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CLIMATOLOGICAL BULLETIN

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ON SCALES IN METEOROLOGY AND CLIMATOLOGY

by

D.G. Steyn, T.R. Oke, J.E. Hay and J.L. Knox*

INTRODUCTION

Atmospheric processes present themselves on a continuum of temporal and spatial scales, ranging from an upper limit of 10^8 m and 10^7 s for atmospheric standing waves to 10^{-2} m and 10^0 s for the smallest turbulent eddies. Meteorologists customarily view this continuum as being composed of a set of scales which are really groups of processes having some common genetic basis. These groups of processes may be graphically represented by indicating scale boundaries on a plot of time scale against horizontal length scale as shown in figure 1. More complete representation of the scales would be a three-dimensional graph which included vertical length scales (Orlanski, 1975). Such generalization of figure 1 would show vertical length scales ranging from 10^{-2} m to 10^4 m. The two excluded regions represent processes that are not conventionally considered to be part of meteorology. The scales shown in figure 1 may be subdivided to produce, for example, the local-scale (Oke, 1978) which lies between the micro- and meso-scales or even as many as the eight scales defined by Orlanski (1975).

The definition of scales in the meteorological context must be pursued from some genetic base, so that the scales are intrinsic to the atmosphere and not extrinsically imposed by external forcing functions, data sampling and averaging processes or intended applications in particular contexts. There are two possible genetic bases from which to derive scale boundaries.

Consideration of the spectrum of kinetic energy of atmospheric motions (the spectrum presented by Van der Hoven (1957) is a good example) shows three well defined spectral maxima or peaks. Each peak having

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* The authors are listed according to their scales of interest in climatology, in increasing order. Their affiliations are with the Department of Geography at the University of British Columbia as follows: Postdoctoral Fellow and part-time Assistant Professor (D.G.S.), Professor (T.R.O.), Associate Professor (J.E.H.) and Sessional Instructor (J.L.K.).

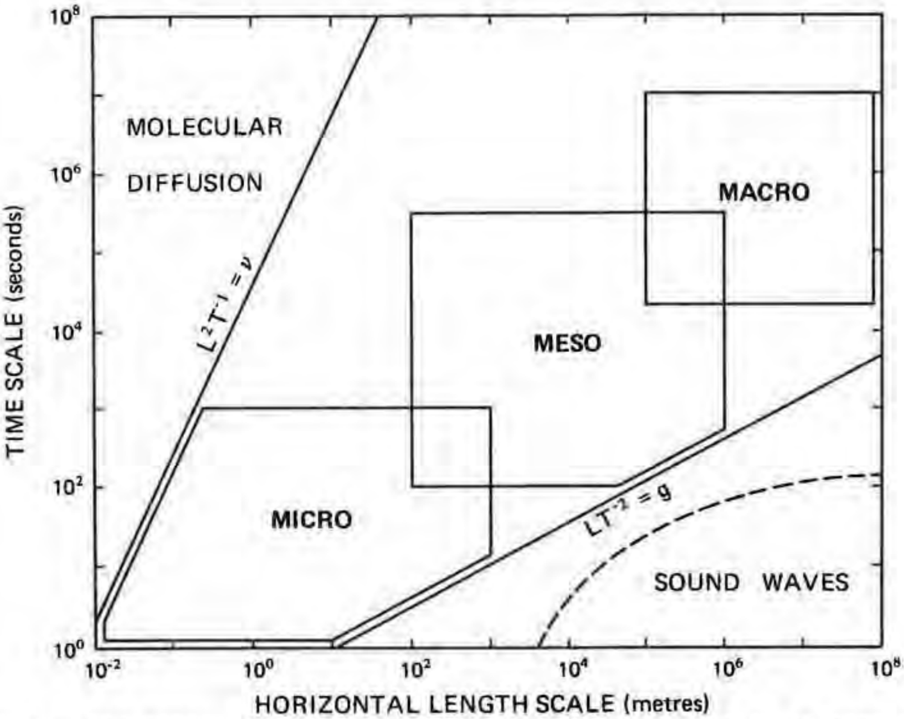

Fig. 1. The range of temporal and horizontal length scales of atmospheric processes. The boundaries shown represent a consensus of previously published limits.

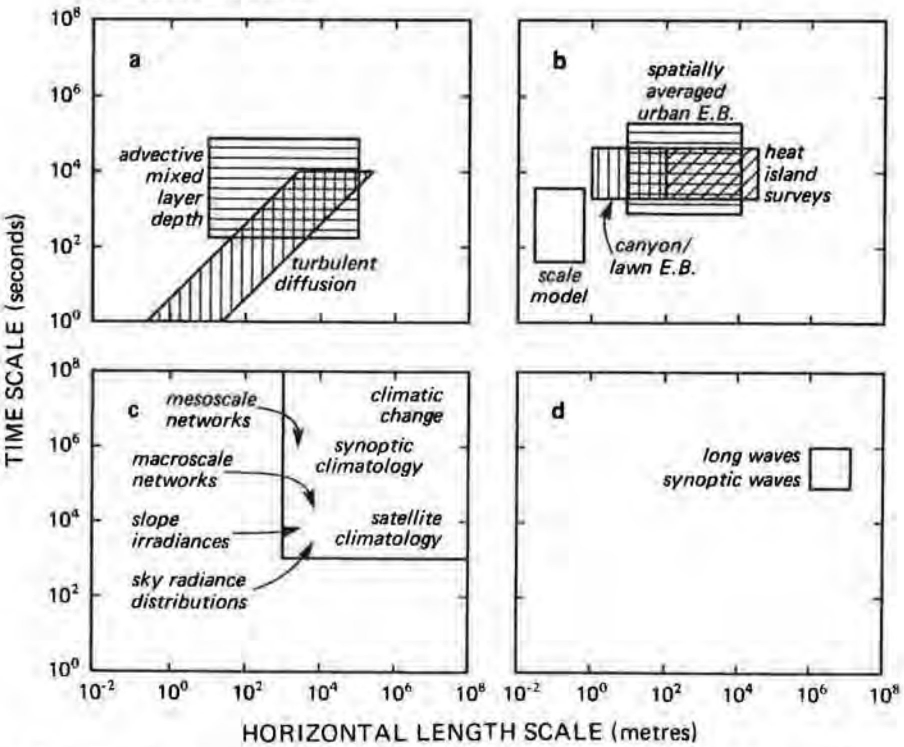

Fig. 2. The range of scales of phenomena studied by the four climatologists. a) D.G. Steyn b) T.R. Oke c) J.E. Hay d) J.L. Knox.

