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Truncation Error in a Spectral Model[1,2]

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ABSTRACT

A series of experimental integrations of a hemispheric spectral barotropic model using different spectral truncations is described. The results indicate that truncation errors vary as $N^{-\alpha}$, where $\alpha \simeq 1.4$ and N is the wave number of the resolution. However, it is also suggested that spectrum truncation error should probably be regarded as an assumption about a physical process rather than as a purely mathematical approximation.

1 Introduction

The representation of derivatives of a meteorological field by finite differences involves an error which has been commonly referred to as "truncation error." The term "truncation" arises because of the truncation of a Taylor's series which is used to develop appropriate finite-difference approximations. Further, this type of mathematical error has long been recognized as a serious contributor to the decay of forecast models with time (see, for example, Shuman and Vanderman, (1965)). One typical characteristic error that it produces is slow movement of the smaller scale synoptic systems. There is another type of truncation error that is present in all models of finite resolution, which has generally been referred to as "resolution error." This error is connected to the truncation of the spectrum of variance of the meterological field with which we are dealing, and in fact applies not only to the derivatives of meteorological fields, but to each field itself. Because of the nature of our observing systems and presuming that the atmosphere has variance in all scales, then this type of "truncation error" will always be present. If the atmosphere were a *linear* dynamical system, then "spectral truncation error" would not be a serious problem, because any deficiencies of the observing system or model resolution would only result in deficiencies in forecasting those scales which are not represented. Such is not the case however, and the exchange of variance between scales is rapid and widespread with respect to the spectrum; and this fact results in a major limiting factor on the predictability of the atmosphere as illustrated by Lorenz (1969) and Leith (1971).

In order to visualize further the difference between the two types of truncation error, consider the following pair of thought experiments. Imagine that at $t = 0$, the 500-mb flow field can be represented exactly by a finite number of

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coefficients of a set of spectral functions (e.g., a trigonometric series, in one dimension). We presume for the sake of argument that the evolution of the flow is governed by the conservation of vorticity. If we integrated this system using a grid-point technique, then we will have truncation error of the first type when we evaluate the derivatives of the original field. This type of error will be present even if the flow field behaved linearly. If we integrated this system using the spectral technique, then we will not have this type of truncation error since we evaluate derivatives exactly.

Because the evolution of the flow field is non-linear, there will be variance generated in scales which were not present initially. Eventually there will be variance generated in scales which are not represented in the grid-point or spectral model. It is at this point that truncation error of the second type begins. Thus we see that when we discuss truncation error in a spectral model we consider the second type.

In the following we study the development of spectrum truncation error using a hemispheric spectral barotropic model.

2 The model

The essential mechanism for the development of spectrum truncation error is the non-linear exchange of variance or energy which results from the advection terms in the equations of motion. Therefore it seems reasonable to consider a very simple model possessing this property in order to obtain some insight into the nature of this error. Although it is a crude representation of atmospheric flow, the barotropic model has displayed considerable realism and has been of substantial value in forecasting for many years.

Let ψ be a stream function representing the 500-mb flow; then the governing equation for the model is:

$$\frac{\partial Q}{\partial t} = -J(\psi, Q + f) + \kappa^2 \frac{\partial \psi}{\partial t}, \tag{1}$$

where $Q = \nabla^2\psi$, $f = 2\Omega \sin \varphi$, κ^2 is the long-wave stabilization factor, φ is latitude, and J indicates the usual Jacobian operator.

Equation (1) is integrated using the spectral method with the following set of spectral functions:

$$G_k^n = \cos^n \varphi \cos (2k - 1)(\varphi + \pi/2) \begin{Bmatrix} \cos n\lambda \\ \sin n\lambda \end{Bmatrix}, \tag{2}$$

$$n = 0,1,2, \ldots N; k = 1,2, \ldots . K.$$

Note that since $2k - 1$ is odd, then

$$\cos (2k - 1)(\varphi + \pi/2) = (-)^k \sin (2k - 1)\varphi$$

and thus the southern hemisphere will be a mirror image of the northern hemisphere. This is why it is called a hemispheric model. This is basically the same model as was integrated by Robert (1968), although his was a global version.

In all the experiments to be described here the resolution in the north-south direction is given by $K = 6$, which corresponds to wave number 11 in that direction. At the same time N varies from 6 to 21. All experiments have been integrated using a centered difference formula with a time step of 2 hours and a period of integration of five days.

3 The experiments

Two basic experiments have been conducted to this point. The basic initial field is the 500-mb stream function for 0000 GMT, November 6, 1969 which was obtained from the Central Analysis Office, Montreal. In the first experiment an initial field with resolution $N = 6$ was obtained by harmonic analysis of the basic initial chart. In the second experiment the resolution was $N = 9$. Subsequent integrations of equation (1) were carried out using these initial fields with varying resolutions for integration. In the first experiments runs were made with resolution corresponding to $N = 6$, 9, 12, 15, 18; while in the second, $N = 9$, 12, 15, 18, 21. Within each experiment the fields were initially identical, but developed differences as the integration proceeded. The development of these differences was studied as a function of time and resolution.

