APPLICATIONS OF CLIMATOLOGY:

PROCEEDINGS OF THE WORKSHOP AND ANNUAL MEETING SPONSORED BY THE ALBERTA CLIMATOLOGICAL COMMITTEE

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FOREWORD

Climate plays a pervasive role in human activities and in all processes of life, forming an integral part of the environment. Today technology has advanced to where we are able to compensate for many of the vagaries of the weather; however, we should plan to use to advantage the benefits of the atmosphere, including the exploitation of our inexhaustible natural energy sources such as solar radiation and wind. In building design much can be done to minimize requirements for energy resources by climatically sound design. In urban planning the effects of the urban heat island and its associated air pollution can be minimized with sound land-use planning. Similarly, cooperative studies by climatologists and other professions can eliminate or minimize adverse effects of climate in other areas of our society. A great deal of basic information on the elements of climate is required or could be used by planners and other decision-makers in a large number of professions or activities. In the past the climatologist has largely supplied mean values of atmospheric conditions with respect to time or season. Now there is an increasing need for detailed statistical presentations of the various climatological elements with emphasis on space as well as time. However, if climatological information is to be intelligently applied, a dual education problem has to be overcome. First we have to educate climatologists (and meteorologists) to think in terms of these special applications, and secondly, we have to educate the users in the intelligent use of climatological (and meteorological) information and projections.

With these various concerns in mind, the Alberta Climatological Committee (now renamed an Association) selected the topic "Applications of Climatology" as the theme for the workshop. With the time available speakers were invited to discuss or give examples of how climatic data can be applied in a number of areas. From this it was hoped that greater dialogue and interaction would develop between suppliers and users of climatic data, and that the Committee would receive feedback or guidelines as to where they should put their future efforts in this area. One recommendation received by the Committee during the Annual Meeting on the afternoon of the Workshop was that they should plan a similar workshop next year.

These Proceedings report the seven papers given at the morning workshop session, either in full or in extended summary, and indicate other references giving more detail. The Proceedings also include the brief reports presented by a number of agencies and universities with an interest in climatology; a report from the Alberta Agrometeorology Advisory Committee; an outline of the Peace River Land Evaluation Project; and other highlights from the Annual Meeting in the afternoon.

C. W. Gietz, W. E. Kerr, B. Janz, and J. M. Powell planned the meeting. The Committee wishes to thank Alberta Environment for preparing, printing, and mailing the publicity brochure, which was all coordinated by the secretary, W. E. Kerr. We thank Dr. G. T. Silver, Director of the Northern Forest Research Centre, Environment Canada for his opening words of welcome, for the facilities for the meeting, and for publishing the Proceedings of the meeting. We also thank Mrs. P. Logan, of the Northern Forest Research Centre, Environment Canada, for editorial assistance. Finally we wish to thank all participants for making the meeting a success.

J. M. Powell
Chairman
Alberta Climatological Association

WORKSHOP

APPLICATIONS OF CLIMATOLOGY

INTRODUCTORY REMARKS

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As an introduction to this workshop I would like to tell you something about the Alberta Climatological Committee. Some of you probably knew nothing about the committee and its work until very recently. It was formed following an informal meeting attended by 8 persons from six agencies on March 23, 1967 under the sponsorship of the Research Council of Alberta and at the initiative of Professor R.W. Longley. At the second meeting on June 5, 1967, at which 16 representatives were present, it was decided that representatives from the following widely separated interest groups should be on the committee: the old Meteorological Branch, Department of Transport; Alberta Department of Lands and Forests ; Federal Department of Forestry; Alberta Department of Agriculture; Private Industry; and the University of Alberta. These agencies were selected as representative of known interest groups with the intention that they should maintain communication with other agencies or firms in their own area. The immediate goals of the committee at that time were established as follows:

1) To establish and maintain at a central location a registry of the climatological and related data that are being collected within the province and to make such information available upon request
2) To discover from different users and potential users the needs for data not now being obtained and to investigate ways and means of obtaining them
3) To prepare a bibliography on the climate of Alberta
4) To act as a consultant for users of climatological data on sources and use of data to the limit of the time and ability of the members

Since the initial meetings, the committee has met on an average of twice a year for a half-day session, first under the chairmanship of Professor R.W. Longley of the University of Alberta from 1967 until his retirement in 1973, then under Ed Stashko, Alberta Forest Service, from

1973-1976, then during the last year under my chairmanship. In October 1969 the continuing committee membership was formally expanded to include a member from the University of Calgary and a second representative from private industry. On two previous occasions the meetings have been open to all interested agencies. The active membership on the committee has been on an informal basis. During our meetings last year 10 agencies were represented, with an average attendance of 15 persons.

The work of the committee over the years has produced some positive action which can be summed up as follows: the publishing of a number of items, helping to make improvements in the climatological network, and acting as a forum for discussion by generators and users of climatological data.

Among the published items are:

1. "Climatic maps for Alberta." July 1968.
2. Meteorological data in Alberta not collected by the Atmospheric Environment Service. First prepared in July 1968 and the latest edition in October 1972.
3. Climate of Alberta, with data for Yukon and Northwest Territories. Tables of temperature, precipitation and sunshine 1971-1975. The data are supplied by the Atmospheric Environment Service and published by Alberta Environment.
4. Bibliography of climatology for the Prairie Provinces 1957-1969, compiled by R.W. Longley and J.M. Powell, University of Alberta. Studies in Geography, Bibliographies 1. University of Alberta Press. 1971.
5. A directory of climate and related courses and persons interested in climatology in Alberta, compiled by J.M. Powell. Environment Canada, Canadian Forestry Service, Northern Forest Research Centre, Edmonton. Information Report NOR-X-172. Dec. 1976.

A current project is the compilation of a hydrometeorological data source sheet for Alberta indicating the agencies involved, the types of data collected, whether such data is published, and the sources of information. We should hear more about the progress with this this afternoon. We are also presently updating the inventory of climatological data not collected by the Atmospheric Environment Service in Alberta.

Today's workshop is a new venture for the committee. As indicated earlier, one of the prime goals of the committee has always been to discover from users their needs for climatological data and to find better ways of disseminating the available data to users. Sometimes potential users are not aware of the data available. At other times they know that the information they want is not available, but they fail to recognize that their problem might be solved by adapting the data which have been collected. Consultation with a climatologist could help the user reexamine his problem in the light of the available data. We believe our various publications have helped the user and the public at large become more knowledgeable about the available data. The publication _Climate of Alberta_ is available free for any schools or persons wishing to receive it. Today we have invited speakers to tell us some of the ways they are applying existing climatological data in their own special fields of interest. We have also included speakers who have collected their own climatological data and applied it.

We hope that as a result of this workshop certain climatological needs of the present or potential user can be identified, on which the committee can take future action. If any of you in the audience have concerns we hope you will express them today or to the committee at some future date. This afternoon after the workshop we will continue with the annual meeting of the Alberta Climatological Committee, and all of you are welcome to attend to hear the brief reports from some of the agencies represented and to partake in other discussions.

APPLICATIONS OF CLIMATOLOGY

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ABSTRACT

Consideration is given to the large amount of weather data recorded in Canada. These data are processed by the Climatological Division, Atmospheric Environment Service, and some of their summary data are published. The extent to which the published data are used by the general public is considered. Also, examples of the need for data not supplied by the published data are presented. The question is then raised about processing the data in other ways to make the results more useful to the general public.

Climatological data present summaries of the weather of a district. As with other statistical problems, a condensation of weather data is necessary in order that it may be used effectively. The simplest measures are the mean values, often on a monthly basis, but other data are useful to some people. Climatological data are used by the general public and also by some scientists whose research treats the variability of weather in time and space.

The mass of climatological data is extremely great. A recent issue of Monthly Record of Meteorological Observations in Canada published by the Atmospheric Environment Service contains over 250,000 items. (This count includes the observations of days with zero precipitation, which are indicated in the booklets by blanks.) Of these items, about 200,000 are raw data; the others are derived values such as the total precipitation for the month or the mean hourly wind. The Atmospheric Environment Service publishes other monthly journals, a Radiation Bulletin, an Upper-Air Bulletin, etc., which increase the amount of published raw data. Other data are not published. Hourly observations are taken at airports, each containing about 10 items, but these are not usually published. Private studies in micrometeorology and other phases of meteorology produce many more. One concludes that the number of individual items of weather data recorded in Canada is about one-third of a million each month.

The Climatological Division of the Atmospheric Environment Service stores and processes the data collected by the division. As with all statistical treatment of data, the processing omits some information that some people may wish, but this summarization of the mass of data produced is necessary for efficient use. For example, the 30-year normal May maximum temperature for Brooks is derived from 1860 observations and is the average of half of these.

There are many texts which discuss, briefly or at length, the applications of climatic data. Griffith (1966) discusses climate as it relates to the following topics: soil, vegetation, agriculture, forestry, animals, the comfort, clothing, health, and food of humans, building, hydrology, transportation, industry, communications, and military science.

Climate and weather affect all these in varying degrees. A pertinent question is to know what climatic information a student of one of these fields must have to understand the past or to plan for the future. For example, how much information does a medical student need in order to relate the climate of a district to the health of the inhabitants?

For many situations, the climatic normals provide sufficient information to determine the answers to the questions that arise. Of these, the most-used normals are the mean monthly maximum and minimum temperatures and the mean monthly precipitation. The soil scientist relates most of the differences he finds in soils to the differences in these normals. The clothing merchant adopts his purchases to meet the demands determined by the average temperature and precipitation. Work out of doors, i.e., farming and road building, can be planned on the basis of climatic means. Of course, the day-to-day operations are often adjusted because of changes in the weather, but such climatic data as mean number of days with precipitation warn the planner that these changes are probable. Military strategy considers the probable weather as it is described by the means. For example, the dry Polish autumn prompted the Germans to choose the date of 1 September 1939 for their attack on Poland.

There are situations where further data are necessary but these data can be estimated from the means. The growth of plants is determined by the temperature as well as by the supply of moisture. Plant scientists relate plant growth and maturing to the number of heat units, the degree-days above a certain base. This quantity for a specific period is related to the mean temperature of the period, but the relationship is not exact when the value varies about the base temperature. Similarly, the heat required for a building is related to the mean temperature, but again the relationship is not exact when the temperature varies above and below the base temperature. The corrections in these cases are not usually significant.

To the agriculturalist, the occurrences of frost and other critical temperatures are important. And the soil scientist wishes to know the frequency of freeze-thaw cycles. The Atmospheric Environment Service does publish frost data to meet the need, but does not attempt to cover all the critical values such as, for example, the winter temperature which damages peach trees. Some guide to the occurrence of these latter values is given in the mean of the monthly minimum temperatures and the extreme values, both of which are published. The snow load on the roof of a large building can at times be excessive and cause the roof to collapse. Architects are anxious to know the probable maximum snow load in order to plan for this additional pressure, and so to keep the building safe when the weight of snow is heavy.

Streamflow, excessive moisture, and periods of drought are all related to weather and climate. The mean streamflow is related to the mean precipitation, account being taken of the losses through evaporation and ground flow. But floods are related to exceptional situations that cannot be detected by examining means. Neither can we study the variation of soil moisture and the probability of drought from mean data. Hydrologists who study such phenomena need to go to the original data to obtain the answers to their questions. The Atmospheric Environment Service publishes storm data for significant storms to aid the hydrologist in some of his studies.

The foregoing has touched on only a sample of the ways that climatic data are applied, but I think it is a representative sample. A knowledge of the mean temperature and precipitation seems to be adequate for many users. Additional data on the occurrence of frosts are helpful to agriculturalists. They, of course, are aware, when they use the data, that it applies to a specific location and that the occurrence of frost varies locally, even from one part of a farm to another.

The physical reaction of a person to the weather is related to the temperature, occurrence of precipitation, humidity, wind speed, and solar radiation. Mean monthly values of all these may be obtained from climatic normals, but these fail to assist in knowing the periods of unpleasant weather during the month. Scientists have developed complex formulas to give the measure of discomfort, but these use concurrent values. The wind chill and the comfort index are two of these measures. There has been very little study on the variation in discomfort from one region to another based on these measures. To do this, one must refer to the raw data, which are unpublished.

Airline companies plan their schedules using mean upper-level winds, and these are available from the Climatological Division. But other activities of mankind are related not to the mean wind but the extreme. The stress on a building or a bridge depends on the wind strength. The architect must prepare for the worst conditions. He then must know the extreme observed wind speed and its probable maximum in the area of interest. These are sometimes not available from climatological records.

Some users then need to know not only the means but also some information on the distribution of values. The publications of the Atmospheric Environment Service usually give the recorded extremes for temperature and precipitation. It may be that data in another form might be more useful. For example, the publication might list the 75th percentiles or the 90th percentiles. A discussion between the users of the data and the Climatological Division might be helpful in determining the most useful statistics for publication.

As noted, there are some measures based on weather data that cannot be derived accurately from published normals. These can be calculated only by specialized treatment of the data. Although the Atmospheric Environment Service might be helpful in sorting the data, the user must be willing to put considerable effort into the work of obtaining the values he needs.

Although the amount of weather data is large, some scientists may not be able to answer their questions from the information available. Consider the difference between the conditions on the south bank and the north bank of the North Saskatchewan River. Because of the difference in absorbed solar radiation, the sides have different climates. This is an example where microclimate makes a difference. If someone feels that such microclimatic differences are significant to his work, then it is necessary that he arrange for his own observations. The Atmospheric Environment Service cannot be responsible for determining the microclimatic differences across Canada. There are too many, and they are too complex. At times the standard observations can be used to detect differences, but this can be considered a side-effect of the task of the Climatological Division to evaluate the Canadian climate.

One may wonder how many of the millions of data that we collect annually are used. When we have long-term and well-cared-for stations at Lethbridge and Medicine Hat, are we using the data from the intermediate stations--Winnifred, Hays, Vauxhall, Bow Island, and Taber--sufficiently to warrant continuing them? The residents of these towns want to have local weather data. And, of course, we would like to have all we can get. But the law of diminishing returns enters. At what point does the addition of an extra station cease making a significant contribution to our climatological knowledge? I do not know.

BIBLIOGRAPHY

Climatic Normals, Vol. 1 - Temperature
Vol. 2 - Precipitation
Vol. 3 - Wind
Environ. Can., Atmosph. Environ. Serv. Downsview. These are three of a projected 6 volumes giving normals for the period 1941-1970.

Griffiths, J.F. 1966. Applied climatology. London. Oxford University Press. 118 pp.

LOCAL HISTORY AS A SOURCE OF CLIMATIC INFORMATION

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ABSTRACT

Local or community history in its many forms contains numerous observations of the impact of weather and climate on life and property, and of weather events of small time and space scales that are usually lost between official weather stations. Large numbers of local histories have been compiled by community organizations in recent years and these are being used as sources of data for a study of tornadoes in Alberta. Preliminary results, based on a small unverified sample, are shown for southern Alberta (Townships 1-25) and south-central Alberta (Townships 26-50). Special attention is paid to possible temporal and spacial bias exhibited by these data and by the official list of Alberta tornadoes to interpretation problems and to date-time verification problems. Formulas for estimating average lengths and widths of tornado destruction paths from census and local history statistics are presented as examples to illustrate the kinds of parameters and assumptions that will be needed in future quantitative analyses.

INTRODUCTION

Is is probably true to say that most local history of Alberta since it became a province in 1905 exists unwritten in the minds of those who experienced the events of days gone by. Nevertheless, many records do exist as potential sources of information on past weather and climate. Some of the most common and accessible kinds of records are the following:

Archives

Newspapers and other periodicals, diaries, letters, official documents, photographs, unpublished manuscripts, taped interviews.

Books and Pamphlets

Biographies and Autobiographies
Anniversary booklets
Tourist booklets
Travel accounts
Church, School, Town, Municipal District, County Histories
Community and Regional Histories by one or a few authors
Community Histories compiled by local organizations.

The number of community histories compiled by local organizations for Alberta and other provinces has increased dramatically since the mid-1960s, stimulated perhaps by jubilee and centennial celebrations, but continuing unabated to the present. More than 50% of the content of such books is in the form of individual family histories often prepared by family members who participated in the events that are described, or by direct descendants of such family members. It is this latter, largely unedited type of history that has proven to be, in the writer's experience, an important source of certain kinds of information on past weather and climate.

With a few major exceptions the type of information found in local histories may be classed as the impact of weather and climate on life, property, and activities, rather than the more familiar numerical statistics of common weather elements. Examples are hail, winds, lightning, summer frost, blizzards, drought, floods, severe winters, and local weather peculiarities when these events were accompanied by serious impact or attracted attention because of rarity, beauty, or other reasons. A light frost in July, for example, may pass almost unnoticed but a "black frost" in July will be remembered by many as a major event. Not all events are catastrophic. Favourable crop weather, mild winters, and locations relatively free of frost, hail, or destructive winds, for example, are mentioned frequently. Many of the events listed above are large-scale events that are known from existing climatic records at widely spaced stations. However, local histories, including newspapers, represent the only comprehensive sources of data for small-scale events that have a major impact on individuals or families.

TORNADO CLIMATOLOGY FOR ALBERTA

In 1975 a small data collection project was initiated as a basis for studies of the climatology of tornadoes in Alberta. At first sight it seems logical to turn to the archives of daily and weekly newspapers as a source of data for such a study. However, when one considers that between 100 and 200 newspapers are published each year in Alberta alone it is obvious that a comprehensive search is not feasible in a small project. It is believed that some 600,000 to 800,000 newspaper issues exist. At an optimistic rate of perusal of 10 minutes per issue one person would be occupied for more than 50 years even if no new issues appeared.

Local history books and booklets represent a much more manageable source of information on tornado occurrences in Alberta. A tornado is an example of a small-scale weather event that may have serious impact without being observed or recorded by conventional weather stations. In subsequent sections of this paper I hope to illustrate the usefulness of such books as sources of special kinds of data. However, the project is in its infancy and the results must be viewed as the tentative, perhaps speculative, results of a progress report.

The initial objective was to gather all recorded data on date, time of day, location, direction of motion, path length and width, number of funnels, and damage for each tornado. It was hoped that adequate samples could be obtained for analyses of mean path length and width, frequency distribution of path lengths, variations in tornado frequencies with latitude, proximity to the Rocky Mountains, and proximity to hail frequency maxima, and for studies of tornado occurrences in relation to synoptic-scale features of the weather map.

An important step toward these goals was realized many years ago in the well-known publications of McKay and Lowe (1960) and Lowe and McKay (1962). In subsequent years annual lists of know tornado occurrences in Alberta were prepared by C.E. Thompson of the Atmospheric Environment Service, Environment Canada. The complete official list to 1970 was published by the Alberta Emergency Measures Organization (1971) (now Alberta Disaster Services). These data, together with information from the Alberta Weather Centre of the Atmospheric Environment Service for 1971-75, represent the starting point of the present project.

As expected, the official list of Alberta tornadoes exhibits possible spatial and temporal bias. The spatial distribution of occurrences (Fig. 1) shows a tendency for clustering of points around Edmonton and Calgary and over the region between the two major cities. This may be real or it may be due to the fact that major sources of information have been the weather offices in Edmonton and Calgary, drawing upon local observations and local newspapers. In addition, the Alberta Hail Project with field headquarters at Penhold has been a major source of data since its beginning in 1956.

The solid-line histogram in Fig. 2 represents 5-year total tornado occurrences from the official list for the period 1905 to 1975. The initial rise in frequencies after 1950 is attributed to increased attention to the problem by staff members in the Edmonton weather office. Further increases after about 1960 are attributed to data from the Alberta Hail Project. It seemed clear in 1975 that further data collections were needed in order to obtain much more detailed information on individual tornadoes and to test the validity of the apparent time and space variations.

At the present time, little can be said about intensities or true frequencies of tornadoes in various parts of Alberta. McKay and Lowe (1960) came to the tentative conclusions that prairie tornadoes

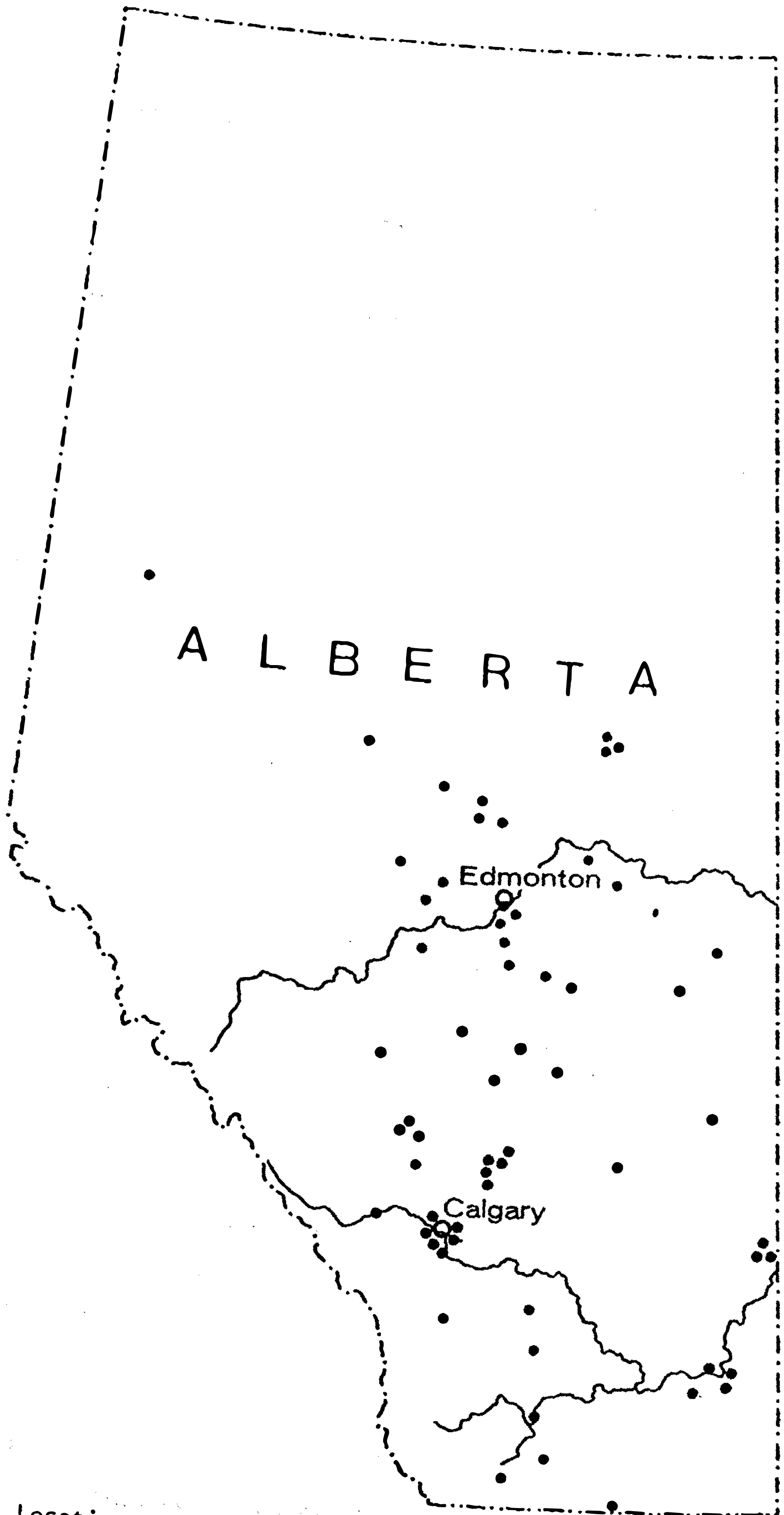
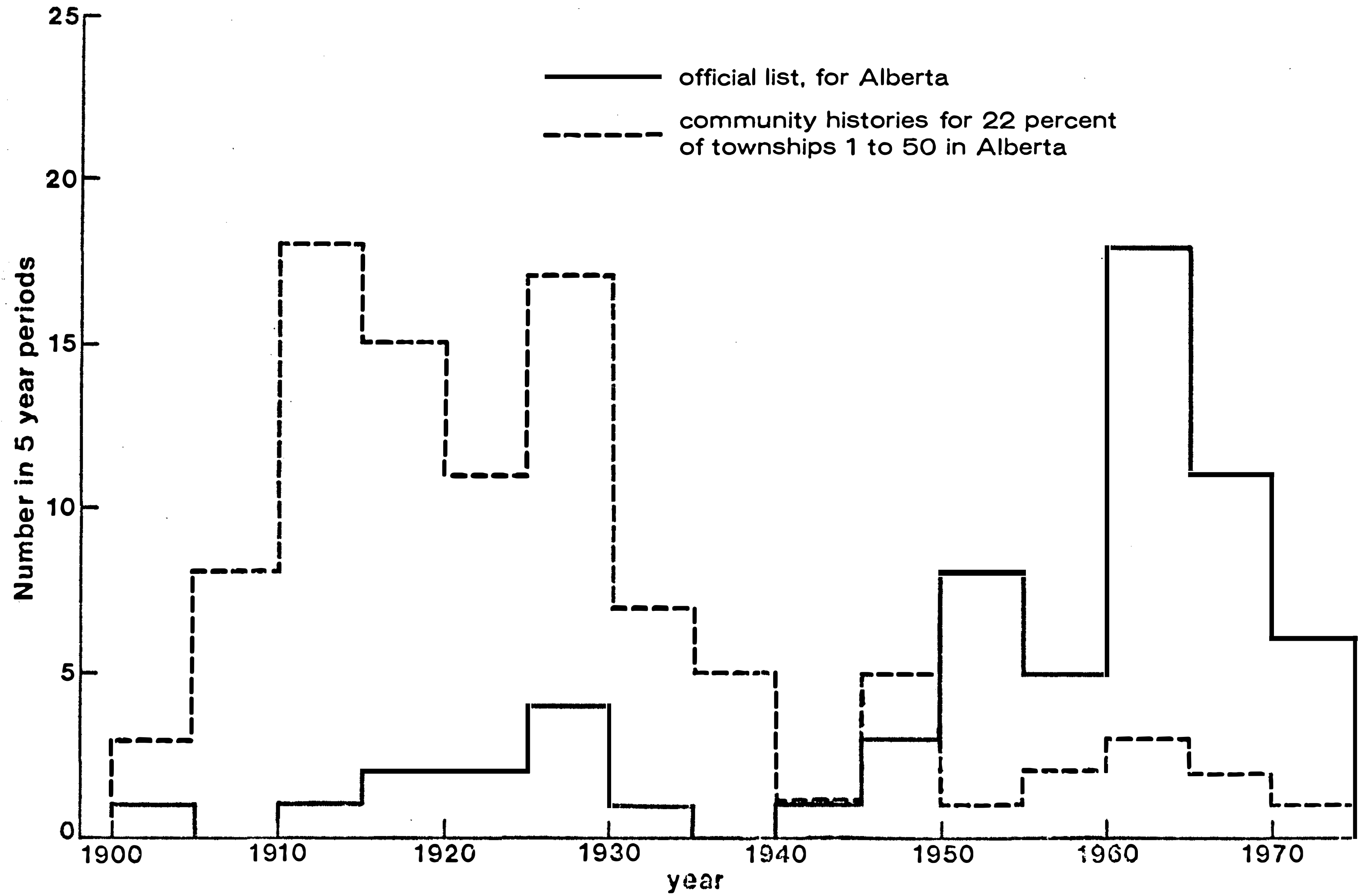


Fig. 1. Locations of tornadoes in the official list for Alberta (1900-1975) showing possible spatial bias.

Fig. 2. Five-year tornado frequencies for Alberta (1900-1975) showing possible temporal bias of the data sources.



were most frequent in July, most frequent in late afternoon and evening, and increased in frequency eastward from Alberta to southern Manitoba. With rapid urban growth and increasing numbers of major industries and power plants scattered across the province it seems reasonable to re-examine the problem and try to improve our understanding of the characteristics of such storms in this area. In addition, because Alberta is thought to be a marginal region for tornado development, an adequate data sample may shed some light on their formation. From a sampling point of view, local histories are very attractive because they tend to focus on the time period from first homesteads to the 1930s--a period of maximum rural population density in Alberta. Average areas of individual inhabited farms have increased greatly since the days of homestead and preemption quarter sections.

PROGRESS REPORT FOR TOWNSHIPS 1 TO 50

At the time of writing 96 books had been logged, including 60 that describe the histories of individual families within districts south of Township 51. The districts included were not always defined explicitly but usually could be determined fairly precisely from the text. The average areal coverage was found to be 6.2 townships (571 km^2) per book, with a range from 0.5 to 22 townships.