an associated band of wavelengths or frequencies and thus spatial or temporal scales. These may be used as scale boundaries, based on the notion that each distinct energy carrying range represents an atmospheric mode of motion or scale. The three scales thus defined fit well into the macro-, meso- and micro-scales as indicated on figure 1.

At a deeper level, atmospheric phenomena may be approached from the viewpoint of a set of governing equations. This set is comprised of the Navier-Stokes equations, conservation equations for mass and water vapour, the equation of state, the hydrostatic equation, a radiative transfer equation and the first law of thermodynamics. There exist no general solutions for this set of equations in which all possible atmospheric motions are implicit. It is, however, possible to define at least two sets of approximations under which the equations are either numerically tractable or will serve as the basis for a semi-empirical theory of atmospheric motion. The sets of approximations each limit the applicability of the equations to some range of scales and this can be viewed as scale defining approximations. The so-called Boussinesq equations (Busch, 1973) are an approximate set with applicability to the micro-scale, while an entirely different set of approximations results in the so-called shallow water equations (Pedlosky, 1980) with applicability to the macro-scale. This approach highlights the difficulty in defining the meso-scale. Orlanski (1975) provides a scale defining list that consists of processes for the macro- and micro-scales but phenomena for the meso-scale. Within the present rationale there exists no set of scale defining assumptions for the meso-scale.

Scale definition in climatology presents a less clear picture than the above discussion for meteorology. The reason for this is the tendency of climatologists to concentrate on phenomena rather than processes. The scales of the phenomena under study will then dictate the scale range. These scales are extrinsic to the atmosphere by contrast with the intrinsically defined scales encountered in the earlier arguments. Climatology is involved with integrals (both spatial and temporal) of atmospheric processes and is characterized by phenomenon-based rather than process-based scales. A climatological study usually integrates processes at scales smaller than the phenomenon under study and must consider as forcing functions processes at larger scales.

Having briefly examined the definition of scales in climatology we would like to show how our research interests span the scales, and how our approach to the subject leads us to the present view of scale definition.

D.G. STEYN

The research of this member of the department has been directed at a better understanding of factors controlling pollutant concentrations in the lower atmosphere and at the Earth's surface. Two such factors are the volume of atmosphere available for dilution of pollutants and the rate of such dilution. These factors have been studied under unstable atmospheric conditions over an urban surface (Steyn, 1980, 1981a, 1981b, 1981c, 1981d).

The volume of atmosphere available for dilution of pollutants is dependent on the mean wind speed and the mixed layer depth. The former variable is an external forcing function, while the details of the latter are products of a host of contributing processes acting at the meteorological micro-scale. The temporal scales for this phenomenon range from those of individual convective plumes and breaking gravity waves to the daily cycle of solar heating (10^2 s to 10^5 s). While the spatial scales have a lower bound determined by the same processes, their upper bound is determined by the fact that the mixed layer under study was advectively controlled, thus the dimensions of the city provide a scale limit (10^1 m to 10^4 m).

Atmospheric diffusion is driven by turbulent fluctuations, and any study of this phenomenon must encompass all the scales relevant to atmospheric turbulence. The range of temporal scales will thus be from that of the smallest turbulent eddy to the sampling time required to cover all fluctuations (10^0 s to 10^4 s). Since the processes are advective, the spatial and temporal scales must be linked by a relationship $LT^{-1} = u$, where u is the advecting velocity. The range of u encountered will define the range of scales.

The above ranges of scales are shown on figure 2a indicating that this work lies within the micro- and meso-scales by the meteorological definition, but extends to somewhat shorter spatial scales than are conventionally assigned to the meso-scale.

T.R. OKE

This individual is primarily interested in studying features of the urban atmospheric environment. A review has been reported in a previous Bulletin (Oke, 1977) so only a summary and update is given here. Distinctly urban phenomena exist on length scales characteristic of buildings to those of a metropolitan region and beyond (10^0 to $>10^5$ m) and have time scales extending from the life of a plume to the life of a city (say 10^2 to $>10^9$ s). The scales encompassed in the individuals's research (figure 2b) are very much more restricted.

The work can be organized under two headings: urban heat island and energy/water balance studies. Both have been conducted on at least two scales. The heat island work is usually carried out at the total city scale with a single city block as the lower limit. Interest has centred on the heat island intensity, morphology and temporal variability in relation to land-use, meteorological and city size controls and on the structure of the internal boundary layer (for references see Oke, 1977). Most recently, hardware scale models have been utilized in a study of the role of radiation geometry and thermal admittance in heat island development (Oke, 1981a).

The energy and water balance work is based on field observation of the relevant fluxes of heat and water. Spatially-averaged fluxes from the whole city surface have been measured using specially designed eddy correlation and Bowen ratio-energy balance instrumentation mounted on tall towers (Oke, 1978a; Kalanda et al., 1980). Similar studies have also been conducted to investigate the contribution of individual surface units (such as a lawn and an urban canyon) to the spatially-averaged values (Nunez and Oke, 1980, Oke, 1978b).

The research is linked by the core objective of seeking the meteorological mechanisms underlying urban climate effects (Oke, 1981b). The investigations fall in the micro- and meso-meteorological ranges (figure 2b) except that they extend to longer time scales. This is consistent with the individual's view of climatological scales.