4 The growth of differences

In Figures 1 and 2 we present the time variation of the root mean square difference between an integration using the resolution indicated and the largest resolution used. In Fig. 1, the integrations are all compared to resolution 18, while in Fig. 2, they are compared to resolution 21. Note that while the curves on the two figures resemble one another, the ordinate on Fig. 2 is twice that of Fig. 1. There are a number of tentative conclusions to be drawn from these curves. The spectrum truncation error decreases with increasing resolution in both experiments, while the comparison of the two experiments indicates that the rate of growth of difference is much larger with a higher data resolution. These conclusions must be taken as very tentative since the data resolutions used are not sufficiently high to be completely representative of the atmosphere. In fact one would hope that as the data resolution is increased, the growth rate should approach some limiting value. The difference curves do not show any significant tendency to slow their growth in the period to five days, but this is because the total difference variance is still well below the variance in the fields themselves, and we must expect the growth to decelerate at some later time.

In order to relate the decrease in difference to the increase in resolution we have plotted in Figs. 3 and 4 the RMS difference between a particular resolution and the maximum resolution for the two experiments. We have plotted them against N^2 only to make the diagram rectangular and not for any theoretical reason. Both experiments show essentially the same features. In the initial

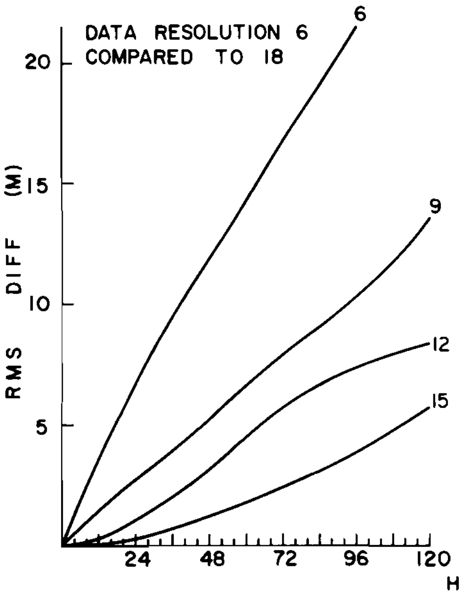


Fig. 1

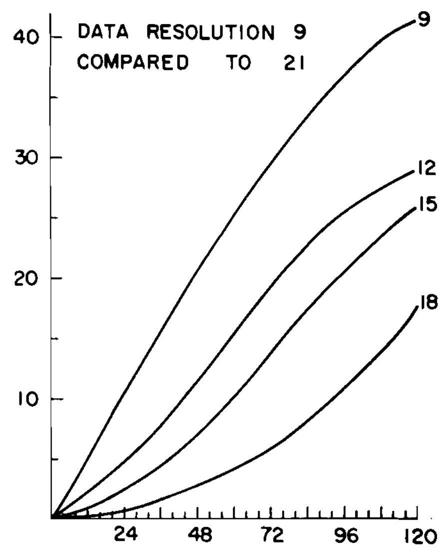


Fig. 2

Fig. 1 The growth of the root-mean-square differences, in metres, over the northern hemisphere for integrations of the spectral barotropic model at various resolutions. The initial data in each case are the same and correspond to a data resolution up to wave number 6. All integrations are compared to the integration with resolution to wave number 18.

Fig. 2 Same as Fig. 1 except initial data have wave number 9 resolution and integrations are compared to wave number 21 integration. Note the ordinate is double that of Fig. 1.

stages of integration the differences fall off rapidly with resolution but at the later stages the differences in the higher resolutions catch up, resulting in curves which have substantially the same slopes from 3 to 5 days. By roughly fitting a straight line to represent the slope of these curves between 3 and 5 days we find the slope to be approximately -0.7, which indicates that the differences fall off with $N^{-1.4}$.

So far we have discussed the differences over the entire hemisphere and all wavelengths. Naturally the question arises as to how these differences are distributed over different scales. Before we go into this, however, it is interesting to see an example of maps of the forecast field produced by two different resolutions. For this purpose we present the 500-mb charts of stream function for an area covering North America. Fig. 5 is the initial chart for the first experiment while Figs. 6 and 7 are the 5-day forecast produced with resolution $N = 6$ and $N = 18$, respectively. While the two forecasts have some features in common, troughs and ridges have substantial differences both in position and intensity.

