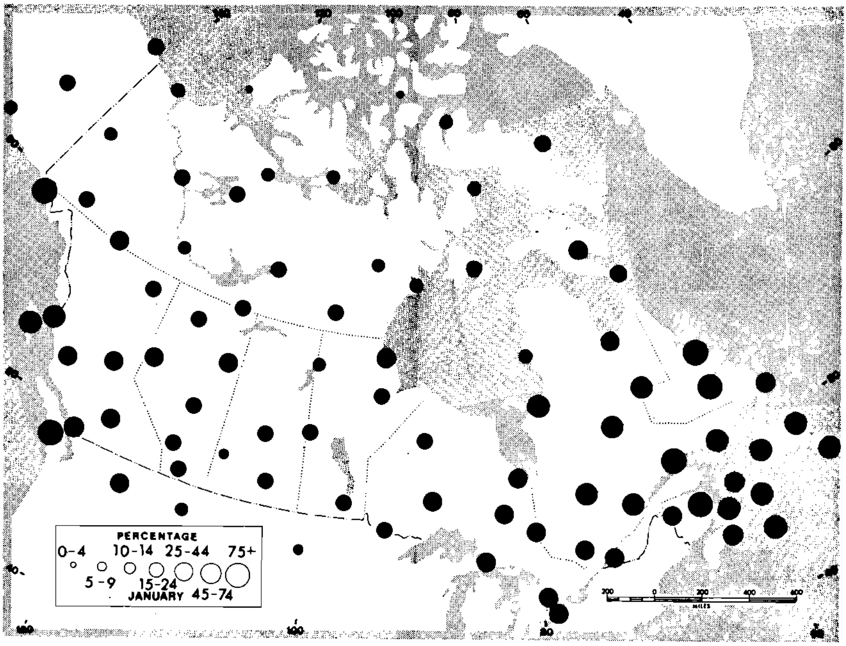


Fig. 6 Mean precipitation efficiency, January.

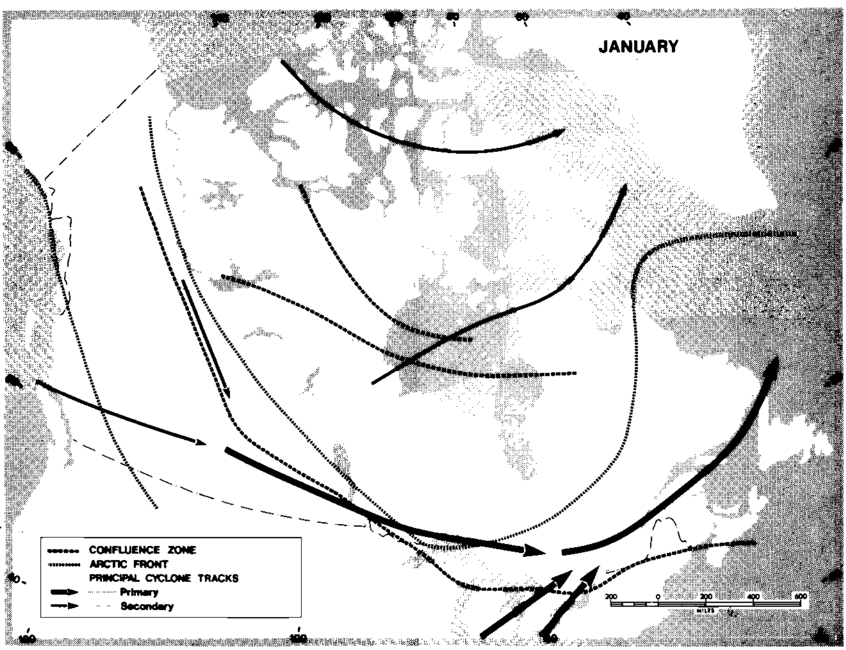


Fig. 7 Storm tracks (Klein, 1957), interquartile range of the Arctic front from maps by Barry (1967), and confluence zones from streamline analysis (Bryson, 1966); January.

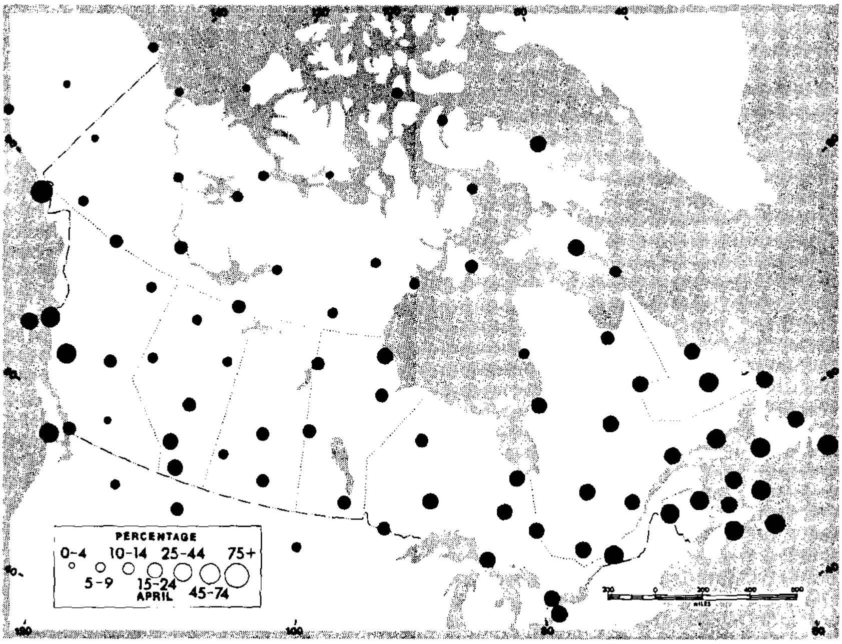


Fig. 8 Mean precipitation efficiency, April.