J.E. HAY

The research endeavours of this climatologist are illustrated in a space/time context in figure 2c. In all these studies there is an overriding interest in solar radiation, though an exception is the "reading interest" in climatic change ($>10^7$ m, $>10^8$ s), an interest which has yet to result in a personally published paper!

The major research activities place a strong emphasis on scale and an assessment of the standard solar radiation monitoring network ($10^3 - 10^7$ m, $10^4 - 10^9$ s, Hay and Suckling, 1979) lead to the establishment of a 12 station network in the Lower Mainland ($10^3 - 10^5$ m, $10^3 - 10^8$ s, Hay and Tooms, 1979). For some environments there is a continuity between the meso- and macro-scale variabilities (Suckling and Hay, 1976) but the magnitude of the meso-scale variations requires that new monitoring approaches be developed. The high cost of conventional networks and the availability of appropriate satellite data favoured the latter and has resulted in research into satellite radiation climatology ($10^3 - 10^7$ m, $10^3 - 10^8$ s) and the use of the meso-scale network as "ground truth" (Hay, 1981).

The other extrema of research interests are exemplified by development of solar radiation climatologies (for scales from the Lower Mainland to North America, $10^4 - 10^7$ m, $10^7 - 10^9$ s, Hare and Hay, 1970), with an overriding interest in the numerical modelling that such studies necessitate, and in the studies of sky radiance distributions including research related to the anisotropy of the radiation (10^3 m, 10^2 s, McArthur and Hay, 1981). All these investigations are in many ways held together by the interests represented in the synoptic approach to solar radiation climatology (10^5 m, 10^5 s, Suckling and Hay, 1978).

Despite an obvious shift to longer time scales, the foregoing research activities are clearly related to the meso- and macro- meteorological scales, an observation which is in accord with the personal viewpoint of a "macro-scale climatologist moving into the meso-scale".

J.L. KNOX

The background of weather forecasting and a recent return to graduate studies have had a profound impact on the research interests of this atmospheric scientist. A forecaster cannot ignore the substantial impact that blocking (the obstruction of normal west to east motion of the mid-latitude pressure systems) has on the weather, but the phenomenon is not well understood and is therefore difficult to predict. Knox' thesis assembles a large data set (33 years of daily data at two pressure levels for 1977 grid points in the Northern Hemisphere) and investigates the statistics and diagnostics of blocking in the Northern Hemisphere.

A major difficulty has been the objective identification of blocking regimes but use of large positive anomalies in the 5 day mean 500 MB height as "blocking signatures" has alleviated this problem (Knox, 1979) and made it possible to present a rigorous analysis of the blocking phenomena ($10^6 - 10^7$ m, $10^5 - 10^6$ s). Results include the seasonal frequency of occurrence of blocking signatures with an intriguing maximum centred in the area of the normal Baffin trough (the "Baffin Island Paradox"). To investigate this and other characteristics of blocking a variety of analytical techniques are used. The departure of the geopotential height from Gaussian (as measured by skewness and kurtosis) was frequently associated with areas of preferred or incipient blocking activity. The decomposition of the hemispheric wave pattern into its zonal harmonics reveals configurations that are distinctive of the blocking regime, not only for the entire hemisphere but also to the region in which they occur.

The appropriate preoccupation with a very limited set of time and space scales is clearly evident from figure 2d and a classification of "macro-scale" is consistent with both the meteorological scales and the personal interests of this atmospheric scientist.

CONCLUSION

The foregoing personal statements show quite clearly the wide range of scales occupied by the research interests of the four climatologists in the Department of Geography at UBC. An interesting feature is that different meso-scale phenomena hold the interest of three of the four, and that while these phenomena occupy the same range of scales, the phenomena (advective mixed layer depth, urban heat islands and energy budgets and solar radiation variability) are quite distinct. It appears that the meso-scale is filled with overlapping and interacting phenomena. The intensity of activity at the meso-scale reflects our estimation of the importance of these phenomena.

Our view that scale definitions in meteorology do not apply easily to climatology stems from our process-based approach to atmospheric science, and the accompanying need to integrate sub-phenomena scale processes in order to understand the specifics of our research interests.

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THE CANADIAN CLIMATE PROGRAM

by

Staff Members, Canadian Climate Program*

CANADA AND CLIMATE

Events over the past decade have demonstrated the great sensitivity of nations to climate variations. Food production, water supply, energy demand and other factors vital to society have been repeatedly under stress from drought and floods, from abnormal cold and heat, and often the results have been disastrous in human and economic terms. Such climate impacts are not new to our society. Our vulnerability to them, however, increases as populations grow and new technologies are introduced. A Canadian Climate Program that would assist all segments of our society in the use of the best climate knowledge for the management and wise use of resources is needed now. Such a program can be realized only by collaborative and concerted action by all governments.

Climate is a vital component of Canada's natural environment and its anomalies or variations, regardless of any long term trends, have marked socio-economic effects. The past year or so has provided several examples. During the 1979-80 winter, only one third to one half of normal snowfall occurred in the heavily populated region stretching from Windsor to Quebec City and the result was a disastrous season for winter outdoor recreation businesses, although millions of dollars were saved in snow removal costs. Drought has been a worry in the Prairies where a shortage of surface water supplies still exists. A very costly aspect of the drought in 1980 was the record number of forest fires in Ontario and the Western Provinces. Monetary loss exceeded a billion dollars in Ontario alone and fire fighting operations cost nearly $200 million across the country. The early winter of 1980-81 produced mudslides and floods in British Columbia, record high heating bills in Eastern Canada and paralyzing snowstorms to areas of the Atlantic Provinces. In mid winter the abnormally warm conditions in western Canada spread over the east to the dismay of winter sport enthusiasts but to the delight of motorists and most householders.