The distributions of areal coverages in Townships 1-25 and in Townships 26-50 are shown in Figs. 3 and 4. These districts represent 26 and 19%, respectively, of the total surveyed agricultural lands in each township belt. The spatial and temporal coverage is not random, but this is not necessarily a problem because the statistics needed to estimate actual coverage are available from township maps and from the history books. For example, one may find that a particular community history includes descriptions of 37 farms for an average period of 30 years out of a maximum possible coverage of 60 farms for 70 years in one township. Random sampling of such data for individual townships in a region should provide the correction factors needed to remove systematic space and time sampling errors.

In order to avoid arbitrary preliminary decisions about the

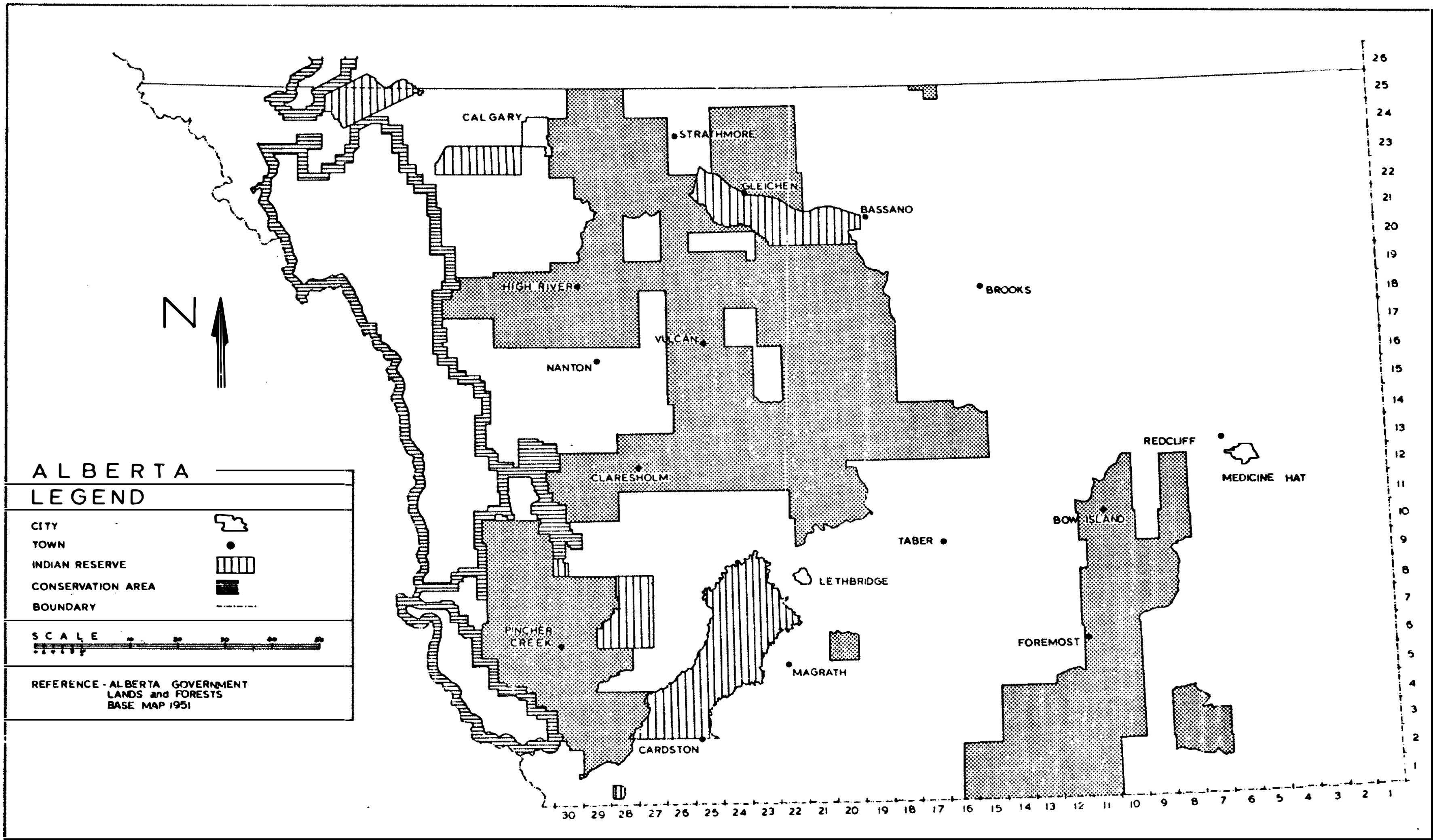


Fig. 3. Areas covered in the initial sample of local histories (townships 1-25).

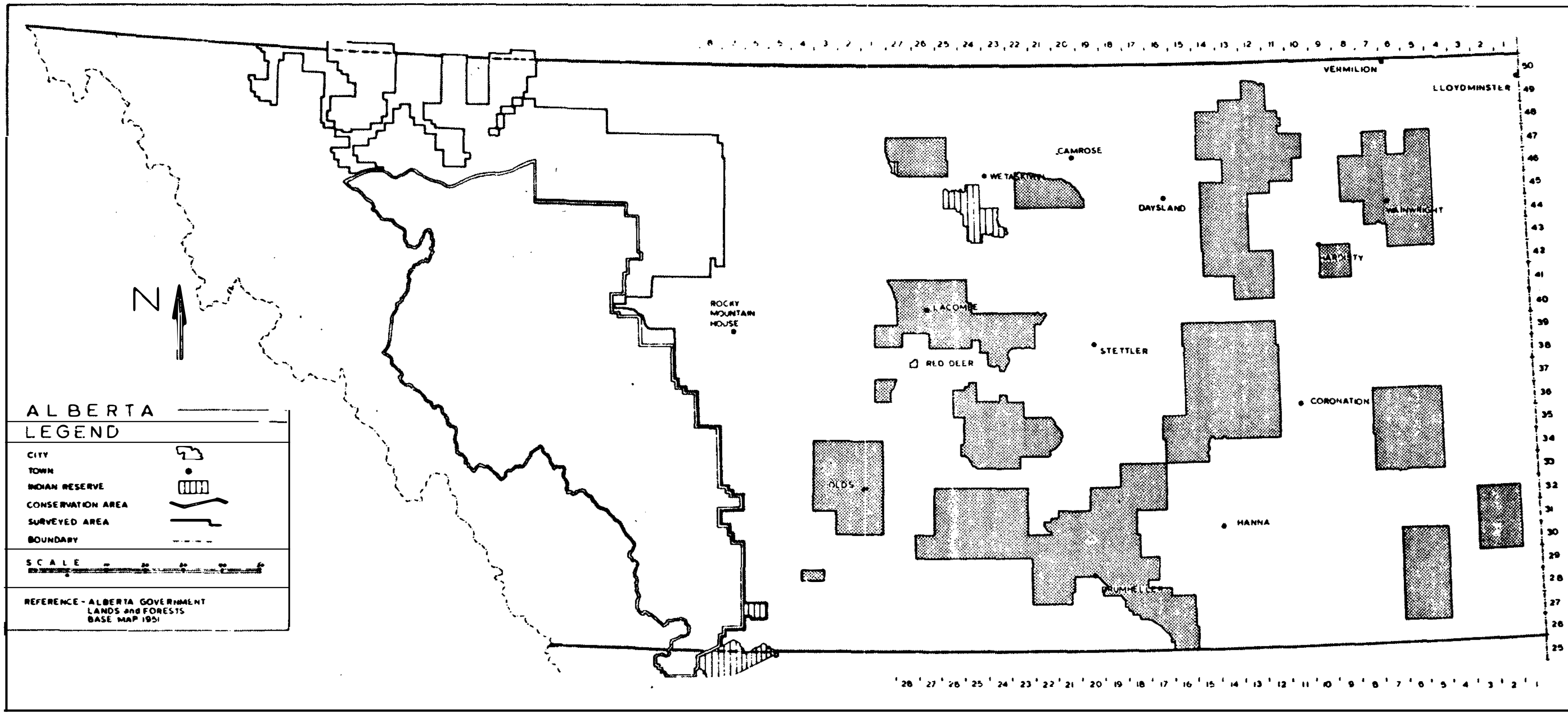


Fig. 4. Areas covered in the initial sample of local histories (townships 26-50).

definition of a tornado, all reported occurrences of destructive winds were logged. Instances of relatively minor damage such as removal of shingles or roofing materials, blowdown of one or a few trees, or broken windows were not included unless accompanied by additional evidence that a tornado had passed. Nontornadic destructive winds known to occur in Alberta are those associated with cold fronts, synoptic-scale pressure gradients accompanying intense low-pressure centers, fire whirls, chinooks, mountain pass or valley winds in fixed geographical locations, and thunderstorm downdrafts. The last-named are the most difficult to distinguish from tornadoes because both are associated with thunderstorms. In the absence of observations of funnel clouds the principal clues are:

(a) Low-pressure effects (explosive or lifting) associated with tornadoes; missile effects

(b) Narrow path or small area of damage

(c) Evidence of rotary motions

No evidence has been found to date of significant damage due to dust devils in Alberta.

The histories referred to above described 169 destructive wind events. Of these 91 were identified tentatively as tornadoes, either because they were called tornadoes (cyclones, twisters, or whirlwinds) or because of the nature of the damage. Only 7 of these coincided with events in the official list of tornadoes in Alberta. In each case additional evidence and confirmation of dates and times will be sought in local archives and local newspapers.

Five-year total tornado frequencies derived from local histories from all parts of Alberta are shown by the dashed histogram in Fig. 2. The abrupt rise from 1900 to 1910 is attributed to the rapid settlement of land in those years, and the decline after 1930 is attributed partly to declining rural population density, particularly in some districts, and partly to the tendency for local histories to neglect events of the more recent past in favour of those of earlier days. It seems clear from Fig. 2 that alternative data sources such as local newspapers are needed for the period 1930-1960.

The spatial distribution of reports derived solely from local histories in southern Alberta (Townships 1-25) and south-central Alberta

(Townships 26-50) are shown in Figs. 5 and 6. When we sum the occurrences in Figs. 5 and 6 we find standardized frequencies of 0.2 per 10 000 km^2 per year in southern Alberta and 0.4 per 10 000 km^2 per year in south-central Alberta for the period 1900-1975. Kessler and Lee (1976) have published statistics for the United States, but the numbers are not comparable because of the restrictions in the present study to areas covered by the sources of data. Comparable statistics for Alberta can be obtained only if we divide the total number of known or suspected tornadoes for the province as a whole (205 at the time of writing) by the total area of the province (653 530 km^2). The result is .04 per 10 000 km^2 per year for 1900 to 1975. A frequency of .08 per 10 000 km^2 per year for the period 1953-1974 is given by Kessler and Lee (1976) for Montana.

THEORETICAL ESTIMATES OF MEAN TORNADO PATH LENGTHS, WIDTHS, AND AREAS

If adequate samples of unbiased tornado frequency data can be obtained, and if certain basic assumptions can be made about these frequency distributions, then it should be possible to estimate the average area of tornado damage paths and from this the "true" frequency of occurrence. The required assumptions are (a) that the true frequency distribution of tornadoes is constant over a selected period of years and over a selected region and (b) that groups of buildings such as farmsteads, schools, churches, or villages and towns are randomly distributed in distance and direction with respect to the distribution of tornado damage paths. Assumption (b) is necessary because almost all known tornado occurrences involved damage to one or more buildings in such groups. If an additional assumption is made that damage path widths are statistically independent of damage path lengths it should be possible to estimate mean path widths and lengths separately. The estimates referred to above require knowledge of certain parameters that can be obtained from local histories or from census data.

Let M represent the number of farmsteads and N_T the true number of tornadoes in a region of area A_R and within a specified time period T. If W and L represent the mean width and mean length respectively of tornado damage paths, then the area of influence A_T,

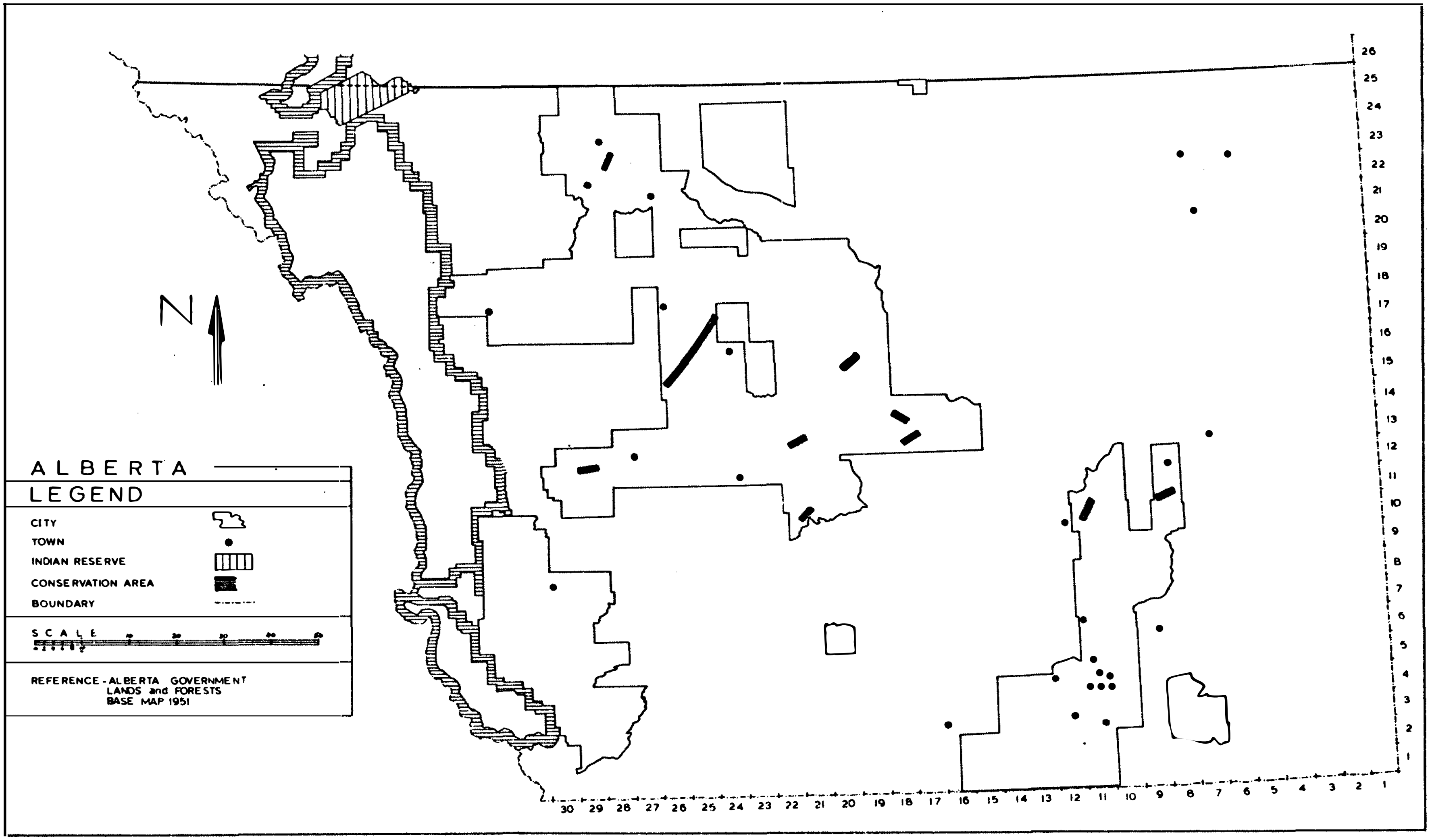


Fig. 5. Locations of tornadoes derived from the initial sample of local histories (townships 1-25).

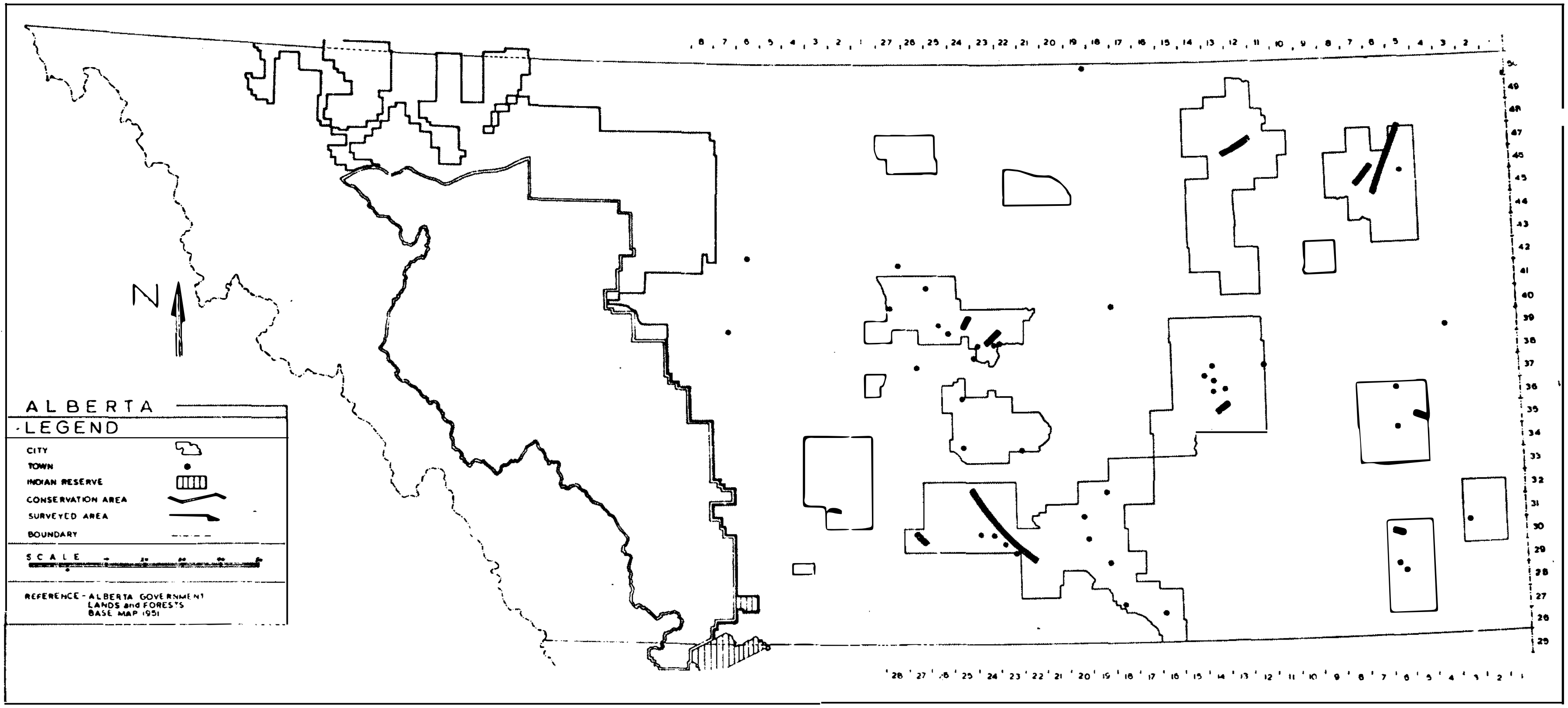


Fig. 6. Locations of tornadoes derived from the initial sample of local histories (townships 26-50).

assumed to be rectangular, is

$$A_T = (W + \ell)(L + \ell) \qquad (1)$$

where ℓ is the diameter of a circle having area equal to the mean farmstead area in A_R. The number of farmsteads expected to suffer damage (N_1) is given by

$$N_1 = \frac{M\ N_T\ A_T}{A_R} \qquad (2)$$

Similarly, if S is the number of rural schools in A_R, and if A_S is the area of influence of tornadoes that damage school buildings, then the number of schoolyards expected to suffer damage (N_2) is given by

$$N_2 = \frac{S\ N_T\ A_S}{A_R} \qquad (3)$$

where

$$A_S = (W + d)(L + d) \qquad (4)$$

and d is the diameter of a circle having area equal to the mean area of a schoolyard.

One additional equation is needed in order to solve for the unknown quantities N_T, W, and L. The necessary equation can be derived from a consideration of the probabilities of damage to one or more farmsteads by one tornado.

Let the probability of having exactly one farmstead within the influence area A_T be p ($p \leq 1$). If the probabilities of damage to sequential farmsteads are independent of each other then the probability of having exactly n farmsteads with A_T is p^n where n is an integer ($n \geq 1$). The probability P of damage to one or more farmsteads is obtained by summation

$$P = \sum_{n=1}^{\infty} p^n = \frac{p}{(1 - p)} \qquad (5)$$

From (2) the expected value of n in area A_T is

$$\bar{n} = \frac{M A_T}{A_R} \tag{6}$$

But

$$\bar{n} = \sum_{n=1}^{\infty} n\, p^n = \frac{p}{(1 - p)^2} \tag{7}$$

The solution to (7), subject ot the condition $p \leq 1$ is

$$p = \frac{(2\bar{n} + 1) - (4\bar{n} + 1)^{\frac{1}{2}}}{2\bar{n}} \tag{8}$$

Now, if N_3 is the number of tornadoes that resulted in damage to one or more farmsteads in Area A_R and time T

$$N_3 = N_T P = \frac{N_T P}{(1 - p)} \tag{9}$$

Combining (8) and (9)

$$N_3 = N_T \left\{ \frac{(2\bar{n} + 1) - (4\bar{n} + 1)^{\frac{1}{2}}}{(4\bar{n} + 1)^{\frac{1}{2}} - 1} \right\} \tag{10}$$

Therefore, given observations of N_1, N_2, N_3, M, A_R, ℓ, and d, equations (1), (2), (3), (4), (6), and (10) can be solved for the unknowns N_T, W, and L.

An alternative estimate of W can be obtained in the following way. Consider a subsample of all tornadoes that having caused damage at one farmstead moved on to cause damage at a second farmstead at distances greater than or equal to r. The assumed path is shown in Fig. 7.

The area $(W+\ell)r$ would be expected to contain N_4 farmsteads where

$$N_4 = \frac{M(W+\ell)r}{A_R}$$

Therefore,

Farmstead area of diameter ℓ

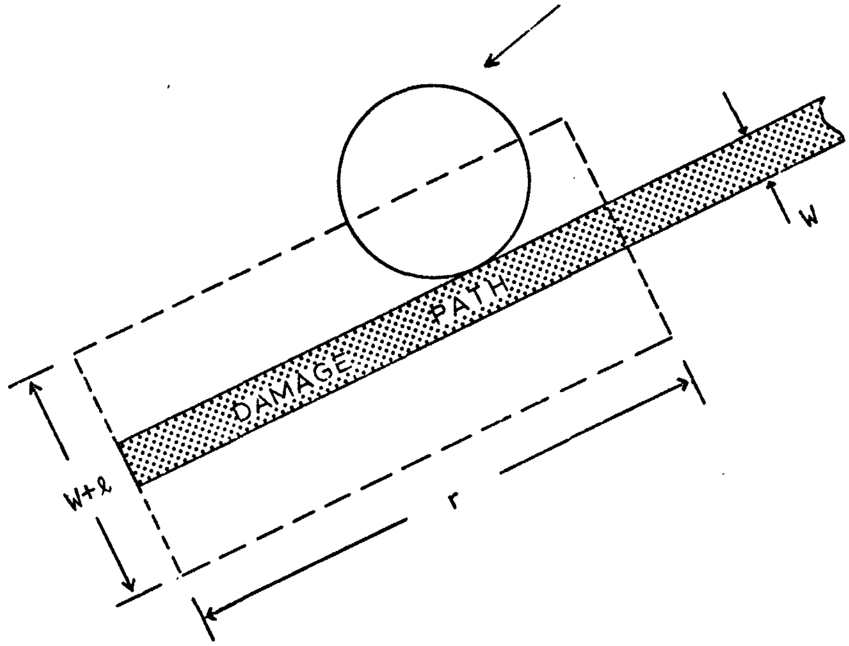


Fig. 7. Dimensions of tornado damage path

$$W = \frac{N_4 A_R}{Mr} - \ell \qquad (N_4 = 1,2, \ldots) \qquad (11)$$

For a given r, the width W must be assumed constant. However, as r varies W may vary also, and (11) permits a rough check on variations of W with L if adequate samples are available.

If, in a significant number of cases, the path of damage is intermittent then the value of W estimated by (11) will be too small. If multiple tornadoes occur in proximity the estimate of W based on (11) may still be useful but, of course, it will be no longer the path width for individual tornadoes. Finally, it is evident from Fig. 7 that W will not be sensitive to path curvature as long as the curvature is not excessive. Large curvatures of long-path tornadoes should be apparent from the observations, and appropriate corrections can be introduced into (11).

The parameters M and ℓ will vary from place to place within A_R and from year to year within T. However, reliable mean values can be obtained by proper sampling.

The statistics N_1, N_2, N_3, and N_4 derived from farm histories will require correction factors because not all farms are included for all years. It should be possible to estimate these correction factors by sampling supplementary data in the community histories. Alternatively, the value of M can be equated to farms that are described in the histories rather than to all farms. Incomplete coverage is not expected to be a serious problem for rural schools or for villages and towns.

No attempt has been made to estimate N_T, W, L, and A_T because currently available data samples need additional confirmation and expansion. Nevertheless it seems clear that, in principle, all necessary parameters can be obtained from local histories or from census data. If adequate samples are available, it should be possible to estimate frequencies and dimensions with reasonable confidence and to carry out certain tests for the presence of bias in the data. It would be naive to suppose that absolute values of N_T can be derived. However, relative values of N_T, e.g., from region to region, should be possible. Furthermore, as shown by (11), not all tornado path characteristics of interest require knowledge of the true frequency N_T.

SUMMARY AND CONCLUSIONS

Community histories compiled by residents and local organizations represent potential sources of data on the impact of weather and climate on life, property, and activities and on important small-scale weather events. Such histories are now available for a large fraction of the total agricultural lands of Alberta.

A progress report is presented on the results of attempts to use local histories as sources of data for a climatology of tornadoes in Alberta. The histories show no evidence of spatial bias but exhibit a preference for the years prior to the 1940s. Verification of dates and times by reference to local newspapers and archives may be necessary in some cases.

Formulas for estimation of "true" tornado frequencies and damage path characteristics are derived using two or three key assumptions. The required parameters in these formulas are available from local histories and census data. It is concluded that local histories can be valuable supplements to conventional sources of climatic data.

ACKNOWLEDGMENTS

The preceding study was made possible by the efforts of many individuals and community organizations who compiled local histories after uncounted hours of search and interviews. A bibliography of source documents is in preparation as the study progresses.

Thanks are due to C.E. Thompson for information on tornadoes in Alberta after 1960 and to my colleague Prof. E.P. Lozowski for his important contributions to the statistical analysis of tornado paths.

REFERENCES

Alberta Emergency Measures Organization. 1971. Twister. Survival 7(2): 6-7.

Kessler, E. and J.T. Lee. 1976. Normalized indices of destruction and deaths by tornadoes. NOAA Technical Memorandum ERL-NSSL-77. 47 pp.

Lowe, A.B. and G.A. McKay. 1962. The tornadoes of western Canada. Canada Department of Transport, Meteorological Branch. 42 pp.

McKay, G.A., and A.B. Lowe. 1960. The tornado in western Canada. Bull. Am. Meteorol. Soc. 41(1): 1-8.

CLIMATOLOGICAL ASPECTS OF WIND AND SOLAR ENERGY

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ABSTRACT

The increasing concern for energy and the renewed interest in alternate energy require climatologists to provide more and better data. The data needed for wind and solar energy calculations are discussed.

INTRODUCTION

Solar energy is a broad classification and from many points of view, it is expedient to consider solar energy as the insolation onto the earth's surface, and the air movement that occurs because of this insolation as potential wind energy.

I shall consider wind energy first.

WIND ENERGY

It has been estimated that the wind power of the atmosphere available for turbines is of the order of 2×10^{10} kW (World Meteorological Organization, Geneva). According to an NSF/NASA estimate, the USA has enough harnessable wind to generate 1.28×10^{9} kW.h of electrical energy per year (Machine Design, May 20, 1976). This is about one-half the annual output of all fossil fuelled generating plants in the U.S.A. Dr. Templin of the Low Speed Aerodynamics Laboratory of the National Research Council in Ottawa says that the wind power potential of the James Bay area is equivalent to the hydro potential--without the flooding. Calculations show that some 22,000 wind generators, similar to the NASA test model in Ohio, placed in Southern Alberta could generate the equivalent annual thermo electric power in all Alberta.

