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Contributors should submit manuscripts to Stewart J. Cohen, Editor, CLIMATOLOGICAL BULLETIN, Canadian Climate Centre, 4905 Dufferin St., Downsview, Ontario, M3H 5T4. All manuscripts should be typed double spaced on one side of good quality white paper, 28 cm x 21.5 cm, or its nearest equivalent. The abstract, list of references, tables, and a list of figure captions should be typed doubled spaced on separate sheets. Comments (including book reviews and opinions) and news items should not exceed 1 500 words. Furnish an original and three copies if possible, in the order listed below.

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Publication de la Société canadienne de météorologie et d'océanographie, le Bulletin climatologique offre un moyen d'information sur la climatologie. Le comité de rédaction encourage en particulier la soumission de manuscrits sur la climatologie appliquée (comme l'agriculture, le commerce, l'énergie, l'environnement, la pêcherie, la sylviculture, la santé, les loisirs, les transports, et les ressources en eau), les changements et la variabilité du climat, la prospective climatologique, les applications des modèles du climat (inclus la climatologie physique), et les études régional (inclus les océans). Il est publié grâce à une subvention accordée par le gouvernement canadien par l'intermédiare du Conseil de recherches en sciences naturelles et en génie.

Les auteurs peuvent choisir de soumettre leurs manuscrits aux "Articles", "Notes de Recherches", ou "Nouvelles et Commentaires". Ils doivent l'indiquer sur la lettre d'accompagnement du manuscrit. Les articles de recherche et les "Notes" sont indépendamment soumis à l'examen d'au moins deux appréciateurs anonymes. Le rédacteur en chef examine les "Nouvelles et Commentaires" conjointement avec le comité de rédaction. On accepte les articles soit en français, soit en anglais. Il faut envoyer un résumé, de préférence en français et en anglais.

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LE RÉSUMÉ, dactylographié sur une page à part, ne doit pas compter plus de 250 mots.

LE TEXTE. Il faut taper à double interligne, sur des pages numérotées, le texte des articles plus longs et le diviser en sections, chacune dotée d'une en-tête à part et numérotée dans l'ordre. Il faut dactylographier l'en-tête de section sur une ligne à part.

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Foreword / Avant-Propos

This issue officially marks the fifth anniversary of an important event in the history of this publication. On 25 May 1982, CMOS Council Meeting No. 3 was held at the University of Ottawa. One of the items on the agenda was a proposal to take over a McGill University publication, the *Climatological Bulletin*.

Professor B. Garnier of the Department of Geography started CB in 1967 as a semi-annual "in-house" publication. Issue no. 1 was published in January of that year. Outside contributions (from non-McGill authors) were first accepted in 1970. For the next 12 years, Prof. Garnier continued to produce CB on a shoestring budget. In all, there were 32 issues containing 104 research articles and reviews, and a number of news items. Many of the former were on radiation and heat balance, bioclimatology, and microclimatology in urban and rural settings. Students contributed about one-fourth of the articles.

When Prof. Garnier announced in 1980 that he was planning to discontinue CB, due to his pending retirement in 1982, a number of climatologists from universities and AES contacted him. AES awarded him a small contract for the purpose of evaluating the future status of CB. Was there a need in Canada for a national publication on climatology? What kind of topics should be considered? How would the publication be supported?

Over the next two years, a number of people across Canada were contacted. An interim editorial board was formed, including representatives from CMOS, AES, and the Canadian Association of Geographers. During this period, the Canadian Climate Program was being organized at AES, and climatological associations were being formed in Alberta and Quebec. On the international scene, the United Nations had sponsored the World Climate Conference (1977) and a conference on desertification (1979). New journals appeared, including *Climatic Change* and *Journal of Climatology*. The American Meteorological Society announced that in 1983, the *Journal of Applied Meteorology* would become the *Journal of Climate and Applied Meteorology*. Clearly, interest in climate and climatology was growing, and CB could fill a useful role in providing a Canadian forum for research, news, and comments.

My first contact with the interim board (active members at this time were B. Garnier, G. McKay, D. Phillips, J. Powell, W. Rouse, M. Sanderson) was in the fall of 1981. At that time, CMOS was cautiously positive about CB, but future financial and logistical support was still questionable. The commitment made at the CMOS Council Meeting in Ottawa on that fateful day in 1982 allowed the interim board to take its first tentative steps forward. I was asked to become the interim editor and establish a review process. Other board members and the CMOS executive assisted in publicity and identifying potential authors and reviewers. AES provided logistical support for the 1983 issues.

There remained a very important question regarding CB's scope. What topics would CB publish? Would all submissions be reviewed? How could overlap with *Atmosphere-Ocean* be avoided? After discussion with the editors of A-O (H. Leighton, P. Merilees) during 1983-1984, a clearer division of topics was established. A-O would publish articles describing climatology as a physical system. CB would be oriented towards articles that consider climatic issues as a physical system with biological, economic, social, or other physical connections. These would include applied climatology, climatic change and variability, climate impacts, climate model applications, and regional studies (including ocean areas).

In addition, it was the interim board's intention to continue CB's mixed format by publishing "News and Comments." This section would include conference and workshop reviews, news of research in progress, comments on previous articles, and news of other organizations' activities, including the Alberta and Quebec climatological associations, the Friends of Climatology, provincial Climate Advisory Committees, AES, and various scholarly societies within and outside the atmospheric sciences (e.g. geography, agriculture, forestry, landscape ecology and management, etc.). It was meant to provide a national forum for communication between groups that may not otherwise have regular contact with each other.

Climatology has become an extremely broad field of study, largely because of the growing interest in climatic change and weather/climate impacts on the bio-physical and socio-economic environments. From its roots in physical geography and the atmospheric sciences, the discipline has expanded in scope. Researchers actively involved in climatology and climate-related studies (e.g. natural hazards, etc.) now come from diverse backgrounds, including agriculture, biological sciences, computer science, economics, engineering, forestry, geology, history, human geography, hydrology, mathematics, oceanography, and physics. I even know of a few psychologists and philosophers who have contributed to this literature. With such diversity in people and topics, it is vital to have regular publications, periodicals, that can provide a focus, and a window, on climatology. The *Climatological Bulletin* aspires to be the focus and window in Canada. Will CB achieve this goal?

Since 1982, CB has made slow but steady progress. In 1984, the interim editorial board was disbanded, and CB now operates with a nationwide editorial board established by CMOS Council. I was nominated for a 3-year term as editor in chief. In 1986, publication frequency increased from 2 to 3 issues per year. In addition, CB received a 3-year operating grant from the Natural Sciences and Engineering Research Council, a welcome sign of recognition from the Canadian scientific community.

Over the next 5 years, I hope to see CB expand to 4 issues per year. I believe that this would provide the added visibility necessary for the journal to meet its goals.

My term as editor expires this year. The board is now in the process of searching for a new editor. Hopefully, it will be possible to announce the selection in the October issue.

Stewart J. Cohen

Some Temporal, Spatial and Climatological Aspects of Dust Storms in Saskatchewan

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ABSTRACT

Despite the fact that dust storms are prevalent on the Canadian Prairies, few papers have been published that provide a systematic study of the nature and impact of dust storms.

This paper provides a scientific definition, scope, origin and classification of dust storms suited to the prairie climatic environment. This is a preliminary step in depicting temporal and spatial patterns of dust storms in Saskatchewan.