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* This report has been compiled by the staff members of the Atmospheric Environment Service in Toronto who are directly concerned with developing the Canadian Climate Program.

Not all years produce striking climate anomalies, and some areas are more vulnerable than others. Undoubtedly the climatic anomalies that have caused the greatest socio-economic impacts in Canada have been droughts. The drought in the depression years of the 1930s was a very significant event in our national history. But Canadians are also vulnerable to climate anomalies in other countries. Drought in the wheat producing areas of the USSR, frost in the coffee plantations of Brazil or similar freezing weather in the orange groves of Florida all affect Canada's balance of payments, the value of our own crops and our pocket books in general.

The prudent management of resources requires a sound knowledge of how growth and operations are influenced by climate. It also requires the ability to predict the way in which human activities may alter climate and thereby the resource base. It is interesting to note that in publications such as the Global 2000 Report to the President of the United States, carbon dioxide increases in the global atmosphere are rated as potentially of far greater importance than any other effect on man since it could alter the distribution of the earth's renewable resources. From observations taken at ocean weather station Papa, in the Canadian arctic and at other stations around the world we know that the concentration of CO_2 in the atmosphere is increasing. With this increase most numerical models predict higher global temperatures with the greatest increase in northern latitude countries such as Canada. When this will occur is very difficult to predict but it is essential for Canada to know as much as possible and as soon as possible.

While the possibility of significant and permanent change in our climate is reason enough to be concerned over the impacts of climate on our economic system and society in general, there is much we can and must do, even without that prospect, to respond to the impacts of ordinary or natural climate variations. Climate variations or anomalies lasting for weeks, months, or even seasons are part of our natural climate and are to be expected to continue to occur in the future. We do not know the root cause of these natural climate anomalies nor why there are more in some decades than in others. The ability to predict such occurrences would have enormous economic and resource implications and the development of such a capability is a matter of prime importance.

Weather forecasts are an accepted aid in everyday life in Canada. Many people know about the availability of climate data and information. But relatively few, however, are aware of the enormous untapped potential of using climate information as an aid in making their operational and planning decisions. For instance, climate risk data can be estimated from historical and statistical data and such information can be of great relevance in design work and in planning capital investments. In that sense, relatively skilled climate prediction is already available, and it has been used, for example, in projects ranging from the spillway design and operating strategy for the Gardiner Dam to the design of roofs to protect against excessive snow weights. Applied climatologists are similar to consulting engineers, or economists who must have an understanding of the relationships, some simple, but most complex, between their field and the various economic sectors. As with most applied science, more needs to be known about Canada's climate and its fluctuations but much knowledge exists that is not being fully exploited. Making this information widely available is essential if we are to mitigate or optimize the impacts of climate and climate anomalies on the various sectors of the economy. That is but one role of a national climate program; the time has come to put applied climatology to work.

TOWARDS A CLIMATE PROGRAM

Over the past several years, climate activities have been increasing across Canada in response to an escalating need for climate information, climate prediction, and an understanding of climate impacts in support of planning and resource management. The diversity of both suppliers and users of information, the critical knowledge gaps, and the global nature of climate has underscored the need to systematize climate activities in the best interests of all concerned. In the light of these circumstances, and parallel with participation in the development of a World Climate Program within the United Nations framework, a nucleus for a Canadian national program was formed.

Canada is not alone in developing a national climate program. In the United States a National Climate Program Act was enacted by Congress in 1978 "to establish a national climate program that will assist the nation and the world to understand and respond to natural and man induced climate processes and their implications". There is also a climate plan taking shape in the Federal Republic of Germany while the Commission of European Communities has developed a multi-million dollar climate program dedicated principally to climate prediction and the impacts of energy use on natural resources. On a global basis, a World Climate Program was established in 1979 which calls for all nations to establish workable methods to make better use of climate information in all sectors of activity, to identify ways by which the adverse impacts of climate change and variability may be mitigated and to identify advantages of any climate opportunities arising. The Canadian Climate Program, which was initiated in Environment Canada in 1978, has the following general objectives:

1. to develop the capability to predict climate and climate change;
2. to assess and quantify the impact of man's activities on the climate of Canada;
3. to assess the socio-economic impacts of likely future climates;
4. to greatly improve applications of climate information to Canada's economic activities;
5. to assist, where practical, in improving applications of climate information in developing countries through the World Climate Program.

In order to oversee the development of policy, and to provide liaison and guidance to ensure successful operation on national and international levels, a Climate Planning Board has been established. Currently, the Board, chaired by Dr. F.K. Hare, consists of a dozen members, most of whom are Assistant Deputy Ministers in federal government departments. To evaluate needs, to develop proposals, and to advise the Board on program strategies, a Climate Advisory Committee was also established. The Committee consists of representatives of government departments, universities, and private sector national organizations with climate interests. Some provinces and regions of Canada have associated Climate Advisory Committees to evaluate, coordinate, and advise on activities and strategies, while in other parts of the country such committees are being organized.

To aid in the initial development of the program, existing climate and climate related programs across Canada were identified and assessed to ascertain the level of, and gaps in, climate services provided to both public and private sectors. Through a series of sector workshops and seminars during the winter season of 1979-80 recommendations were made regarding mechanisms to meet current and potential demands. The sectors examined were agriculture, fisheries and oceans, forestry, energy, and water, while other meetings were held to deal with climate research, construction, transportation and recreation and tourism. Furthermore, a seminar was held to evaluate Canada's capabilities and perceptions relative to the increasing atmospheric carbon dioxide content of the atmosphere. These workshops and meetings were particularly rewarding for the participants and were most valuable for planning the future of a Canadian Climate Program. Workshop Proceedings for each sector will be published and sector summary reports are being incorporated into a climate program planning document to be published later this year.