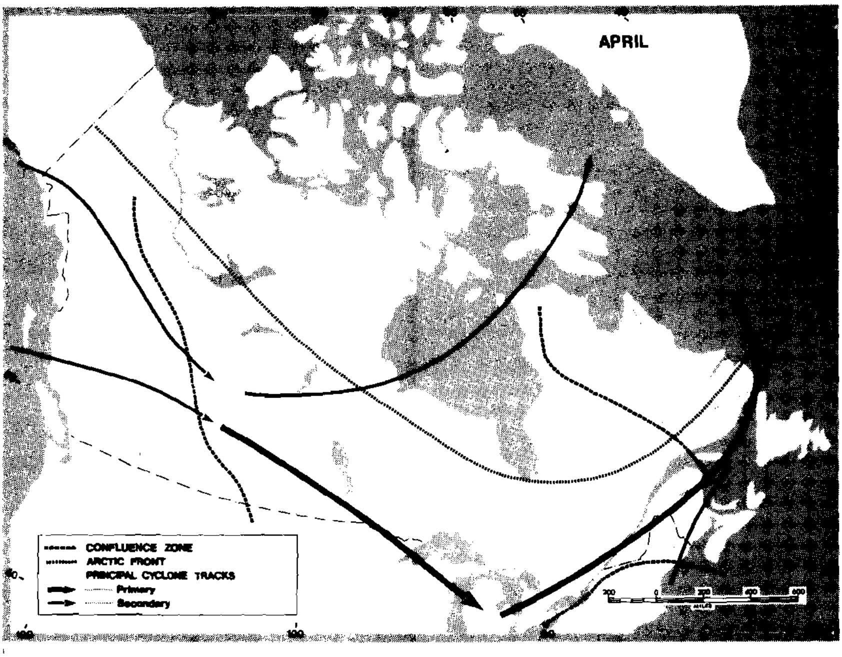


Fig. 9 Storm tracks (Klein, 1957), median position of the Arctic front interpolated from maps by Barry (1967), and confluence zones from streamline analysis (Bryson, 1966); April.

### c *Summer*

There is a rather uniform pattern of $P_{eff}$ throughout the country in summer (June–August). Values are lower than in the spring, averaging about 8% to 12% in July (Fig. 10).

A comparison of Figs. 10 and 11 illustrates very well that most stations with higher $P_{eff}$ are located near mean storm tracks or the frontal and confluence zones. The ability of precipitation efficiency to focus attention on the dynamic mechanisms responsible for creating precipitation, means that this index could provide an additional method of locating mean storm tracks or frontal zones over regions of uniform relief.

Although summer is the time of maximum precipitation in the North, $P_{eff}$ is low. Increased precipitation results from greater vapor content associated with warmer air, more immediate sources of evaporation and inflow of moist air from adjacent water bodies.

The British Columbia valleys partake of the general west coast pattern of protection offered by the sub-tropical high pressure cell. They are further protected by the leeward location with respect to the mountain ranges that parallel the coast. Another example is Sandspit in the lee of the Queen Charlotte Islands.

The region of highest summer efficiency is the East, especially Quebec and the Maritimes. Unstable (mT) air masses, which are very warm and humid in their surface layers, along with surface heating, land-sea temperature contrasts and available storm tracks all contribute to the higher efficiencies in this region.

### d *Fall*

Fall $P_{eff}$ (Fig. 12) rapidly increases along the West Coast as the sub-tropical high pressure cell withdraws to the south and more cyclonic storms affect the coast. The south-north gradient in $P_{eff}$ which is quite clear during the other seasons is somewhat reversed during the fall. West of Hudson Bay the highest efficiencies are located in the North along the most frequent storm paths and the Arctic front (Fig. 13). By December the winter pattern is again well developed.

### e *Seasonal Trends*

Stations in different regions of the country show different seasonal regimes of $P_{eff}$. Patterns for four typical stations, (Fig. 14) illustrate the ideas discussed previously. West Coast stations (Quillayute) show a pronounced winter peak. The summer minimum is associated with the presence of the Pacific sub-tropical high pressure cell. East Coast stations (Stephenville) have a similar pattern but orographic effects are lacking and late summer convective activity is better developed. The annual range, therefore, is lower than that found on the West Coast. The Prairie curve (Edmonton) is bimodal with summer convective storms and winter cyclones producing equal efficiencies. The North

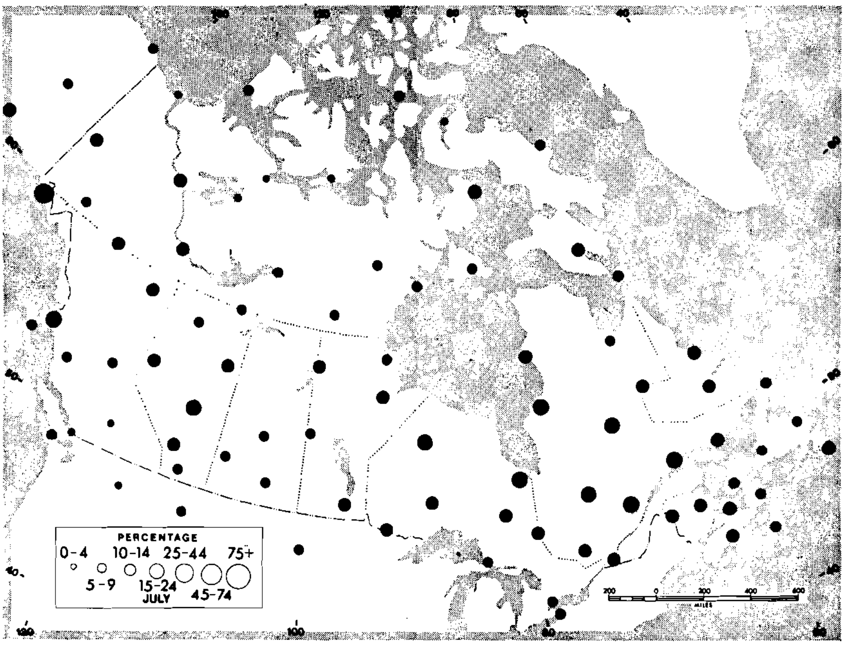


Fig. 10 Mean precipitation efficiency, July.

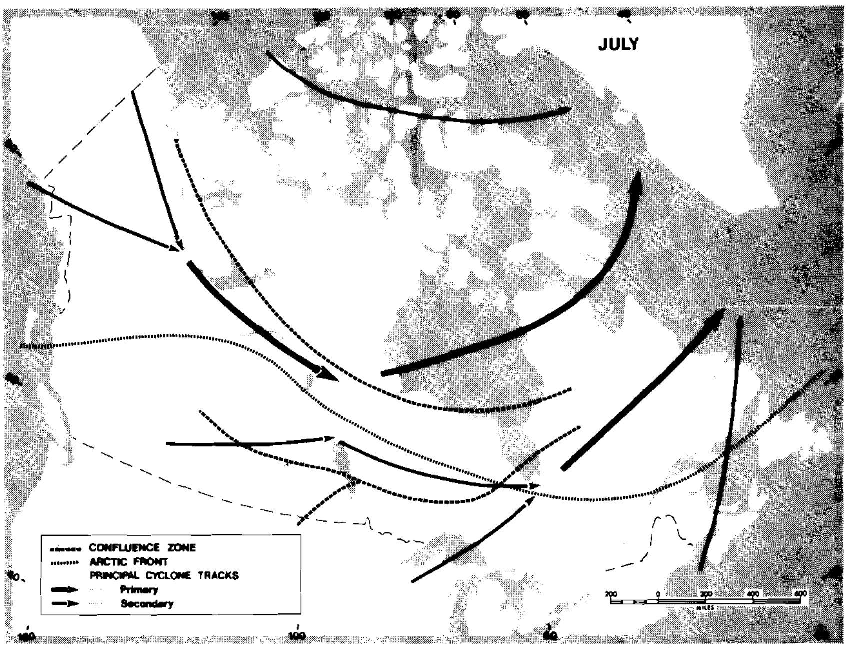


Fig. 11 Storm tracks (Klein, 1957), median position of the maritime Arctic front interpolated from maps by Barry (1967), and confluence zones from streamline analysis (Bryson, 1966); July.