Dust storms occur at least once to as often as five times per year, on average, in agricultural Saskatchewan. More than ten times the number of dust storms take place in the spring, specifically April and May, than most other months. The spatial pattern of dust storms reveals a low risk in northern agricultural Saskatchewan ranging to the highest risk in the south central area. The knowledge of these patterns should facilitate the control or avoidance of such impacts of dust storms as wind erosion of soils, traffic accidents and general environmental degradation.

RÉSUMÉ

Bien que les tempêtes de poussière soient fréquentes dans la prairie canadienne, peu d'articles concernant l'étude systématique de leur nature et de leur impact ont été publiés.

Cet article définit un cadre scientifique pour l'étude des tempêtes de poussière qui est adapté à l'environnement climatique de la prairie, et en examine les aspects suivants: définition, rayon d'action, origine et classification. Ceci constitue un premier pas vers la description de la répartition temporelle et géographique des tempêtes de poussière en Saskatchewan.

Les tempêtes de poussière se déclenchent au moins une fois l'an et jusqu'à cinq fois l'an, en moyenne, dans la partie agricole de la Saskatchewan. La probabilité qu'une tempête de poussière se déclenche au printemps, en particulier durant les mois d'avril et mai, est dix fois plus grande que pour la plupart des autres mois. L'étude de la répartition géographique des tempêtes de poussière révèle un risque faible dans la partie nord de la Saskatchewan agricole, qui va en croissant jusqu'à un risque élevé dans la partie centrale sud. La connaissance de cette répartition temporelle et géographique devrait permettre de contrôler plus facilement, et peut-être même d'éviter, les impacts bien connus des tempêtes de poussière: érosion éolienne des sols, accidents de la circulation, et dégradation générale de l'environnement.

1. INTRODUCTION

Dust storms associated with blowing dust and soil erosion are causing serious concern in the Canadian Prairies. The annual soil loss due to wind and water erosion is conservatively estimated to be 277 million tonnes (Sparrow, 1984). Nearly 58 percent of this total soil loss in the Prairies is ascribed to wind erosion. Farming is suggested to be one of the major activities affected by dust storms (Pewe, 1981). Dust storms with blowing soil particles are frequent during growing seasons but are also reported during winter (Environment Canada, 1985; Nikiforuk and Eisler, 1986).

There are few studies that examine dust storms. Goudie (1978, 1983) has discussed the geomorphological implications of dust storms, including their frequency and distribution and exclaims that many climatological texts say little about an important climatological phenomenon – dust storms. The scientific studies, including the nature, origin and even a definition of dust storms in the Canadian Prairies are almost negligible. Gray (1978) has referred to the dust storms in the Prairies and some of their impacts during the thirties. Orgill and Sehmel (1976) have analyzed the frequency and diurnal variation of dust storms in the contiguous United States. McCauley *et al.* (1981) provide a brief account of the dust storms throughout the historical times on the Western Great Plains of the United States. They report that the "dirty thirties" were followed by severe dust storms in the 1950's and again in the mid 1970's. Changery (1983) has examined the seasonal and annual episodes of dust storms in the western United States. Nickling and Brazel (1984) and Brazel and Nickling (1986) studied the characteristics of Arizona dust storms. Anderson (1984) has discussed, in general, the nature and types of dust storms as observed in the Prairies.

In view of the growing concern about dust storms and the associated soil losses, there is an urgent need for a scientific analysis of dust storms in the Canadian Prairie. A knowledge of these characteristics should facilitate planning for the mitigation or avoidance of impacts associated with dust storms. There are many impacts of dust storms ranging from soil and crop damages to traffic fatalities, air pollution and general environmental degradation (Wheaton, 1984b). This preliminary study examines the temporal and spatial characteristics and the origin and types of dust storms in Saskatchewan.

2. NATURE, SCOPE AND DATA AVAILABILITY

Few books in meteorology or climatology include any definition or discussion of dust storms, although dust devils are mentioned more frequently. Generally, a definition of dust storms mentions the winds, the blowing dust and reduced visibility but there is no reference to any weather disturbance. No clear, generally accepted definition of dust storm as yet exists (WMO, 1983). A dust

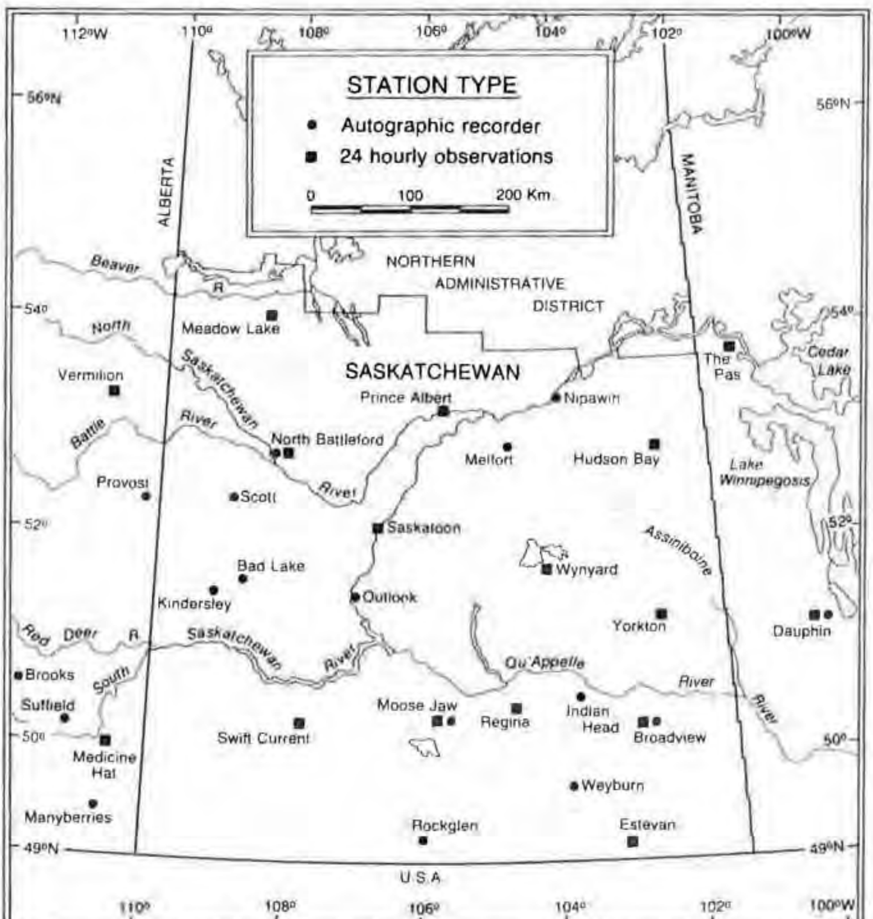

FIGURE 1 The study area and recording wind network. Source (wind network): Environment Canada, 1981.

haze also reduces visibility due to particles suspended in the air. These particles may be raised at some distance from the observer prior to the time of observation. However a dust haze, unlike a dust storm, is not associated with moderate to strong winds and blowing dust. For a scientific analysis, a more precise and quantitative definition of a dust storm is necessary. Therefore in this paper, a dust storm is defined as an atmospheric disturbance with moderate to strong winds, blowing soil particles and reduced visibility to 1 km or less at eye level.