Although provincial and private sector scientists participated in the workshops and meetings and contribute to planning through the Climate Advisory Committee, there is as yet no provincial recognition of the Canadian Climate Program nor any formal mechanism to ensure that the best interests of the provinces are served by the Program. In short, the initial program planning is federal and not national in character. This situation is understandable in the incipient stage but the plan has now developed to the point where provincial participation in the program is essential.

Over the past several months, the involved federal agencies have considered the desirability of presenting a submission to the federal cabinet during the summer of 1981. The intent of the submission is to establish the program and to request resources that are urgently needed in the national interest. However, the provinces are major suppliers and users of climate data and information, and the private sector is now a major contributor of data as well as a beneficiary of climate programs. Firm links must be forged with both. A Canadian climate plan should embrace all major interests and needs. This integrated approach to climate is essential in the interest of economy, effectiveness and efficiency. We hope that through this seminar and the CCREM we can turn a federal proposal into a truly national one.

Each of our governments, and Canadians in general, will benefit substantially from a world and a Canadian climate program. This seminar provides an excellent opportunity for all of us to learn more about the needs for climate information and to undertake steps towards the development of an appropriate national program.

THE CANADIAN CLIMATE PROGRAM, 1981

Conceptually, a Canadian Climate Program should embrace all climate activities in the country. Several federal agencies have programs that fall within, or are affiliated with the program at its present level of development. These include all climate activities of the Departments of the Environment, Agriculture, Fisheries and Oceans and certain climate oriented activities of the National Museum. Other affiliated federal agencies include the Department of Regional Economic Expansion, the National Research Council, and the Ministry of State for Science and Technology. Other organizations interested in the program are the Quebec Meteorological Service, the Canadian Meteorological and Oceanographic Society, and the Alberta Climatological Association.

To meet the general objectives of a comprehensive national climate program, planning is being developed according to four sub-programs having to do with climate data, climate applications, climate impacts studies, and climate research. These components are similar to those used in the World

Climate Program and other national climate programs.

(a) Canadian Climate Data Program

Major difficulties exist today in obtaining the climate data and information required for resource management and planning. Data exist to which many users have little or no access. Limitations of some data are unknown. The standardization of data, their identification, appropriateness and availability are common problems facing resource managers. The draft Climate Data Program contains plans to overcome these deficiencies, to aid in the acquisition and archiving of what was previously considered non-standard data, to exploit new opportunities provided by technology to acquire more useful data. Invaluable information needed in support of resource programs can and will be obtained from historical records and such proxy records as those obtained from tree rings, ice cores, and sediment layers. The program will enable all suppliers and users to contribute to the development, operation, and use of an increasingly effective and efficient system.

(b) Canadian Climate Applications Program

Enough climate knowledge exists to respond to many of today's resource problems. Putting this knowledge to work is the role of the Applications Program. This will be done much more effectively in the future by a greatly enhanced exchange of information on needs, methods, and skills, both nationally and internationally. Increased consultation will allow feedback to better develop the required data base and information. Known applications methodologies currently are not used to full potential. Attempts will be made to improve the situation by supplier/user meetings, and by general liaison and coordination. Specific studies to be undertaken include the development of climate risk statistics and examination of the linkages between climate and biological processes and climate and water resources. Other studies will deal with transposition techniques for synthesizing climate information in data sparse areas.

(c) The Canadian Climate Impact Studies Program

The ability to predict the consequences of climate anomalies on society, the economy, and the environment is a major requirement in the evaluation of alternative policy strategies in such sectors as food production and energy requirements. These are very important but difficult sectors and although several initiatives have been taken, there is at present no single group in Canada dedicated to research and documentation in the Impacts Studies sector. Impact assessment models will be developed and specific studies to be undertaken include assessment of the effects of climate warming and/or cooling on food production, on energy requirement projections, arctic and winter transportation, etc.

(d) The Canadian Climate Research Program

We do not yet know the extent to which climate can be predicted. An active numerical modelling program is being developed in this sector along with the development of prediction models. An Expert Committee on Carbon Dioxide, formed by the Climate Planning Board, is preparing plans to develop the Canadian capability to understand and predict the effects of carbon dioxide in the atmosphere. Research studies into the actual atmospheric processes involving climate and agriculture, forestry, oceans, etc. are underway in several agencies.

Although university personnel may apply for grants to support their work in climate and climate related studies under Science Subvention programs of both NSERC and AES, there is a shortage of both human and financial resources. Much greater attention and support must be given to the universities than exists today. Similarly, it is all too apparent that improved computing services must be available for those engaged in climate research in both government and the universities. The Canadian National Committee of the World Climate Research Program provides expert advice in climate research to those engaged in developing the Canadian Climate Program.

THE FUTURE

Canada's climate results from the global climate system and all other components of our earthly environment. To improve our understanding of the earth's atmosphere, global cooperation is required as the dimensions are too great to be handled by any one group, agency, government or country. A better knowledge of our climate system, the development of methodologies to advance climate prediction and a better understandnng of man's effect on climate and climate anomalies are matters of global concern. Scientists in universities, governments and private institutions around the world are attacking these problems within the World Climate Program which was launched to facilitate sharing of knowledge, data and information and to encourage better liaison and cooperation amongst nations.

Canada participates in the global climate program and within its framework there is much to be done to gain a better understanding of our climate anomalies and their impacts on our economy and society. Research and the effective development and implementation of systems require highly effective communications between the users, the providers of service, and those undertaking research. There must be much coordination and close liaison if data gathering, data analysis, research and climate applications are to be appropriate and effective in the future.

Putting a Canadian Climate Program together requires the combined efforts of governments and non-governmental institutions. A Canadian Climate Program is needed. The alternative is for different governments to develop scattered efforts suited to their particular interests. This would result in great redundancy and less than optimal use of our collective scientific talents and technological opportunities. In this era of rapid change, of increasing concern for the environment, of concern about the availability tomorrow of natural resources and of the prospect of scarce energy, integration of our efforts makes good common sense. The wise use of resources and the prudent planning of tomorrow's environmental quality demands that we act in concert now to avoid the major costs levied by climate variability and the risks of inadvertent climate change.