It is not necessary to try to reconcile the above data since most calculations have been based on very sparse meteorological data. It illustrates that the power in the wind, if properly harnessed, could be significant.

It is my intent to show the type of climatological data needed in order to get a quantitative appreciation of how much wind power one might expect in any given location in Alberta.

Power is energy per unit time. The kinetic energy of any moving particle is $1/2\ mV^2$ where:

m is the mass of the particle

V is the velocity of the particle

The volume of wind moving with a velocity V through a given area, A, per unit time is A times V.

The mass per unit time is ρAV, where ρ is the air density.

The power of the wind having a velocity V and a density ρ passing through a propellor of area A is therefore:

$$\text{Power} = 1/2\ mV^2 = 1/2\ (\rho AV)V^2 = 1/2\ \rho AV^3$$

The power in the wind is proportional to the density of the air, the swept area of the propellor, and the cube of the wind velocity.

Professor Betz at Gottingen in 1927 was able to show that the maximum power (not energy) that any windmill could extract from the wind was only 16/27 or 59.3% of the power contained in the wind. This was obtained by a momentum balance on the wind passing through the rotor; details of the derivation are given in several elementary texts.

With this information and an annual average wind velocity, the annual power potential for a given area can supposedly be calculated. But the average of the sum of cubes is generally not the same as the cube of the average of the sums. This means that by simply cubing the average annual velocity for the given location the correct estimate of the annual power in the wind will not be obtained. The data needed for the location are the number of hours the wind blows at given speeds. The smaller the wind speed increment, the more exact is the calculation. It is a formidable task to obtain this data from anemograph records by evaluating mean velocities over short intervals of time. Computers have solved this problem, and the Atmospheric Environment Service can provide the data in a suitable form for some locations.

The data for twelve such locations in Alberta were obtained from the Atmospheric Environment Service and were used to calculate the tables of the Research Council of Alberta report, Wind Power in Alberta (Hawrelak et al. 1976). These data were used to plot the very illustrative velocity duration curves in the report, which show on an annual basis the percentage of time winds exceed any given velocity.

Wind energy is site-dependent and for major installation, extensive surveys should be conducted.

The influence of height has been studied, and the often-used rule is that wind speed increases with the one-seventh power of height. The power in the wind should therefore increase with the three-sevenths power of height above the ground. This approach is adequate for most preliminary design calculations.

Wind machines require a minimum speed before they can produce power. The historical data can be used to estimate the longest period that the wind blows below this minimum speed. The longer the available data, the more reliable is this estimate.

Maximum wind speed data are required for design purposes only. It is unlikely that wind machines would be designed to extract the energy from winds blowing at their maximum velocities.

It is desirable to know the diurnal variation of wind speed. For example, a wind generator for household power generation would probably need to provide most power in the early evening and nighttime hours. Also, in the next section on solar energy, the difference between wind speeds during daylight and nighttime hours is necessary information.

In site selection and design of wind power generation stations, prevailing wind direction must be considered. The climatologist must therefore provide:

1. Maximum wind speed data
2. Maximum duration of calm or very light winds (say 13 km per hour)
3. Hourly wind speeds throughout the year and possibly for as many years as they are available
4. Diurnal variation of wind speed
5. Prevailing wind direction

SOLAR ENERGY

Approximately 4,000 MJ are incident on each metre each year in the Edmonton area. This is a significant amount of energy. However, application of this energy to domestic water heating, space heating, grain drying, swimming pool heating, steam generation, photovoltaic electric power generation, etc. requires more data than just an annual amount of insolation.

The examples listed above require energy for part or all of the year, and some depend on direct or beam energy while others can use both direct and diffuse energy.

The instrument to measure the amount of insolation is the pyranometer, which depending on how it is installed, can measure diffuse, direct, or total radiant energy.

There are more than 50 stations across Canada measuring total radiation on a horizontal surface but only three are located in Alberta (Beaverlodge, Edmonton, Stony Plain, and Suffield). This is very sparse coverage for an area as large as Alberta, but there may be some changes in the near future.

At the present time, the latitude and the total radiation data are used to predict both the direct and diffuse components of radiation. Generally a correlation such as that of Liu and Jordan (1960) of the USA is used. But in Canada the errors could be significant, especially when a comparison is made with the more recent and Canadian study by Ruth and Chant (1976). It is evident from the graph that other factors not considered in these correlations are important.

Although solar radiation data are not as site-specific as wind data are, microclimates do exist, and only a multitude of observation stations could identify them.

Three separate instruments could provide hourly direct, diffuse, and total radiation data. If funds are available for only two instruments, then values for the third could be obtained by difference since direct radiation plus diffuse radiation equals total radiation on a horizontal surface. This installation will give hourly insolation data.

Insolation on nonhorizontal surfaces can be obtained by calculation provided that a good estimate of the albedo can be made. The diffuse radiation calculations assume on isotropic sky. The direct radiation calculations depend strictly on geometry. A study has just commenced to verify the validity of the assumptions in calculating insolation on nonhorizontal surfaces.

The amount of insolation that can be captured depends on the physical properties of the incident surface. It also depends on ambient temperature and wind conditions. For this reason, in quantitative solar energy calculations it is necessary to know the ambient air temperature and wind speed and direction for the periods when solar energy is captured. Generally this means that average air temperature and wind data are needed for daylight hours. Similar data for nighttime hours for heat loss calculations would also be useful. The climatologist should therefore be prepared to provide:

1. Direct radiation
2. Diffuse radiation
3. Total radiation
4. Diurnal average ambient temperatures
5. Diurnal average wind velocities and direction
6. Maximum duration of low solar radiation (say 50 langleys per day)

REFERENCES

Hawrelak, J., T. Rachuk and J. Barlishen. 1976. Wind power in Alberta. Alberta Research Council, Information Series No. 70. 112 pp.

Liu, B.Y.H. and R.C. Jordan. 1960. The interrelationship and characteristic distribution of direct, diffuse and total solar radiation. Solar Energy 4(3):1-19.

Ruth, D.W. and R.E. Chant. 1976. The relationship of diffuse radiation to total radiation in Canada. Solar Energy 18:153-154.

PRECIPITATION MEASUREMENT BY WEATHER RADAR

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ABSTRACT

Precipitation measurements are of prime importance in studies of meteorology, climatology, and hydrology. These measurements can be improved by weather radars used in conjunction with conventional rain gauges and snow gauges.

Weather radars, similar to the radar operated by the Alberta Research Council at Penhold Alberta, are able to determine the variability in precipitation patterns, a fundamental limitation of most gauge networks. Because weather radars can also provide a quantitative measure of falling precipitation, such measurements can be used to interpolate between gauges, thereby providing improved estimates of areal precipitation amounts. The improvement is considerable, since over an area of 1000 km^2 the amount of showery precipitation accumulated during a 1-hour period measured by 10 gauges can be correct to within about 40%; a radar calibrated with the same gauges can provide an estimate to better than 20%.

Advances in digital radar data management have now made possible easy use of improved precipitation estimates for agricultural applications that depend upon measurements of precipitation, hydrological applications such as flood forecasting, and other climatological purposes.

1. INTRODUCTION

It is well known that precipitation observations occupy a central role in studies of meteorology and climatology. Such observations serve a multitude of purposes, and it is not surprising that other fields such as agriculture and hydrology commonly require information on precipitation amounts at the surface. In this regard, considerable attention is given to various methods for determining characteristics of falling precipitation.

As a result of variability in precipitation patterns, traditional methods of precipitation measurement by gauges (e.g., rain gauges and snow gauges) are sometimes limited. Fortunately, these limitations can often be overcome by using a weather radar in conjunction with the gauges. Recognizing the critical need for accurate precipitation measurements, this report provides a short review of the success to be expected in measuring precipitation with both a weather radar and gauges.

Although conventional gauges probably provide the most accurate measure of precipitation at a point on the surface, variability in precipitation patterns implies that a network of gauges is required to measure precipitation amounts over an area. The accuracy of areal precipitation amounts is then determined by the density of gauges within the network. This problem of estimating precipitation amounts using gauges remains far from solved (Rainbird 1967) although recent studies (e.g., Zawadzki 1973) provide significant contributions. On the other hand, weather radars offer two fundamental advantages for precipitation measurement. Most importantly, they are able to remotely estimate distributions of precipitation amounts over areas as large as 50 000 km^2. In addition, weather radars detect precipitation that would go undetected by many gauge networks. For example, intense storms 10 km across can pass undetected through a network of rain gauges spaced 20 km apart. It follows that weather radar data used in conjunction with surface gauge data probably provide one of the most accurate estimates of precipitation falling to the surface.

Advancements in radar meteorology have continued since the 1940's when radars were first used to observe the weather, and when the first quantitative relationships between radar measurements and surface rainfall rates were established (Marshall and Palmer 1948). A significant achievement was the implementation of computers to record the large quantities of radar data. It is now possible to use radar data quickly and easily to determine precipitation rates or areal precipitation amounts. The results of improvements in technology have therefore made improved estimates of precipitation available. However, there are new challenges in data management. Solutions to these challenges are in progress (Ramsden et al. 1976) and are considered further in this report; it is shown that weather radar precipitation measurements can be made more readily available for easy use by nonradar meteorologists.

Although the utility of digitized weather radar precipitation data is recognized elsewhere in fields such as hydrology (e.g., Cummings et al. 1974; Green 1975), it was found in a recent study by Barge et al. (1976) that weather radars add a new dimension to precipitation observations in Alberta. Although the capabilities of weather radars extend far beyond the ability to measure precipitation falling to the surface (Battan 1973), Appendix I lists some practical uses of precipitation measurements[1]. Other uses such as forecasting wheat yields from rainfall data (Lomas 1972), and river basin management and reservoir sluice operation (Harding 1972) depend upon improved estimates of precipitation. Weather radars, subject to the qualifications outlined in sec. 3, provide such measurements.

2. PRINCIPLES OF WEATHER RADAR MEASUREMENTS

This section briefly outlines principles behind the measurement of rainfall by radar. A more detailed account can be found in Battan (1973).

Radar Detection of Precipitation

A radar periodically (e.g., 300 times per second) transmits from an antenna a pulse of microwave radiation, the duration of the pulse being typically a few microseconds, the peak power transmitted usually several hundred kilowatts, and the frequency in the gigahertz range. When this pulse of microwave energy intercepts precipitation, some of the energy is scattered back to the antenna, where it is detected and processed; resulting data can be displayed on a cathode ray tube indicator or possibly stored on computer-compatible magnetic tape. The time between transmission of the pulse and reception of the backscattered radiation determines the range of the precipitation from the radar, while the antenna position determines the azimuth and elevation of the precipitation with respect to the radar site. The magnitude of the received power is a measure of the precipitation intensity.

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[1] Such weather radar measurements are currently made in Alberta near Red Deer and Edmonton.

For spherical particles, small compared to the wavelength of the transmitted radiation (Rayleigh scattering), the average received power from a unit volume can be represented as

$$\overline{P}_r = \frac{C|K|^2}{r^2} \sum_{\substack{\text{unit}\\ \text{vol}}} D_i^6 \qquad (1)$$

where C is a constant representing radar dependent parameters, $|K|^2$ is the dielectric constant, r is the range from the radar to the particles, and D_i is the particle diameter. Equation (1) can be written as

$$\overline{P}_r = \frac{C|K|^2}{r^2} Z \qquad (2)$$

where Z is the reflectivity factor. For an assumed dielectric constant when the conditons for Rayleigh scattering are not fulfilled, Z can be replaced by Z_e, the equivalent radar reflectivity factor. Since Z is the sum over a unit volume of the sixth power of the particle diameters, it is usually expressed as millimetres to the sixth power per cubic metre (mm^6m^{-3}).

Rate of Precipitation

The rate of precipitation (R) is defined as the flux of water volume reaching the ground per unit time. The precipitation intercepted by the radar beam can also be interpreted in terms of flux. A single drop contributes to the precipitation rate according to the relation

$$\Delta R_i \propto \frac{\pi}{6} D_i^3 w_i \qquad (3)$$

where w_i is the fall speed of a raindrop with diameter D_i. The precipitation rate from a unit volume is just

$$R = \sum_{\substack{\text{unit}\\ \text{vol}}} \Delta R_i = \frac{\pi}{6} \sum_{\substack{\text{unit}\\ \text{vol}}} D_i^3 w_i \qquad (4)$$

Terminal fall speeds of water drops have been measured and found to be a function of the drop diameter (du Toit 1967). Very small drops ($D < 80\ \mu m$) fall according to Stoke's law with a terminal speed proportional to the square of their diameters. For drops with very large diameters ($D > 4.5$ mm) the terminal fall speeds is nearly independent of diameter. Therefore, the contribution to the precipitation rate for very small and large drops is as follows:

$$\Delta R_i \ \alpha D_i^{\ 5} \text{ for } D_i < 80\ \mu m \tag{5}$$

and

$$\Delta R_i \ \alpha D_i^{\ 3} \text{ for } D_i > 4.5 \text{ mm} \tag{6}$$

Z-R Relationships

It has been shown that both the precipitation rate (R) and the reflectivity factor (Z) are related to the diameter of precipitation particles. It is therefore possible to relate the precipitation rate to measurements of the reflectivity factor. From equations (1) and (2) it is apparent that the contribution to the reflectivity factor from drops in any one diameter interval is

$$\Delta Z_i \ \alpha D_i^{\ 6} \tag{7}$$

For very large drops equation (6) shows that $\Delta R_i \ \alpha D_i^{\ 3}$ so that $\Delta Z_i \ \alpha (\Delta R_i)^2$. Therefore, if all the drops in a unit volume are very large

$$Z = \Sigma\ \Delta Z_i \ \alpha \ \Sigma(\Delta R_i)^2 < (\Sigma\ \Delta R_i)^2 = R^2 \tag{8}$$

Similarly, for a unit volume containing only very small drops, equations (5) and (7) show that

$$Z = \Sigma\ \Delta Z_i \ \alpha \ \Sigma(\Delta R_i)^{1.2} < (\Sigma\ \Delta R_i)^{1.2} = R^{1.2} \tag{9}$$

Consequently, the reflectivity can be related to the precipitation rate by an expression of the form

$$Z = AR^{b} \tag{10}$$

where, based on the arguments above, $1.2 < b < 2$. The actual values of A and b depend upon the distribution of the raindrops with size.

Calibration of the Radar

Marshall and Palmer (1948) measured the distribution of raindrops with size in stratiform rain and found an exponential relation between the drop diameter and the number of drops per unit volume. They found a Z-R relationship to be

$$Z = 200R^{1.6} \tag{11}$$

(note the exponent lies within the limits determined above). It is well known that the distribution of raindrops with size varies with time, geographical location, and meteorological conditions, so that equation (11) cannot generally be used to determine precipitation rates from radar measurements. Therefore, it is necessary to determine the appropriate Z-R relation by measuring raindrop sizes or measuring R with a rain gauge and comparing to radar measurements of Z. The latter method is most common but there are limitations that must be considered (see sec. 3). By combining equations (2) and (10) it is possible to relate the average received power to the precipitation rate:

$$\overline{P}_r = \frac{CAR^b}{r^2} \tag{12}$$

where C now includes the dielectric constant as well as the radar parameters. Rearranging equation (12) gives

$$R = \left(\frac{r^2\overline{P}_r}{CA}\right)^{1/b} \tag{13}$$

The calibration problem is to determine A and b by comparing rain gauge measurements of R with radar measurements of Z. As an example, the parameters A or b can be determined by comparing rain accumulations at a particular gauge with $\Sigma\overline{P}_r^{\,1/b}$ over that gauge for intervals of 1 h. The values of P_r used in the summation would be mean values of the average received power for some appropriate area (say 2 km^2) above the gauge. If there are several rain gauges within the area of radar coverage then the calibration can be determined for appropriate areas around each gauge. Once the calibration is complete, other measurements of Z can be interpreted in terms of areal rainfall rates and amounts. The spatial and temporal stability of such calibration relationships then determines the accuracy of further radar-derived precipitation measurements made elsewhere.

Resolution

The spatial resolution of radar measurements is determined primarily by the size of the radar antenna. Beam widths about 1° are common, which implies about 2 km resolution in azimuth at 100-km range from the radar. Although the resolution in range can be as small as half a pulse length of the transmitted radiation, the received signal is usually averaged over range intervals of about 1 km. Therefore, within 100 km distance from a radar the spatial resolution can easily be 2 km. The temporal resolution depends upon the time interval between sequential observations immediately above specified surface locations. This time interval depends upon the rate of rotation of the radar antenna and can be as small as a few seconds, but for hydrological use it can be greater than 30 seconds.

The resolution requirements of radar measurements are fairly obvious, while on the other hand determination of the accuracy of quantitative measurements can sometimes be a bewildering affair. The complexity of the problem unfortunately cannot be overlooked. The following section considers the accuracy of radar measurements of precipitation.

3. ACCURACY

The shortcomings of rain gauges mentioned previously, especially their inability to provide areal estimates of precipitation, are somewhat overcome by radar techniques. Signals received by radar after scattering from precipitation are interpreted in terms of rainfall amount as described above. However, fundamental limitations of radar techniques and the variable nature of precipitation lead to uncertainties in the interpretation of radar signals. Some of the causes (perhaps not all!) of errors in radar estimation of rainfall or snowfall are listed in Table 1. Notwithstanding these difficulties, it has been shown, for example, by Wilson (1970), that the radar accuracy of precipitation estimation can be improved if the radar is calibrated against rain gauges, an excitement shared by Lowing et al. (1975) who indicated "The rain gauge alternative in radar estimation of rainfall is comparatively inaccurate for areal estimation of rainfall."

Table 1. Some sources of error in the measurement of rainfall or snowfall which result from the precipitation disposition itself, or which are inherent in radar techniques.

- Frequency of radar data collection
- Errors in electronic radar calibration
- Anomalous propagation
- Attenuation of the radar beam
- Errors due to radar averaging of precipitation
- Nonuniform filling of the radar beam
- Radar beam intercepting the melting level
- Presence of hail or other hydrometeors
- Variations in distributions with size of raindrops
- Variations in snow crystal type
- Vertical air motions which affect fall-speed of raindrops
- Evaporation or growth of precipitation below the radar beam

In recent years there have been significant advances in radar calibration and data analysis procedures. These steps facilitate more precise comments on the accuracy of precipitation measurement by radar.

Therefore, it is considered expedient to dwell upon the ability of a radar-rain gauge system to quantitatively measure precipitation, rain gauges being used to calibrate the radar.

To assess the accuracy of radar precipitation measurements an exact standard is required that is considered to represent, for example, the amount of rainfall over some specified area. Because rain gauge networks are usually structured with less than an infinite density of rain gauges, such networks cannot represent areal rainfall exactly. However, some studies have considered the rainfall measured from a relatively dense network (1 gauge per 7 km^2, Wilson 1970; 1 gauge per 3 km^2, Woodley et al. 1975) to be a measure of actual average rainfall. Other studies (Harrold et al. 1974; Collier et al. 1975) have used the radar echo intensity pattern to interpolate between gauges within a dense network to obtain an "optimum" field. In all the above cases the difference between calibrated radar measurements and the "actual" or "optimum" measurements is considered as a measure of accuracy.

The philosophy of precipitation measurement by radar is to utilize a radar calibrated against some number of surface measuring precipitation gauges, the number of calibration gauges being less than that required to obtain the "actual" or "optimum" measurements referred to above. With a few calibration gauges the areal rainfall is determined using a radar to provide the spatial precipitation distribution and the gauges to specify the precipitation magnitude (Wilson 1976). The precipitation measured by radar is determined by comparison of radar and surface precipitation measurements to establish an appropriate Z-R relationship. Such Z-R relationships are then applied to radar measurements elsewhere (where there are no rain gauges) and therefore used to improve areal precipitation measurements.

To determine quantitative areal precipitation measurements with radar, either a climatological Z-R relationship is used[2], or a Z-R relation is derived using a rain gauge in the vicinity of the precipitation

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[2] $Z = 200\ R^{1.6}$ is a typical "climatological" Z-R relationship (Marshall and Palmer 1948).

being observed. Although useful in general, the "climatological" relationship clearly cannot apply to specific precipitation events; it is therefore limited in its spatial and temporal stability. Examples of the use of the climatological relationships are cited by Wilson (1970) and Brandes (1975). Calibration relationships derived closer in space and time to the precipitation being observed were used by Harrold et al. (1974) and Collier et al. (1975). Regardless of the calibration relationship, however, it is recognized (Wilson 1976) that the utility of calibration factors decreases with increasing distance from surface-located calibration gauges. Rainfall over an area is therefore better estimated using a scattered distribution of gauges (rather than one) to specify the precipitation magnitude in adjustment of spatial precipitation distributions measured by radar. Although the accuracy of total rainfall obtained by radar-rain gauge systems is improved by increasing the calibration gauge density, other parameters are even more important in understanding the accuracy of a radar calibrated with rain gauges. In fact, the chance of each individual calibration gauge being rained upon is extremely important in the design of a calibration gauge network needed to support operational adjustment of radar rainfall estimates (Smith and Dixon 1976).

Each rain gauge calibration site can be composed of one gauge (Wilson 1970) or a cluster of gauges (Woodley et al. 1975; Collier et al. 1975). The adjustment of the radar pattern using calibration sites can then proceed in several different manners. Within a specified area, precipitation from one or more calibration sites can be compared to radar measurements taken over the sites. Such comparisons can be combined to give an average adjustment factor (Woodley et al. 1975; Harrold et al. 1974) to be applied to radar measurements at other locations. Alternatively, radar measurements can be adjusted using calibration sites by weighting the radar measurements according to their inverse distance from the calibration site. In this manner, single adjustments can be obtained for small individual regions called subcatchment areas (Collier et al. 1975). Similar to the weighted adjustments are field adjustment factors described by Brandes (1975). Field adjustments, although they require a network of gauges as calibration sites, are considered to be better than average adjustments. The field adjustments ensure that the derived radar-rain gauge precipitation field closely fits the actual gauge measurements, but at the same time the radar-observed detail between gauges is retained. Although it is common to adjust radar rainfall estimates by simply multiplying by an adjustment factor, it is now recognized that such procedures sometimes give unsatisfactory results (Cain and Smith 1976). Clearly, progress is still being made towards using radar to determine areal rainfall amounts.

Once a radar-rain gauge calibration Z-R relationship is obtained by one of the adjustment methods mentioned above, it is used in conjunction with other spatial precipitation measurements determined by radar to obtain the areal rainfall. The amount of precipitation accumulated during various periods of time over specified areas, derived from gauge-adjusted radar measurements, is then compared with the accumulated amount of precipitation obtained from "actual" or "optimum" measurements. A summary comparison of the average error in gauge-adjusted radar estimates for various experiments is given in Table 2. In this table the average error in accumulated precipitation is defined by

$$|R_{a,o} - R_e|/R_{a,o}$$

$R_{a,o}$ = "actual" or "optimum" rainfall

R_e = gauge adjusted radar estimate

It is apparent from this table that the average error in accumulated amounts is between 9 and 28%.

Fig. 1 shows the mean absolute percentage difference (modulus of average error) between radar estimates of accumulated rainfall using one calibration site and "optimum" estimates (Collier 1975). The accuracy so indicated is given in terms of the time during which the accumulated amounts were measured and the area over which the measurements were taken.

Table 2. Comparison among experiments of the average error in gauge adjusted radar estimates.

Data Source	Experiment [Reference]						
	Wilson['70]	Brandes['75]	Woodley['75]	Wilson['75]	Harrold['74]	Collier['75]	Wilson['75]
	Oklahoma Thdrstms	Oklahoma Thdrstms	Florida Showers	Great Lakes Summer	Wales Rain	Wales Rain	Great Lakes Winter
Area Size (km^2)	3500	4000	570	170	500	700	855
Time Interval	storm	storm	24 h	24 h	1 h	3 h	24 h
Radar Range (km)	37–95	37–95	65–140	95–112	12–48	12–48	18–64
Collection Frequency (per h)	6–12	12	12	6	60	60	6
Calibration Gauge Density ($1/km^2$)	1/1100	1/900	1/3250	1/275	1/700	1/700	1/800
Adjustment Procedure*	A	F	A	F	A	W	F
Average Error (%)	28	13	~20	24	14	9	15

* A – average adjustment, F – field adjustment, and W – weighted adjustment.

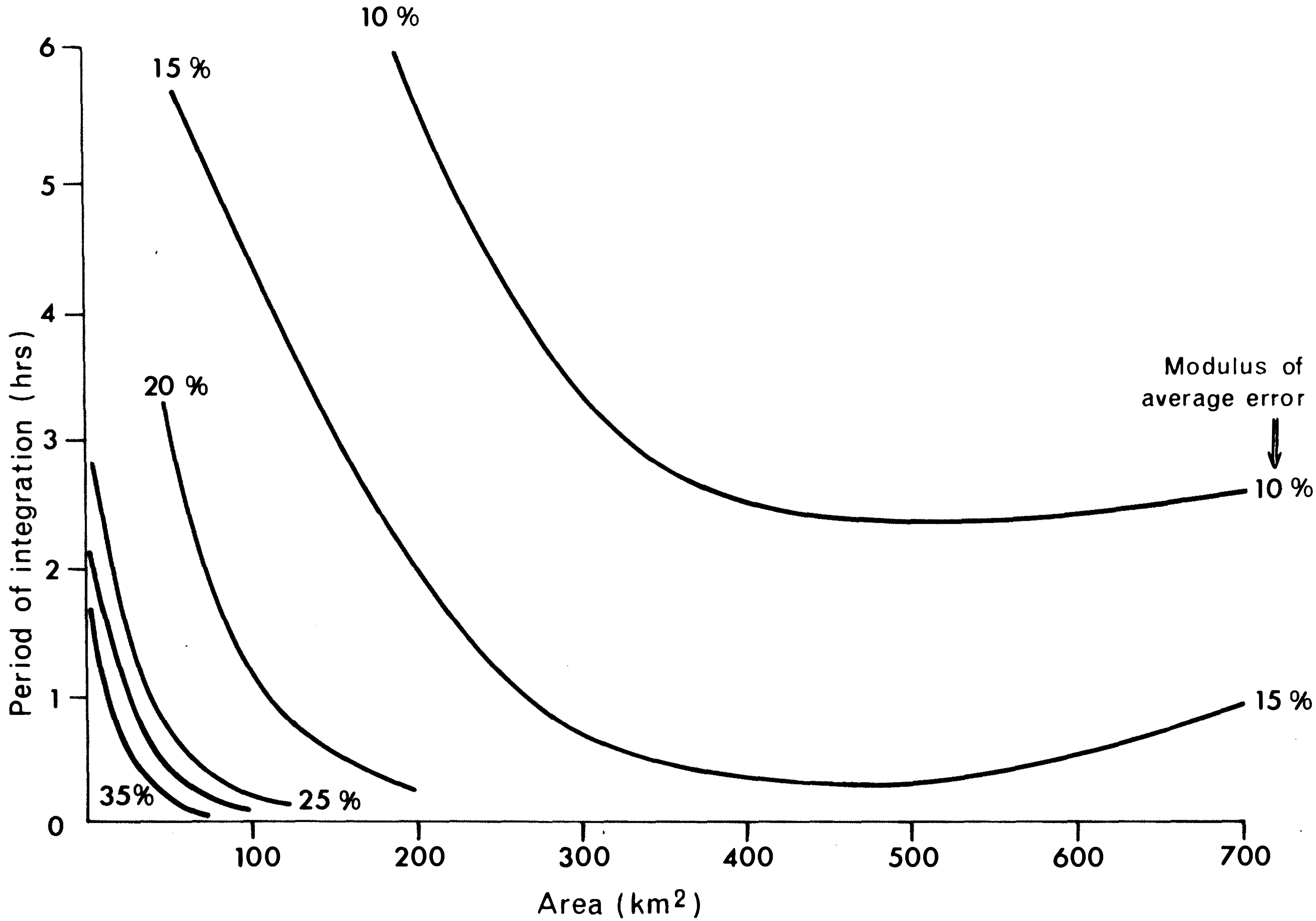

Fig. 1. Mean absolute percentage difference (modulus of average error) between radar estimates and optimum estimates of accumulated rainfall (after Collier 1975).