The study area is the agricultural part of southern Saskatchewan limited in the north by the boundary of the Northern Administrative District. Farms and occurrences of dust storms are generally rare north of this area as indicated by lower wind speeds, extensive forest cover, and poor soils. In addition, the network of weather stations with necessary data has better coverage in the agricultural south than in the north (Figure 1).

There is no direct reporting of dust storms by the weather stations. The weather stations report blowing dust or sand with reduced visibilities and not specifically a dust storm (Environment Canada, 1977). Therefore, an occurrence of a dust storm has been designated by the authors to occur when the weather station reported blowing dust and reduced visibility of one kilometre or less. The network of weather stations that record blowing dust and visibility data consists of 12 stations fairly distributed across the study area (Figure 1). Visibility data have been published including the number of days with blowing dust since 1977 for these stations (Environment Canada 1977 to 1983). An obvious handicap, therefore, for a detailed analysis is the limited period of time (seven years) for which necessary data are readily available.

3. TEMPORAL CHARACTERISTICS OF DUST STORMS

To evaluate the problem and possibly control the soil losses caused by dust storms, it is essential to examine both the time and the place of occurrence of dust storms. Both the mean annual and mean monthly frequencies of days with dust storms have been analyzed and plotted for Saskatchewan (Figures 2 and 3).

The annual mean areal number of dust storms was calculated by summing the annual totals for all stations (thus areal) for each year and dividing the sum by the number of stations as follows.

$$Ya = \left(\sum_{i=1}^{N} Da_i \right) / N \qquad (1)$$

where:
Ya = annual mean areal number of dust storms
i = station number
N = number of stations
Da_i = the annual total number of dust storms at station i in a given year.

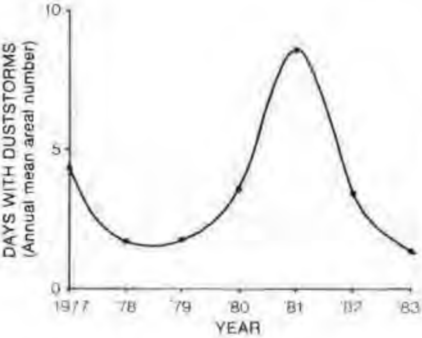

FIGURE 2 Annual mean areal frequency of days with dust storms, Saskatchewan (1977-1983).

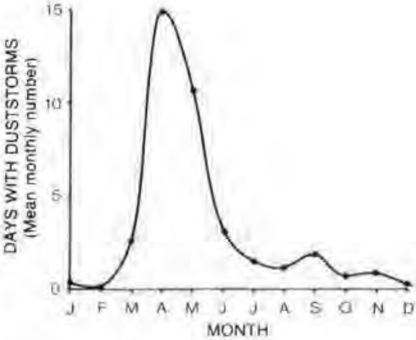

FIGURE 3 Distribution of the mean monthly frequency of dust storms, Saskatchewan (1977-1983).

The available data indicate that usually one dust storm to as many as 19 dust storms occur annually. The annual mean areal value for the seven-year period of record shows that, on average, dust storms occur at least once and often three to four times annually in agricultural Saskatchewan. The frequency of the mean areal number of days with dust storms, however, exhibits a cyclical tendency (Figure 2). There is a primary peak in 1981 and a secondary peak in 1977 and perhaps earlier. The most recent drought years, 1984 and 1985, might indicate other peaks as well. A primary trough occurred in 1983 and a close secondary trough in 1978, but dust storms continued to occur even in these years. The short record length of data is a limitation as only a short portion of the cyclical variation can be studied.

The monthly frequency of dust storms reveals a definite seasonal pattern (Figure 3). The mean monthly frequency of dust storms was calculated using the following equation:

$$Ym = \left(\sum_{k=1}^{N} Dm_k \right) / N \qquad (2)$$

where: Ym = the mean monthly frequency of dust storms
k = the year number in the period of record, where the first year is numbered 1
N = the number of years of monthly records. For example, if there are seven complete Januaries, $N = 7$
Dm_k = the total number of days in a month with dust storms in year k.

The primary peak of dust storm frequency generally occurs in the spring for most years. Only one year, 1983, had a primary peak in the fall.

Some of the main reasons for this seasonality are the high wind speeds at this time of the year, the sparse vegetative cover and the low precipitation amounts and soil moisture (Wheaton, 1984a). The distribution of mean monthly dust storm frequencies has a pronounced peak in April, a weak secondary peak in September and very low to non-existent amounts in the winter months (Figure 3).

4. SPATIAL PATTERN OF DUST STORMS

The spatial characteristics of dust storms are the least examined features of the dust storm in the Canadian Prairies. Orgill and Sehmel (1976), Changery (1983) and Nickling and Brazel (1984) have studied the frequency and distribution of dust storms in the contiguous or western United States and Arizona. As far as the authors are aware, the spatial distribution of dust storms have not previously been mapped for any location in the Canadian Prairies.

The spatial pattern of dust storms is plotted by using the same data and stations as those derived for showing the temporal frequencies (figures 2, 3 and 4). As Figure 4 indicates, the central parts of farming land in Saskatchewan within the Regina, Moose Jaw, Swift Current, Saskatoon, Wynyard and Yorkton areas have the greatest mean annual number of dust storms (Figure 4). In this area where grain farming is the dominant land use, as many as four to five dust storms were recorded per year on average. This area is shaped like an ellipse and reaches northward past Saskatoon and southward past Regina and probably on into the Great Plains of the United States. Regina is the station with the greatest mean annual number of dust storms, with an extreme maximum of 19 in 1981. The average annual number of dust storms, as expected, decreases northward to less than two per year beyond Prince Albert. A serious gap of stations makes it difficult to determine the frequency of dust storms in the southern parts where the number of dust storms is expected to be the highest (Figure 4).

Generally, it appears that the northern agricultural portion of the study area has low dust storm risk, the southeast and central southwest have intermediate risk and the central to central south have high to very high risk of dust storms and the related loss of fertile topsoils.

5. CLIMATIC FACTORS AND DUST STORMS

Climatic conditions both directly and indirectly affect dust storms in the Canadian Prairies. An example of the indirect effect is the climatic influence on vegetation and soil properties including soil moisture. Vegetative growth is limited by lack of precipitation. Freeze-thaw cycles break down soil aggregates which could result in more susceptible particle sizes. Rain drop impacts and the alternate swelling and drying of particles can also cause detachment of soil