NOTE ON A RELATIONSHIP BETWEEN DAILY HOURS OF BRIGHT SUNSHINE AND MEAN DAILY ATMOSPHERIC TRANSMISSIVITY

by

Mario Daoust, Jean-Claude Préfontaine, and Robert van Wyngarden*

In the last two or three decades increasing interest has been shown in solar radiation as a potential source of renewable energy for our economy. Particular attention has been paid to solar energy as a source of heating and also to its role in agriculture through its influence on evapotranspiration.

If the potential for solar energy is to be fully realised it is necessary to be able to evaluate its flux on slopes of different gradient and orientation. To do this one must be able to distinguish between the direct beam component (S↓) and the sky-diffuse component (D↓). This is because gradient and orientation are generally more sensitive to the flux of direct radiation than to that of sky-diffuse radiation (Garnier and Ohmura, 1970).

Several models for distinguishing between S↓ and D↓ have been developed. Their application is somewhat limited both because they require a knowledge of a large number of factors, such as estimates of cloud cover, cloud height, and cloud base albedo in addition to the basic facts of solar radiation flux (Hay, 1976, Suckling and Hay, 1977) or else they apply only to cloudless days (Suckling and Hay, 1976).

That part of the solar radiation flux which arrives at the surface as direct solar radiation (S↓) is a function of the extraterrestrial radiation, the atmospheric transmissivity, and the depth of atmosphere (optical air mass) through which the beam passes. Garnier and Ohmura (1968) used this relationship for developing a method of calculating direct solar radiation income on a slope. Their fundamental formula is:

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* The authors of this note were members of a class in advanced climatology in the Department of Geography, McGill University, during the 1980/81 academic session. The note is an edited summary of a longer study prepared as part of course work.

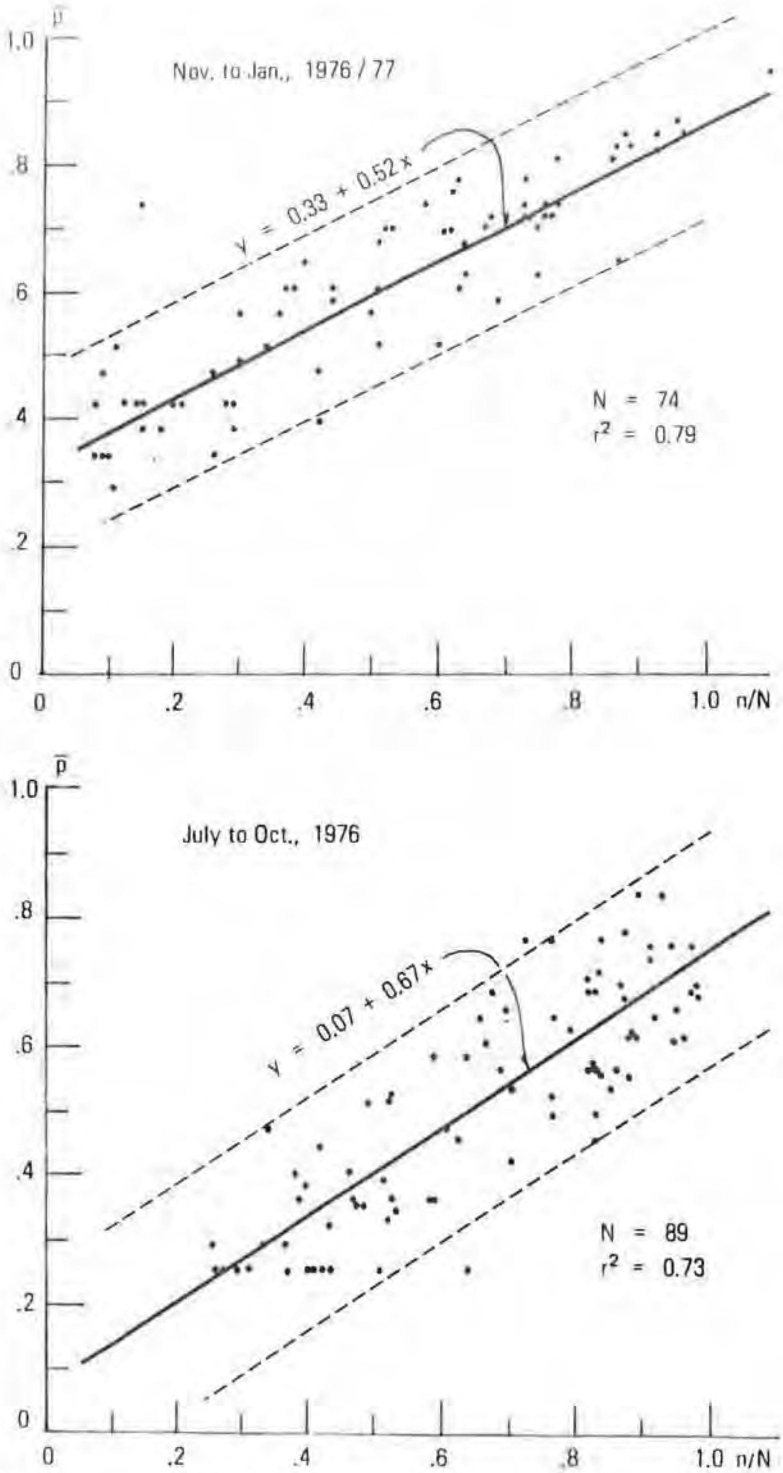


Fig. 1. Regression Analyses for Toronto.

$$I_s = I_r p^m \cos(\vec{X}_\Lambda \vec{S}) \qquad \text{equation (1)}$$

where I_s is the flux of S↓ per minute on a slope,

I_r is extraterrestrial radiation per minute on a surface normal to the sun's rays,

p is atmospheric transmissivity,

m is the optical air mass, and

$(\vec{X}_\Lambda \vec{S})$ denotes the angular difference between a unit co-ordinate vector normal to and pointing away from the slope and a unit co-ordinate vector expressing the sun's position in the sky.