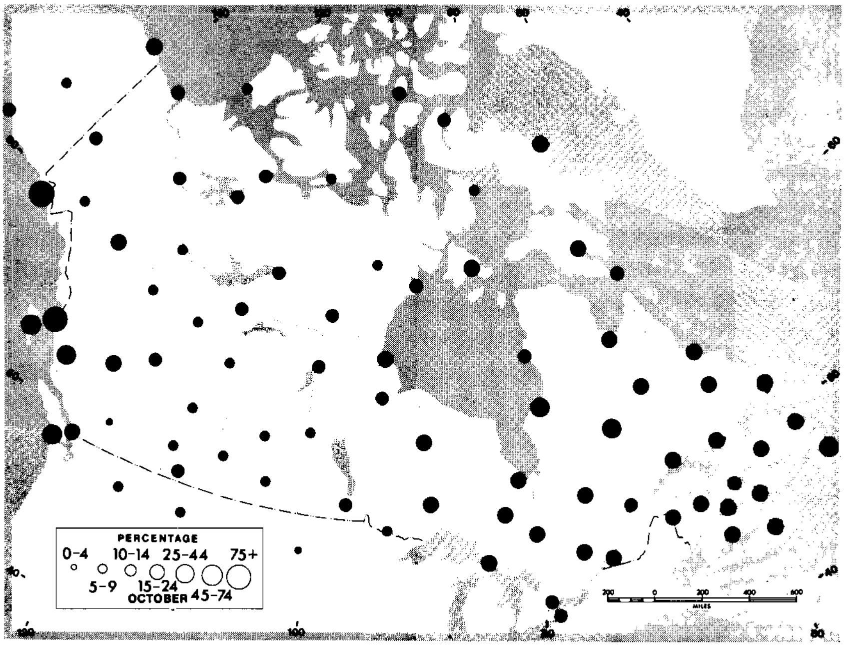


Fig. 12 Mean precipitation efficiency, October.

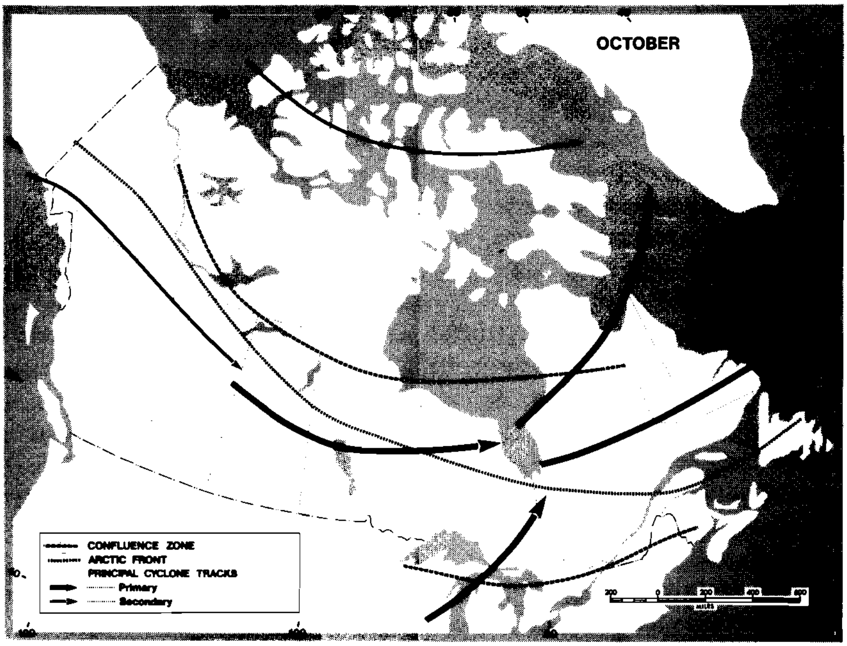


Fig. 13 Storm tracks (Klein, 1957), median position of the Arctic front interpolated from maps by Barry (1967), and confluence zones from streamline analysis (Bryson, 1966); October.

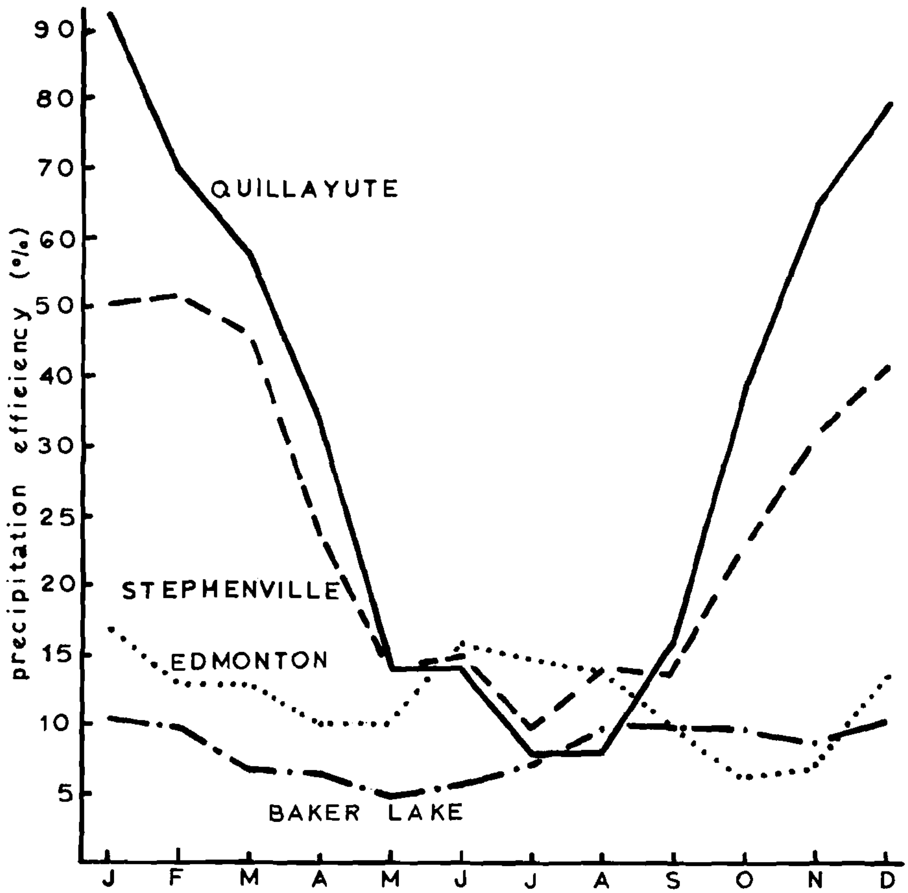


Fig. 14 Seasonal trends of precipitation efficiency at selected stations.