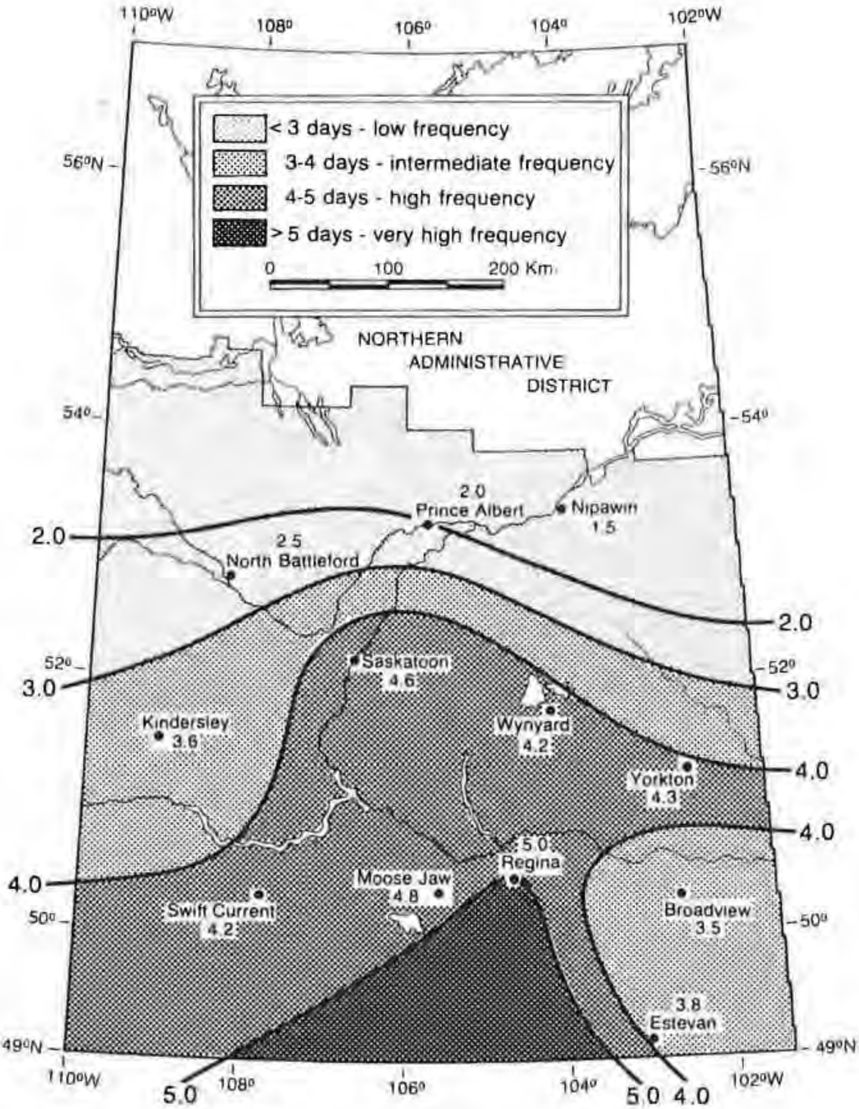

FIGURE 4 Mean annual dust storm frequency (days), Saskatchewan (1977-1983).

particles, thus rendering them more susceptible to erosion.

The climatic elements that directly affect wind erosion of soils and thus dust storms include wind, precipitation and temperature. Erosion is initiated when wind speeds are greater than the threshold value required to set the susceptible particles in motion. Threshold velocities vary according to the particle size and the specific gravity of dry particles (WMO, 1983:75). Continued moderate to strong winds sustain the blowing dust. Saltation, the bouncing, jumping motion of the particles driven by the wind (Bagnold, 1941), also acts to sustain particle movement by the force of impact of the bouncing particles. When saltation is occurring, the velocity of wind required to sustain the dust storm is less than the threshold velocity required to initiate the storm (WMO, 1983:76). Bagnold (1941) first established that the total discharge of the moving particles is a function of the cube of the wind velocity.

Moisture in the soil inhibits movement of the soil particles. The resisting forces of cohesion and gravity are described mathematically as being a function of the square of the equivalent soil moisture. The equivalent soil moisture is defined as the amount of water held by the soil grains divided by the amount of water held by the soil grains at a suction of 15 atmospheres (WMO, 1983:91). The soil moisture is determined by precipitation, evapotranspiration as well as the soil properties.

The effectiveness of soil moisture in reducing wind erosion and dust storms is questionable, however, as the upper layer of soil that is affected by wind erosion is rapidly desiccated (WMO, 1983:20, Wheaton 1984a:11). Brazel and Hsu (1983:302) conclude that rains from one thunderstorm are not usually effective for dust suppression for the succeeding storm unless a surface crust forms. Therefore, it can be seen that wind speed is of primary importance in the formation of dust storms and also determines the quantity of the soil moved. Indeed, two necessary conditions for the origin of dust storms are: moderate to strong winds and available soil particles (Figure 5).

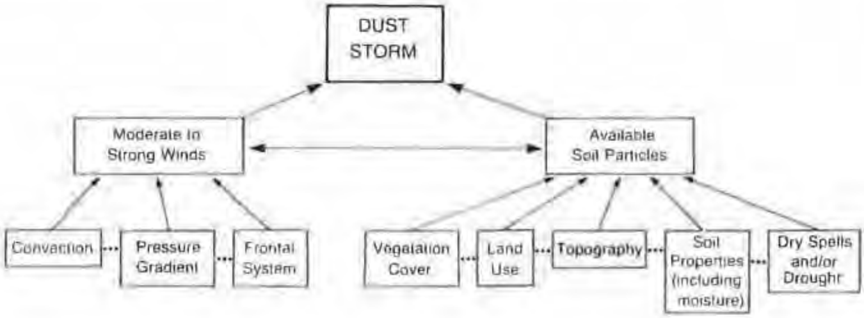

FIGURE 5 A basic model of the dust storm – wind erosion process.

Although human activities may have increased the blowing dust hazard (Goudie, 1982; Changnon, 1983; Chakravarti, 1978, 1984), semiarid areas were subjected to dust storms long before settlement as prairie fires and drought acted to expose the soil to wind erosion (McCauley *et al.*, 1981; Pewe, 1981). Therefore, it appears that there will often be exposed soil and an availability of dust on the prairies. This will result in dust storms under specific weather conditions (Figure 5).

6. CLIMATIC ORIGIN AND TYPES OF DUST STORMS

There are a few studies that have discussed the nature and classification of dust storms. Some studies include classification based on such heterogeneous factors as timing, duration, wind velocity, origin and range of dust, scale and location (Shikula, 1981; WMO, 1983). The synoptic and meteorological conditions associated with dust storms have also been examined by many authors (McCauley *et al.*, 1981; Morales, 1979; Shoa-jin, 1981; Sheng *et al.*, 1981; Burritt and Hyers, 1981; Wilshire *et al.*, 1981; LaDochy and Annett, 1982; Changnon, 1983; Lourensz and Abe, 1983; WMO, 1983; Garratt, 1984; Anderson, 1984). These studies either examined the synoptic conditions of only a few dust storms, often only one as a case study, or only mentioned the synoptic situation of several storms generally without analyzing the genesis. Henz and Woiceshyn (1980), Wigner and Peterson (1985) and Brazel and Nickling (1986) examined more storms but did not study Canadian conditions. Therefore, this paper suggests a genetic classification of dust storms as experienced in the Canadian Prairies. There are four types of dust storms which may develop in the Canadian Prairies:

1) convective dust storms (air mass)
2) frontal dust storms (wind shift)
3) pressure gradient dust storms (wind storm), and
4) mixed type dust storms (combinations of more than one of the above types).

In the above classification, the convective dust storm is the type triggered by the convective winds of surface heating. This type has a distinct diurnal periodicity with a maximum frequency in the afternoon and a minimum just before sunrise. Convective dust storms are quite seasonal, being restricted to the summer months, with occasional occurrences in the spring and fall.

Frontal dust storms are those triggered by an advancing frontal system. Cold fronts are more likely to induce dust storms as they have stronger winds than the warm, occluded or stationary fronts. A cold front associated with unstable air masses may produce more frequent and severe dust storms than the dry cold front depending on the wind speeds associated with the fronts. Although the rain may wash out some of the dust, rain drop impact tends to detach more particles. The down draft associated with a thunderstorm of the cold front may intensify the dust storm (Burritt and Hyers, 1981; Brazel and Hsu, 1981). Dust storms may be associated with warm fronts, especially if the warm air is unstable and thunderstorms result.