By addition over suitable time intervals from sunrise to sunset on a slope, this expression can be used to evaluate the value of S↓ for a given day. Moreover, for a fixed slope, such as a suitably inclined flat-plate solar collector for example, all factors except atmospheric transmissivity (p) can be evaluated over the given time intervals from a knowledge of the latitude of the site, the sun's declination, and the value of extraterrestrial radiation given by the solar constant divided by the square of the sun's radius vector (I_o/r^2 in the original formulation).

Garnier and Ohmura used a mean transmissivity ($\bar{p}$) for the day, evaluated from daily totals of S↓, to calculate daily totals of direct beam radiation on a slope. It follows, therefore, that if a way can be found to estimate $\bar{p}$ from normal meteorological data, the problem of evaluating S↓ on any surface is solved.

Hours of bright sunshine have been used for many years to estimate global solar radiation (K↓) by means of a relationship in the form

$$K{\downarrow} = Q_o\ (a + b.n/N) \qquad \text{equation (2)}$$

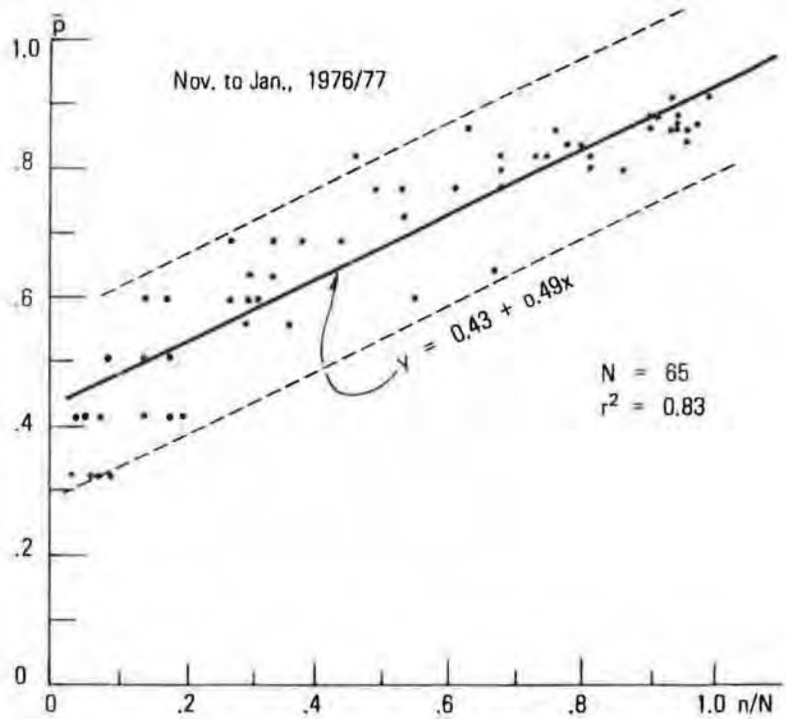
where Q_o is the total flux of extraterrestrial radiation at the top of the atmosphere for a given day,

n/N is the ratio of actual to possible sunshine recorded for the day in question, and

a and b are constants.

The most commonly used instrument for recording hours of bright sunshine is the Campbell-Stokes sunshine recorder. This consists of a glass ball which concentrates the sun's rays on a recording card. A trace is burnt on the card only when the sun is shining on the glass ball. It follows that the record of hours of bright sunshine is really a record of when the direct solar beam is shining on the observation site. It seems logical, therefore, that the ratio n/N in equation (2) could be used to estimate $\bar{p}$.

This conjecture was tested for two stations in Canada: Goose Bay and Toronto Meteorological Research Station. The data used were those in the



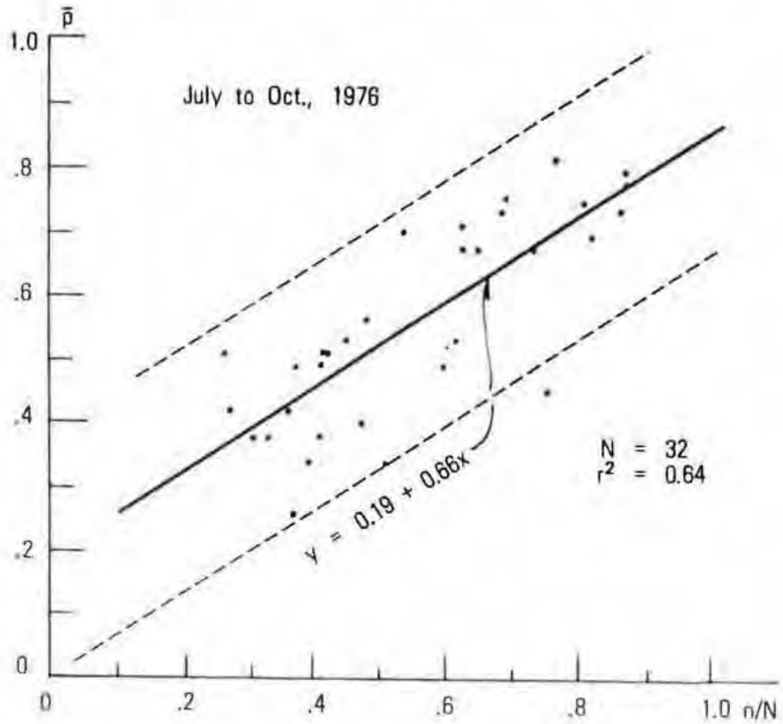


Fig. 2. Regression Analyses for Goose Bay.

monthly statistics and summary of radiation observations published by the Atmospheric Environment Service. Both sky- diffuse radiation (D↓) and the global radiation (K↓) are recorded at the two stations, together with hours of bright sunshine. Thus, the daily values of S↓, obtained as the difference between K↓ and D↓, were used to evaluate $\bar{p}$ for the day following the procedures used by Garnier and Ohmura (1968, 1970). Two periods were analysed: the late summer and early fall (July to October), 1976, and the winter months (November to January) of 1976-77.