The curves presented were derived using a new radar calibration determined each hour. For a specified area and increasing periods of time, the error decreases mostly because meteorological factors that influence the accuracy of each calibration event tend to cancel out with time. If instead the calibration relationship was determined over a 6- to 12-hour period, and used to determine radar-adjusted rainfall measurements over that period, the error could be greater than that given in Fig. 1. This is because precipitation events which occur during the longer period (e.g. 6-12 hours) could cause bias in the type of rainfall which fell into the calibration gauge. For example, over a long time period, much of the rain which fell into a calibration gauge may have been due to a small convective storm lasting a short time, while most of the rainfall over the area of interest may have been due to widespread rain. Because convective and widespread rains may produce different calibration adjustments to be applied to the radar measurements, it is clear in this case that the convective adjustment may not be appropriate for much of the area of interest. Therefore, the applicability of individual rain gauge-radar calibrations decrease with time and changing precipitation conditions.

It is shown in Fig. 1 for a fixed time period of integration that the error in measurement of accumulated rainfall decreases with increasing area. For small areas wind drift appears to degrade the accuracy (Harrold et al. 1974). Errors due to the representativeness[3] of the calibration rain gauge tend to cancel out with increasing area; further increasing the area causes greater errors since the calibration rain gauge is no longer representative of the larger area. That the calibration gauges lose their representativeness with range was also mentioned by Wilson (1970).

Fig. 1 can be also used to determine the accuracy in the movement of average rainfall rates, which can be considered as the amount of accumulated precipitation divided by the time interval during which the precipitation was collected. Depending upon the accuracy of the calibration Z-R relationship, it appears from Fig. 1 that the areas less

[3] In context here, the representativeness of calibration rain gauges refers to their ability to represent distributions with drop size (and the corresponding calibration Z-R relationship) over extended areas.

than 50 km^2 and time intervals less than 10 min, say, the accuracy in measurement of precipitation rate is worse than 35%. Average rates calculated over large areas or using data collected over longer periods of time can be expected, on the basis of data presented in Fig. 1, to be somewhat more accurate. Instantaneous radar measurements of precipitation may be less accurate. Based upon the variability of climatological Z-R relationships, Stout and Mueller (1968) indicate that for any one measurement of Z the rainfall rate will be between 0.66 and 1.52 times the true rate 68% of the time. They also indicate that uncertainty in the radar measurement of Z after electronic calibration is about the same as that introduced by uncertainties in the Z-R relationship. Instantaneous rainfall rates therefore, using a climatological relationship, could deviate from the true rate by as much as factors 0.2-0.5 or 2-5. Such is the case for instantaneous radar rainfall rate measurements in Alberta because a climatological Z-R relationship has not been established for this region. Some improvement, however, might be expected using a Z-R relationship derived from radar-rain gauge comparisons made close in space and time to the precipitation being measured.

The accuracies indicated in Fig. 1 are generally better than those obtained in other experiments. This is also evident from Table 2 where smaller average errors are reported by Harrold et al. (1974) and Collier et al. (1975). It is suggested by Collier (1975) that the prime reason for the smaller errors may be because the maximum range from the radar was smaller than in some other studies, and that the "actual" rainfall was more accurately known. Fig. 2a shows the performance of a radar-rain gauge system as a function of range taken from Collier (1975). Although it is not clear how these results were obtained, it appears that the accuracy remains relatively constant with increasing range until about 100 km. The accuracy then beings to diminish quite rapidly with range.

Shown in Fig. 2b are accuracies when temperatures at 850 mb (about 1.5 km above sea leavel) are below freezing. It is apparent that at a fixed range (60 km, say) rainfall is measured less accurately when

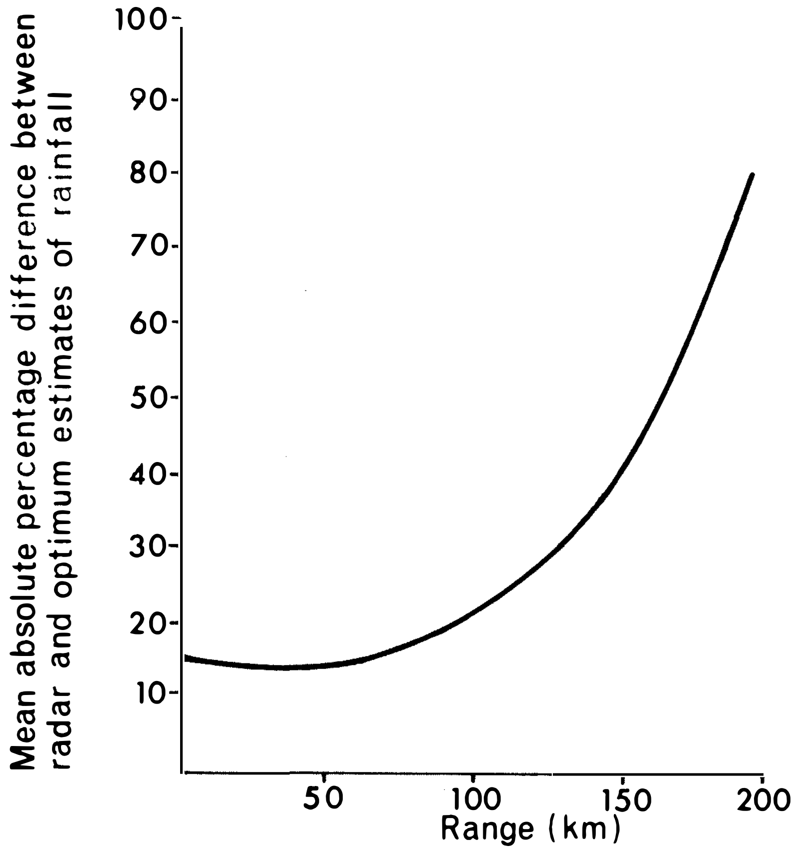

Fig. 2a. Accuracy of calibrated radar precipitation measurements as a function of range (after Collier 1975).

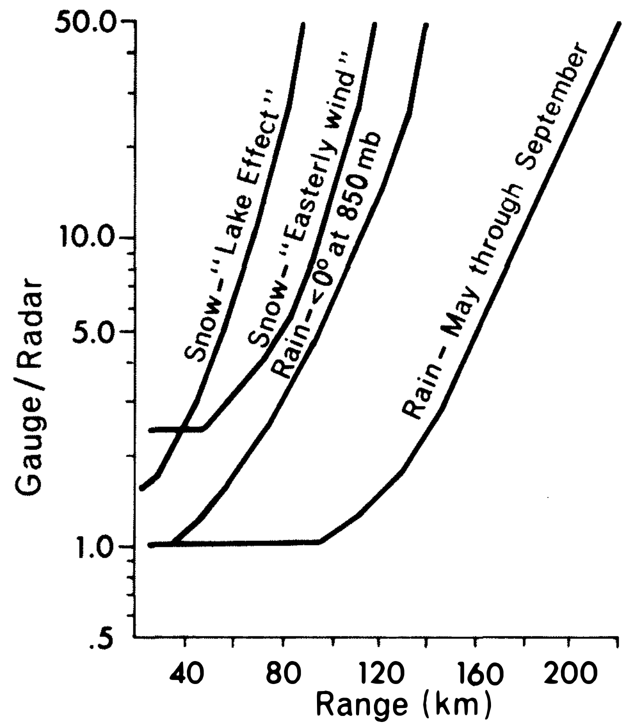

Fig. 2b. Accuracy of radar measurements for various precipitation conditions as a function of range (after Wilson 1976).

the atmosphere is cooler. This is in agreement with studies conducted in Wales (e.g. Harrold et al. 1974), which indicate that radar measurements of rainfall, made when the radar beam intersects the melting level, agree less perfectly with "actual" or "optimum" measurements of rainfall. Such results are especially relevant for precipitation measurements in Alberta because the climate is substantially cooler than that of Wales.

Fig. 2b also shows the ability of radars to measure snowfall. In broad agreement with earlier results reported by Carlson and Marshall (1972), it is evident that snowfall is somewhat more difficult to measure than rainfall[4]. The accuracy of snowfall measurement also diminishes much more rapidly with range than for measurement of rainfall.

Summary of Accuracies

Based upon the foregoing discussion it is possible to generalize the accuracy estimates. Such generalizations substantially agree with Wilson (1976), who suggests that radar precipitation estimates between 10 and 20% can be obtained for the following approximate conditions:

area $\geq$ 100 km^2
integration time interval $\geq$ 3 h
radar range 50-100 km
calibration gauge density $\geq$ 1 per 3000 km^2
collection frequency[5] $\geq$ 6/h
precipitation amounts $\geq$ 1 mm/h^{-1}

Smaller errors are likely for collection frequencies > 12/h, new calibration Z-R relationships at least every 3 h, and the melting level to be located entirely above the radar beam.

It is important to emphasize that results obtained in other parts of the world are not necessarily applicable in Alberta. With this proviso, it is expedient to compare the accuracy of a radar-rain gauge system to rain gauges alone, especially in the context of its applicability to Alberta.

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[4] Conventional measurements of snowfall at the surface are sometimes inaccurate. Such inaccuracies cannot be overlooked since they degrade any adjustments made to the radar measurements of snowfall.

[5] If the radar collects data less frequently, important rainfall changes may pass undetected by the radar.

The mean difference between estimates and "optimum" or "actual" rainfall, appropriate for Wales, as a function of rain gauge numbers is illustrated in Fig. 3 taken from Collier (1975). This diagram indicates the accuracy of radar estimates for gauge calibration sites distributed over 1000 km^2. The accuracy of rain gauges without radar is also shown. It is evident for this 1000-km^2 area that the accuracy which can be obtained using a radar and more than one calibration gauge site is usually better than 20%. The radar-rain gauge system is particularly superior over rain gauges for shower rainfall measurements. In typical showers, a radar system calibrated using two rain-gauge sites gives the same accuracy as a rain-gauge network of about 50 gauges over 1000 km^2.

In an attempt to apply the results of Fig. 3 to Alberta, Fig. 4 was drawn as a first estimate of the expected accuracy of precipitation measurements using a radar and existing rain gauges in the Fort McMurray region. For the purposes here, the radar was assumed to be located at the Fort McMurray airport. A range of 100 km is indicated. Within this distance, Fig. 2a indicates that precipitation can be measured to better than 20%, provided that there are sufficient calibration sites. Each rain gauge with recorded data having a time resolution of 1 h or better was treated as a calibration site. According to Fig. 3, precipitation within an area of 1000 km^2 in the vicinity of the calibration site can be measured with an accuracy of about 20%. Therefore, those circular areas of 1000 km^2 within 100 km range and centered over each rain gauge are shown on Fig. 4 to depict the total area within which precipitation may be measured with 20% accuracy. Circular areas that overlap imply a gauge density greater than 1 per 1000 km^2 and therefore an accuracy better than 20%. Extreme caution must be exercised in the use of Fig. 4, since the data used to derive the diagram were obtained in Wales, and intercontinental transfer of such results may be questionable. Furthermore, attempts to interpolate between the gauges to adjust the radar measurements are not considered. It is also assumed of course that the calibration sites (if rained upon) are representative of the 1000-km^2 circular area. The accuracy possible using a radar in conjunction with the rain gauges

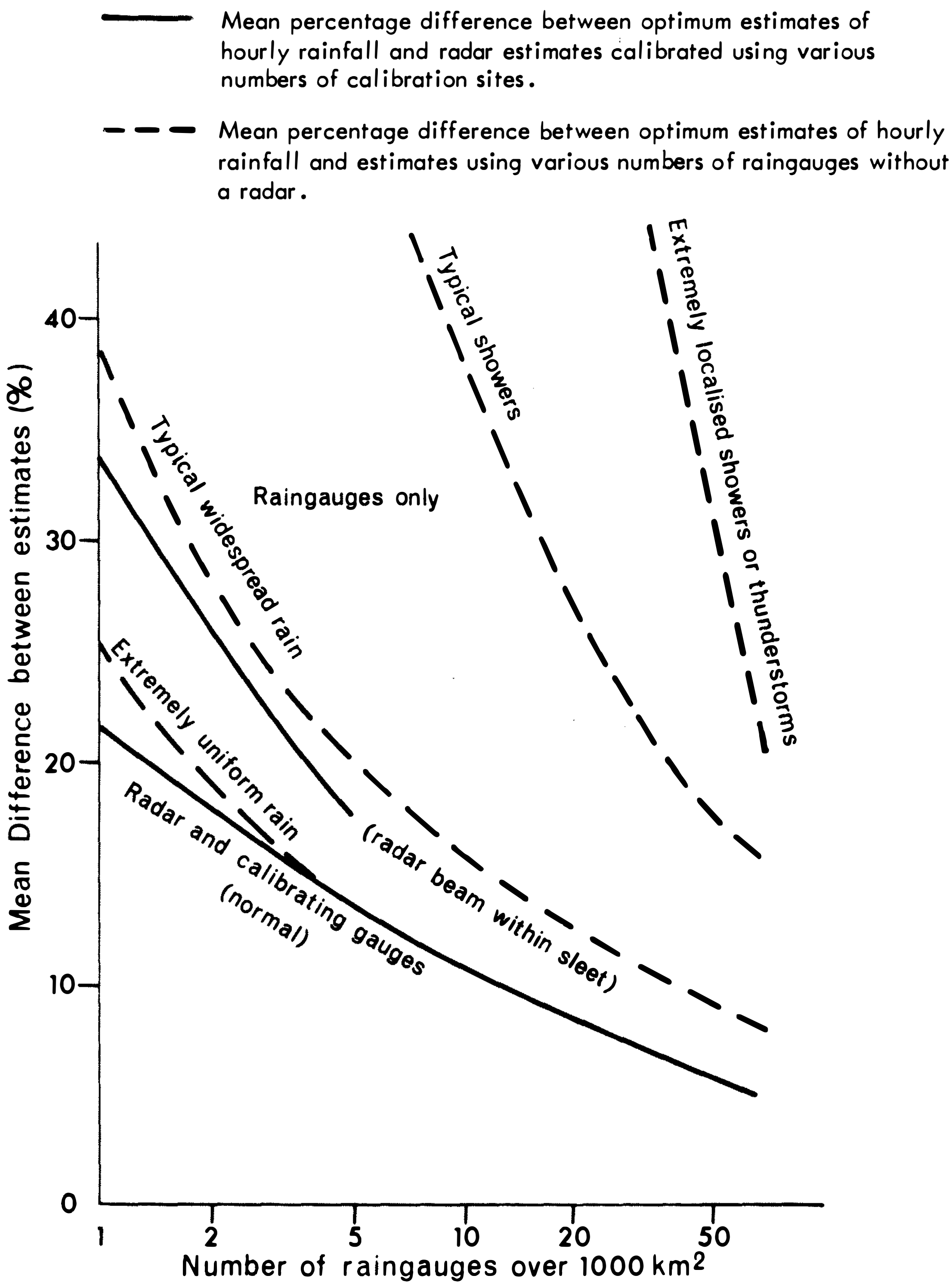

Fig. 3. Difference between estimates of hourly rainfall related to raingauge density (see text for explanation; after Collier 1975).

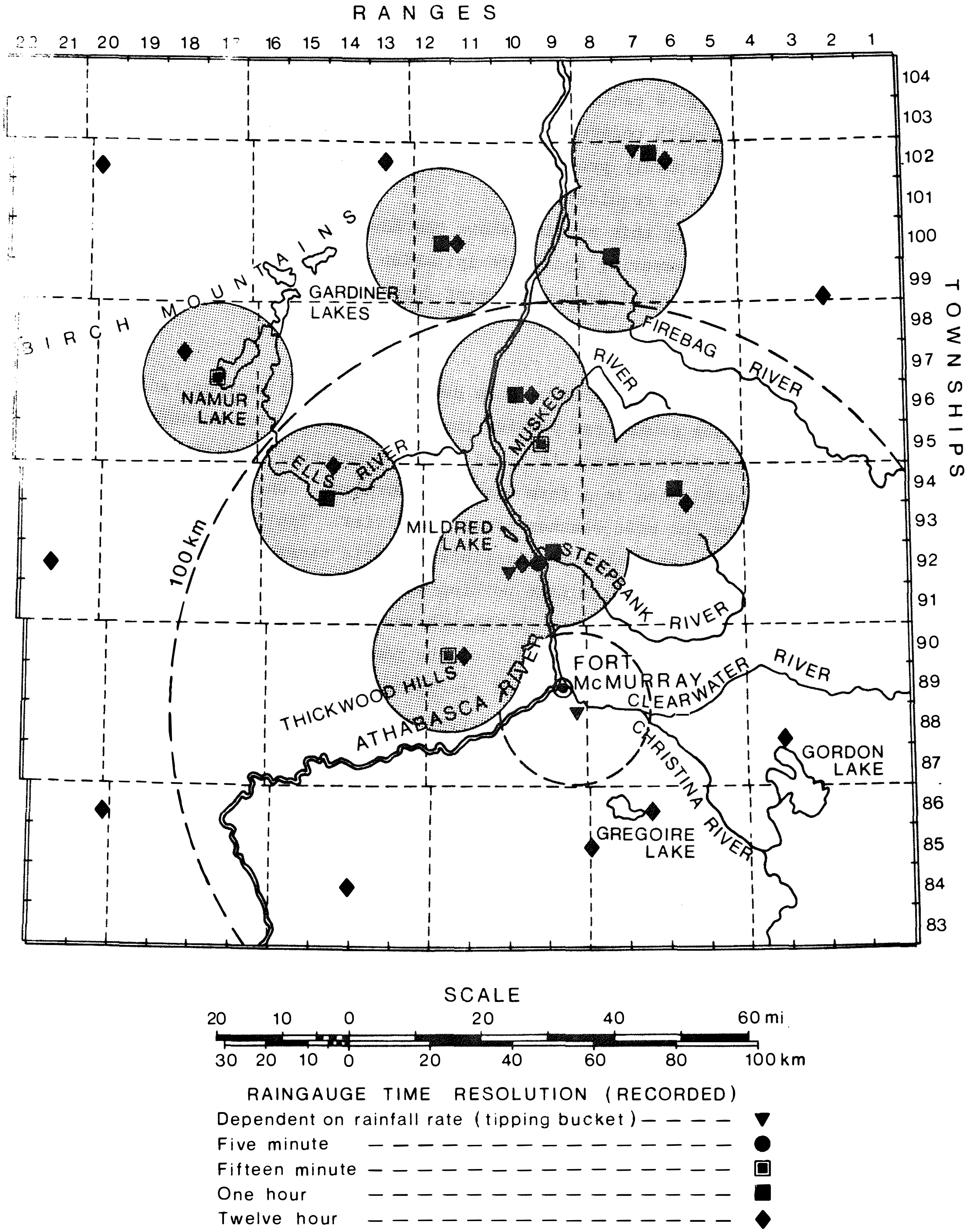

Fig. 4. Regions where accuracy of precipitation measurements with weather radar and raingauges in the vicinity of Fort McMurray may be better than 20 percent. Circular areas are 1000 km^2. Radar range of 100 km is also shown (see text for further explanation).

illustrated in Fig. 4 can be clearly understood (despite uncertainties mentioned above) with reference to Fig. 3. For each of the circular areas, to measure showery precipitation with similar accuracy, about 20-50 rain gauges would be required.

In summary this section shows the advantage of a gauge-calibrated radar system for measuring areal precipitation amounts. The next section considers the problem of data management for such a system.

4. DATA MANAGEMENT

The preceding sections have demonstrated that weather radars and precipitation gauges can provide improved precipitation measurements. To realize this improvement, it is of prime consequence that the data be readily accessible and in a form easy to comprehend. Unfortunately, this is not the case for most weather radar facilities. Typically, raw radar data are recorded on computer-compatible magnetic tapes as numbers (e.g. binary numbers) which mean nothing to someone who wants a rainfall rate. The data must therefore go through several steps before they are in a useful format. Transformation of the raw radar data, for example, into maps of accumulated amounts of precipitation is a problem in data management. The philosophy behind proper management of radar data, which has previously been overlooked by many, will be outlined in this section.

Fig. 5 is a schematic diagram representing various steps required to transform radar data into a simple and useful form. The first step is associated with recording the received signals on computer-compatible magnetic tape. Weather radars, such as the Alberta Hail Radars at Red Deer, provide information about the three-dimensional structure of precipitation, a necessity for someone studying the morphology of thunderstorms. However, to provide useful measurements of precipitation falling to the surface, it is required that frequent observations at a low elevation be provided.

In the second step, electrical calibrations and the radar equation (see sec. 2) convert the raw digital data values to received powers and/or equivalent radar reflectivity factors, as described in Barge

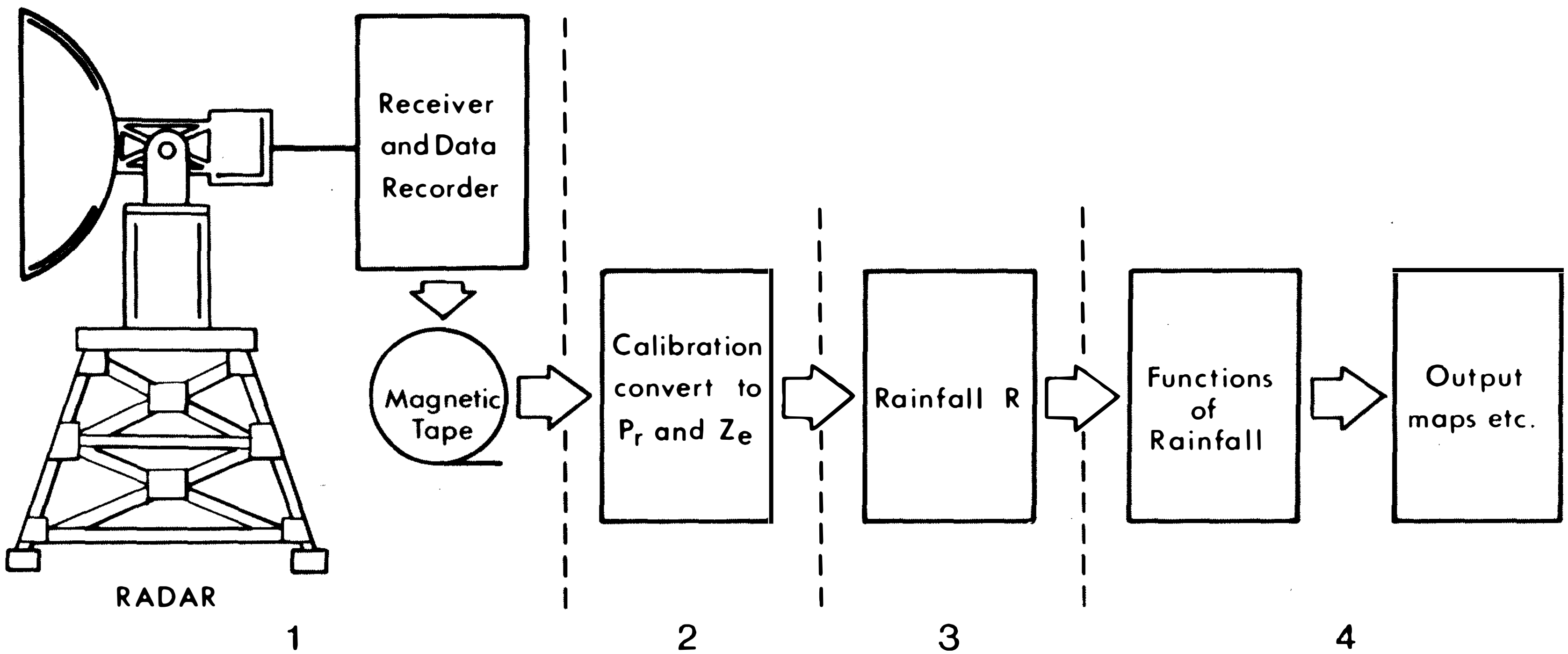

Fig. 5. A schematic of the four steps required to transform the received radar signals into useful precipitation data.

et al. (1976c) for the Alberta Hail Radars. The data are now in the units usually required by radar meteorologists. To make the radar data easy to use, it is important that this second step be carried out quickly and automatically, without burden to the data analyst. This problem has been considered by Humphries et al. (1977). A procedure has been developed whereby the electrical calibrations and radar constants appropriate for each day are stored on computer files. This allows any data analyst not familiar with the radar-computer system to access the radar data without becoming involved with radar-computer log books or calculations of radar constants. In fact, the data are automatically converted to values of received power or reflectivity at the time the digital data are first examined.

Others, for example hydrologists, who require maps of accumulated amounts of precipitation require a third operation upon the received radar signals. As mentioned in Sec. 2, a Z-R relationship is needed to transform the radar data from values of reflectivity to values of rainfall rates or accumulated amounts. Depending upon accuracy constraints, this could entail a simple climatological relationship such as $Z = 200\ R^{1.6}$ (Marshall and Palmer 1948) or a sophisticated process using a gauge network to calibrate the radar. Also, nonmeteorological echoes should be removed from the data. This can be carried out automatically by a computer program or interactively with a facility like the one described by Ramsden et al. (1976). Regardless, the data at this stage represent rainfall, with appropriate time and location information.

After the third step the rainfall data in a standard format can either be stored on magnetic tape for future use or used directly by programs developed for the fourth step. These programs, for example, might calculate accumulated rainfall amounts and present the results in the form of tables, graphs, or maps.

In order for the potential of improved precipitation estimates by weather radar to be fully realized it is important that provision for nonradar meteorologists to carry out the steps above be considered. This is allowed for in step two where consideration of radar constants and provision to access radar data is taken into account automatically. Also, in step three, standard formats of rainfall data facilitate straightforward construction of computer programs to compute various functions of rainfall, such as accumulated amounts. In other words, to realize the potential of weather radar data in precipitation measurement, it is necessary that details to carry out the first three steps described above remain invisible to a data analyst. It is also important that the programs developed to analyze the rainfall data be easy to use by analysts not familiar with computers. Thus, with a requirement for precipitation information, a data analyst in step four need merely decide upon a particular data output format for various functions of rainfall by using simple computer instructions. Such a facility is described by Ramsden et al. (1976) whereby it is possible to readily analyze the radar data without detailed knowledge of computers or radars.

To establish the data management scheme outlined above, both radar meteorologists and computer experts are required in the development stage. However, once a data management system is established it is possible to derive precipitation measurements and quickly present them in a particular form without concern about calibration procedures, data quality, or computer programming details.

SUMMARY

Among the most noteworthy achievements in radar meteorology are the observations presented by Marshall and Palmer (1948), which have made quantitative precipitation measurement capabilities of weather radar easily understood and well known. Following such contributions, it is now possible to obtain improved estimates of precipitation rates and/or accumulated precipitation amounts at the surface by using weather radars in conjunction with surface gauge networks. This brief review shows, for example, that a radar and one calibration rain gauge per 1000 km^2 can measure accumulated amounts of showery rainfall to within about 20%. To obtain the same accuracy with rain gauges alone, a network of 50 gauges per 1000 km^2 is required.

The ability to successfully handle large volumes of weather radar data with digital computers has been another significant accomplishment of radar meteorologists. Consequently, precipitation measurements by weather radars can now be more readily available for easy use. This report develops an approach aimed to make the improved precipitation estimates more accessible to fields other than radar meteorology. Although some problems remain in the management of large volumes of weather radar data, steps to overcome these problems are already in progress (Humphries et al. 1977; Ramsden et al. 1976).

The usefulness of weather radar has not yet been fully realized in fields other than radar meteorology. For example, fields such as agriculture, hydrology, and climatology commonly require estimates of areal precipitation amounts at the surface. In fact, it was found recently by Barge et al. (1976b) that weather radar adds a new dimension to precipitation measurements in Alberta. With the quantitative precipitation measurement capabilities of weather radar reasonably well understood, and with rapid and easy data handling possible, it follows that weather radars can become even more commonplace in providing improved measurements of precipitation.

ACKNOWLEDGMENTS

The authors are indebted to S. Olson for her assistance throughout this study.

APPENDIX I

SOME PRACTICAL APPLICATIONS OF PRECIPITATION MEASUREMENTS

This appendix lists some practical applications of precipitation measurements. Such measurements are usually made with surface gauges, but improved estimates are available by using weather radars in conjunction with surface gauges. The list is not intended to be complete; it is merely to give examples of activities that may find weather radars useful. Although a more extensive bibliography on radar as a tool for precipitation measurement is given by Barge et al. (1976b) the references included here are intended to be of specific interest to agricultural, meteorological, hydrological, climatological, etc. activities carried out in Alberta. With respect to hydrological applications, special reference is made to Flanders (1969) and Kessler and Welk (1968). A significant study entitled Use of Ground-Based Radar in Meteorology is presented by the World Meteorological Organization as Technical Note #78.