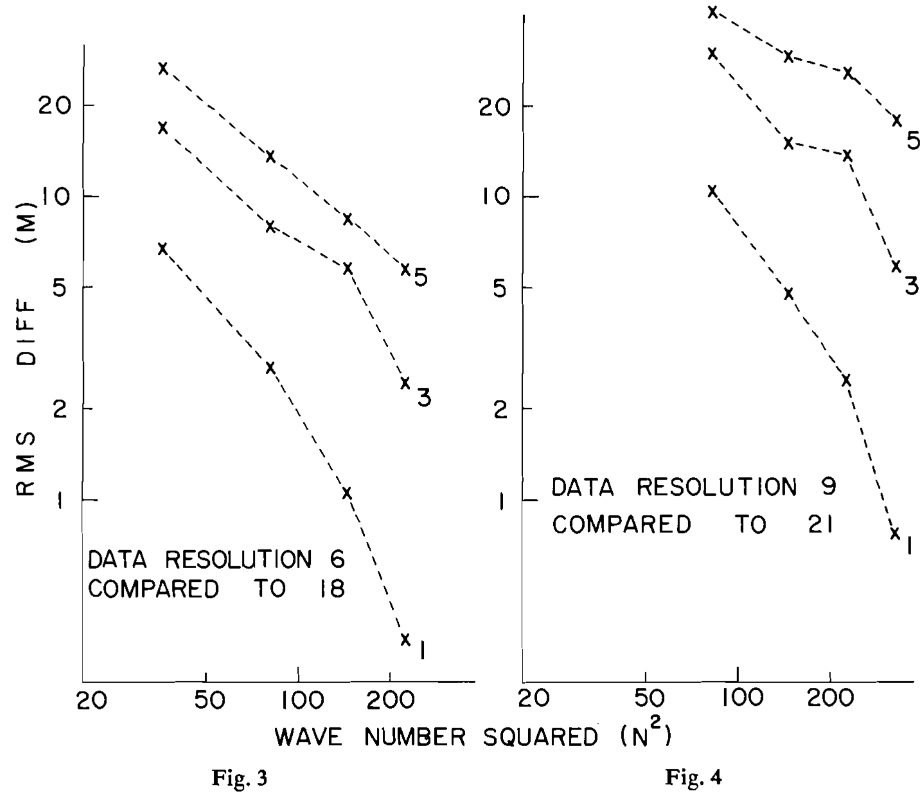


Fig. 3 The root-mean-square differences, in metres, over the northern hemisphere for integrations of the spectral barotropic model as a function of integration resolution wave number N after 1 day, 3 days and 5 days. Both ordinate and abscissa are logarithmic scales. Initial data have a resolution of wave number 6 and all comparisons are made with the integration of resolution 18.

Fig. 4 Same as Fig. 3, except that initial data have resolution 9 and comparisons are made to the integration of resolution 21.

5 The spectra of differences

We have seen how the differences between two integrations starting with the same initial field grow with time and now we discuss the spectrum of these differences and its evolution. In fact this description gives the essential mechanism of the growth of the differences. In Fig. 8 we present the spectrum of the difference between an integration with resolution 9 and one with resolution 12 where the initial data has a resolution 6. We have also plotted the spectrum of variance of the higher resolution forecast at five days. There are a number of interesting features in these curves. The break in the spectrum at wave number 9 is due to the fact that there is no variance in the lower resolution forecast for wave numbers larger than 9. It is also noteworthy that it is not obvious from these curves that the data resolution is 6. We note that the difference spectrum has a characteristic shape which persists for about 1 to 2 days, while the variance grows by orders of magnitude. However, since it is still quite small during this whole period, one may look on this growth in a sort of linear way.