(Baker Lake) has low $P_{eff}$ values throughout the year. The minimum is in the late spring, the season of highest mean air pressure for northern regions. The autumn is warmer with a more unstable atmosphere.

## 5 Summary and conclusions

The index of precipitation efficiency is a useful supplement to standard precipitation maps to help focus attention on the efficiency of dynamic precipitation mechanisms in an area, and illustrate the relative importance of available moisture and these mechanisms in producing the observed precipitation pattern. In effect the influence of atmospheric water vapor content is removed. Many areas such as the North and East have highest precipitation totals during the summer but highest efficiencies during the winter. This illustrates the effect that low available moisture has on limiting the winter precipitation. On the West Coast,

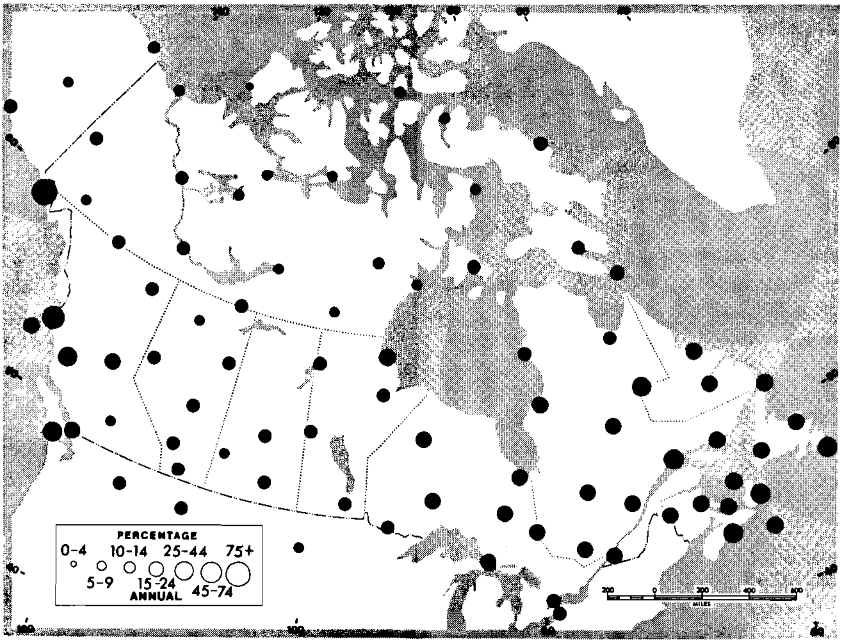


Fig. 15 Mean precipitation efficiency, Annual.

however, both the precipitation totals and efficiency follow the same seasonal pattern.

Low precipitation can result from either a lack of moisture, want of precipitation mechanism, or both. Cloud seeding is one method of increasing the efficiency of the dynamic mechanisms. It would have little additional effect if most of the available moisture was already being converted to precipitation.

Fig. 15 shows the annual $P_{eff}$ for Canada and illustrates the major distributional patterns seen during individual seasons. The West Coast has the national high followed by the St. Lawrence-Maritimes region. Cyclonic activity is the major source of precipitation. In most cases the pattern of $P_{eff}$ shows a good correlation with mean storm tracks and frontal zones. Orographic effects are well illustrated on the West Coast. Lower values are found in the interior of the country and in the North mainly because of remoteness from continuous moisture sources, lack of orographic effects, and the relatively large distances from cyclone tracks.

Sellers (1965) reported the average value of annual $P_{eff}$ for the world to be 12%. Franceschini (1968) obtained 11% for the United States. The present study gives values for all of Canada except the North above these figures. This is especially true in the East and West. Canada, therefore, is better endowed than many countries with an effective system of dynamic mechanisms that are efficient converters of available water vapor into measurable precipitation.

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## ANNOUNCEMENT

### International Symposium on Building Climatology

Because of the outstanding success of the symposium conducted by the International Council for Building Research Studies and Documentation in Stockholm in 1972 and the growing importance of utilizing meteorological, climatological and physiological knowledge in building practice and planning, another symposium is to be held in Zurich, Switzerland, from 25 to 27 September 1974 in cooperation with the World Meteorological Organisation and the International Federation for Housing and Planning. The problems of the environment, physics, medicine as related to building research, education, construction and architecture will be dealt with, as will the climatological problems involved in local and regional planning. As a public symposium to be held in the German, French and English languages, the gathering will be open to all interested professionals. Application data can be requested from the Symposium Secretariat, Swiss Building Documentation, CH–4249 Blauen.

# Forecast Research Symposium

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*Atmospheric Environment Service, Toronto*

Approximately 140 people attended a Forecast Research Symposium on May 3, 1973 at the Toronto Headquarters of the Atmospheric Environment Service (AES, Environment Canada). The Symposium was sponsored by the Meteorological Services Research Branch (MSRB, Atmospheric Research Directorate), which has components located in Toronto and in Montreal, as the culmination of an annual conference of the Branch. Those who attended or participated came from other components of AES Headquarters, Regional Weather Centrals and Weather Offices, various universities and industries, the Government of Ontario and the U.S. National Weather Service. The diversity of this representation indicates the widespread interest in the scientific and practical problems of forecast research encountered by a national weather service, especially since the Symposium was the first of its kind to be held in Canada.

Joseph Clodman, Director of MSRB, chaired both morning and afternoon sessions which mainly dealt with mission-oriented research and development work currently in progress on weather forecast procedures. Pre-prints of most of the papers had been made available for preliminary study so that more time could be devoted to discussion instead of more formal presentation. The discussions were enhanced by the participation of William Klein, Director of the Techniques Development Laboratory (TDL) of the U.S. National Weather Service, who also presented a comprehensive review of related work at TDL.

André Robert, Chief of the Dynamic Prediction Research (DPR) Division of MSRB, outlined the progress already made to create an operational primitive equations model for the Canadian Meteorological Centre (CMC). He quickly reviewed early DPR activity in this field before describing the semi-implicit time integration scheme developed from 1969 to 1972. Some of the results are reflected in the S-1 scores of Fig. 1. Predictions obtained by the implicit method compared quite favourably with those obtained by an explicit technique, even though the implicit model ran about four times faster. Methods for parameterizing physical processes were examined, in order to improve performance of the current highly-"tuned" operational model. At CMC the change-over to the primitive equations model is planned for the fall of 1973 after a CDC CYB 7600 computer has been received.