- Farm management, crop indices
  (Lomas 1972; Mihara 1974; Gardner 1965)
- Severe weather warnings
  (Elvander 1975; Zittel 1976)
- Public interest
  (Bigler 1969)
- Agricultural planning
  (Kohler 1958)
- Drought
  (Krueger 1968)
- Forestry
  (Krueger 1968)
- Water management
  (Green 1975; Harding 1972)
- Reservoirs and dams
  (Harding 1972)
- Floods
  (Green and Clark 1974; Hudlow and Clark 1968)
- Identification of important precipitation events (significance)
  (Blackmer and Duda 1972)
- Irrigation water distribution
  (Kohler 1958)
- Construction
  (Kohler 1958)
- Land use - pollution
  (Changnon 1975; Barge et al. 1976b)
- Communications Systems
  (Drufuca 1974; Marshall et al. 1976)

- Weather forecasts, terminal forecasting
  (Try 1972; Bellon and Austin 1976)
- Satellite-radar compositing
  (Booth et al. 1972)
- Weather modification
  (Barge et al. 1976a)
- Movement and trends in precipitation patterns
  (Blackmer and Duda 1972)
- Aviation
  (Kohler 1958)
- Research and operational applications
  (Smith et al. 1974)

REFERENCES

Barge, B.L., F. Bergwall, G.G. Goyer and J.H. Renick. 1976a. Fine scale structure of convective storms - implications for cloud seeding in Alberta. Alberta Res. Counc., Atmos. Sci. Div. Edmonton, Alberta. Rep. 76-3. 19 pp.

Barge, B.L., R.G. Humphries and S.L. Olson. 1976b. The feasibility of a weather radar near Fort McMurray, Alberta. Alberta Res. Counc., Atmos. Sci. Div. Rep. for Meteorology and Air Quality Technical Research Committee, Alberta Oil Sands Environmental Research Program (AOSERP), Project ME 1.6. Edmonton, Alberta 67 pp.

Barge, B.L., R.G. Humphries and M.R. Johnson. 1976. Alberta hail radar - Computer considerations. Alberta Res. Counc.,Atmos. Sci. Div. Edmonton, Alberta. Rep. 76-1:45-67.

Battan, L.J. 1973. Radar observation of the atmosphere. Univ. of Chicago Press, Chicago, Ill. 324 pp.

Bellon, A., and G.L. Austin. 1976. SHARP (Short-term Automated Radar Prediction) a real-time test. Pages 522-525 _in_ Preprints, Seventeenth Conf., Radar Meteor. Am. Meteor. Soc.

Bigler, S.G. 1969. Dial a radar. Bull. Am. Meteor. Soc. 50:428-431.

Blackmer, R.H., Jr. and R.O. Duba. 1972. Application of pattern recognition techniques to digitized radar data. Pages 138-143 in Preprints, Fifteenth Conf. Radar Meteor. Am. Meteor. Soc.

Booth, A.L., A.G. DeCotiis and J.A. Leese. 1972. Automated procedures for mapping and display of digitized radar data. Pages 199-203 in Preprints, Fifteenth Conf. Radar Meteor. Am. Meteor. Soc.

Brandes, E.A. 1975. Optimizing rainfall estimates with the aid of radar. J. Appl. Meteor. 14:1339-1345.

Cain, D.E. and P.L. Smith, Jr. 1976. Operational adjustment of radar estimated rainfall with rain gauge data: a statistical evaluation. Pages 533-538 in Preprints, Seventeenth Conf. Radar Meteor. Am. Meteor. Soc.

Carlson, P.E. and J.S. Marshall. 1972. Measurement of snowfall by radar. J. Appl. Meteor. 11:494-500.

Changnon, S.A., Jr. 1975. Operations of mesoscale networks, illustrated by METROMEX. Bull. Am. Meteor. Soc. 56:971-977.

Collier, C.G. 1975. Rainfall measurement by radar. Proc. Symp. Weather Radar Water Manage. Water Res. Cent., Medmenham, Eng. Paper 1 + Suppl. 31 pp.

Collier, C.G., T.W. Harrold and C.A. Nicholass. 1975. A comparison of areal rainfall as measured by a raingauge-calibrated radar system and raingauge networks of various densities. Pages 467-472 in Preprints of Papers, Sixteenth Radar Meteor. Conf. Am. Meteor. Soc.

Cummings, A.D., P.L. Moore and D.L. Smith. 1974. Digital radar data as a predictor of flash flood potential. Pages 111-116 in Proc. Fifth Conf. Weather Forecasting Anal. Am. Meteor. Soc.

Drufuca, G. 1974. Rain attenuation statistics for frequencies above 10 GHz from radar observations. J. Rech. Atmos. 8:413-420.

Elvander, R.G. 1975. The relationship between digital weather radar data and reported severe weather occurrences. Pages 333-336 in Preprints, Sixteenth Conf. Radar Meteor. Am. Meteor. Soc.

Flanders, A.F. 1969. Hydrological requirements for weather radar data. World Meteor. Org., Geneva. WMO/IHD Proj. Rep. No. 9 16 pp.

Gardner, W.R. 1965. Rainfall, runoff, and return. Am. Meteor. Soc. Meteor. Mono. 6(28):138-139.

Green, D.R. 1975. Hydrologic application of digital radar data. Pages 353-360 _in_ Preprints, Sixteenth Conf. Radar Meteor. Am. Meteor. Soc.

Green, D.R. and R.A. Clark. 1974. The operational use of digital radar data for flash flood monitoring. Flash Floods Symp. Am. Geophys. Union. IAHS - AISH publication No. 112:100-105.

Harding, J. 1972. Rainfall measurement by radar - Dee Weather Radar Project. WMO Bull. 21(2):90-94.

Harrold, T.W., E.J. English and C.A. Nicholass. 1974. The accuracy of radar-derived rainfall measurements in hilly terrain. Quart. J. R. Meteor. Soc. 100:331-350.

Hudlow, M.D. and R.A. Clark. 1968. The feasibility of using radar measurements in the synthesis of flood hydrographs. Pages 412-415 _in_ Proc. Thirteenth Radar Meteor. Conf. Am. Meteor. Soc.

Humphries, R.G., B.L. Barge and M.R. Johnson. 1977. Alberta hail radar - Computer considerations - II. Alberta Res. Counc., Atmos. Sci. Div. Edmonton, Alberta. Rep. 77-3:35-42.

Kessler, E. and K.E. Wilk. 1968. Radar measurement of precipitation for hydrological purposes. World Meteor. Org., Geneva. WMO/IHD Proj. Rep. No. 5. 46 pp.

Kohler, M.A. 1958. Design of hydrological networks. World Meteor. Org., Geneva. WMO Tech. Note No. 78:1-16.

Krueger, D.W. 1968. The use of radar data to delineate areas of high forest fire danger. Pages 408-411 _in_ Proc. Thirteenth Radar Meteor. Conf. Am. Meteor. Soc.

Lomas, J. 1972. Forecasting wheat yields from rainfall data in Iran. WMO Bull. 21:9-14.

Lowing, M.J., R.K. Price and R.A. Harvey. 1975. Real-time conversion of rainfall to runoff the flow forecasting in the River Dee. Proc. Symp. Weather Radar Water Manage. Water Res. Cent., Medmenham, Eng. Pap. 6. 22 pp.

Marshall, J.S. and W. McK. Palmer. 1948. The distribution of raindrops with size. J. Meteor. 5:165-166.

Marshall, J.S., S. Radhakant and E. Cherna. 1976. Shadow-mapping to study attenuation by rain on satellite microwave link. Pages 79-80 _in_ Preprints, Seventeenth Conf. Radar Meteor. Am. Meteor. Soc.

Mihara, Y. (Ed.). 1974. Agricultural Meteorology of Japan. Univ. Tokyo Press, Tokyo, Japan. 215 pp.

Rainbird, A.F. 1967. Methods of estimating areal average precipitation. World Meteor. Org., Geneva. WMO/IHD Proj. Rep. No. 3.

Ramsden, J., M.R. Johnson, R.G. Humphries and B.L. Barge. 1976. Interactive computer-generated displays of radar data. Pages 468-473 _in_ Preprints, Seventeenth Conf. Radar Meteor. Am. Meteor. Soc.

Smith, P.L. and R.W. Dixon. 1976. Radar echo patterns in North Dakota and their implications for operational rainfall measurements. Pages 539-547 _in_ Preprints of Papers, Seventeenth Conf. Radar Meteor. Am. Meteor. Soc.

Smith, P.L., K.R. Hardy and K.M. Glover. 1974. Applications of radar to meteorological operations and research. Proc. Inst. Electrical and Electronics Eng. 62:734-745.

Stout, G.E. and E.A. Mueller. 1968. Survey of relationships between rainfall rate and radar reflectivity in the measurement of precipitation. J. Appl. Meteor. 7:465-474.

Try, E.F. 1972. Remoting of CAPPI pictures by computer. Pages 189-192 _in_ Preprints, Fifteenth Conf. Radar Meteor. Am. Meteor. Soc.

Wilson, J.W. 1970. Integration of radar and raingauge data for improved rainfall measurements. J. Appl. Meteor. 9:489-497.

Wilson, J.W. 1975. Measurement of snowfall by radar during the IFYGL. Pages 508-513 _in_ Preprints of Papers, Sixteenth Radar Meteor. Conf. Am. Meteor. Soc.

Wilson, J.W. 1976. Radar-raingauge precipitation measurements: a summary. Pages 72-76 in 1976 Conf. Hydro-Meteor. Am. Meteor. Soc.

Woodley, W.L., A.R. Olsen, A. Herndon and V. Wiggert. 1975. Comparison of gage and radar methods of convective rain measurement. J. Appl. Meteor. 14:909-928.

Zawadzki, I.I. 1973. Errors and fluctuations of raingauge estimates of areal rainfall. J. Hydrol. 18:243-256.

Zawadzki, I.I. 1975. On radar-raingauge comparison. J. Appl. Meteor. 14:1419-1429.

Zittel, W.P. 1976. Computer applications and techniques for storm tracking and warning. Pages 514-521 in Preprints, Seventeenth Conf. Radar Meteor. Am. Meteor. Soc.

INFLUENCE OF FERTILIZERS, SOIL NUTRIENTS, AND WEATHER ON BARLEY AND FORAGE YIELDS IN CENTRAL ALBERTA

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ABSTRACT

Field fertilizer experiments on barley and forage were conducted each year at six locations between 1964 and 1969. At each site a barley experiment and a forage experiment each received nitrogen, phosphorus, and potassium at five rates. Regression equations were derived relating barley and forage yields to various independent variables: applied nitrogen and phosphorus, soil tests for nitrogen and phosphorus, a "weather" term, and soil order (separated Chernozemic from Luvisolic soils). The "weather" term for the barley was a rather sophisticated one involving stress days that occurred during the growing season. Climatological data, soil moisture measurements, and growth characteristics of the plant were required for the stress day calculation. The regression equation relating yields to the various independent variables explained 55% of the yield variation.

The "weather" term for the forage mixture involved only soil moisture in the spring plus rainfall up to the first cut. More information on such items as rooting characteristics of forage species is required before a more meaningful term can be generated. The regression equation relating forage yields to various independent variables--applied nitrogen and phosphorus, soil tests for nitrogen and phosphorus, soil moisture in spring plus rainfall up to the first cut, and a soil order term -- explained only 30% of the yield variation.

METHODS

Field fertilizer experiments on barley and forage (brome-alfalfa mixture) were conducted each year at six locations between 1964 and 1969. Three sites were located on Black Chernozemic soils and three on Gray Luvisolic soils. At each site a barley experiment and a forage experiment each received five rates of nitrogen, five rates of phosphorus, and five rates of potassium applied in a central composite design. The fertilizers were applied annually to plots that retained their treatment identities throughout the course of the study.

Each spring soil samples were collected from each of the 48 individual plots at each site using a core sampler. The plot cores were divided into four samples representing depths of 0-15, 15-30, 30-61 and 61-91 cm. Soil analysis for nitrogen, phosphorus, and potassium and soil moisture were performed on the samples.

Regression equations were derived relating barley and forage yields to various independent variables: applied nitrogen, applied phosphorus, applied potassium, soil test for nitrogen, soil test for phosphorus, soil test for potassium, a "weather" term, and a soil order term (separated Chernozemic soils from Luvisolic soils).

SUMMARY AND CONCLUSIONS FOR THE BARLEY STUDY

The yield of barley was regressed on linear and quadratic terms of applied nitrogen and phosphorus for each site, and the amount of yield variation explained by the regression equations for 17 site-years was 23%. When soil test for phosphorus was added to the model in addition to applied nitrogen and phosphorus, 38% of the yield variation was explained.

A rather sophisticated "weather" term was developed involving a stress-day concept. Atmometers were installed at the beginning of the study to measure evaporation; however, the readings were not reliable. Consequently, instruments were installed at each site to measure air humidity and wind for the calculation of potential evaporation by the Penman method. Daily soil moisture budgets were calculated using potential evaporation, precipitation, and soil moisture contents by a method similar to that used by Baier and Robertson. For the purposes of stress analysis, the root zone was divided into four depths and the growing period into seven intervals of physiological development. A value for daily moisture index of 1.125 (45% of the maximum value of 2.50) was chosen as the criterion for a moisture stress day. This choice was made after stress frequencies resulting from several criteria had been examined on yield and moisture data collected external to the present study.

Barley yields were regressed on applied nitrogen and phosphorus, soil tests for nitrogen and phosphorus, a dummy variable for soil order, and the "weather" term involving stress days. The amount of yield variation explained was 55%. This equation should be useful for agencies such as grain companies and government departments who each year commence in early summer predicting what the final yield of barley will be on the Western Prairies. The equation should be useful for interpreting yield response of barley for fertilizer experiments conducted in the past, provided, of course, that appropriate soil moisture and meteorological parameters are available. For further details, the readers are directed to the following publications:

Heapy, L.A. 1971. Production of Gateway barley as influenced by fertilizer, soil test levels and moisture stress. Ph.D. Thesis, Univ. Alberta.

Heapy, L.A., G.R. Webster, H.C. Love, D.K. McBeath, U.M. von Maydell and J.A. Robertson. 1976 Development of a barley yield equation for central Alberta. 2. Effects of soil moisture stress. Can. J. Soil Sci. 56:249-256.

SUMMARY AND CONCLUSIONS FOR THE FORAGE STUDY

The yield of forage was regressed on linear and quadratic terms of applied nitrogen and phosphorus for each site, and the amount of yield variation explained by the regression equations ranged from 11 to 77% for the various individual sites. When the data were pooled on a site basis (all cuts for all years at a site) the foregoing variables explained only 6-38% of the yield variation. When data were pooled on a yearly basis (all cuts for all sites for each year) only 6-12% of the yield variation was explained. Hence, applied nitrogen and phosphorus explained an unsatisfactory amount of yield variation for all groupings. When soil test for phosphorus was added to the model in addition to applied nitrogen and phosphorus the yield variation explained was only 13%, which is again unsatisfactory.

The model was expanded to include a dummy variable for soil order (separated Chernozemic soils from Luvisolic soils) and a soil moisture term. Actually, two versions of the soil moisture term were tested in turn; the first was soil moisture in the spring and the second was soil moisture in the spring plus rainfall up to the first cut. Regression analysis was done for 21 site-years regressing forage yield on the following variables: applied nitrogen, applied phosphorus, soil test values for phosphorus, soil moisture (spring), and soil order. Only 29% of the yield variation was explained. The analysis was repeated only substituting soil moisture in spring with a term for soil moisture in spring plus rainfall up to the first cut. Only 30% of the variation was explained. This soil moisture term was not nearly as effective as the more sophisticated "weather" term used for the barley experiments. However, more research is required on such items as rooting habits of forage species before a more meaningful weather term can be developed for them. More information may be obtained from the following publication:

Webster, G.R., D.K. McBeath, L.A. Heapy, H.C. Love, U.M. von Maydell and J.A. Robertson. 1976. Influence of fertilizers, soil nutrients, and weather on forage yield and quality in central Alberta. Alberta Inst. Pedol. Publ. No. M-76-10. 145 pp.

URBAN HEAT ISLAND IN CALGARY: DIURNAL PATTERN AND TIME TRENDS

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ABSTRACT

A study conducted in 1975 shows that urban heat island intensity has almost doubled in the 10 years since the last comprehensive survey of the island was undertaken. During that period the population of the city grew almost 50%, from 300 000 to about 450 000. The diurnal distribution of intensities has a double maxima, with the higher value occurring by midmorning and a secondary one just before midnight. While heat overload may be responsible for the morning peak (the active peak), it is suggested that the midnight maximum (the passive peak) is prompted by differential cooling between city and country. Elevation is not significant in the determination of the form of the temperature field but the general topography is responsible for much of the complexity observed in the spatial and temporal distribution of temperatures.

INTRODUCTION

Urban heat island is the name given to the elevated temperature surface found in most cities in the midst of lower regional temperatures. The concept is not new. In fact, studies of heat islands have been conducted for most cities in North America and Europe.

The brief report presented here is based on a study of temperature fields in Calgary that was begun in 1974. Only the surface pattern is considered; report on the atmospheric field will be presented at a later date. This is not the first study of urban temperature fields in Calgary. Yudcovitch (1967) had conducted a survey of surface temperature patterns in the city in 1965/66. Consequently, we have two sets of data that indicate the change in urban heat island intensity and its distribution over the past 10 years.

Data for this study were obtained from a network of 28 permanent thermograph stations distributed in the city and outlying district (Fig. 1) such that the network reflected variations in topography and land use intensity. A number of stations were placed at points that automobile transects suggested were critical to an accurate representation of the form of the temperature field in the study area. Data gathering was begun in September 1974 and was concluded in August 1975.

Urban heat island intensity was computed as the difference between the average temperature in the inner city (downtown and Ogden) and the average temperature over the rural station outside the city. The use of the average for the rural locations should contain some of the problems which may arise from the presence of sources and sinks in the thermal pattern over the area.

DIRUNAL PATTERN OF URBAN HEAT ISLAND INTENSITY

Fig. 2 is the mean diurnal pattern of heat island intensities during the observation period. The major characteristics of the pattern are as follows.

1. There is always a positive temperature differential (in the mean) between the city and the surrounding country in all hours. The lowest mean intensity is in excess of 5°C. This runs counter to observations in many cities where daytime intensities are negative, as observed for summer periods in London, England (Chandler 1962) or minimal enough to lie within the margin of instrumental error (Ludwig and Kealoha 1968, for Albuquerque and New Orleans).

The consistently high diurnal intensity maintained in the study area may be attributed to its climate. Calgary is one of the few fair-sized cities to be found north of latitude 50°. Summers are short and cool. There is no month with a mean temperature of up to 18°C, the threshold temperature on which computations for heating requirements are based. Subsequently, it is the rare month when buildings are not heated by fuel burning. Fossil fuel burning pours large quantities of anthropogenic heat into the atmosphere. This type of energy is more differentially applied in favor of the built-up area. The result is the persistently high temperature differential between city and country. The valley location of the city discussed below also contributes significantly to

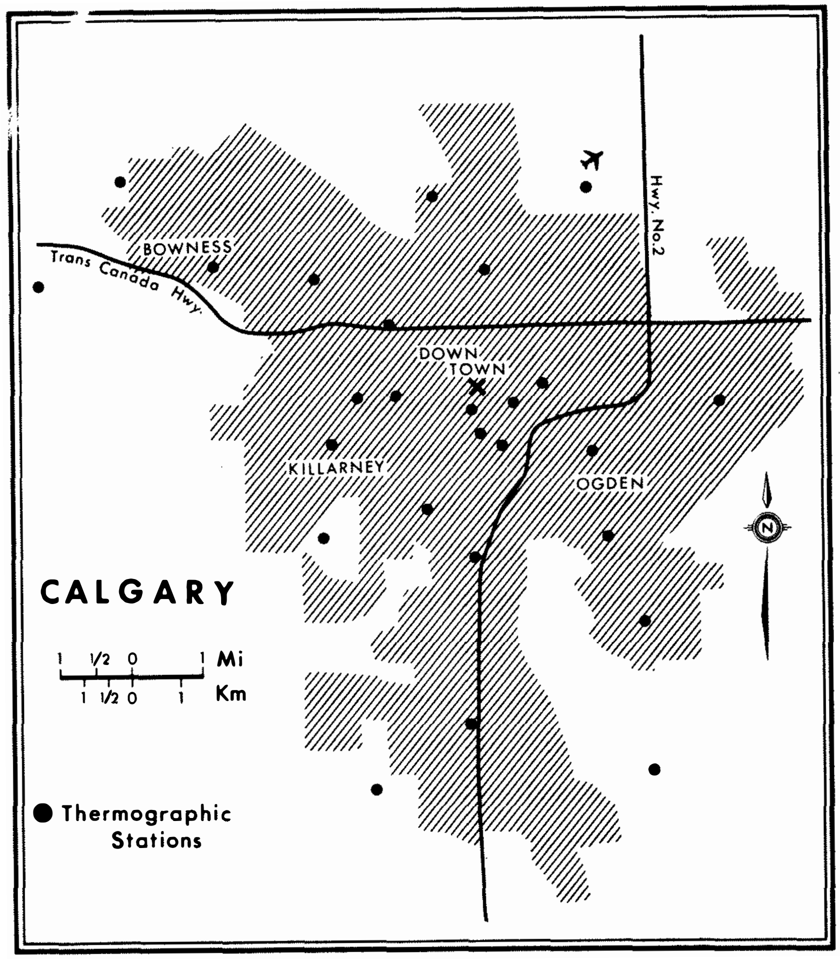

Fig. 1. Temperature sampling points.

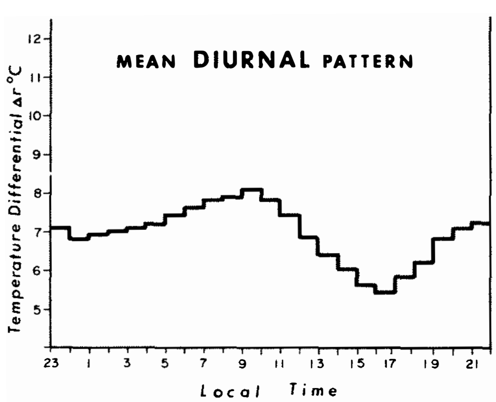

Fig. 2. Mean diurnal pattern of urban heat island intensity.

the high differentials.

2. The distribution is bimodal. There are two peaks: a primary one (8°C) occurs in midmorning and a secondary maximum (7.2°C) is observed just before midnight. The primary peak about midmorning may be caused by the combined effects of physiography, wind velocity, differential energy input, and depth of the mixing layer.

The physiography of the study area is shown in Fig. 3. The mean elevation of the area is about 1100 m msl. It is an area of rolling hills and flat plains. Elevation drops generally from northwest to southeast. There is a height differential of more than 200 m between the highest and lowest points. A prominent feature of the city is the presence of the floodplains of the Bow and Elbow river system which run through the middle of the city. East and west of the floodplain, the land rises steeply to the west and gently to the east. These features give the city the shape of an inclined bowl. The core of the city containing the head offices of many firms and major retail outlets is located almost in the middle of the bowl. Residential development follows the river and the terraced hills surrounding the river system.

During the morning rush hour, significant quantities of heat are added to the atmosphere of the central city by vehicular traffic. The buildup of heat along Macleod Trail South, a major north-south artery during the morning rush hour (Yudcovitch 1967; Truch 1977) attests to the significance of this energy source. Emissions from offices are also enhanced by the greater energy release from poorly insulated buildings as thermostats are turned up. The net result of this is the buildup of a heat "overload" within the core of the city.

Dispersion of the energy is impeded by the following factors:

1. The regional winds in the morning on the average prevail from the NW (Fig. 4). The city center where the heat buildup occurs is protected from the winds by the shape of the valley. A protection model is illustrated in Fig. 5(a).

2. Leighton (1966) shows that the regional winds have to be unusually strong to flush out the valley air where protection as in (a) occurs. Fig. 6 shows that morning winds are in general weaker than afternoon winds. These morning winds may not be sufficiently strong to penetrate the valley to induce

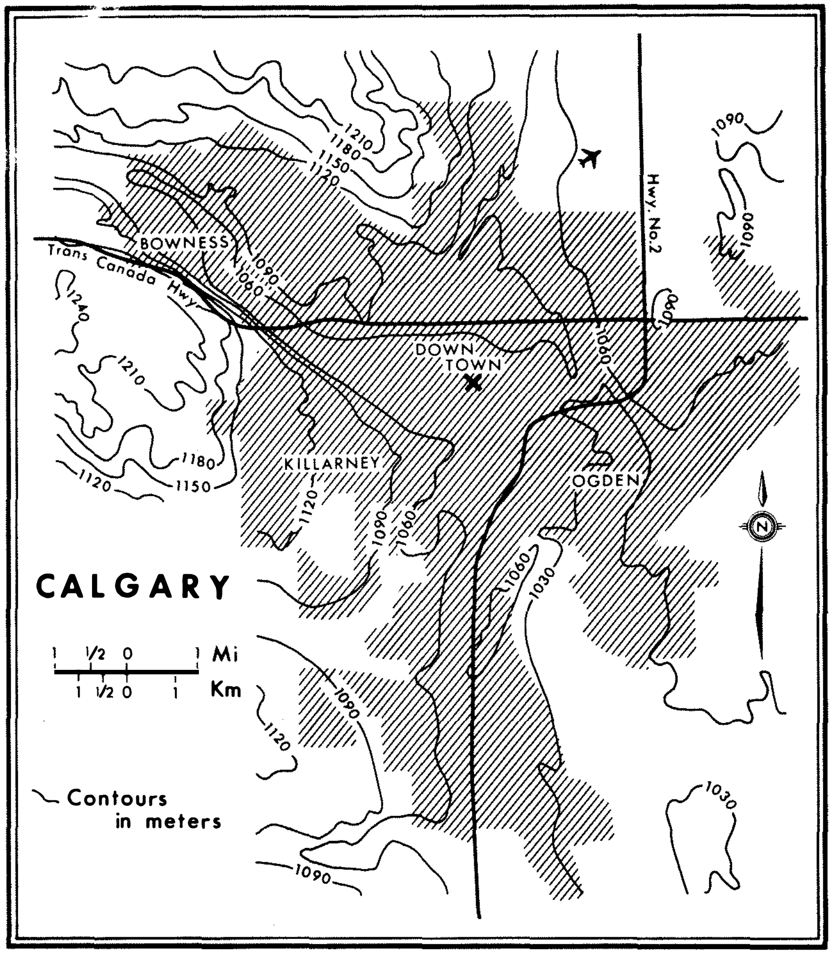

Fig. 3. Calgary: Topography.

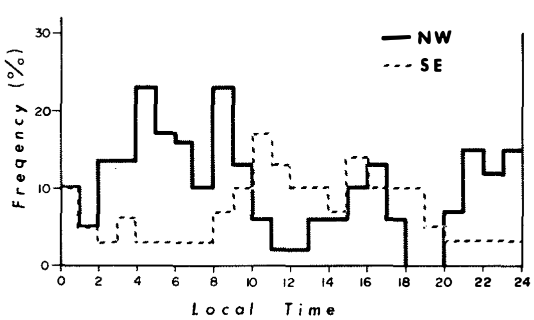

Figure 4. Diurnal distribution of wind direction.

Fig. 5a.

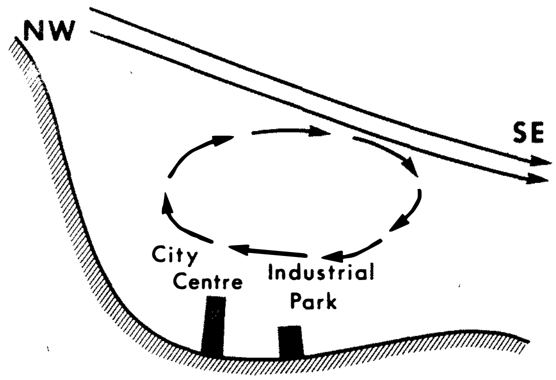

Fig. 5b.

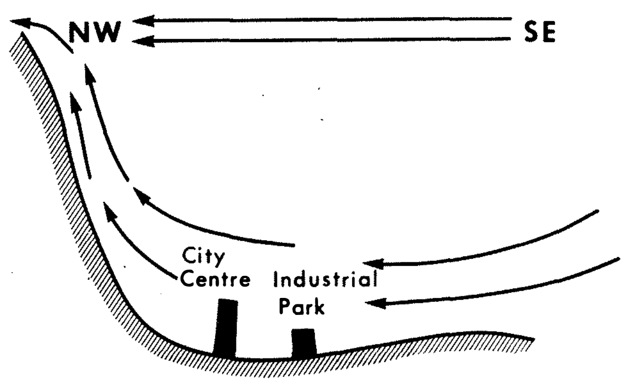

Fig. 5. Schematic representation of airflow through the valley.