The pressure gradient type of dust storm is a result of the strong wind associated with the steep pressure gradient between low and high pressure systems. The pressure gradient is steep enough to produce winds that are greater than or equal to the threshold velocities of the soil particles. The dust storms formed with the strong outpouring of air in these transition zones are the ones that can occur at any time of day and can have the longest durations of all the types except for the mixed type. With this latter storm one type may be dying out as another replaces it.

Some dust storms may occur as a result of a combination of more than one synoptic condition discussed above and thus termed a mixed type. For instance, the convective type could be triggered by a frontal system or a cold front in a cyclonic system may trigger a dust storm which is sustained by the pressure gradient. This pressure gradient is set up between the receding low and the advancing high pressure systems.

For a systematic study, the above classification may be used for a more detailed analysis and evaluation of the nature, scale, frequency and intensity of dust storms and their impact on soil erosion in the Canadian Prairies.

7. CONCLUSION

This paper focusses on a particular need for a more scientific study of dust storms and their impact on soil erosion in the Canadian Prairies. This paper suggests a definition, scope, origin and classification of dust storms within a climatological framework. A preliminary effort is made to show, for the first time, the temporal variation and spatial patterns of dust storms in Saskatchewan. This study should provide a foundation for further and more detailed analyses of dust storms in the Canadian Prairies.

ACKNOWLEDGEMENTS

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News and Comments
Nouvelles et commentaires

OCEANIC CHANGES ASSOCIATED WITH GLOBAL INCREASES IN ATMOSPHERIC CARBON DIOXIDE: A PRELIMINARY REPORT FOR THE ATLANTIC COAST OF CANADA.[1]

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Measurements over the past few decades clearly indicate that the concentration of atmospheric carbon dioxide and other so-called "greenhouse" gases is on the rise. Model studies indicate that this trend will result in a significant alteration of the Earth's climate during the next century. Expected changes include: a global increase in atmospheric surface temperature especially in winter and at high latitudes; an intensified hydrological cycle including increased continental run-off at high latitudes; a decrease in the strength of winds in the lower atmosphere; a decrease in the areal coverage and thickness of sea ice in polar regions; an earlier seasonal snow-melt and sea-ice break-up; and a later freeze-up. In a scenario with the atmospheric concentration of CO_2 twice pre-industrial levels, predicted surface warming is of the order of a few degrees Celsius and associated changes in regional hydrological balances and wind forcing are of the order of 5 to 10 per cent of present-day values. These changes could have far-reaching effects. This report was prepared at the request of the Atlantic Research Directors Committee of the Department of Fisheries and Oceans of Canada as a resource document to begin to address the question of how such changes might affect conditions in the waters off eastern Canada and hence the Atlantic Canadian fisheries industry.

Our basic approach has been to present our understanding of the dynamics which maintain the ocean in its present state and, based on this

1 The full report has been published in 1986 as *Can. Tech. Rep. Fish. Aquat. Sci.* 1426:vii + 78 pp., and is available from Supply and Services Canada, Cat. No. Fs 97-6/1426E. This summary is reproduced with permission of the authors.

dynamical framework, to outline changes expected to accompany CO_2-induced climate changes predicted by atmospheric models. This approach does not fully account for the coupling between the atmosphere and the ocean, but it allows us to make reasonable predictions based on well-defined assumptions.

Some predictions for large-scale oceanic changes are relatively robust. Sea-surface temperatures will generally rise with the largest changes expected near 60°N; meridional gradients in surface salinity will increase creating fresher northern conditions and saltier subtropical conditions; and the thickness, areal extent and duration of sea-ice cover will decrease. Warmer and fresher northern surface waters and reduced wind mixing should generally result in thinner and more gravitationally stable high-latitude surface mixed layers. However, in regions where and during times when ice-cover is removed, enhanced mixing may locally counteract and even reverse the tendency towards thinner mixed layers. Reduced wind stress magnitudes should lead to weakened wind-driven ocean gyres, and an intensification of the hydrological cycle should lead to stronger buoyancy-driven ocean currents. Thus the Gulf Stream may relax somewhat while the Labrador Current may be enhanced. Reduced wind stress could also lead to a reduction in the cyclonic wind-driven circulation within the Labrador Sea and, combined with more gravitationally-stable surface mixed layers, this could result in a reduction in the rate of deep-water formation by convective processes in this region. As a response to warmer atmospheric temperatures, there may be a transient increase in iceberg production rates. The resulting addition of water to the ocean together with thermal expansion could raise sea levels by several tens of centimeters per century.

These predicted oceanic responses would follow climatic change on decadal or shorter time scales and hence should be roughly synchronous with atmospheric changes. In addition there may be much slower adjustments of abyssal ocean properties to climate change. An increase in the average value of evaporation minus precipitation over the Atlantic Ocean should result in an increase in basin-averaged surface salinity and, coupled with increased high-latitude air and sea-surface temperatures, should result in saltier and warmer abyssal waters. Such adjustments would probably occur over several centuries.

The general high-latitude tendencies towards warmer and fresher ocean waters, thinner and more stable surface mixed layers, and reduced thickness, extent and seasonal duration of ice cover should also hold over the continental shelves off eastern Canada. However, shelf-water conditions should also be strongly influenced by changes in the regional circulation. The expected increases in precipitation minus evaporation, and continental run-off in high latitudes should increase the strength and further reduce the salinity of the relatively cold and fresh, buoyancy-driven currents which account for the general southward flow over these shelves. These currents include the Labrador Current, which has a major influence on water properties over the entire eastern Canadian coastal region, and the outflow from the Gulf of St.

Lawrence, which influences the Scotian Shelf and Gulf of Maine waters. The increased strength of these flows leads to the possibility that the shelf waters off eastern Canada may be warmed by a lesser amount than offshore waters at similar latitudes, but enhanced warming of the high-latitude source waters may offset this tendency. The tendencies towards reduced warming and increased freshening of shelf waters may be enhanced by the reduction in the strength and variability, and hence the influence, of the relatively warm and salty Gulf Stream. The increase in freshwater run-off should also result in small offshore displacements of the coastal and shelf-break fronts throughout the region, and the increased net solar radiation should lead to a reduction in the spatial extent of year-round tidally-mixed waters in areas such as the Gulf of Maine.

Associated with the warmer air and sea temperatures, there should generally be earlier seasonal snow-melts, spring thaws and ice break-ups; an increased occurrence of ice-free years in areas such as the Gulf of St. Lawrence; and a reduction in the seasonal extent of ice in areas such as the Labrador Shelf. As noted earlier, such changes in seasonal ice cover may allow increased wintertime mixing in these areas, opposing the general tendency towards thinner mixed layers.

We emphasize that these predictions are preliminary in nature. More definite statements will be possible with further development and understanding of fully coupled atmosphere-ocean-cryosphere models, detailed regional simulations, and validation of model predictions against relevant observations.

RECENT PUBLICATIONS OF THE CANADIAN CLIMATE CENTRE

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Canadian Climate Centre
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The Canadian Climate Centre of AES is probably best known for its regular data publications, including Climatic Perspectives, monthly and annual meteorological summaries, and statistical data publications, which include the 1951-1980 normals for temperature, precipitation, and other elements. Recently, the Great Lakes Climatological Atlas was published (see the October 1986 issue of the *Bulletin*).