Bernard Muller, Chief of the Forecast Research Division of MSRB, gave an overview of the problems that should be considered in developing a mission-oriented forecast-research program relevant to the needs of a national weather service. He summarised work on the development of the MSRB Regional Update Model (RUM), which is designed to update standard NWP prognostics using

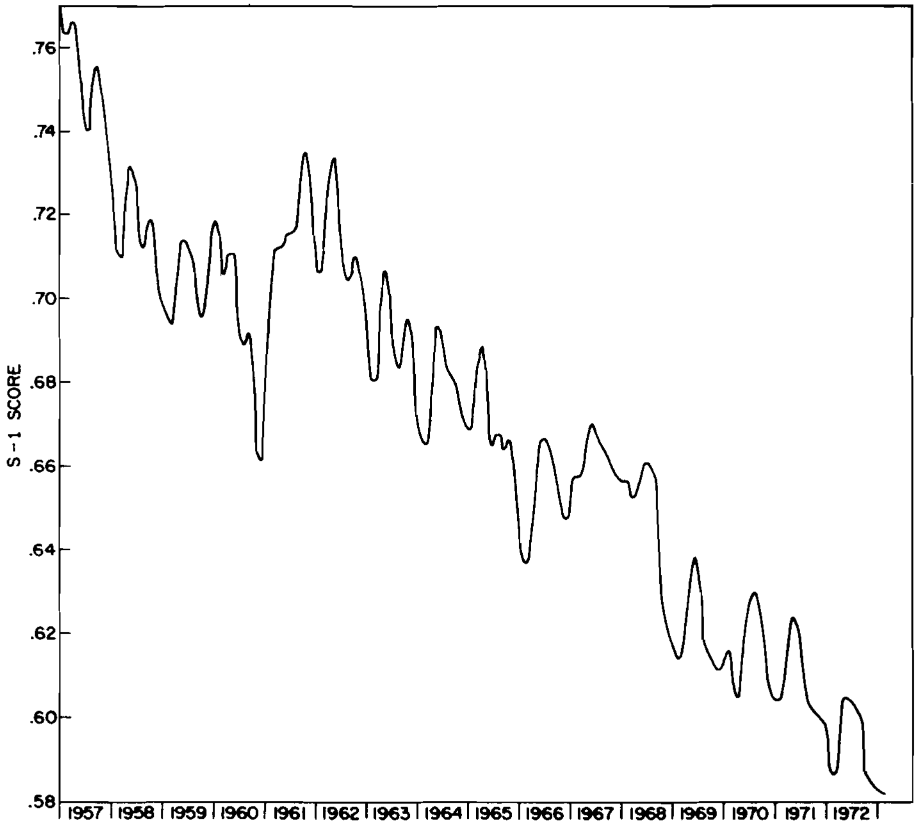


Fig. 1 Smoothed monthly mean S - 1 scores for 36-h surface prognostics, CMC Analysis and Prognosis Unit.

hourly surface data. Results obtained over 5 months with the first version were entirely comparable with operational subjective updating and are considered encouraging (Fig. 2). Frank Winninghoff outlined several potential refinements including the introduction of terrain-induced vertical motions, the parameterization of physical processes such as surface heating and cooling, and the release of the latent heat of condensation.

In a highlight of the Symposium Dr. Klein of TDL explained the methods used to obtain improved forecasts of local weather elements. The "perfect prog" method specifies local weather by means of regression equations derived from observed circulation parameters and then applied to the output of numerical prognoses. It has been successfully used in the operational prediction of maximum and minimum surface temperatures, extratropical storm surges along the Atlantic Coast and Lake Erie water levels. This technique has a special advantage in that the forecast output automatically improves as the results from numerical models improve. The second method, Model Output Statistics (MOS)

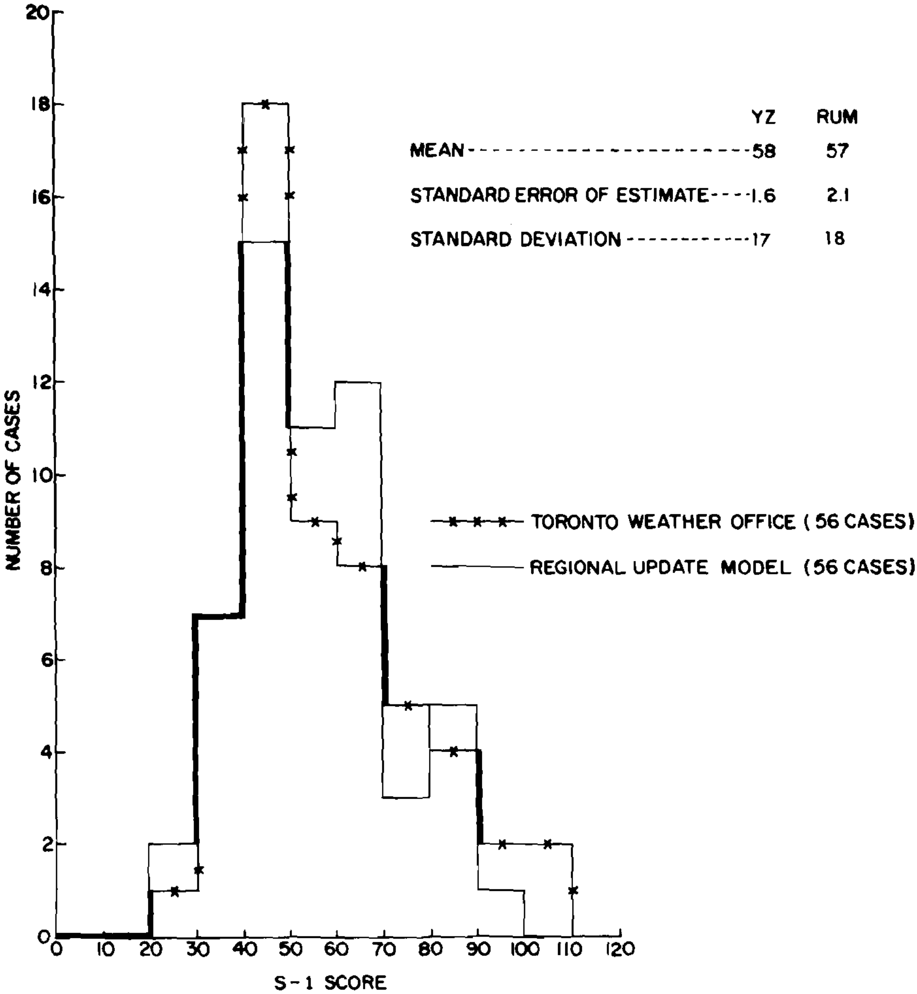


Fig. 2 Relative frequency of S-1 scores for 56 surface prognostics from the Toronto Weather Office and from the Regional Update Model. Weather Office – scores for 22-h progs. RUM – mean of scores for 18 and 24 h.

requires that output from numerical models be archived and correlated with local weather. MOS has been applied operationally to produce forecasts of precipitation probability and type, surface wind, ceiling, visibility, showers and severe local storms. Plans are underway to combine the two methods and extend them to elements such as sky cover, fog and surface humidity. The numerical-statistical output is expected to give accurate forecast guidance for nearly all local-weather parameters.