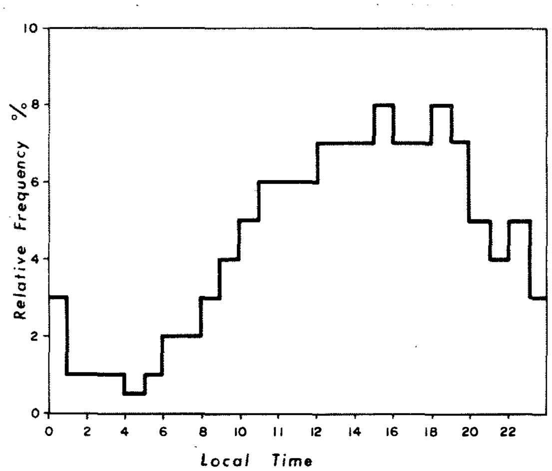

Fig. 6. Frequency distribution of windspeed greater than 3.5 m sec^{-1}.

the horizontal mixing necessary to dissipate the energy.

3. Nkemdirim (1976) shows that a shallow mixing layer persists through midmorning in Calgary. Whereas the energy required to enhance the mixing layer is present, the regional wind strength appears to be insufficient for the desired erosion of the inversion base above the city.

The midmorning peak may be called an active peak because heating is the forcing function. The peak contrasts with the passive maximum which occurs just before midnight. That maximum is presumably caused by the differential cooling between city and country of the classical urban climate literature. The switch of the winds from SE to NW (Fig. 4) shortly after dusk also corresponds to buildup in the intensity of the heat differential.

Breakup of the inversion over the city occurs by midday. This event corresponds to a switch in wind direction (Fig. 4) to the southeast where enhanced penetration into the city center and industrial sector is offered. Fig. 5b schematically illustrates a ventilation process with which these winds may be associated. It also corresponds with a pickup in the strength of the wind (Fig. 6). Indeed, the combination of the two factors in the presence of available energy could completely explain the breakup of the inversion. The vertical and horizontal mixing of the energy at a time when the rural portion is coming off its own heat overload following the midday peak insolation may be responsible for the smaller differential noted observed through the afternoon.

TIME TRENDS

The main results of Yudcovitch's 1965 work are as follows:

1. the mean annual heat island intensity was 3.8° C.
2. the diurnal distribution of intensities was marked by a primary peak at about 2300 hours and a secondary one about midmorning.
3. the maximum intensity was about 17°C.

During the decade following the completion of the study, the city's population has grown 50% from a little over 300 000 to 450 000. The 1975 study showed that the intensity of the island was 6.7°C, an increase of 80% over the 1965 figure. With only two points to work with, it is not possible to discuss the form of the growth curve. Averages, however, indicate an annual growth rate of 6% compounded in the heat island intensity, or about .25°C/year. Thus it can be argued that a 1% population increase has induced the rise of about 1.5% in the urban heat island intensity.

It is extremely doubtful that this growth rate can be sustained, especially given the possibility that an urban heat island has a built-in "self-destruct" mechanism which may be triggered when the phenomenon attains a very high value. However, the figures given above may well illustrate the form of urban heat island growth at the lower end of city size spectrum. Lawrence (1968), for example, noted an increase of only 2°F (1.1°C) in 20 years in Manchester, England.

The maximum intensity increased at a slower rate, from 17°C to 28°C. This is about three-quarters of the increase in the annual mean. While it may be premature to suggest that the rate of increase in maximum intensity is always below similar rate in the annual mean, there may be sufficient theoretical justification for the construction of a hypothesis with universal application, based on the evidence presented above.

The double peak was repeated. But the timing of the primary and secondary peaks were reserved. In the course of the decade, the downtown area has seen a marked change in fabric. The change in skyline is probably the best indicator of the degree of this change. The structural change not only implies a significant increase in the amount of thermal energy released into the atmosphere from the buildings, it also offers additional protection against wind erosion of the energy. Thus, the active peak seemed to have gained more impressively in its growth than the passive one.

Finally, the present limits of Calgary's built-up area include what used to be open country when the 1965 study was conducted. If the two experiments were conducted over the same areal unit, what is now the intraurban differential should be comparable to the urban/rural contrast reported in the 1965 work. The gain in intensity in such a case from 3.8°C to 10.6°C would have been even more impressive. It will, however, be difficult to justify such a comparison since it is held that the intraurban differential in the 1975 study is dependent on internal differences in the urban morphology of the built-up area.

CONCLUSION

The report presented in the foregoing section is part of a comprehensive study of Calgary's urban climate. It appears to us that this is one of the few continuous intensive surveys of urban temperatures ever undertaken. It is also a study which we hope may assume some importance in urban climate studies for subarctic cities, especially those set in areas with strong topographical control. The work raises some important questions about the growth of urban heat island intensities in modest-sized cities.

REFERENCES CITED

Chandler, J.T. 1962. London's urban climate. Geog. J. 128: 279-298.

Lawrence, E.N. 1968. Changes in air temperatures at Manchester Airport. Meteor. Mag. 97: 43-48.

Leighton, P.A. 1966. Geographical aspects of air pollution. Geogr. Rev. 56: 151-174.

Ludwig, F.L. and J.H.S. Kealoha. 1968. Urban climatological studies. Stanford Res. Inst. Final Rep. Contract #OCD-DAHC-20-67-C-0136.

Nkemdirim, L.C. 1976. Dynamics of an urban temperature surface. J. Appl. Meteor. 15: 818-828.

Truch, P. 1977. Spatial and temporal variation of Calgary's surficial temperature field. M.Sc. thesis, Univ. Calgary.

Yudcovitch, T.N. 1967. Some aspects of temperature conditions in Calgary, Alberta: An urban climate study. M.Sc. thesis, Univ. Calgary: 136 pp.

THE IMPORTANCE OF CLIMATOLOGICAL DATA TO THE ENVIRONMENTAL CONSULTANT

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ABSTRACT

The environmental consultant uses climatological data for a number of purposes: describing baseline conditions for environmental impact assessment, assessing air pollution potential and control methods, and assessing impacts that the climate may have on a development. The climatological parameters primarily used are wind, temperature, and precipitation. Inversions, mixing heights, and humidity are often used; other parameters such as sunshine, storms, fog, visibility, hail, and blowing snow are sometimes used. Climatological data are obtained from a number of sources including government data summaries such as Canadian Normals and Climate of Alberta, from Atmospheric Environment Service papers, and from journals. Information retrieval is initially difficult.

Recent studies are discussed with particular emphasis on the role of climatological data. The process by which environmental consultants determine data needs, acquire data, and put them to use are discussed.

Finally, current problems in the reporting format of climatological data are discussed especially those associated with data interpretation. Recommendations are made for improving data reduction, reporting, and abstraction.

INTRODUCTION

Today's environmental consultant must be prepared to use climatological data for a number of purposes. A brief general discussion of the author's experience with the application of climatological data is provided here.

1. Description of Baseline Conditions for Environmental Impact Assessments

   The purpose of an environmental impact assessment is to assess the impact a proposed development will have on its surrounding environment. The first step in such an assessment is full description of the existing environment prior to development. Climatology of the area is usually provided and can be based on existing data from nearby stations or data collected over a number of months at the specific location.

2. Assessment of Air Pollution Potential and Control Strategies

   This application of climatological data may or may not be part of an environmental impact assessment. Here the objective is to determine the climate's influence on emissions from single or multiple sources and to develop control strategies that can reduce the effect of emissions to acceptable levels.

3. Assessment of Climatological Impacts

   This application of climatological data is often overlooked since "environmentalists" are usually concerned with the effects man has on nature. But nature can also have significant effects on man.

This paper discusses the importance of climatological data to these environmental applications.

CLIMATOLOGICAL PARAMETERS

The prime climatic elements used in the environmental applications previously mentioned are temperature, wind, and precipitation. These parameters are normally described in terms of annual and monthly averages and, just as important, in terms of extremes, ranges, and distributions of recorded data. Furthermore, inversions and mixing heights play an important role in air pollution studies. Sometimes other parameters are used, including fog, humidity, storms, visibility, hail, blowing snow, sunshine, and evaporation.

DATA SOURCES

The major, and often the only, source of climatological data is the Atmospheric Environment Service (AES) of Environment Canada. AES has the responsibility for establishing and maintaining observing stations and for collecting and analyzing the data on a national basis. Often this is done in collaboration with provincial and other agencies. A number of basic data summaries are published by AES and these are described briefly below.

1. Canadian Normals (1941 - 1970)

   Volume 1 - Temperature
   Volume 2 - Precipitation
   Volume 3 - Wind

   Climatic Normals (1931 - 1960)

   Volume 3 - Sunshine, Cloud Pressure and Thunderstorms
   Volume 4 - Humidity

   These normals provide monthly and annual means, extremes, and percent frequencies for observing stations across Canada.

2. Hourly Data Summaries

   These have been compiled for over 100 locations, usually airports, from the regular hourly weather observations. These summaries provide more detail than the normals and include the following elements:

   - dry and wet-bulb temperatures
   - wind speed and direction
   - mean temperatures and standard deviations
   - mean dry and wet-bulb temperatures at the four synoptic hours and maximum wet-bulb temperatures
   - observations of thunderstorms, rain, freezing rain, snow, hail, fog, and blowing snow
   - average values of wet and dry-bulb temperatures for each hour

3. General Summary of Hourly Weather Observation

   Data from many stations across Canada were summarized every year under this program, which was discontinued in 1961. Tables provide records of hourly observations for each month of the year for a variety of conditions. This summary was designed for aviation purposes.

4. Climatological Studies

   This series of climatic studies have and are being prepared for different regions in Canada. Over 20 have been published, of which 7 or 8 have application in Alberta.

5. Canadian Meteorological Memoirs

   This series is similar to the above studies and was generally prepared prior to the mid-1960's.

A catalogue entitled Selected Publications in Climatology and Applied Meteorology is available from AES for ordering purposes.

In addition, Alberta Environment annually publishes Climate of Alberta, which contains temperature, precipitation, and sunshine data compiled by AES. Data for the Yukon and Northwest Territories are also included.

An important source of data and data analyses are the reports, articles, and papers published each year by meteorologists and climatologists. An excellent bibliography of these reports is the 1973 publication compiled by Morley K. Thomas of AES: A Bibliography of Canadian Climate 1958-1971.

Another source of climatological data that has only recently become significant is major industrial plants. These plants have been required by Alberta Environment to collect wind and temperature information at some air quality monitoring stations. These data are correlated to air pollution levels and a "pollution rose" can be plotted.

In addition, the environmental consultant may require raw data, which are available through AES, or may require special analysis of data for a specific location, in which case arrangements can be made with the Edmonton AES office to have a special computer analysis carried out in Toronto.

It has been found that basic climatological information can be retrieved easily and rapidly after one has become familiar with the major data sources outlined above. However, becoming familiar with the many sources can take time and on occasion can be frustrating. This is discussed later.

RECENT APPLICATIONS OF CLIMATOLOGICAL DATA

This section briefly describes three studies with emphasis on the determination of data needs, data acquisition, and the final use for the data. The following discussions provide the reader with three examples of environmental uses for climatological data.

1. Planning and Land Development

   A number of projects have been carried out which fall into this category. The example chosen is the proposed annexation of 7,000 acres of land to the north boundary of Calgary. This potential development has been called Calgary North.

   Climatological data were used in this overall environmental impact assessment to:

   - determine the effect of city emissions on Calgary North
   - determine the effect of emissions from a nearby sour gas plant on the development
   - determine the effect of Calgary North's emissions on adjacent communities

   The data required to conduct this study were primarily wind speed and wind direction. Wind direction was the most important because effect of emissions on a specific area is related largely to firstly, the frequency with which wind blows toward the area and secondly, the quantity of emissions.

Wind data from the Canadian Normals was used to determine the annual average wind rose, which was the time period most relevant to this planning type study. City emissions were then found to cause a calculated and measured air quality level at Calgary North. The frequency with which wind caused these concentrations in this area was compared with expected frequencies at other potential city growth areas.

Impact of the gas plant was analyzed through dispersion calculations, wind direction frequency, and inversion frequency data. This analysis was much the same as for city emissions discussed above as was the analysis for the effect of Calgary North's emissions on adjacent communities.

An interesting outcome of this study was the presentation of results before the Provincial Local Authorities Board at which time the meaning of common meteorological and climatological terms had to be explained very carefully.

2. Industrial Development

The example used here is an environmental overview study that was undertaken for a 1500 MW coal-fired power plant and associated strip mine. Climatological data were used to describe baseline conditions, assess air pollution potential, assess control strategies, and assess climatological impact. Climatological data used in this study included temperature, precipitation, wind, fog, inversions, and mixing heights. All of these parameters were important and were used in addressing problems associated with both the power plant and the strip mine. For example, the more significant problems considered were: plant location, method of cooling (pond or tower), fog or steam impacts, mine and plant area runoff, air quality (before and after), stack height, and fugitive dust.

For some of these problems data were needed to describe the worst case situation (ie. air quality) whereas other problems required sufficient data to determine occurrence probabilities (ie. fog and runoff) and some problems needed only annual average conditions (ie. fugitive dust).

It should be emphasized that the environmental consultant, when carrying out an impact study, spends a significant amount of time determining all potential impacts. The impacts having been identified, it is possible to determine the high-priority impact areas. These receive the major emphasis in determining degree of impact and evaluating control strategies for mitigation.

This was an overview study; therefore, additional objectives included identification of knowledge gaps and recommended studies for the detailed environmental impact assessment that will be required if the project proves to be feasible.

3. Applied Research

A project was recently completed for the Alberta Oil Sands Environmental Research Program (AOSERP) that investigated the magnitude and occurrence of fog in the oil sands area and its associated problems. Climatological data were used to describe baseline fog conditions, assess potential fog conditions, and assess fog-pollutant interaction. Data used in this study included parameters affecting fog formation, frequency, growth, persistence, drift and interaction with pollutants including fog, temperature, wind, humidity, inversions, and mixing heights.

These data were obtained from the basic sources discussed previously, through literature searches, and through close cooperation with AES to obtain obscure or litte-known information. During this study some problems were encountered in data reporting and interpretation.

PROBLEMS IN DATA REPORTING AND INTERPRETATION

This section provides a brief discussion of problems that arose during the AOSERP fog study and includes some recommendations for alleviating these and similar problems. During the fog study a number of data sources were searched and relevant fog data abstracted. The problems encountered were:

1. Variations in the Definition of Fog

   The international definition is a visibility reduction to 1 km or less caused by water droplets or ice crystals. A number of data summaries (mainly those developed for aviation use) used a visibility criteria of 9.6 km (6 miles).

2. Variations in the Time Distribution of Fog Occurrence

   The problem mentioned above was compounded by the time period for which fog is observed and reported. Airport observers normally record meteorological parameters on the hour; however, it was learned through discussion with AES that "special" observations are sometimes made between the hour observations. Whether or not a data summary included these "specials" was vague. Also, some data summaries indicated only the number of days during which fog was observed. This confusion, combined with variations in the visibility criteria, proved to be frustrating. Authors of some data summaries attempted to resolve the problem and the following example was extracted from a 1969 summary of national fog data by the Meteorological Branch:

   > In this summary a day with fog is a day on which the visibility was reported to be less than 5/8 of a mile. This does not imply that fog existed for the whole day or during any precise portion of the day, but means that it did occur during at least part of the 24-hour period.

   In this particular summary the author also indicates that 170 of the 285 stations reported made observations around the clock while the 115 did not. But that is the only indication of a variation in the daily observation routine. The 24-hour stations were not identified nor was it indicated over what time period observations were recorded at the other stations.

RECOMMENDATIONS

To reduce the potential of data misinterpretation, it is recommended that:

1. Future data summaries should include a more comprehensive description of the raw data used in the summary. This should include all parameters which may affect the ultimate interpretation and application of data from the summary.

2. Users of climatological data summaries should be aware of the data limitations and should discuss the way raw data is collected, recorded, reduced, and summarized with airport weather observers and AES officials.

ALBERTA CLIMATOLOGICAL COMMITTEE ANNUAL MEETING

REPORTS

CHAIRMAN'S REPORT

John M. Powell

During the past year the Alberta Climatological Committee has held three meetings. The first, last February, was our Annual Meeting, at which we received 12 agency or section reports and discussed other ongoing topics. Other meetings were held in June and October. Through the year some 10 agencies were represented, and two retired meteorologists were also in attendance.

Topics for discussion have included the annual publication of *Climate of Alberta*, installation of recording precipitation gauges, winter climatology programs at selected Alberta Forest Service Ranger Stations, a prototype PVC Stevenson Screen, Wheat Pool Climatological Records, Red Deer Dam proposal, snowfall water equivalents, metrification, support from other agencies for the Alberta Forest Service fire-weather network of climatological stations, snow survey and snow pillow data, value of long-term climatological stations and the representativeness of stations, availability of climatic data on microfiche and on magnetic computer tape, wind data in industrial reports, chinook studies and timber blowdown, the establishment of a mesoclimatic zonation study in the Peace River Region, and the status of the "Medicine Lodge" stations.

In addition to the above, several of which we will hear more of this afternoon, *A directory of climate and related courses and of persons interested in climatology in Alberta* was compiled by myself and published by the Canadian Forestry Service. This directory lists references on climate published since 1969 by Alberta authors. Your secretary, Elliot Kerr, has also been busy compiling an Alberta Hydrometeorology Data Source Sheet. Work has also begun on an update of the inventory of climatological data collected in Alberta but not published by the Atmospheric Environment Service. The last inventory was published in October 1972, and much climate information has been collected since.

Your chairman was invited to attend the March 24, 1976 meeting and workshop of the Alberta Agrometeorology Advisory Committee (AAAC) in Lethbridge, at which time an opportunity was taken to inform them of the past and present activities of the Alberta Climatological Committee. The AAAC is in its infancy, and we plan to maintain a good liaison with this new specialist interest committee. This should not be difficult, because three members of their present executive are regular members of our committee. A brief report from the AAAC is on our agenda this afternoon.

In mid-January this year your chairman also had the opportunity to be an invited observer and participant in the two-day meeting of the Canada Committee on Agrometeorology, held in Winnipeg. Once again I was able to inform them of the past and present activities of the Alberta Climatological Committee.

During the past year we lost the services of two active members of our Committee. Don Storr, hydrometeorologist with the Atmospheric Environment Service, retired and settled in warmer climes on the coast of British Columbia, and Peter Lester of the Environmental Sciences Centre (Kananaskis) of the University of Calgary, who was undertaking studies of the chinook, returned to San Jose State University in California. We shall miss these two members, and I wish to record our appreciation for their input to the work of this committee. At this time I would also like to record my appreciation of and thanks to our secretary, Elliot Kerr, for his work during the year, and to Ben Janz and Conrad Geitz, who helped Elliot and me plan for the workshop this morning. The workshop was a new venture for the committee, and I shall be interested to hear later whether you felt it was a success and fulfilled its purpose and whether the committee should consider something similar another year.

The committee would also like to know whether it should consider a more formal structure and seek a regular source of funding with which to plan its program and projects. This is the second year we have had an annual meeting with agencies invited to present brief oral or written reports for inclusion in the minutes. The committee plans to put together a proceedings of today's activities: the papers presented at the morning workshop and the highlights of this annual meeting, together with the agency reports. However, to publish the proceedings and thereby maintain communication with those that attended today and with others interested in the work of the committee requires funding. Perhaps the committee should seek to reestablish the sponsorship of the Research Council of Alberta or some other interested agency.

I have enjoyed my year as chairman and would be prepared to continue if the committee so wishes. We shall hold elections at the end of the meeting today. If the work of the committee is to continue or increase after our discussions today, I believe we should consider appointing one or two other committee members to the executive to assist the chairman and secretary, as required. In this way your executive will work in less isolation between meetings and be able to more effectively advance the goals of the committee.

ATMOSPHERIC ENVIRONMENT SERVICE, FISHERIES AND ENVIRONMENT CANADA

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Western Regional Office
Atmospheric Environment Service
Environment Canada, Edmonton

Items that are new or areas where there have been changes during the past year are reported on.

Metrication

As of February 1, 1977, all Atmospheric Environment Service (AES) first-order stations had been converted to metric instruments for measuring temperature and precipitation. Some parameters are still being measured in Imperial units but are converted by station personnel.

Climatological stations (Precipitation and Temperature) are being converted to SI as they are inspected. All new stations are being supplied with metric instruments. The change to metric should be completed in about 1-1/2 to 2 years.

Automatic Climatological Stations - MATER

Instrument Branch at AES Headquarters has developed an automatic climatological station that is suitable for collection of data at remote or unattended sites. The MATER has several advantages over other automatic stations:

1. Events are recorded on magnetic tape rather than on paper charts.
2. They can be left unattended for periods of 3-4 months.
3. There is no need for manual abstracting of the data, as data are retrieved via computer printout.
4. The station has been designed to use currently available sensors, such as the 45B anemometer and the tipping bucket rain gauge.
5. Wind and liquid precipitation events can be recorded much more frequently than is possible at the ordinary climatological station.

Disadvantages of the MATER include:

1. A time lag in the data retrieval--the cassete tape must be processed by a computer. It does not lend itself to retrieval or reading of data between tape changes.
2. As yet a sensor to measure solid precipitation is not available for the MATER. A Fischer-Porter could be adapted to the electronics, but there is no real advantage in this because the Fischer-Porter has its own recording device.

Climatological Station Census

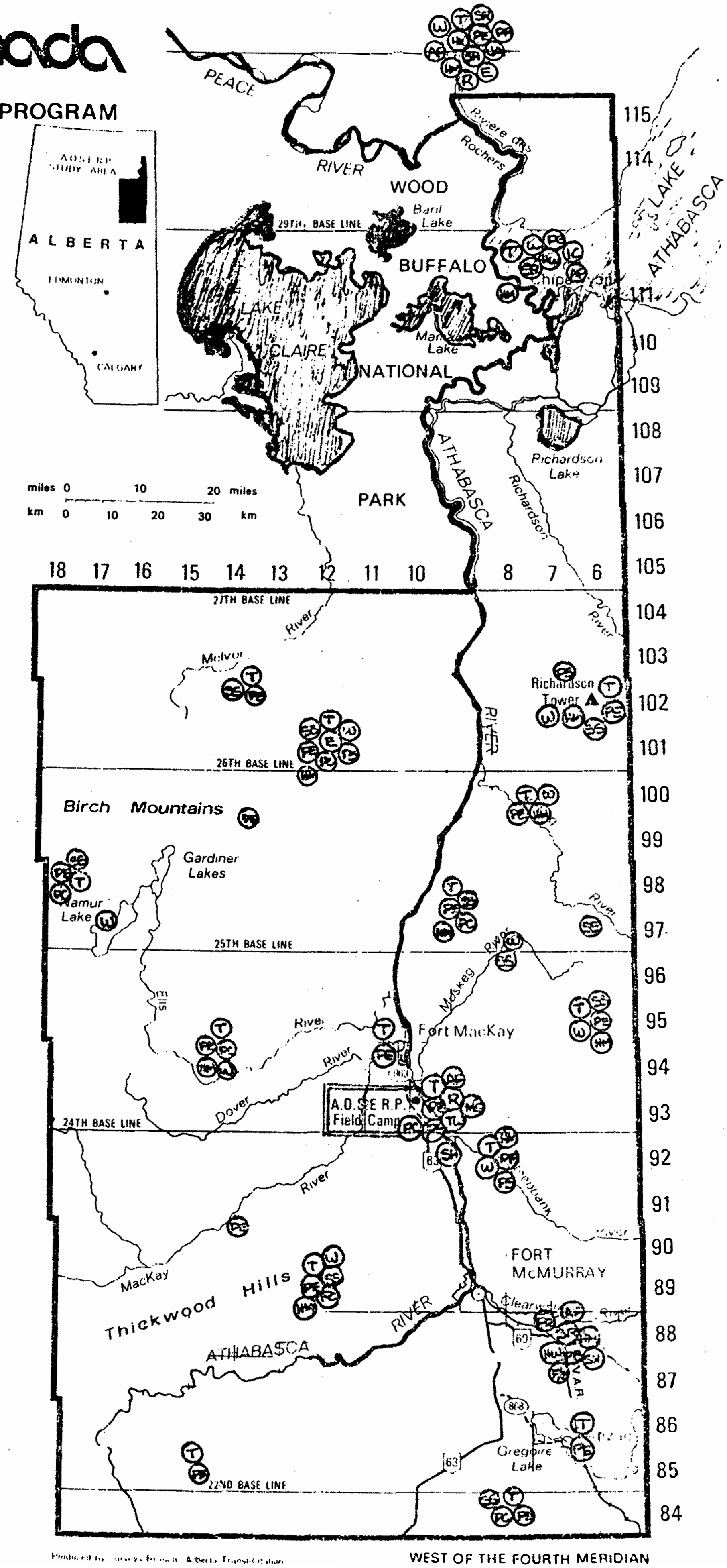
At the end of 1976 there were just over 400 stations in Alberta providing climatological data. Of this number, 140 were seasonal stations operated during the summer months by the Alberta Forest Service. During 1976 there was a net loss of 18 climatological stations in Alberta. Other provinces in Western Canada also reported net losses in the number of climatological stations; British Columbia and the Northwest Territories lost 17 each, Manitoba 6, and Saskatchewan 9.

Alberta Oil Sands Environmental Research Program (AOSERP)

A number of stations collecting data of a climatological nature are now operating in support of this program. In addition to climatological stations collecting data of a conventional nature (temperature, precipitation, wind, and humidity) there is a program of ongoing data acquisition in the boundary layer. A 150-m meteorological tower with sensors at five levels is operating continuously. The minisonde program, although not continuous, is intended to provide data on temperature and wind profiles in the boundary layer at various locations in the project area. Data from the AOSERP program will contribute to the boundary layer climatology and provide quantitative data on mixing heights, ventilation coefficients, and inversion frequencies. A map showing the observational network is attached. The climatological data from this project are archived at AES, Edmonton and Toronto.

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM STUDY AREA

- SYNOPTIC REPORT
- HOURLY WEATHER
- TEMPERATURE
- PRECIPITATION (EVENT)
- PRECIPITATION (STORAGE)
- RATE OF RAINFALL
- WIND SPEED & DIRECTION
- EVAPORATION
- SUNSHINE
- MINISONDE
- UPPER AIR
- PIBAL
- TOWER
- SNOW SURVEY
- PRECIPITATION CHEMISTRY
- ATMOSPHERIC PRESSURE
- HUMIDITY
- ICE MEASUREMENT
- FREEZEUP/BREAKUP



AIR QUALITY CONTROL BRANCH, ALBERTA ENVIRONMENT

R. Angle
Alberta Environment, Edmonton

The role and general activities of the Air Quality Control Branch, Alberta Environment were outlined in the 1975 agency report (February 19, 1976).

In 1976 the development of urban air pollution models for the cities of Calgary and Edmonton was completed. Copies of summary reports may be obtained, free of charge, upon request.

Two of Edmonton's air quality monitoring units (ERMU and EIMU) were equipped with digital printout, electronic averaging wind sets. These sensitive, high-quality instruments have a threshold of less than .3 m/s and an accuracy of ± 1%. The vane has a distance constant of less than 1 m and a damping ration of 0.4, while the cups have a distance constant of less than 1.5 m. The instruments are mounted at a height of 15 m to overcome the disturbances caused by obstacles near the sites. The hourly average wind speed to the nearest 0.1 m/s and hourly average wind direction to the nearest degree will be reported in the quarterly air monitoring data publications of the Branch. Similar instruments will go into service in Calgary later this year.

In a letter to the Climatological Committee dated June 29, 1976, a list of gas plants that regularly measure wind in conjunction with air quality monitoring was supplied. At that time users were cautioned that the anemometers rarely had a standard exposure. The Branch issued a new Air Monitoring Directive (AMD-76-1) in December requiring that all air monitoring stations conform to standard site criteria by the end of 1977. Complete site documentation is also required. A random site inspection program will be initiated in the near future to ensure adherence to the siting criteria.

Commencing in the summer of 1977, in cooperation with the Research Secretariat, Alberta Environment, measurements of global solar radiation and ultraviolet radiation will be made on the roof of Oxbridge Place in downtown Edmonton. The data will be made available upon request. A similar radiation measurement program is planned for Calgary the following year.

Alberta Environment. 1976. An application of an air pollution model to the City of Calgary. A summary report. Prepared by Western Research & Development Ltd. June 1976. 33p.