The CCC also produces 3 series of research publications: CCC Reports, CLI Circulars, and Climatological Studies (CS). CCC Reports are internal reports which have not been subjected to extensive editing. CCC Reports are distributed at the discretion of the authors and the Canadian

Climate Program Office, and are usually printed in small quantities. CLI Circulars are generally on less technical subjects, are written for a wider audience, and have larger print runs. The CS series includes a number of regional climate studies, *available in english and french (anglais ou français)*, and are distributed by Supply and Services Canada.

Recent publications in the 3 series are listed below. For further information on these and other reports published in previous years, contact

Climatological Services Division
Atmospheric Environment Service
4905 Dufferin Street
Downsview, Ontario M3H 5T4

CCC REPORTS

86-1	Etkin, D., and W. Macdonald. Annual and Seasonal Climate Scenarios for a Warmer Arctic	$ 8.00
86-2	Phillips, D.W. Economic Benefits of Climate Applications	5.00
86-3	Newark, M.J., A. Caillet, N. Bussieres, and T. Jang. Verification of AES Experimental Long Range Forecasts for 1985 *(bilingual/bilingue)*	5.00
86-4	AES Drought Study Group. An Applied Climatology of Drought in the Prairie Provinces	20.80
86-5	Thomson, R.B., M.P. Brennand, and J.P. Ross. Arctic Non-Standard Data Catalogue	6.60
86-6	Lewis, P.J. Severe Storms over Hudson Bay-Foxe Basin. A Catalogue Summary for the Period 1957 to 1983	31.60
86-7	Gullett, D.W. Smoothing Daily Climatic Normals	5.50
86-8	Skinner, W.R. The Break-Up and Freeze-Up of Lake and Sea Ice in Northern Canada	6.20
86-9	Olson, R. An Assessment of Canadian Arctic Wind Data Sets	5.80
86-10	Brown, R.D., N. Balaskas, L.D. Mortsch, A. Saulesleja, and V.R. Swail. Marine Climatological Atlas–Canadian West Coast	37.20
86-11	Guiot, J. Reconstruction of Temperature and Pressure for the Hudson Bay Region from 1700 to the Present	11.80
86-12	W.F. Baird and Assoc. Ltd., Hydrotek Inc., and J.F. Lawless. Review and Assessment Procedures for Extreme Value Analysis for Selected Geophysical Data	7.10
86-13	Evaluation of Existing Climatologies for the Beaufort Sea	13.60

86-14	Brown, R.D., and K. Walsh. Canadian Seasonal Climate Scenarios for a CO_2-Induced Global Warming	13.90
86-15	Stuart, A. A Spatial Permafrost Model for Northern Canada and its Application to Scenarios of Climate Change	10.70
86-16	Etkin, D., K. Higuchi, and W. Macdonald. A Note on the Semi-Annual Temperature Cycle in the Canadian Arctic	5.00
86-17	MEP Co. Ltd. Interannual Variability of Climate off the Canadian East Coast	32.70
86-18	Newell, J.P., and L.W. Davidson. Regional Marine Climate Comparisons for Offshore Drilling Locations Worldwide. Parts I and II.	47.70
87-1	Brown, R.D., and V,R. Swail. The Spatial and Temporal Coherence of Marine Wind Observations.	7.70

CLI CIRCULARS

1-86	Mortsch, L.D., and K. Bolohan. Applied Climate Bibliography for Architects, Planners, Landscape Architects and Builders. *(bilingual/bilingue)*	5.00
2-86	Gullett, D.W., and D.W. Phillips. Historical Analysis of Population Weighted Heating Degree Days for Canada, 1939-1984.	6.00

CS SERIES (E=english, F=français)

35	The Climate of Ottawa-Hull, The Climate of Canadian Cities Number 1. *Cat. No. EN57-7/35 (E or F)*	Canada 3.50 other 4.20
36	Swail, V.R., and L.D. Mortsch. A Review of the State-of-the-Art in Marine Climatology on the East Coast of Canada. *Cat. No. EN57-7/36 (bilingual/bilingue)*	Canada 10.00 other 12.00
37	The Climate of Edmonton, The Climate of Canadian Cities Number 2. *Cat. No. EN57-7/37 (E or F)*	Canada 6.95 other 8.35

SOME AGROMETEOROLOGICAL ACTIVITIES IN SASKATCHEWAN IN 1986

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Several agencies were engaged in agrometeorological work over the past year. Those mentioned here are: the University of Saskatchewan (U of S), Agriculture Canada (AC), Scientific Services Division of Atmospheric Environment Service (AES), Saskatchewan Research Council (SRC), National Hydrology Research Centre (NHRC) and the Saskatchewan Intercouncil Committee on Agrometeorology (SICAM). (This news item is a summary of the report to the Expert Committee on Agrometeorology. For a copy of the report please contact the author.)

Some of the projects undertaken during the year were joint efforts. A project to simulate spring wheat yields for the Saskatoon area using the CERES model and Saskatoon SRC weather data was completed by the U of S and SRC. Another U of S and SRC project analyzed the temporal, spatial and climatological aspects of dust storms in Saskatchewan. AC/SRC herbicide spray drift trials were conducted to evaluate and compare the performance of four different types of sprayers. A chapter based on an AES/SRC/AC project to estimate the impacts of climatic change on agriculture in Saskatchewan has gone to the publishers.

Other agrometeorological work at the U of S consisted of projects such as an evaluation of the precipitation trend of some climate stations, and the climate, water use and productivity of savannas. Student projects with a definite agrometeorological component were also developed.

A study was undertaken by SRC to compare the evaporation estimates from several evaporimeters at the SRC Climatological Reference Station. Atmospheric, soil and crop studies to determine the chemistry and nutrient characteristics of the rainfall in the vicinity of a thermoelectric power plant were continued by SRC for another year.

AC continued to collect meteorological data for use in assessing wheat midge characteristics. Several projects, such as the water use of continuous direct seeded winter wheat and the effect of moisture stress on wheat, have been undertaken by AC.

Some studies conducted by NHRC include the assessment of precipitation distribution and variability on a small agricultural watershed, for example.

SICAM revised the agrometeorological section of the "Guide to Farm Practice". Recommendations concerning agrometeorological data were also made.

Thus there were several agencies/groups working on agrometeorological problems in Saskatchewan during 1986. Also several requests for agrometeorological information to support the agricultural community were handled by these agencies.

NOUVELLES DE L'A.C.L.I.Q.

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a) Un nouveau conseil a été élu en octobre 1986 et les activités principales peuvent se résumer comme suit:

- des représentations seront faites pour que la climatologie soit reconnue comme une spécialité dans le fichier central des fournisseurs du gouvernement du Québec.
- le Comité continue à participer au comité consultatif national sur les données et les applications climatiques.
- le rapport sur le bilan de recherche en climatologie au Québec a été présenté. L'analyse du financement a permis de constater que la climatologie en tant que telle est peu visible et que la plupart des recherches subventionnées le sont de manière indirecte, quand la climatologie est associée à un autre domaine (météorologie, génie civil, écologie, etc.). La quasi totalité des projets (utilisent des données climatiques) ou rentrent dans la catégorie "recherche appliquée", dont très peu de recherche fondamentale subventionnée.