A planetary boundary-layer prediction model under development at MSRB was described by Jacob Padro and is a variation of similar ones in operation at the U.S. Air Force Global Weather Central and the U.S. National Meteorological Center. The model is slated to undergo comprehensive testing using conventional aerological reports for input data, together with the series of hourly m.s.l. pressure analyses available for the hours between the aerological reporting time and the start-up time for each run. Improvements will then be tackled for both data assimilation and model design.

Tom Agnew outlined the development and prediction of a Relative Air Pollution Potential Index (RAPPI) for use in conjunction with the Regional Update Model. The value of the index, when related to climatology and accumulated over a given number of hours, is in inverse relation to the predicted dispersive effects of vertical diffusion and horizontal ventilation.

The general planning of an automated weather-element prediction system was discussed by Don Bellows. Attention is being focussed on the production of basic fields of weather elements over a regional grid with 127-km spacing. Point values would then be related statistically to the set of surrounding grid-point predictions and predictor fields.

Bill Harley explained a diagnostic and forecast technique applicable to convective storms in terms of calculations of the total instability energy available in given atmospheric layers. The performance of instability indices he has developed is being compared, using a relatively large data sample, with the performance of other indices in common use.

A program for automatic tracking and prediction of digitized weather-radar echoes was described by Cliff Holtz. Significant echoes are automatically located, identified, tracked and predicted using cross-correlations between matched echoes in consecutive data sets. In addition, Geoff Austin (Department of Meteorology, McGill University) reported successful results in about 30 test cases using cross-correlation vectoring to predict mean echo motion over the total area of radar coverage as well as for selected sub-areas.

The present status regarding automation of upper-air observations in the AES was discussed by Oscar Koren. It appears economically justifiable to do this, even in the relatively short-term, for upper winds but not for the GMD sounding program in its entirety.

Bryan Kerman described a similarity model for the viscoelastic sub-layer. He showed that a contradiction arises if parallelism is assumed between stress and shear, an assumption which is made in eddy viscosity and mixing-length theories for boundary-layer models. Some basic results arising from his model for co-existing waves, turbulence and mean flow were also presented.

Procedures for updating short-range (6- and 12-h) forecast fields with observed data in order to estimate the prevailing state of the atmosphere were described by Ian Rutherford. Examples were given of the coupled updating approach, in which all variables are updated in such a way as to maintain an approximate dynamic balance. Simple geostrophy was used to relate the correlation functions for the forecast errors in the wind-components to those for the geopotential height. Test results, using a barotropic primitive equations model, suggest that further balancing of the updated fields may not be necessary.

William Creswick outlined the implementation of a new six-hourly cycle at

CMC to assimilate data from routine surface observations as well as from the latest available asynoptic upper-air temperature profiles as determined by satellite. The urgency of this project was heightened by the prospect that the U.S. will terminate their ocean weather-ship program. A six-hour forecast is made from a special analysis and prognosis run that assimilates the six-hourly satellite and surface data, which provide initial fields for the next twelve-hourly analysis and prognosis cycle. Tests have shown that this initialization produces improvements at 1000 mb which continue out to 72 hours.

Dave Davies described the manner in which large-scale moisture effects are being incorporated into the DPR primitive equations model. Dewpoint depression is selected as the primary moisture parameter, special techniques provide for a gradual transition from saturated to unsaturated conditions at the gridpoints, and predicted precipitation is broken down into large- and small-scale components. The small-scale moisture effects are being re-designed by combining empirical techniques, used in the regular operational scheme, with parcel ascent techniques.

The current stage of development of a multi-level *spectral* primitive-equations model was described by Roger Daley. Considerable effort has been expended to refine the initialization procedure, improve the vertical discretization, increase the versatility of the input/output operations and implement a semi-implicit algorithm (time-integration method). Encouraging results have been obtained on running the model with real data for forecast periods up to thirty-six hours.

The Symposium served as a forum in two ways: to present the details of continuing research programs and to permit scientists in common areas of work to test their concepts among themselves. Dr. Klein's participation marked a new stage in cross-fertilizing the development of forecast research in Canada and the U.S., where a parallel program has been in progress for about eight years. Since this Symposium was successful in promoting the exchange of information and ideas, it is planned as an annual event of the Meteorological Services Research Branch Conference. Next year's Symposium will likely be lengthened to two days to allow more time for both presentation and discussion.

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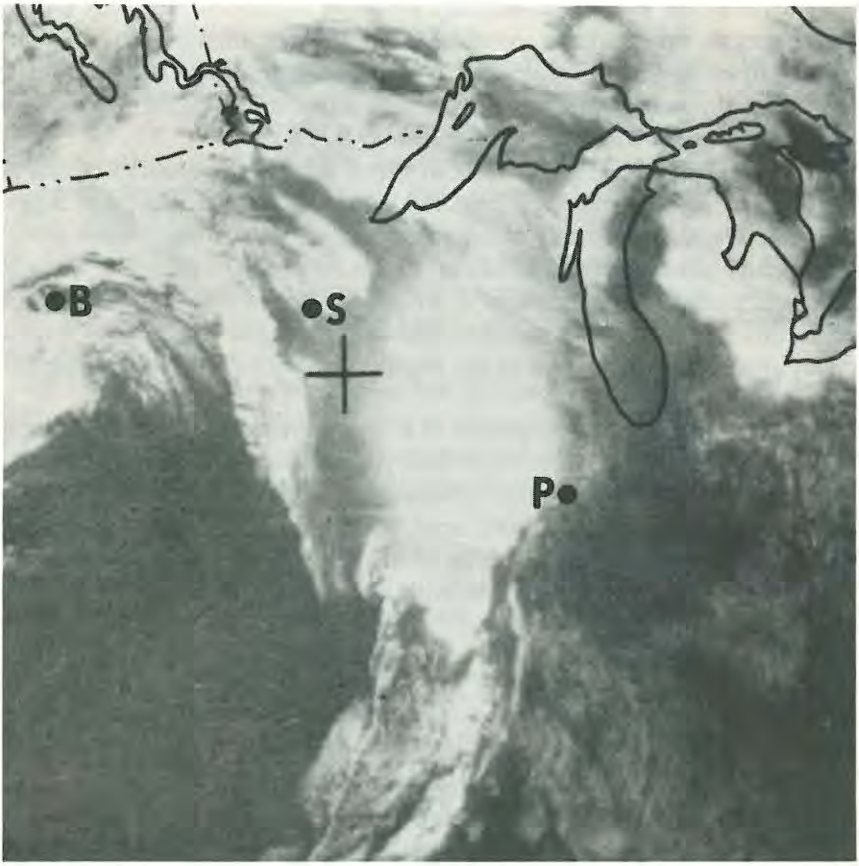