A simple regression correlation was undertaken between n/N as the X value of the regression and $\bar{p}$ as the Y value of the regression. The results are shown in figures 1 and 2. The dashed lines in the figures represent 95% confidence limits of the regression analysis. It can be seen that all but one or two of the individual correlations fall within these limits. This fact and the values of r^2 imply a high degree of statistical significance between mean atmospheric transmissivity for the day and recorded hours of bright sunshine.*

The results suggest a simple method of evaluating solar radiation income on slopes. Sunshine is a widely recorded phenomenon. By using it to evaluate $\bar{p}$ and combining the resulting values of S↓ with observations of K↓ to obtain D↓, the total solar radiation flux on a slope may be obtained to a sufficient degree of accuracy for many practical purposes (Garnier and Ohmura, 1970, Garnier, 1980). K↓ is routinely measured in Canada at a large number of places. Alternatively it, too, can be calculated from sunshine records by widely-accepted procedures. Moreover, sunshine records have been kept in many places for many years. Thus, they could be used to establish meaningful estimates of solar energy by way of frequency analyses of the occurrence of days of different potential solar energy income as has been suggested elsewhere (Garnier, 1980).

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*The intercept in the regressions has been affected by the fact that only days when $\bar{p}$ > 0.25 were used in the analysis.

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NEWS AND COMMENTS

Although the Friends of Climatology did not manage to get together for an annual 1981 meeting, the climatologists in orbit succeeded in performing their customary function. The following note has been provided by Bruce Findlay for the 1980-81 "orbiting year".

> "Each year the 'Friends of Climatology' a non-organization of persons keenly interested in climatology who live in Ontario, and neighbouring portions of Quebec, New York State, Ohio and Michigan, select a travelling speaker to visit universities in order to promote enthusiasm for the subject. In 1980-81 this role was accepted by Dr. F.K. Hare, University of Toronto, but regrettably work pressures obliged Dr. Hare to relinquish this assignment. Fortunately, Mr. Gordon McKay, Director of the Climatological Applications Branch, Atmospheric Environment Service, agreed to provide suitable speakers from the Canadian Climate Centre. In March 1981, Dr. D.C. McKay, Superintendent of the Energy and Industrial Applications Section and Mr. Bruce Findlay, Superintendent of the Physical Climatology Section visited the western and eastern regions respectively. Don McKay spoke on climatological applications with particular emphasis on energy and industrial matters to the Universities of Windsor, Wilfrid Laurier, Guelph and on the energy balance of a snow cover to McMaster University.
>
> Bruce Findlay addressed geography classes at the Universities of Toronto, Trent, Queens, Concordia and Montréal on the Canadian Climate Programme and drought studies in western Canada.
>
> Both speakers reported appreciative audiences and university staff members and expressed gratitude for the kind hospitality afforded them."

Not all readers of the Climatological Bulletin may be aware of the weekly publication Climatic Perspectives which is produced by the Canadian Climate Centre (AES, 4905 Dufferin St., Downsview, Ontario M3H 5T4). This is a mimeographed sheet with notes, maps, and statistics covering a period of a week. Climatic Perspectives began in January, 1979, and has appeared regularly each week ever since -- in itself a remarkable tribute to the editor and staff who produce it. The latest number available at time of writing is Vol. 3, No. 41 covering the week of October 6-12, 1981. There are notes on weather highlights for the week and statistics of temperature and rainfall for the main climatological stations. These are regular features. Maps may vary somewhat in content according to circumstance. They usually cover such features as temperature departures from normal, rainfall distribution, and heating degree days. In no. 41 there is a courageous 15-day temperature anomaly forecast for the period October 13-27, and an instructive map of low pressure centre trajectories from October 6-12. Altogether a valuable publication for those interested in monitoring weekly climate and its variability.

Climatologists interested in solar energy applications should find a great deal of relevant material in an international conference, ENERGEX '82, which is to be held in Regina from August 23-29, 1982. Energex '82 will include the annual meeting and technical conference of the Solar Energy Society of Canada, a comprehensive energy exhibition, tours of various kinds (including one to a major energy conservation housing project), and a two-day period of workshops and lectures. A large international attendance is expected. Headquarters for the conference is the University of Regina, Regina, Saskatchewan S4S 0A2.

The present number of the Bulletin contains an article on the Canadian climate program. A recent comprehensive publication in the wider sphere of the World Climate Program is the report of the proceedings of the Technical Conference on Climate - Asia and Western Pacific (WMO, publication no. 578). The conference was held in Gvangzhou, China, 15-20 December, 1980. The proceedings were by no means related solely to the specific area of the conference. In addition to papers on Asia and the Western Pacific there are authoritative reviews by established scientists of general problems of climate and climate modelling, together with a valuable review of the activities and objectives of the world climate program.

Volume I of The Climate of the Canadian Arctic Islands and Adjacent Waters by J.B. Maxwell has now been published. It reviews climatic controls, temperature and wind, precipitation and snow cover. Volume II will deal with the sea and sea ice, aviation-related aspects of the climate, pollution potential and related matters, synoptic systems, and climatic regions. The price of Volume I is $35 and can be obtained from the Government Publishing Centre, Hull, Quebec K1A 0S9.

"In this city there was a wintertime pattern to the weather. First it snowed. Then it rained. Then it grew bitterly cold, turning the streets and sidewalks to ice. Then it snowed again. And then, more often than not, it rained. And turned to ice again. It had something to do with fronts moving from yon to hither. It was a supreme pain in the ass."

From Ed. McBain, Ghosts, Viking Press, 1980.

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