Parmi les recommandations du comité:

- Continuer à faire des projets ayant des applications socio-économiques, en y intéressant des ministères ou des experts dans le domaine d'application.
- Augmenter la "visibilité" de la climatologie dans les congrès, les expositions scientifiques et auprès des étudiants du secondaire et du CEGEP. (L'ACLIQ participera cette année encore à l'ACFAS, qui se tiendra à Ottawa en mai 1987. Roger Barry sera le conférencier invité.)[1]
- Faire des pressions auprès des universités et des organismes subventionnaires pour que des recherches en climatologie en tant que telle puissent se poursuivre.

1 Ed. Note: The ACFAS meeting dates were published in the February 1987 issue.

b) La revue "Le Climat" progresse avec la nomination d'un comité de lecture pour les articles scientifiques; elle remplit un rôle de liaison qui commence à être reconnu (adhésion de nouveaux membres corporatifs) et une subvention sera demandée pour l'année 1987-88.

CONGRÈS INTERNATIONAL DE GÉOGRAPHIE, 1988

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Pendant le prochain Congrès international de géographie, qui aura lieu en Australie et en Nouvelle-Zélande en août 1988, plusieurs colloques réuniront des climatologues autour des thèmes suivants: climatologie tropicale et habitats humains, changements climatiques, topoclimatologie. En particulier:

a) le groupe d'études sur les "changements climatiques récents" (Adélaide, août 1988). S'adresser à:

   Pr. S. Gregory
   Dept. of Geography, University of Sheffield
   Sheffield, S10 2TN, England.

b) le groupe d'études en climatologie (Christchurch (Nouvelle-Zélande) du 10 au 20 août 1988); trois sous-thèmes:

   1. Topoclimatologie responsable:
      théorie, modélisation, cartographie;
      Prof. J. Paszynski (Pologne) et
      Dr. W. Endlicher (Allemagne fédérale).

   2. Climatologie urbaine responsable:
      H. Wanner (Suisse).

   3. Agrotopoclimatologie responsable:
      A. Hufty (Canada).

Pour présenter une communication au groupe de topoclimatologie, il faut y penser d'avance, à partir du printemps 1987. Comme les résumés (entre 200 et 400 mots) seront publiés avant le congrès, il faudra les envoyer en Nouvelle-Zélande pour le 1er octobre 1987. Si vous avez l'intention de participer à ce colloque, vous pouvez écrire directement avant le 30 avril 1987 à l'adresse suivante:

Dr. A. Sturman
Dept. of Geography
University of Canterbury
Christchurch, New Zealand.

ALBERTA CLIMATOLOGICAL ASSOCIATION ANNUAL MEETING

Patti Papirnik
Research Management Division
Alberta Environment
Edmonton Alberta

The Alberta Climatological Association celebrated its eleventh anniversary at its annual meeting on February 24, 1987 in Edmonton, Alberta. The meeting was hosted by the Northern Forest Research Centre. Approximately 30 people attended.

The keynote address was delivered by Dr. Bob Humphries of the Alberta Research Council. He spoke on the future directions of climatology in Alberta. He suggested that regional impacts of climate change needed to be researched and greater planning for climate change should be promoted.

A brief business meeting was held. A new executive was chosen and agency reports of climate related activities were given. For the first time, the ACA discussed its role as a communicator or provider of climate information to the public with the intent of increasing public awareness and interest in climatology. This issue will be discussed again at future meetings.

The technical session was comprised of five papers dealing with topics ranging from evapotranspiration to applications of climatological information in Saskatchewan. Dr. John Wilson from the University of Alberta reviewed methods of estimating or measuring evapotranspiration. Techniques to obtain evaporation from measurements of related atmospheric parameters were presented. Dr. Wilson summarized by noting that many methods are easily described mathematically and are well-founded physically but are very tedious to use in field applications. Following Dr. Wilson, Dr. Barry Grace of Agriculture Canada in Lethbridge described his experiences with application of the many field techniques for estimating evaporation. Results of tests using actual data did not identify one method as particularly better than another. The spread of data was rather remarkable. Dr. Grace did demonstrate that all of the estimates maintained the general trend of evaporation over the test period and that values calculated during light wind situations were much better than those during windy cases.

Mr. Manfred Drews from Atmospheric Environment Service, Edmonton reviewed the hydrometeorological events that led up to the flooding of the Pembina, North Saskatchewan and Red Deer rivers during mid-July of 1986. The main thrust of the paper was to demonstrate that rainfall and snowfall can cause record flooding without breaking precipitation records. A long wet period leading up to the mid-July storm appeared to saturate the river basins providing ideal conditions for flooding.

Topics in applied climatology addressed by the Saskatchewan

Research Council were presented by Dr. Elaine Wheaton. Activities were segregated into two categories: those provided by professional staff within SRC and those provided to various users of climatological data. Dr. Wheaton impressed on the audience the need for climatologists to examine the potential uses of basic climate data in solving problems in the various resource industries. Many times basic data have been used directly or combined with related information and experience to provide very useful answers to client requests. However, much more effort is required in this area to make maximum use out of climatological data.

A unique application of precipitation data was discussed by Dr. Terry Krauss from the Alberta Research Council. Alberta Government Telephones has proposed a backup communications system that involves the transmission of information using microwaves. Unfortunately, microwaves are attenuated by rainfall. Dr. Krauss provided results from tests using radar data to determine rainfall intensity and how these data relate to attenuation of the signal. The outcome was very successful. However, the requirement for more information on rainfall intensity and the climatology of rain events was obvious. Dr. Krauss emphasized that this was only one of many examples where climatology can be used in the resolution of problems in seemingly unrelated areas.

McGILL UNIVERSITY'S CLIMATE RESEARCH GROUP

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McGill University has recently formed Canada's first university Climate Research Group in cooperation with the Natural Science and Engineering Research Council and the Atmospheric Environment Service of Environment Canada. In response to a proposal prepared under the direction of Professor R.R. Rogers, Meteorology Department Chairman, a major grant of $1.1 million over 5 years has been awarded by these agencies to McGill to support the Group, including two new faculty positions in the Department of Meteorology as Industrial Research Chairs in Climatology. Appointed to the chairs are Dr. Charles A. Lin, a specialist in atmospheric dynamics, and Dr. Lawrence A. Mysak, a physical oceanographer, who has also been named Director of the Climate Research Group (CRG).

The CRG will be the centre of the research activities not only of Drs. Lin and Mysak but also of other McGill researchers from the Department of Meteorology (Drs. Jacques Derome, Kevin Hamilton and Svenn Orvig), the Institute of Oceanography (Drs. Max Dunbar and Grant Ingram), and the Department of Geography (Dr. John Lewis). One of the goals of this multidisciplinary group will be to develop an ocean circulation model which will be coupled to the atmospheric general circulation model (AGCM) of the Canadian Climate Centre, Atmospheric Environment Service in Downsview, Ontario. Other current and planned activities of the CRG include studies of atmospheric blocking, high-latitude land surface processes, isopycnal and interdecadal fluctuations in air/sea and air/ice/sea interactions, and the study of climate cycles in relation to the abundance of marine organisms.

The CRG will publish a Newsletter with which we hope to inform interested members of the world climate research community about the activities of the Group. Anyone wishing to receive the Newsletter, to be issued approximately quarterly, should notify the secretary of the CRG. For further information about the activities of the CRG, please write to the Director.