**An Explosion of Convective Activity**

This APT photograph was taken at 1655Z on June 18, 1973 and received at the AES Satellite Data Laboratory, Toronto. The bright cloud mass west of Lake Michigan shows cirrus blow-out in three directions with only the upwind region remaining cirrus free. The brightness of the cloud is augmented by sun glint. Winds at the time were: 210°/50 kt, 5,000 ft; 230°/50 kt, 10,000 ft; and 230°/55 kt, 18,000 ft. Southwest of the cloud mass the 30,000-ft winds were uniformly out of 240°. Extreme diffluence at jet-stream level was evident east, north and northwest of the cloud mass. Winds at 30,000 ft were reported as: 260°/40 kt, Peoria (P); 210°/60 kt, St. Cloud (S); and 140°/50 kt, Bismarck (B). Weather reports from the area included numerous severe thunderstorms, hail, destructive winds and heavy rain.

W. D. Lawrynuik

## NOTES FROM COUNCIL

The following were accepted as members by Council:

April 5, 1973

| | | |
|---|---|---|
| *Member* | George John Boer<br>Paul Joseph Delannoy<br>Kenneth Harry Jones | James Edward Pakiam<br>Mary Patricia Constance Regan |
| *Student Member* | Terrence James Brown<br>Thomas John Lyons | Geoffrey Stuart Strong |

May 8, 1973

| | | |
|---|---|---|
| *Member* | David P. Baumhefner<br>Jay Earl Campbell | Alfred A. Hoover |
| *Student Member* | Wan-Li Cheng | |

**Twelfth Annual Canada-Wide Science Fair**

Lynn Stables and Patti Turner, Grade 9 students from Iroquois Falls, ONT., won the CMS prize for their excellent exhibit on the theory of hurricanes presented at the 12th Annual Canada-Wide Science Fair of the *Youth Science Foundation*, held at Thunder Bay, 15–19 May, 1973. Their exhibit comprised

Patti Turner and Lynn Stables.

a neatly built model that simulated hurricane development and a series of maps and diagrams showing the birth, growth and decay of hurricanes. The model consisted of an enclosed box with a chimney and sliding glass sides and contained a basin of water which could be heated from below. By moving the panels the column of steam produced could be made to rotate in either direction.

Professor David D. Kemp of Lakehead University, who judged the meteorological entries for the CMS, reported that the girls were well aware of the differences between their model and actual hurricanes and were also remarkably well versed in recent studies of hurricane development and modification attempts. They had planned to add AgI crystals but couldn't obtain the chemical.

Two other exhibits of high standard included one to measure wind-chill under differing meteorological conditions, and another to correlate the amount and rate of dust fall in a small prairie town with weather conditions.

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## NEW ADDRESS FOR C.M.S. EXECUTIVE

Correspondence regarding Society affairs should be mailed to the new address:

Corresponding Secretary
Canadian Meteorological Society
P.O. Box 160
Ste-Anne-de-Bellevue 800, P.Q.

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**Back Issues of Atmosphere**

It would be appreciated if members would donate to the CMS copies of the following issues of *Atmosphere* which are either out-of-print or in short supply:

Volume 3, No. 1 (1965)
Volume 4, Nos. 1, 2 (1966)

# ROBERT M. HOLMES
## 1928–1973

It is with deep regret that we report the death of Dr. Robert M. Holmes, President of ERA Sciences Ltd., on June 22, 1973, as a result of a tragic airplane crash near Calgary, Alberta.

Born in Raymond, Alberta in 1928, son of Walter Godfrey and Virginia Mendenhall Holmes, he graduated from Brigham Young University (Provo, Utah) with a B.SC. in Agronomy and Chemistry in 1952. In 1955, he received his PH.D. in Soil Physics and Plant Physiology from Rutgers University (New Brunswick, New Jersey). Following this he was appointed by the Research Branch of the Canada Department of Agriculture as Research Scientist in the Agrometeorology Section, Ottawa where he undertook extensive studies of the microclimate of crops. He undertook post-doctoral studies in Meteorology (Instrumentation) at the University of Michigan in 1961–62. From 1967 to 1971 he conducted research in the environmental sciences for the Inland Waters Branch (Canada Department of the Environment) in the Cypress Hills and the Alberta prairies, with particular emphasis on airborne methods and remote sensing instrumentation. A pioneer in the field of remote sensing in Canada, he served as Western Research Director for the Canada Centre for Remote Sensing in 1971. In 1971 he joined ERA Instruments Ltd. (now ERA Sciences Ltd.) as President and Director of Research.

Dr. Holmes was an eminent scientist and dedicated researcher in many disciplines in the environmental sciences. He was a pioneer in Canada in the field of airborne sensing of the environment, involving both remote and immersion sensing. His extensive scientific knowledge, wide-ranging field experience and well-developed skills in electronics and instrumentation systems design and engineering combined to make him the innovative and consummate scientist that he was. He authored over 40 scientific publications, was a member of many scientific organizations (American Society of Agronomy, Canadian Meteorological Society, American Meteorological Society, International Geographical Society, American Society of Photogrammetry, Fellow of the Royal Meteorological Society) and held a 5-year appointment to the World Meteorological Organization.

In addition to his scientific achievements, Dr. Holmes was an accomplished musician. He played the violin in the B.Y.U. and New Brunswick, N.J., Symphony Orchestras. He managed a fine arts broadcasting radio station in Ottawa and produced *Music Omnibus*, an outstanding classical music program. He was a member of the Board of Directors of the Ottawa Philharmonic and Youth Orchestra, conducted Church choirs and taught music appreciation in Ottawa and Calgary. He wrote the first edition of *An Introduction to Music Literature* in 1965 and a second edition in 1969. Dr. Holmes derived great pleasure from flying. He was an experienced pilot, qualified on single- and twin-engine aircraft and held an instrument rating.

Dr. Holmes was a man of great spiritual convictions and was a devoted member of the Church of Jesus Christ of Latter-Day Saints. He gave a life-time of volunteer service to his church, including several years as a missionary for the L.D.S. Church in New Zealand, Eastern U.S. and Eastern Canada. His faith was shared by all the members of his family and has served them well in bearing the grief of his sudden passing. Dr. Holmes is survived by his wife, Jayna Monette Henrie, and nine children: Julie (21), Kara (19), Claire (18), Robert (16), Douglas (13), Rachel (10), Philip and Ryan (5), and Jennifer (3).

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## MEMBERSHIP APPLICATION FORM

(Please write in Block Letters)

*General or Student Member*

SURNAME ..........