Alberta Environment. 1976. An application of an air pollution model to the City of Edmonton. A summary report. Prepared by Western Research & Development Ltd. June 1976. 60p.

Alberta Environment. 1976. Sour Gas Industry. Air Monitoring Directive AMD-76-1.

FLOW FORECASTING BRANCH
TECHNICAL SERVICES DIVISION
ALBERTA ENVIRONMENT

A.M. Mustapha
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The Technical Services Division maintains a flow forecasting service designed to inform the public of unusual occurrences on the province's rivers, streams, or lakes. Heavy rainfall or rapid snowmelt may result in potentially dangerous high water conditions. The Flow Forecasting Branch is responsible for the development and application of procedures for forecasting floods and operating reservoirs. Monitoring of precipitation amounts and stream discharge plus analysis of river or lake characteristics allow flow forecasts to be developed. Knowledge of probable flood levels allows private landowners, communities, and government agencies to undertake appropriate action to reduce the damage occurring from high water conditions. The Flow Forecasting Branch gives advice on the operation of reservoirs under provincial control to ensure optimum management of the water resources of the province to provide flood control, minimum flow requirements for water supply or pollution abatement, and irrigation water requirements.

In cooperation with the Atmospheric Environment Service, four Fischer-Porter precipitation gauges were installed in the past year at Ghost Ranger Station, Elbow Ranger Station, Jumpingpound Ranger Station, and near Mayerthorpe. These stations are equipped with telemetry units and can be interrogated by the department's computer-based data acquisition system. The prime purpose of these stations is to make precipitation data more readily available for operational streamflow forecasting.

CLIMATOLOGICALLY RELATED HAIL RESEARCH AT THE ALBERTA HAIL PROJECT

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Atmospheric Sciences Division
Alberta Research Council, Edmonton

The Alberta Hail Project is a cooperative investigation into phenomena associated with hailstorms in central Alberta. Its primary aim is to determine the causes and behaviour of hailstorms in Alberta and to devise models of hail stone growth as a basis for developing hail suppression techniques.

Until 1974 the project was directed by Alberta Research Council, with financial and scientific contributions supplied by Atmospheric Environment Service, the National Research Council of Canada, and the Stormy Weather Group of McGill University. The Interim Weather Modification Board of the Alberta Department of Agriculture then assumed direction of the project and began a 5-year program of hail modification tests and research. The project has grown steadily since its inception in 1956. The operations and field research program are based at the Red Deer Industrial Airport near Penhold, Alberta.

The Atmospheric Sciences Division of Alberta Research Council continues to be associated in various climatological aspects of hail research. The following is a summary of such research projects.

1. Upper Air Station Data

The Mobile Rawinsonde System (MORAS), first introduced in 1975, has been extensively used the past 2 years. Sounding data have been collected in conjunction with the passage of hailstorms. This information includes vertical profiles of temperature, humidity, and wind and contributes to hailstorm model development and understanding. These variables play an important role in delineating covariates for hailstorm prediction and project evaluation. An attempt to define the temporal and spatial limits of soundings representative of the hailstorm environment is currently underway. In addition to the MORAS data, three other upper-air stations (at Penhold, Rocky Mountain House, and Calgary) collect data through the summer months.

2. Radar Systems

Three radar systems (C, S, and X-band) are employed at the project. The X-band is used for tracking aircraft, the C-band as a backup facility and for general surveillance, and the S-band for data collection and research programs. In 1976, a total of 250 hours of S-band radar data was collected on computer tapes. The data collected are used in analysis of seeding techniques and storm history and as support data for other research programs on the project. PPI data from the S-band are also collected on 35-mm film as backup to the computer system. The occurrence of radar-observed phenomena is important in studying the climatology of various thunderstorm observations.

3. Computer Support Systems

The Alberta Hail Project PDP 11/50 computer records radar data, digitized hail pad data, rawinsonde data, hail/rain reports, hail swath dimensions, surface weather observations, distrometer data, mailing and telephone lists, and various calibration programs. Programs have been developed to display storm radar data, to run various hail size predictor models (Hirsch, LMA) and to display and contour weather map data.

4. Surface Networks

Three surface networks (two volunteer and one staff-operated) were set up and operated in 1976:

a. Precipitation Network of 500 stations over an area of 34 500 km^2 (Figure 1)

b. Dense Network of 162 stations over an area of 930 km^2 (embedded in the precipitation network in the Rimbey district of Alberta) (Figure 1)

c. Two Microdense Networks of 26 and 16 stations in .6 km^2 (embedded in dense network)

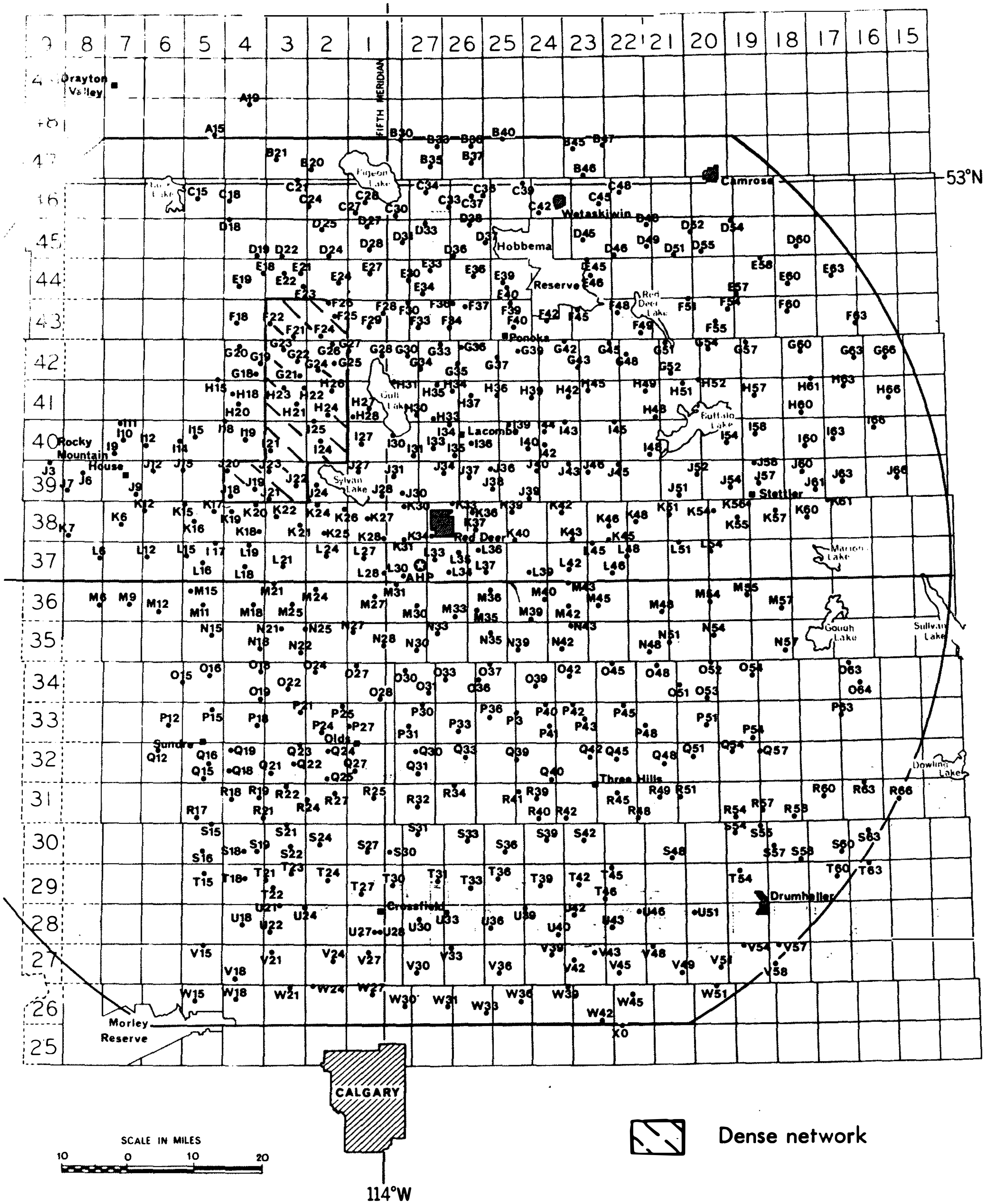

Figure 1. Precipitation sampling network/Dense Network.

All stations in the first two networks were supplied with a rain gauge, hailpads, and rain/hail sample beakers and appropriate forms to report the occurrence of hailfall and total amount of daily precipitation. These collected the following data:

a. Daily rainfall information from June to September, from which daily and monthly rainfall maps for central Alberta are produced
b. Hail occurrences, impact energies, hail size distributions
c. Hail-rain samples for silver analysis

Data from the Dense Network will be used to develop crop-hailfall parameter models as well as mesoscale rainfall patterns. The two microdense networks were set up to examine the variability of hailfall on a smaller scale.

Within the Precipitation Network and Dense Network eight anemometers and eight hygrothermographs were operated from June to September in 1976. These data are used to examine hailfall/crop damage events, as input data to hail predictor models, and as input into other research programs within the Alberta Hail Project.

5. Surface Measurements

Investigations into surface measurements can be grouped into three categories.

a. Mobile Precipitation Sampling

This phase of the project determines the spatial distribution of silver released in cloud seeding. Results of this research include rainfall rates over short time periods, spatial/temporal surface wind measurements during hailstorm passage, and occurrence/nonoccurrence of silver in precipitation samples. An atomic absorption spectrometer was used to determine the background level of silver content in samples, as well as in samples collected during seeding. The typical background level for central Alberta is 6×10^{-12} g ml^{-1}, and samples with concentrations greater than this are considered to have been influenced by seeding.

Silver fallout patterns are used in relation to storm tracks and seeding events in order to better understand the trajectories and dispersion of seeding materials.

b. Correlation of Rainfall Measurements to Radar Measurements

Measurements of rainfall size-distribution with a Joss distrometer were conducted in 1976. Data were collected for numerous storms and are being analyzed at present.

c. Isotype Studies

A program run by the Meteorology Department of the University of Alberta collected precipitation samples to investigate the isotopic content of rain and hail in Alberta storms.

6. Airborne Measurements

Airborne cloud photographs have been taken for documenting cloud seeding events and correlating them with changes in visual and radar echo structures. Seeding and patrol flights regularly take temperature soundings and record the temperature at cloud base. These data are used to supplement rawinsonde data and are useful in hail growth models.

One of the seven seeding aircraft in 1976 was instrumented to provide environmental meteorological measurements of such parameters as temperature, dew point, liquid water content, ice nuclei, and turbulence.

7. Conclusion

In addition to the preceding brief outline of the major research programs undertaken by the Atmospheric Sciences Division the following Bibliography lists major references published in the last few years. A comprehensive list of earlier publications is reported in Wojtiw (1975a).

BIBLIOGRAPHY

Barge, B.L. and F. Bergwall. 1976. Fine scale structure of convective storms associated with hail production. Alberta Res. Counc., Rep. 76-2. 2 volumes.

Barge, B.L., F. Bergwall, G.G. Goyer and J.H. Renick. 1976. Fine scale structure of convective storms -- Implications for cloud seeding in Alberta. Alberta Res. Counc., Rep. 76-3. 19 pp.

Deibert, R.J. and J.H. Renick (eds.). 1975. Alberta Hail Project Field Program 1974. Alberta Agric. 37 pp.

Deibert, R.J. (ed.). 1976. Alberta Hail Project Field Program 1975. Alberta Agric. 67 pp.

Deibert, R.J. (ed.). 1977. Alberta Hail Project Field Program 1976. Alberta Agric.

Goyer, G.G. (ed.). 1975. Current research on Alberta hailstorms, Progress Report 1974-1975. Alberta Res. Counc., Atmos. Sci. Div. 121 pp.

Goyer, G.G. (ed.). 1976. Current research on hailstorms and their modification 1975. Alberta Res. Counc., Atmos. Sci. Rep. 76-1. 145 pp.

Goyer, G.G. (ed.). 1977. Current research on hailstorms and their modification 1976. Alberta Res. Counc., Atmos. Sci. Rep. 77-3. 103 pp.

Oleskiw, M.M. 1976. Simulation of graupel growth in laboratory cloud chamber. Unpubl. M.Sc. Thesis, Geog. Dep. (Meteor.), Univ. Alberta. 164 pp.

Robitaille, F.E. 1977. Development and use of a mobile rawinsonde system. Alberta Res. Counc., Atmos. Sci. Rep. 77-1. 25 pp.

Sackiw, C. and F. Bergwall. 1977. MObile RAwinSonde Training Manual. Alberta Res. Counc., Atmos. Sci. Rep. 77-2. 37 pp.

Strong, G.S. 1974. The objective measurement of Alberta hailfall. Unpubl. M.Sc. Thesis, Geog. Dep. (Meteor.), Univ. Alberta. 102 pp.

Wojtiw, L. 1975a. Climatic summaries of hailfall in central Alberta (1957-1973). Alberta Res. Counc., Atmos. Sci. Rep. 75-1. 102 pp.

Wojtiw, L. 1975b. Climatology of hailstorms in Alberta. Presented at NHRE Symposium/Workshop on Hail. Estes Park, Colorado, September, 1975. Preprint Vol. 4. 14 pp.

Wojtiw, L. 1975c. Hailfall and crop damage in central Alberta. J. Weather Modif. 7(2): 28-42.

CLIMATOLOGICAL DATA AND RESEARCH AT THE ALBERTA HAIL PROJECT

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Mynarski Park, Alberta

Data: Hailfall Records:

1. volunteered by farmers throughout Alberta giving date, time, duration, size, amount, and accompanying rainfall amounts where available.
2. solicited from farmers by telephone in target area (approx. 130-km (80-mile) radius of Red Deer Airport) - same data as above.

Data collected since 1956 from various areas.

Precipitation Measurements:

Obtained from approximately 600 volunteer stations in target area giving rainfall amounts by storm and day, rain samples (discontinued in 1977), hailfall as above, and hailpad measurements from June 1 to August 31.

Data collected since 1974.

Radar records of storms within 160-km (100-mile) radius of Red Deer Airport.

Upper-air observation from University of Calgary and Rocky Mountain House twice daily, mid-June to September 10 and once daily from Red Deer Airport plus irregular soundings by mobile unit within 115-km (70-mile) radius of Red Deer Airport.

Records from Rocky Mountain House since 1969, Calgary since 1975.

Research: Current climatological research includes:

1. long-term trends in various meteorological surface parameters with view to removing any such trends in hailfall records that might otherwise be interpreted as seeding effects

2. establishing an upper-air climatology and relating synoptic-scale meteorological events to hailfall

3. the study of singularities in temperature and precipitation.

ALBERTA FOREST SERVICE - FIRE-WEATHER SECTION

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Alberta Forest Service
Department of Energy and Natural Resources, Edmonton

I. Weather-Reporting Network

The Alberta Forest Service operates a network of 140 lookout stations that were originally set up for the purpose of fire detection but that also assumed duties as a communication and fire-weather network as well. Another 40 ranger stations, provincial parks, Mennonite settlements, Indian reserves, and private individuals complete the A.F.S. weather reporting network.

While some east slopes ranger stations date back to 1914 and earlier, and some of the oldest lookouts to the 1920's, the bulk of the lookout network was built during the 1950's and 1960's. A detailed seasonal historical weather and lightning storm record has accumulated for a period of 10-15 years for most stations. The reporting season is generally considered to be late April to the end of September, although select ranger stations have at times reported all winter as well.

Twice-daily weather reporting of variables similar to the aviation teletype format and as per attached sheet are received on a real-time basis and shared with Alberta Environment (Flow Forecasting Branch) and the Atmospheric Environment Service Weather Office at Edmonton International Airport. Climatological data are published in the *Monthly Record of Meteorological Observations in Canada* series.

II. Alberta Forest Service Fire-Weather Services

Real-time fire-weather operational forecasting during the fire season April-October is the major function of the Weather Section. Its purpose is to provide the basis for allocation and movement of multi-million dollar fire suppression, presuppression, and prevention resources. Forecasts are shared with some agencies or major woods operators who have reciprocal agreements with the Forest Service.

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ALBERTA FOREST SERVICE

WEATHER

....
REGION **DAY/MONTH/YEAR/TIME**

STATION	MORNINGS ONLY			SKY CONDITION	VISIBILITY (km)	PRESENT WEATHER AND OBSTRUCT. TO VISION	DRY BULB TEMPERATURE	RELATIVE HUMIDITY	WINDS			PRECIPITATION				CLOUDS (TENTHS)						DEW POINT	GREEN-UP STAGE	REMARKS
	MAX	MIN	PRES.						DIRECTION FROM	SPEED (km/h)	GUSTS (km/h)	RAIN	SNOW OR HAIL =	WATER EQUIV.	TOTAL PRECIP.	LAYER TYPE			VERTICAL DEV. TYPE					
	AFTN. ONLY											1	2	3	(1 & 3)	HIGH	MIDDLE	LOW	CU	CU+	CB			
	BUI	FWI	FBI																					

ALBERTA AGRICULTURE AGROMETEOROLOGY

C.W. Gietz, Agrometeorologist
Soils Branch, Plant Industry Division
Alberta Agriculture, Edmonton

People engaged in agriculture are of necessity concerned with weather and climate. Climatic conditions have shaped the character of agriculture from place to place within the province and shall continue to do so. Efforts are being directed towards bringing about a greater appreciation of meteorological influences upon specific aspects of agricultural production.

Soil moisture reserves have an important bearing on farm management decisions, particularly in areas of relatively low growing season precipitation. Low levels of soil moisture in some parts of the province have been of particular concern in recent months. During the fall of 1976 maps of precipitation anomaly were updated weekly. These and other data have been used in estimating levels of soil moisture and identifying the areas most affected. A map of precipitation anomaly with suitable interpretation was mailed out to farmers along with their soil test results.

There is an apparent need for the increased use of climatic information in land use decisions where agricultural land is concerned. Because climate influences production potential, agroclimatic analysis is necessary in making the case for agricultural land use in the face of other pressures such as urbanization.

CLIMATE DATA COLLECTED AND THEIR USE BY HYDROLOGY SECTION, NORTHERN FOREST RESEARCH CENTRE

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Northern Forest Research Centre
Fisheries and Environment Canada, Edmonton

Climate data are gathered by the Hydrology Section of Northern Forest Research Centre for research projects carried out either solely by the section or as part of the cooperative studies of the Alberta Watershed Research Program. Following is a brief description of the data collected, the use to which they are put, and the results of several of the studies.

1. The James river study, 24 km southwest of Caroline, has as its objective to determine the influence of small forest openings on snow accumulation amounts, melt rates, and snowmelt runoff patterns. This is to be done through quantitative determination and theoretical process description of snow accumulation and melt within 10 replications of nine circular-opening sizes of ½ H (where H is tree height) to 6 H in diameter, plus control. For the past 4 years snow accumulation has been measured (over 24000 measurements of snow water equivalent) periodically during the accumulation and melt periods. Results are summarized in Figs. 1 and 2. This year will see the end of the empirical part of the study. A start has already been made on the theoretical: evapotranspiration determinations have been made for short periods over the last three summers based on measurements of net radiation, temperature, humidity, and wind at two levels on each of two 30-m towers in the forest. Estimates of transpiration have been made using the heat pulse veolcity method. Baseline data have been recorded for the past 4 years on temperature, relative humidity, precipitation, and wind run at four locations.

2. A study to determine evaporation from snowpack during chinooks and its relation to large-scale topographic features has been carried out for the period January-March, 1975 and 1976. Three transects were established.

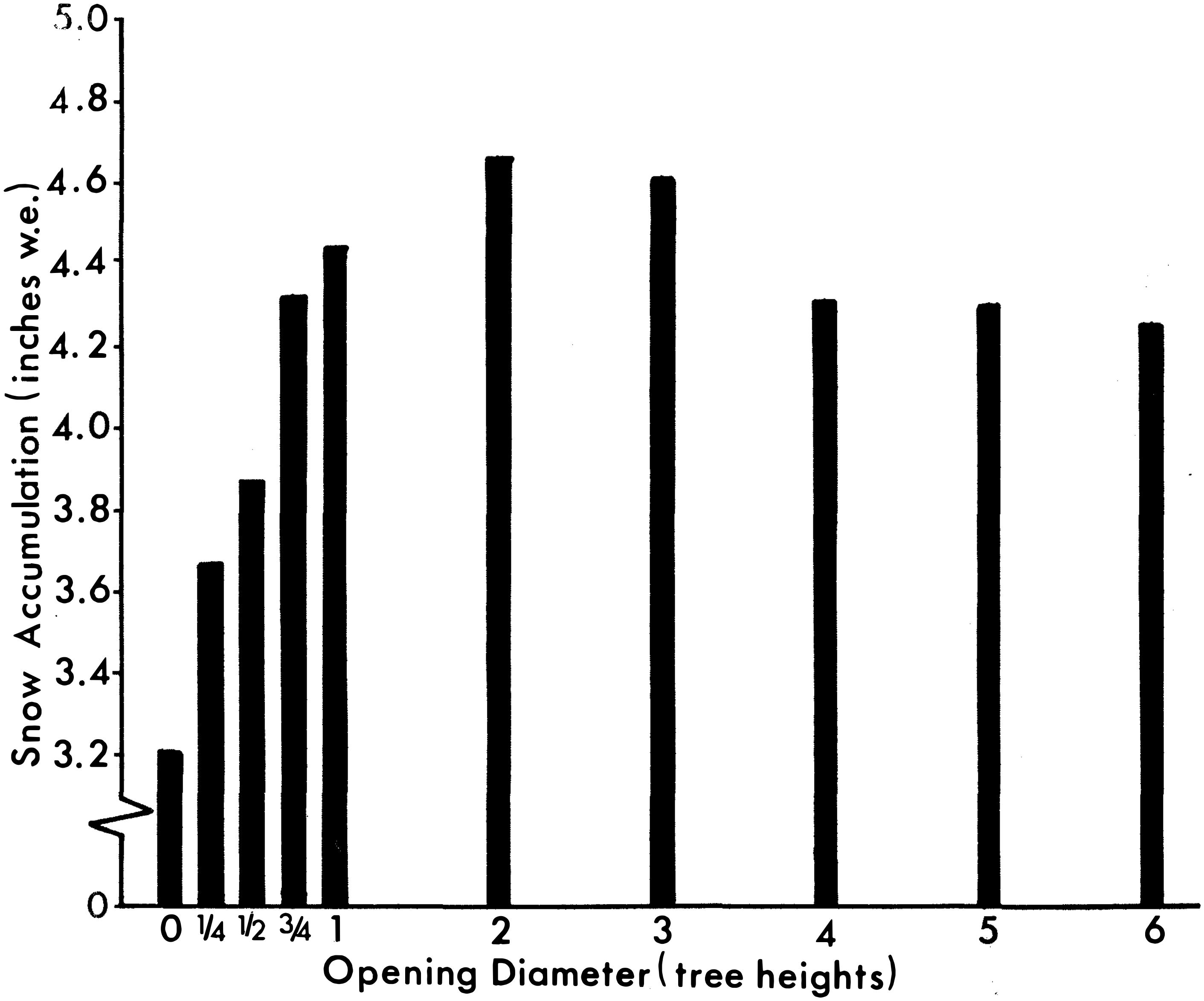

Fig. 1 Mean maximum snow accumulation, 1973-1976, in forest openings at James River

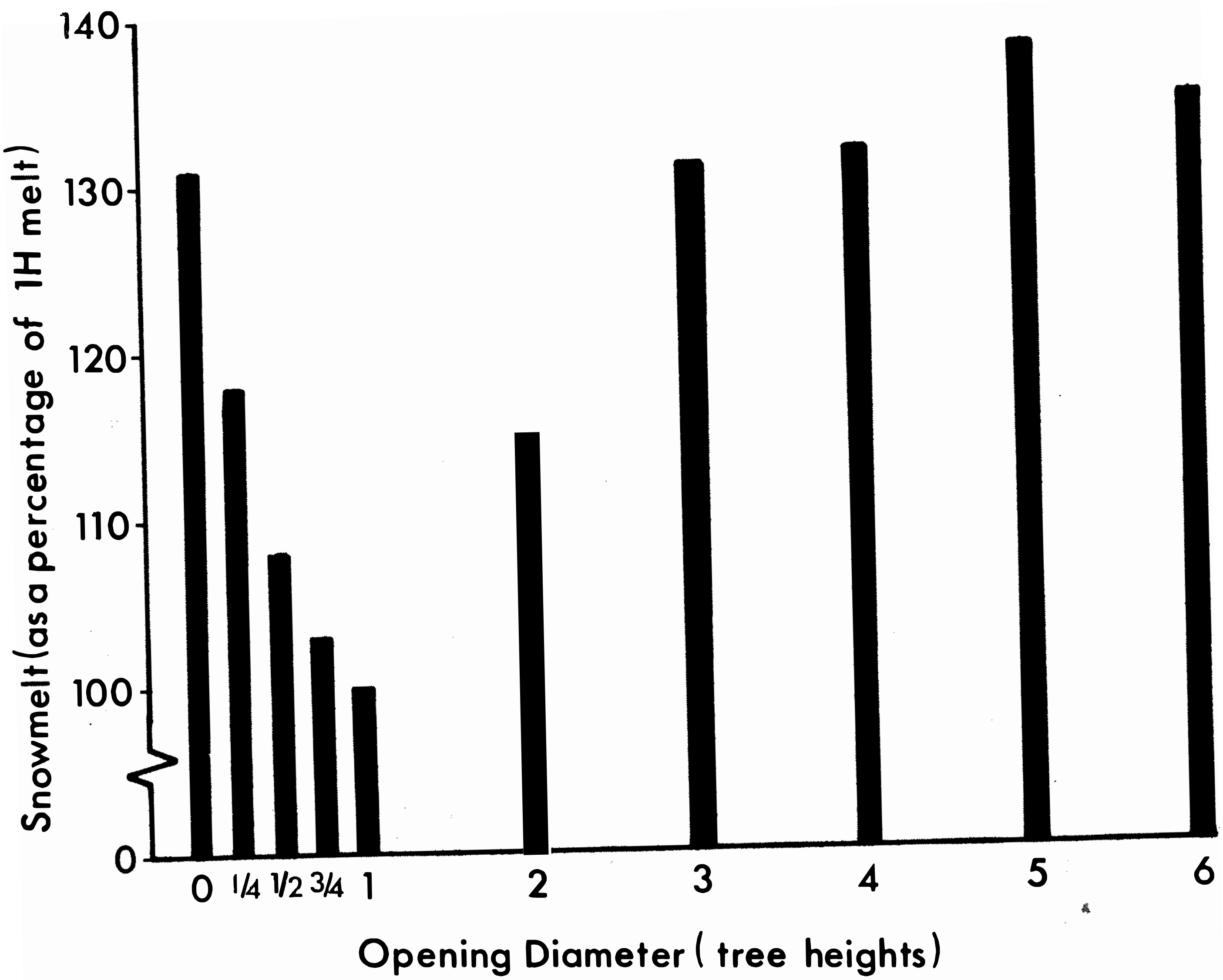

Fig. 2 Mean daily melt, 1973-1976, in forest openings at James River, as a percentage f melt in 1H openings

Two, of five meteorological stations each, were located in mountain gaps (Red Deer and Bow river valleys) at elevations of 1400-2250 m asl. The third transect of nine stations extended 240 km from Nordegg to Kananaskis at elevations of 1370-1670 m. Temperature and relative humidity were recorded at each station and wind speed and direction (6-m towers) were recorded at every other station. Using the method described by Boyd (1967), based on Diamond's (1953) work and equations for eddy conductivity over a snowfield developed by Sverdrup (1936), evaporation, melt, and condensation were calculated for 4-h periods.

Chinook intensity as measured by snowpack evaporation was not consistently greater in the mountain gaps than along the foothills. Evaporation was greatest at the highest elevations (in the mountain gaps), due to higher windspeeds above treeline, although for a given elevation, evaporation was no greater at mountain-gap sites than at other sites. Evaporation amounts were as high as 1 cm/day and over 8 cm for the duration of the four chinooks, a significant loss in an area of relatively shallow snowpack.

Snowmelt amounts reached 3 cm/day and over 15 cm for the period, but most of this percolated into the pack, refroze, and was thus retained in the pack.

3. Rain water has been collected throughout the summer for the past 4 years at three sites on Marmot Creek experimental watershed. Chemical water quality analysis has been carried out on the samples, the results to be used as input to a nutrient budget of the watershed.