DFO CLIMATE RESEARCH WORKSHOP

S. Tabata
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Sidney, B.C.

The Department of Fisheries and Oceans Climate Research Workshop was held on January 21-23, 1987, at the Institute of Ocean Sciences in Sidney, B.C. Its purpose was to exchange information and ideas on climate issues important to the Canadian and World Climate Programs. Objectives included: description of linkages between global scale phenomena studied by the World Climate Research Program and regional impacts important to Canada; outline of the activities necessary to relate the global scale observations to Canadian regional concerns; and development of a framework of a national plan for DFO climate related research.

Proceedings will be published later this year by DFO. Contact DFO Headquarters, 200 Kent St., Ottawa, Ontario, K1A 0E6.

INTERNATIONAL WATER RESOURCES ASSOCIATION WORLD CONGRESS

The Sixth IWRA World Congress on Water Resources will take place from 29 May – 3 June 1988 in Ottawa. The Congress will deal with "Water for World Development" with three major themes: Policies and Strategies, Planning, and Operation. One of the topics to be considered is climate, including climate impacts. Papers are being sought that address both environmental and socio-economic aspects. The IWRA membership comes from a broad range of disciplines, including hydrology, engineering, water management, agriculture, and economics. Several UN agencies are co-operating sponsors, including WMO.

The deadline for abstracts has been extended to August 15, 1987. For more information on the Congress, contact:

The Secretariat
Sixth IWRA World Congress on Water Resources
University of Ottawa
631 King Edward Avenue
Ottawa, Ontario
K1N 6N5
(613-564-3902)

SYMPOSIUM/WORKSHOP ON IMPACTS OF CLIMATE VARIABILITY AND CHANGE IN THE CANADIAN PRAIRIES

There is a growing awareness of the potential economic, environmental, and social impacts of climate variability and change. Short-term climate variability has and will continue to affect the resources and economy of the Canadian Prairies. The management and development of our human and economic resources are significantly affected by climate variability and change. It is important to determine the interrelationships between climate and our resources and whether climate variability and change can be reliably predicted. In the coming years, governments will have to develop and implement strategic plans to minimize the potentially adverse impacts and maximize the positive impacts of climate change and variability. To this end, many questions must be resolved and directions for research set.

The Alberta Climate Advisory Committee in cooperation with the Saskatchewan and Manitoba Climate Advisory Committees and the Canadian Climate Centre will be sponsoring a Symposium/Workshop to consider the issue of climate variability and change. The Symposium/Workshop will span three days, 09-11 September 1987.

The Symposium will be one and a half days long and will provide a formal forum for the presentation and discussion of climate research activities relevant to the Canadian Prairies. The objective of the symposium is to provide perspective on climate variability and change; to enhance public and political awareness of the need for climate research; to exchange information on climate research; and to discuss the causes and impacts of a changing and variable climate on the Canadian Prairies.

Dr. Kenneth Hare will give the opening address. We are hoping to extend invitations to internationally known scientists to address the ensuing major theme sessions:

1. Physical controls and model simulation of global and regional climate change;
2. Socio-economic impacts of climate change and variability on our resources and economy (e.g., agriculture/food production, forestry, water resource availability/management, tourism, recreation, energy, construction, land use planning, etc.); and
3. Policy implications.

The Workshop, covering the remaining one and a half days, will provide the opportunity for intensive discussions of the issues arising from the symposium and for the formulation of recommendations for future research. The objectives of the Workshops are to identify issues and concerns related to climate variability and change and to identify and provide the rationale for future research and resource planning strategies.

For further information please contact Bonnie L. Magill at (403) · 422-2070.

CANADIAN CHEMICAL CONFERENCE AND EXHIBITION

The Canadian Society for Chemistry will hold their 70th Conference 7-11 June 1987, at Université Laval. The program includes a symposium entitled "Chemistry of Acidic Dry Deposition." There will be sessions on measurement techniques, sampling networks, modelling, and source identification. For more information, contact:

Ghislain Jacques
Ministère de l'Environnement
2360, Chemin Sainte-Foy
Sainte-Foy, Qué.
G1V 4H2
(418-644-3482)

Book Review / Critique de livre

WATER BALANCE AND ITS APPLICATIONS (With Special Reference to India). by V.P. Subrahmanyam, Andhra University Series No. 173 Andhra University Press & Publications, Waltair, Visakhapatnam, 530 003, A.P. India, 1982, xiv & 102 pages, Rs. 34/-.

This monograph is dedicated to the application of the Thornthwaite water balance procedure in an Indian setting. It is divided into three parts: the thermal regime, the moisture regime and applications. Each part is developed in an historical framework, followed by examples, tables and nomograms. Very clear guidance is provided on computational procedures.

The book emphasizes both India's water balance and climatic classification. The author's style is professional, clear and interesting. His interpretation of India's water balance and of the evolution of climate classification makes fascinating reading. There are typing and labelling errors, imprecisions in word use, etc., but these do not obscure or detract from the important message the author has to convey. The author advises that they are to be rectified, presumably in a new edition.

India's climates range from desert to among the wettest in the world. Tuning its agriculture to that range of climates, to its variable monsoonal rainfall, and also planning for both drought and flood are major challenges. The author, Dr. Subrahmanyam, has pioneered in Indian climatic water balance studies, dedicated to that goal for over two decades. This book is based on his research and experiences.

Part I of the monograph starts with a discussion of the thermal regime, rather than the water balance, because of the prime importance of temperature in climate classification. Historical concepts are reviewed, leading ultimately to Thornthwaite's thermal classification. Arguments are presented concerning formulation and changes in classification systems used over most of the 19th and 20th centuries.

A review of the importance of 'thermal efficiency' and historical evolution of its expression leads to Thornthwaite's concept of "potential evapotranspiration" – which "... Thornthwaite considered as an index of thermal efficiency, too, for many phytobiological purposes." Thermal efficiency is then used to develop maps that show India's relative continentality, oceanicity (isocontinentals) and basic climate types (megathermal, mesothermal and microthermal). Features of India's agriculture and silviculture are described on the basis of that classification.

In Part II the role of moisture in ecoclimate classification is traced back to Dove (1846). As with temperature, the author describes many attempts to use precipitation effectiveness as an index of plant production. Thorthwaite's search for an appropriate moisture index is traced from 1931. By 1948 the concept of potential evapotranspiration and both humidity and aridity indices based on water balance estimates were widely accepted.

The nature and computation of the moisture index, and seasonal variation of effective moisture are introduced along with their expression in Thornthwaite's classification system. Finally, maps of India's climate zones are presented along with zonal water balances to illustrate the large differences that exist across the peninsula.

Part III combines the thermal and moisture regimes. It starts with the concept of 'ecoclimate.' That is followed by a history of biogeographical concepts that led to Thornthwaite's classification. Accord is shown between India's vegetation and computed thermal efficiency and moisture indices, and between the distribution of rice, wheat and millet culture and estimates of moisture adequacy.

Among other applications, the utility of water balance accounting is shown in defining irrigation need and scheduling, and in estimating soil tractionability. The aridity index is used to show intensity as well as time and space patterns of drought. Successive maps of computed deficiencies are used to show migration or spatial changes in intensity of drought. Empirical approaches are used to transform computed water balance surpluses into basin runoff and its variation.

The high points of the book are the practical message concerning the use of Thornthwaite's water balance and the historical perspective for its development. The problems addressed are common to many developing countries. The description of India's water balance will interest both geographers and climatologists concerned with its climate. The detail provided on computations will be appreciated by students.

G. McKay
Thornhill, Ontario