GIVEN NAMES ..........

PERMANENT ADDRESS ..........

..........

TITLE, RANK, DECORATIONS, DEGREES OR PROFESSIONAL

QUALIFICATIONS ..........

..........

OCCUPATION ..........

(for record purposes only; if student, indicate university and year studies will be completed)

*Sustaining Member*

NAME OR AGENCY ..........

BUSINESS ADDRESS ..........

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*Membership Status Required*

Please enroll me as a .......... member of the Canadian Meteorological Society effective January 1, 19.........., to receive all publications issued by the Society from that date. I attach a cheque for $ .......... payable to the *Canadian Meteorological Society*.

..........

Signature of Applicant

Mail completed application forms to:
Corresponding Secretary
Canadian Meteorological Society
P.O. Box 160, Ste-Anne-de-Bellevue
800, P.Q.

CMS dues for 1973:

| | |
|---|---|
| General Member | $15.00 |
| Student Member | $ 5.00 |
| Sustaining Member | $50.00 (min.) |

## INFORMATION FOR AUTHORS

**Articles** may be contributed either in the English or French language. Authors need not be members of the Canadian Meteorological Society. Manuscripts for *Atmosphere* should be sent to the Editor, *Atmosphere*, P.O. Box 41, Willowdale, Ontario M2N 5S7. After papers have been accepted for publication, authors will receive galley proofs along with reprint order forms.

**Manuscripts** should be submitted in duplicate, typewritten with double-spacing and wide margins. Headings and sub-headings should be clearly designated. A concise, relevant and substantial abstract is required.

**Tables** should be prepared on separate sheets, each with concise headings.

**Figures** should be provided in the form of two copies of an original which should be retained by the author for later revision if required. A list of legends should be typed separately. Labelling should be made in generous size so that characters after reduction are easy to read. Line drawings should be drafted with India ink at least twice the final size on white paper or tracing cloth. Photographs (halftones) should be glossy prints at least twice the final size.

**Units.** The International System (SI) of metric units is preferred. Units should be abbreviated only if accompanied by numerals, e.g., '10 m', but 'several metres.'

**Footnotes** to the text should be avoided.

**Literature citations** should be indicated in the text by author and date. The list of references should be arranged alphabetically by author, and chronologically for each author, if necessary.

**Italics** should be indicated by a single underline.

## RENSEIGNEMENTS POUR LES AUTEURS

Les **articles** peuvent être soumis en anglais ou en français. Les auteurs peuvent être membres ou non de la Société météorologique du Canada. Les manuscrits pour *Atmosphère* doivent être envoyés à: le Rédacteur, *Atmosphère*, C.P. 41, Willowdale, Ontario, M2N 5S7. Une fois les articles acceptés pour publication, les auteurs en recevront des épreuves de même que des formules de commande de copies supplémentaires.

Les **manuscrits** pour *Atmosphère* doivent être en duplicata, dactylographiés en doubles interlignes avec de larges marges. Les titres et sous-titres doivent être clairement indiqués. Chaque article doit comporter un résumé qui soit concis, pertinent et substantiel.

Les **tableaux** doivent être préparés et présentés séparément accompagnés d'un titre et d'un numéro explicatifs concis.

Les **graphiques** doivent être présentés en deux copies dont les originaux devraient être conservés par l'auteur au cas où ils seraient nécessaire de les reviser. Une liste des légendes des graphiques doit être dactylographiée séparément. L'étiquettage doit être de grand format de façon à ce qu'il soit facilement lisible après réduction du format. Le traçage des lignes doit s'effectuer au moyen d'encre de chine en doublant, au moins, le format final, le tout sur papier blanc ou sur papier à calquer et identifié adéquatement. Les photographies (demi-teintes) devraient être présentées sur épreuves glacées au double du format final.

**Les unités.** Le Système International (SI) d'unités métriques est préférable. Les unités devraient être abrégées seulement lorsqu'elles sont accompagnées de nombres, ex: "10m", mais "plusieurs mètres".

Les **notes de renvoi** au texte doivent être évitées.

Les **citations littéraires** doivent être indiquées dans le texte selon l'auteur et la date. La liste des références doit être présentée dans l'ordre alphabétique, par auteur et, si nécessaire, dans l'ordre chronologique pour chaque auteur.

Les **italiques** doivent être indiqués en soulignant les expressions désirées une seule fois.

## The Canadian Meteorological Society / La Société Météorologique du Canada

The Canadian Meteorological Society came into being on January 1, 1967, replacing the Canadian Branch of the Royal Meteorological Society, which had been established in 1940. The Society exists for the advancement of Meteorology, and membership is open to persons and organizations having an interest in Meteorology. At nine local centres of the Society, meetings are held on subjects of meteorological interest. *Atmosphere* as the official publication of the CMS is distributed free to all members. Each spring an annual congress is convened to serve as the National Meteorological Congress.

Correspondence regarding Society affairs should be directed to the Corresponding Secretary, Canadian Meteorological Society, P.O. Box 160, Ste-Anne-de-Bellevue 800, P.Q.

There are three types of membership – Member, Student Member and Sustaining Member. For 1973 the dues are $15.00, $5.00 and $50.00 (min.), respectively. The annual Institutional subscription rate for *Atmosphere* is $10.00.

Correspondence relating to CMS membership or to institutional subscriptions should be directed to the University of Toronto Press, Journals Department, Front Campus, Toronto, Ontario, Canada M5S 1A6. Cheques should be made payable to the University of Toronto Press.

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La Société météorologique du Canada a été fondée le 1er janvier 1967, en remplacement de la Division canadienne de la Société royale de météorologie, établie en 1940. Cette société existe pour le progrès de la météorologie et toute personne ou organisation qui s'intéresse à la météorologie peut en faire partie. Aux neuf centres locaux de la Société, on peut y faire des conférences sur divers sujets d'intérêt météorologique. *Atmosphère*, la revue officielle de la SMC, est distribuée gratuitement à tous les membres. À chaque printemps, la Société organise un congrès qui sert de Congrès national de météorologie.

Toute correspondance concernant les activités de la Société devrait être adressée au Secrétaire-correspondant, Société météorologique du Canada, C.P. 160, Ste-Anne-de-Bellevue 800, P.Q.

Il y a trois types de membres: Membre, Membre-étudiant, et Membre de soutien. La cotisation est, pour 1973, de $15.00, $5.00 et $50.00 (min.) respectivement. Les Institutions peuvent souscrire à *Atmosphère* au coût de $10.00 par année.

La correspondance concernant les souscriptions au SMC ou les souscriptions des institutions doit être envoyée aux Presses de l'Université de Toronto, Département des périodiques, Campus Front, Toronto, Ontario, Canada, M5S 1A6. Les chèques doivent être payables aux Presses de l'Université de Toronto.