4. Since 1969, NFRC has measured snow water equivalent at 1500 points regularly spaced across Marmot Creek basin. These data have been used to relate snow accumulation to topographic and forest variables, to indicate the amount of increased accumulation in the cut blocks on Cabin subbasin, and as input to the mathematical model of the hydrologic system on Marmot Creek basin. Data are published in the annual Compilation of Hydrometeorological Record, Marmot Creek Basin, along with data collected

by Atmospheric Environment Service on precipitation, evaporation, wind, temperature, relative humidity, radiation (short wave and net), and data on streamflow, sediment, groundwater, and water quality.

5. At Streeter Creek Experimental watershed, two 40-point snow courses (one within and one outside the treated subbasin) are measured periodically throughout the winter. These data are used to assess the effect of the 1976 treatment (cutting 0.2- to 0.4-ha openings in the aspen stands) on snow accumulation and melt. They will be published along with the meteorological data collected by AES (precipitation, temperature, relative humidity, wind) in the compilation of Hydrometeorological Record, Streeter Creek Basin.

REFERENCES

Boyd, D.W. 1967. Discussion on moisture loss under chinook conditions. Proc. First Canadian Conference on Meteorology, Toronto. Part II, 307-314 p.

Diamond, M. 1953. Evaporation or melt of snow cover. Snow, Ice and Permafrost Research Establishment, U.S. Army, Research Paper 6.

Sverdrup, H.V. 1936. Eddy conductivity of air over a smooth snow field. Geofysiske Publikasjoner, 11(7):1-69.

STUDIES WITH CLIMATOLOGICAL INPUT IN THE NORTHERN FOREST RESEARCH CENTRE PROGRAM, OTHER THAN HYDROLOGY

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Fisheries and Environment Canada, Edmonton

The Centre has one full-time forest climatologist and one technician who give advice on climate for all other studies in the Centre program. Several other scientists use climate data.

Current climate or related studies are as follows:

1. Climatic zonation for the forested areas of the Prairie Provinces.

This study has been completed other than the reporting. It involved use of nearly 200 stations in Alberta. Daily temperature and precipitation data for May to September for the years 1961-1970 were used as input for a factor analysis with 22 independent variables. The resulting factor scores were used in a hierarchical profile grouping procedure to delineate stations having similar summer climatic regimes. A map classifying the summer climate of the forested and adjacent areas of the Prairie Provinces was produced with 26 groupings.

2. Climate of clear-cut forested areas in the Hinton area.

To date 6 years of summer field data and one of winter have been collected. Each year 40-50 locations were sampled, and in all about 110 sites have been used. All stations were equipped to measure temperature, humidity, and precipitation. Base stations and some other stations have also been equipped to measure wind, radiation, soil temperature, soil moisture, and evaporation. On some cut areas intensive microclimate networks have been established to identify the zones of stand border influence for each climatic parameter. A dense network of precipitation gauges was employed for 4 years in support of a hydrology study. A report on the summer climate of the Hinton-Edson area based on 20 stations for the 1961-1970 period was published.

3. Effect of microclimate of clear-cut areas on pine and spruce seedling growth.

A 3-year study on four areas near Hinton to establish any effect of the forest stand margin on growth. This is the final summer for sampling.

4. Biogeoclimatic ecosystem classification of the Province of Alberta.

A new study to provide an ecological classification of the forested areas -- a joint study by the Alberta Forest Service and the Canadian Forestry Service. The project aims to provide a biogeoclimatic zonation in terms of plant associations.

5. Soil moisture and temperature in relation to topography, soil, vegetation, and climate.

This was a study based on five forest types in the Hinton area, but is being terminated due to the resignation of investigator. All field data were collected.

6. Analysis and synthesis of forest insect and disease survey historical data and information.

Used historical survey and climate data to relate insect outbreaks to climate. Two recent publications were on *Heat units and outbreaks of the forest tent caterpillar* and *Weather and outbreaks of the spruce budworm*.

7. Fire behavior in boreal forest fuels.

Related to improving the Fire Weather Index. Work on four forest types near Slave Lake to develop fire spread and intensity tables for important fuel types by major sites and climate within the region.

8. There are also a number of studies in the AOSERP Program on effects of SO_2 on vegetation that involve climate and its effect on atmospheric effluents.

9. A pathology study has also been looking at the role of winter injury and especially frost damage in poplar canker and dieback. Several papers in this area have recently been published.

UNIVERSITY OF ALBERTA, DEPARTMENT OF GEOGRAPHY - BRIEF SUMMARY OF CURRENT RESEARCH TOPICS

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University of Alberta, Edmonton

1. M.Sc. Thesis Topics with Some Relevance to Climatology

Temperature, Precipitation

A. Lachapelle: Spectral analyses of monthly mean temperature and precipitation data from eight Alberta stations.

Satellite Meteorology

B. Green: Analyses of land-sea horizontal temperature gradients in the Arctic.

J. Broszkowski: Identification and analyses of cloud types and cloud heights over western Canada.

D. Oracheski: Modification of clouds by the Rocky Mountains.

Hail Studies

L. Wojtiw, T. Krauss, P. Wrenshall: Analyses of radar data in relation to crop damage, hail size, and effects of cloud seeding.

Air Pollution

B. Thomson: Prediction model for the depth of the mixing layer.

Microclimate

S. Cohen: Analyses of energy balance components in relation to surface vegetative cover for aspen, spruce, shrub, barley, grass and fallow.

2. Field Studies

C. Labine, G. Reynolds: Measurements of temperature, wind, humidity, precipitation, precipitation interception, radiation components, soil temperature, and soil moisture in a stand of *Pinus banksiana* on a steep sand slope at Richardson Fire Tower in northern Alberta. Field program is now in its second year and is expected to terminate in late summer, 1977.

REPORTS ON CONTINUING PROJECTS AT THE UNIVERSITY OF CALGARY

E.C. Rhodes and L.C. Nkemdirim
Department of Geography
University of Calgary, Calgary

The Department of Geography is continuing work on the urban heat island studies in Calgary. The first stage of the work -- the surface features of the island -- has now been completed, and the second stage is underway. This involves the study of the changing pattern of the urban boundary layer above the city. The target date for its completion is June 1978. The third stage, which should involve the coupling of the surface and atmospheric patterns, is scheduled for completion early in 1979. The final stage, the numerical model of the three dimensional structure of the island, is scheduled for 1980.

The first report is now being published as a monograph that should be ready for distribution by 1 April. Any member who is interested in obtaining a copy should write to:

Calgary's Urban Heat Island (Part 1)
c/o Mr. E.C. Rhodes
Department of Geography
The University of Calgary
CALGARY, Alberta
T2N 1N4

The department is also carrying out diffusion studies from a stack located in an area of varied topography to the northwest of Calgary. The programme should be completed by the fall of 1977.

Dr. Peter Lester is continuing his work on the chinook. A Master's thesis on the mesoscale aspects of the chinook has just been completed by a graduate student in geography under Dr. Lester's supervision. The thesis is available in the Department and the University library.

Dr. Stuart Harris (Geography) continues to maintain meteorological instrument on sites in the Bow Valley and the eastern slopes of the Rockies. Dr. Harris is studying soil movement and permafrost in the area.

Dr. T. Mathews (Physics) is using acoustic sounders to monitor atmospheric stability and motion in the lower atmosphere. His work has already proved useful in the observation of stability profiles, movement of chinook waves and atmospheric turbulence. The first report on the project is appearing in Boundary Layer Meteorology later this year.

Drs. Richard Rowe and Stephen Benjamin (Chemical Engineering) are doing plume studies at Jumping Pound and Crossfield gas plants.

The Alberta Hail Research Project continues this summer from our Weather Research Station. We have some data on the upper atmosphere for three summers. There are a few for selected winter days.

Dr. Alan Legge (Environmental Sciences Centre) is directing a field/laboratory study on the impact of sulphur gas emission from a sour gas processing plant on a forest ecosystem. Surface temperature, wind-speed and direction, and wind and temperature profiles to 28 m are some of the variables in the study.

Finally, we are pleased to announce that our temperature and wind sensors on the CFCN tower to the west of the city are now in operation. The tower instrumentation is designed to complement the Bonnybrook tower profile. The two towers are located almost directly opposite each other at either end of the city, and there is almost a 250-m elevation differential between them due to topography.

THE PEACE RIVER LAND EVALUATION PROJECT

J.S. McKenzie and W.A. Rice
Research Station, Agriculture Canada
Beaverlodge, Alberta

INTRODUCTION

A Land Evaluation Program has been given high priority by Agriculture Canada's Soil Research Institute in Ottawa. Both a long- and short-term plan are developing. The short-term plan will develop a proximate quantitative assessment of the food production capacity of Canada. This project has a target date of December, 1977. Following this, the goal of the second project is to develop a long-term program for land evaluation whose objectives are to obtain an inventory of the land resources of Canada and then to evaluate and interpret the capabilities of these resources for agricultural and other uses.

Planning and development of pilot projects have been initiated in three different regions: 1) southern Ontario, 2) the Great Plains (Saskatchewan), and 3) the Peace River Region of Alberta and B.C. Work on the first two areas and on the proximate quantitative assessment of the food production capacity of Canada is being supported by Agriculture Canada, Research Branch funding through contract research. The research contractors include the University of Guelph, Shawinigan Engineering, University of Manitoba, and the University of Saskatchewan.

The project in the Peace River Region will operate primarily with in-house funds.

THE PEACE RIVER REGION: A suitable area for the Pilot Project.

The Peace River Region was selected as an area for a pilot land evaluation project for several reasons.

1. The region consists of over 250 000 km^2 with approximately 9 million ha of potentially arable land. To date, only 1.2 million ha are under cultivation. Development of the remaining potentially arable land will require the type of information assembled from the Land Evaluation Program.

2. The extreme climatic and soil variability in the Peace River Region produces numerous meso-environments within the region. To optimize agricultural productions these environments must be mapped.
3. There are more than 50 meteorological stations in the Peace Region, many of them continuous since about 1940 and some dating back to 1914. In addition, we are in the process of developing a plan to utilize 32 sets of meteorological equipment for additional sites.
4. There is a wealth of agronomic data collected since 1916 by the Beaverlodge Research Station and former Experimental Farms and Illustration Stations in the region.
5. The Northern Research Group (NRG) at Beaverlodge is very interested in the program. An extensive review of research priorities by the NRG in 1970 clearly defined the need to understand how crops respond to our northern environment. The major thrust of the NRG has since been to develop an understanding of principles that govern crop responses to the northern environment. Consideration of the crop-environment interaction is an important part of every research program at Beaverlodge.

OBJECTIVES OF THE PILOT PROJECT

The objective of the project is to evaluate the potential of the land resources of the Peace River Region for food production. This evaluation is to be achieved by developing methodology to compile the data, then to integrate the following four main work areas:

1. climatic zonation and mapping
2. land resource base evaluation and mapping
3. agronomic data compilation
4. farming systems inventory

The time frame for this project has been divided into 3 phases:

1. Planning - 1 year
2. Compilation - 2 to 3 years
3. Analyses, modelling, etc. - 1 year

WORK AREAS FOR THE PILOT PROJECT

The roles of cooperating agencies are indicated in the following detailed examination of each work area:

1. Climatic Zonation and Mapping

Groups in British Columbia, Alberta, and Ontario have indicated a strong interest in this part of the program. Accordingly, plans are progressing very well and some work is actually underway.

Our objective in this area is to map the numerous mesoclimates in the Alberta and B.C. Peace River Region. We would like to use two types of mapping systems:

1. The B.C. climatic classification scheme or a revision of it
2. The mapping of the photo-thermal resources for barley and wheat

The latter system was developed by Mr. Dan Williams from the Ag Met Section of the Chemistry and Biology Research Institute (CBRI) in Ottawa. This system maps, on the basis of the photothermal resources of a region, isolines indicating the number of days from ripening barley and wheat to the first killing frost in the fall.

Developments and planning this part of the project are as follows:

a. The Ag Met Section, CBRI has summarized data from a large portion of the meteorological stations within the Peace Region.
b. A manuscript on agroclimatic resource analyses mapping methods is in preparation.
c. The Ag Met Section, CBRI is preparing photo-thermal resource maps for barley and wheat. The map for the Grande Prairie country is almost complete.
d. Through a contract, Shawinigan Engineering in Ontario will be developing a first approximation of a climatic resource data bank. This is based on temperature and precipitation normals on a 10 x 10 km grid developed from available climatic data and topographical maps in the Region.

e. Environment Canada, Atmospheric Environment Service, Downsview, have provided the Northern Research Group with 32 sets of meteorological equipment. We now have the capacity to set up 32 additional meteorological sites.

f. The final stages of the climatic modelling and mapping are yet to be planned in detail. The B.C. Environment and Land Use Secretariat, Environment Canada, Atmospheric Environment Service, the Ag Met Section in Ottawa and other groups have indicated a willingness to help us develop the plan.

2. Land Resource Evaluation and Mapping

This section of the program will involve a compilation of the physical land resources in regard to parent material, texture, landform, topography, soil water, salinity, erosion, etc. This area is still in the planning stage. First approximation for key areas is to be compiled this winter, but major work will begin in the fall of 1977. The work will be done cooooperatively by the Soil Research Institute, Edmonton and B.C. Department of Agriculture, Victoria within a framework provided by Soil Research Institute, Ottawa.

3. Agronomic Data Compilation

The Beaverlodge Research Station will carry the main responsibility for this area. Compilation and evaluation are envisioned in two categories:

a. Compilation of crop-environment interaction data. This includes a crop-by-crop compilation of agronomic data indicating requirements, phenology, diseases, plant survival, soil management techniques such as those pertaining to acid soils, fertilizer responses, soil crusting, etc., pertinent to northern agriculture. All data will be entered into the CANSIS Performance/ Management Files.

Tom Peters, Alberta Soil Survey, will be using crop insurance and soil testing data to form a basis for part of the soil productivity rating.

b. Compilation of environmental boundary conditions. The environmental conditions for growth of various crops will be defined as affected by climate, soil, and land characteristics. Where possible these environmental boundary conditions should be substantiated by experimental fact; however, evaluations based on practical experience and unbiased observations are equally acceptable. This format for the compilation of agronomic data is similar to that proposed for a national program in 1974 by a joint meeting of the Canada Soil Fertility Committee and Canada Soil Survey Committee (Charlottetown, 1974).

4. Farming Systems Inventory

This part of the project has received the least amount of planning. It is envisaged as the development of a system classifying farming operations according to type, straight grain farming vs. cow-calf or feedlot operations, for example, and several variations in between. Some discussions have been held with Agriculture Canada's Economics Branch.

THE FINAL INTEGRATION OF DATA

The climate, land resource, agronomic and farming system information will then be integrated to provide an assessment of the total resource in terms of crop production possibilities in the Peace River Region. The final product may be envisaged simply as a climatic map superimposed on a soil map, and each area so delineated will be classified according to agronomic capabilities.

THE POTENTIAL USE OF INFORMATION FROM THE LAND EVAULATION PROGRAM

1. Land use planning

The program will provide the foundation for land classification in the Peace Region and the remaining 8.1 million ha of potentially arable land in northwestern Canada. In addition, a valuable base will be established for the Departments of Environment, Agriculture, Forestry and Northern Affairs to cooperate in programs for the efficient utilization of land in northwestern Canada.

2. Food production capability predictions.

The program will be used to provide a rapid assessment of the impact of land or economic policies on the food production capability of the region. It will also provide valuable information for Agrometeorologists who are developing productivity models based on agronomic, climatic, and soil data for northern regions.

3. Agricultural extension services.

After the compilation of agronomic and climatic data is completed and the environmental boundary conditions identified for each crop, particular problems will be more easily diagnosed. Problem areas will also be easily identified.

4. Agricultural research planning and needs.

To more fully understand the complexity of plant and animal production problems, one cannot separate the plant or animal from its environment. The program will provide researchers with a better understanding of our total environment. It will help us more fully understand the complexity of the crop-environment interaction and it will help us identify the extent of particular problems so that research priorities can be more easily defined on production problems in the area.

The program will also provide an opportunity to verify class intervals from the B.C. climate scheme against actual crop responses to weather factors, and bring greater precision to current climate studies in the N.W.T. and Yukon.

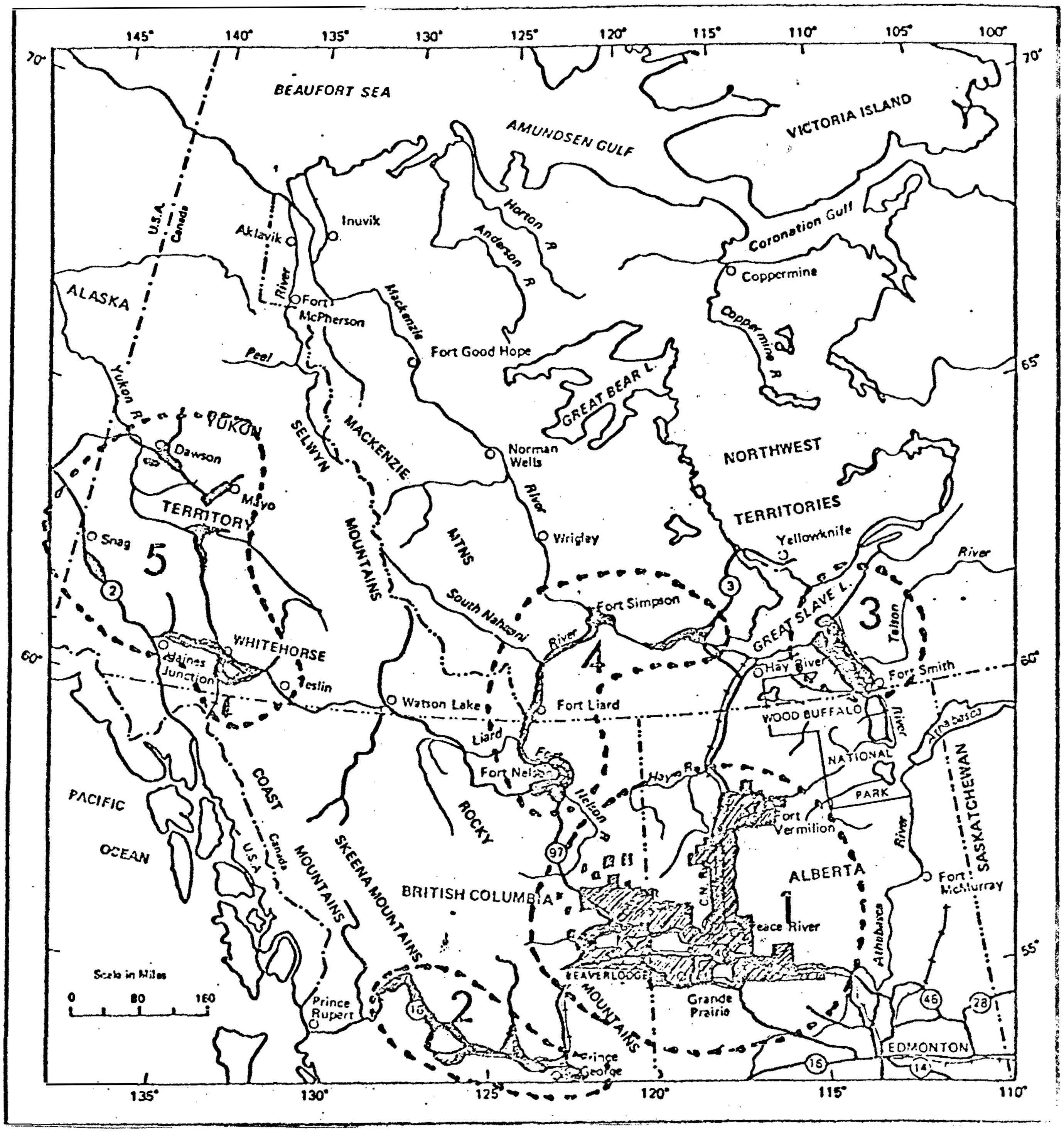
CONCLUSION

The program has many outstanding merits. Its success, however, depends primarily on the support, in terms of budget, manpower, and professional consultation, from many agencies. Since the Peace River Project is to be financed through in-house funds, it is obvious that the Research Branch, Agriculture Canada will provide the leadership through the personnel in the Northern Research Group and the Soils Research Institute.

The program should be challenging, and we welcome both your criticisms and your cooperation.

The following map, listing of land areas and recent reports on northern agriculture were supplied by J.S. McKenzie after the meeting for inclusion in the proceedings.

NORTHWESTERN CANADA AGRICULTURAL POTENTIAL
(Hectares)



	Developed	Undeveloped
(1) Peace River Region of B.C. and Alberta	1,861,554	8,660,272
(2) North Central B.C.	80,937	404,686
(3) Slave River, N.W.T.		687,966
(4) Ft. Nelson - Ft. Simpson - Ft. Providence		1,214,057
(5) Yukon		121,406
Total Owned Pasture (mostly undeveloped)		809,371
Total Community Pasture	17,015	160,255

Pasture - Range Potential - 4,046,856 (approx.)

LAND AREA SERVED BY NORTHERN RESEARCH GROUP - 1975

	Native Pasture (ha)	Cultivated (ha)	Potential (ha)
ALBERTA			
Upper Peace	490,593	1,336,802	5,058,570
Lower Peace	72,385	94,080	2,711,394
BRITISH COLUMBIA			
B.C. Peace	218,877	563,865	890,308
North Central		80,937	404,686
Fort Nelson			202,343
YUKON TERRITORY			121,406
NORTHWEST TERRITORIES			
Slave River			687,966
Mackenzie R.			566,560
Liard River			440,856
TOTAL	781,855	2,075,684	11,084,089
Community Pasture	160,255	17,401	
Rangeland			4,046,856
TOTAL	942,110	2,093,085	15,130,945

In the Peace River area of British Columbia and Alberta there was an increase in total cultivated land from 862,892 ha in 1955 to 1,777,532 ha in 1975.

W.L. Pringle
February 1977

Reports - Northern Agriculture

1965 Report on the Potential of the Slave River Lowlands for Agriculture and the Feasibility of Developing a Viable Cattle Ranching Industry in the Area.
Field Surveys in 1965
Team members, Nowosad, Day, Cody, Looman, Stutt, Philpotts

1974 Agricultural Potential of the Mills Lake and Horn River Areas, N.W.T. (Report to Department of Indian and Northern Affairs) - W.L. Pringle and E. Wiken

1975 Report on Soil Investigations and Agricultural Potential in Parts of the Yukon Territory.
(Prepared for Department of Indian and Northern Affairs) - D.F. Acton and W.L. Pringle

1975 Yukon Agriculture - A Policy Proposal - R.W. Peake & Associates Ltd. Lethbridge, Alberta

1976 Soil Survey and Land Evaluation of the Liard and Mackenzie River Area, N.W.T.
H.P.W. Rostad, R.A. White and D.F. Acton and others
(Grazing potential of the area by W.L. Pringle)

1976 An Assessment of the Agricultural Potential of the Slave River Lowlands, N.W.T., Canada.
By Northern Research Group - (W.L. Pringle, B. Siemens, and A.M.F. Hennig)

1976 Assessment of the Grazing Potential of the Yukon Territory. W.L. Pringle. To be included in a report by the Saskatchewan Institute of Pedology.

SUMMARY OF ALBERTA AGROMETEOROLOGY ADVISORY COMMITTEE ACTIVITIES

D.H. Laverty (Chairman)
Soil and Feed Testing Laboratory
Alberta Agriculture, Edmonton

1. Alberta Agrometeorology Workshop. The committee organized a workshop held at the Research Station in Lethbridge on March 24, 1976. Guest speakers presented papers on agriculture research projects involving meteorology and meteorological services available to agriculture. Copies of the proceedings of this workshop have been distributed to interested agencies and to persons upon request. Further copies are available for distribution from Plant Industry Division, Alberta Agriculture, 9718-107 Street, Edmonton.

2. Requirements for Climatic Information and Research. The committee requested that other agriculture advisory committees submit statements of requirements for climatic information and research. Six statements were received and these have been reviewed by the executive. These statements indicate that agrologists need to define their meteorological requirements more specifically and must be prepared to research climate-related problems. The role of the meteorologist is to assist with requirement definition and to bring meteorological expertise to bear upon the problem once it is defined.

3. Future Action. The committee has planned a working meeting for April 4, 1977 to more clearly identify meteorological requirements for agriculture and to establish priorities.

Recommendations to the Committee

The following recommendations were referred to the executive of the committee and have been acted upon. No formal recommendations or resolutions were forwarded to the Alberta Agriculture Coordination Committee at their annual meeting in January 1977.

Recommendation No. 1: Meteorological Reporting Stations

(a) That the closure of existing climatological stations be avoided, especially those stations that are of key importance because of their location or length of record.

(b) That in the selection of new sites for climatological stations, greatly increased stress be placed on ensuring that the site selected properly represents the surrounding area or a microclimate of special interest.

Recommendation No. 2: Agrometeorology Training

Whereas climate is a major factor in the management of agricultural crops and livestock in Alberta; and

Whereas students studying agriculture at the college and university level should receive some instruction in agrometeorology,

Therefore, it is recommended that ways of emphasizing agrometeorology training need to be investigated with colleges and university faculties of agriculture.

The current membership of the Advisory Committee is as follows:

Representatives and Committee Members:

Animal Industry	-	R.J. Christopherson
Cereal and Oilseeds	-	
Dairying	-	
Economics	-	T.A. Peterson
Education and Rural Extension	-	R.D. Clark
Engineering	-	E.A. Pungor
Forages	-	
Horticulture	-	R.M. Trimmer
Pest Control	-	H.G. Phillips
Pulses	-	
Soils	-	G.R. Webster
	-	D.H. Laverty (Chairman)
Veterinary Medicine	-	W.O. Haufe (Director)
Weeds	-	M.K. Price
Alberta Climatological Committee	-	J.M. Powell
Alberta Agriculture Agrometerologist	-	C.W. Gietz (Secretary)
Weather Modification Board	-	G.T. Sterling
	-	J.H. Renick

Environment Canada, Atmospheric Environment Service	- B. Janz (Director)
	- C.E. Thompson
University of Alberta, Meteorology Department	- K.D. Hage
Canada Committee of Agrometeorology Representative	- W.O. Haufe

OTHER ITEMS OF BUSINESS - ANNUAL MEETING - W.E. KERR, SECRETARY

A. OLD BUSINESS

1. Climate of Alberta Booklet - This booklet will again be published and distributed by Alberta Environment. The 1976 booklet containing A.E.S. precipitation, temperature, and sunshine data will be published in metric units. Please contact Alberta Environment, Communications Branch at 9820 - 106 Street, Edmonton, Alberta T5K 2J6 for more information.

2. Directory of Alberta Climatologists and Climate Related Courses - Copies of this directory, which was compiled by Dr. John M. Powell for the Alberta Climatological Committee, may be obtained by writing the Northern Forest Research Centre, Canadian Forestry Service, Fisheries and Environment Canada, 5320 - 122 Street, Edmonton, Alberta T6H 3S5. Persons wishing to have their names added for any future editions of the directory, please forward their names and addresses to the committee.

3. Alberta Hydrometeorological Data Sources - Continuation of this project will be carried out by a committee consisting of Elliot Kerr, Lub Wojtiw and Will Prusak. Any other interested persons should make their support known by contacting one of the above committee members.

4. Inventory of Unpublished Climate Data - This project to update the 1972 listing has received very little support to date by the members of the Committee. Therefore, a plea goes out to those persons or agencies that have unpublished climatic data to contact John M. Powell at the Northern Forest Research Centre. Also, anyone interested in helping the Committee with this project, please let us know.

B. NEW BUSINESS

The new business portion of the meeting was completely taken over by the following discussion:

Dr. H. Sandhu suggested that the Alberta Climatological Committee should no longer be called such, but should be renamed to form an "assocation". This idea was supported by many, including the "Father of the Committee", Prof. Richmond Longley.

Therefore, the Alberta Climatological Committee was renamed the Alberta Climatological Association and it was decided by the members present at this meeting that a new executive format would consist of a chairman, secretary, and two directors.

An election to select a new executive was then chaired by Ed Stashko, past chairman. By majority consent of the members Dr. John M. Powell was reelected chairman; Elliot Kerr, secretary; Ben Janz, A.E.S., director; Conrad Gietz, Alberta Agriculture, director.

The new executive was instructed to formulate new goals for the Association for discussion and possible approval at the next Annual Meeting. It was also suggested that a similar workshop be held next year.

Meeting was adjourned at 4:30 p.m.

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