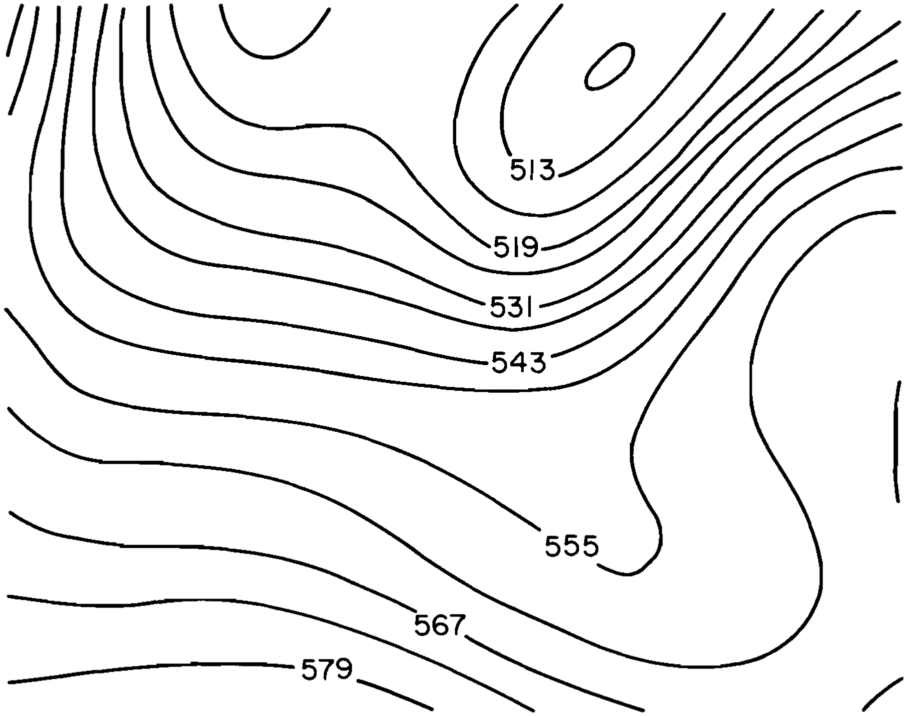
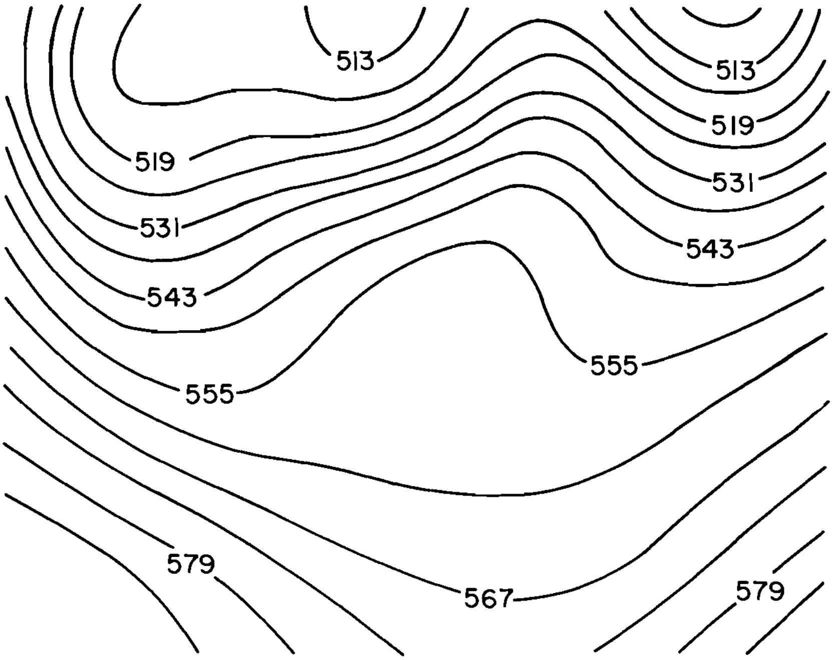


Fig. 5 A section of the initial chart used in the experiments with data resolution 6. Contour values are in decametres.

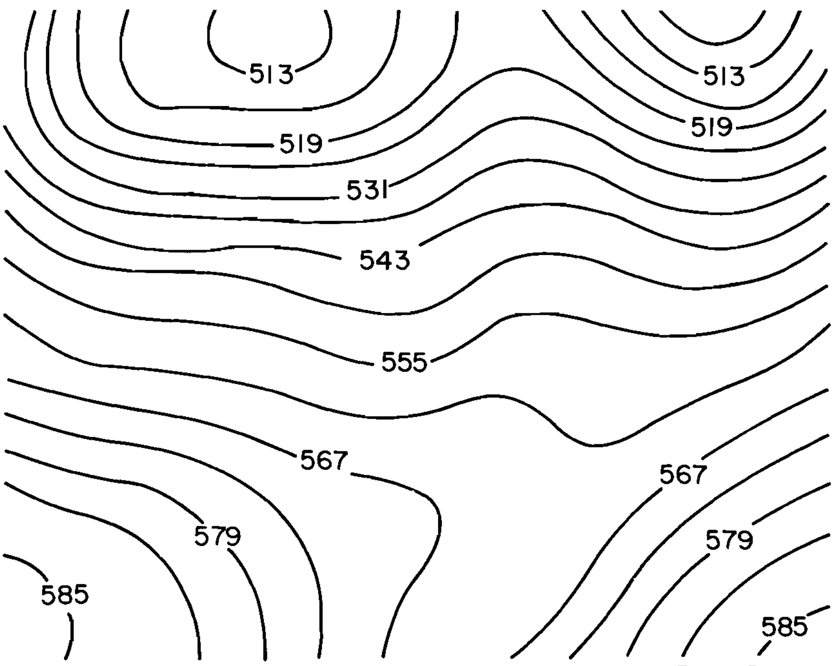
The initial field has a certain spectrum which implies a transfer of variance to wave numbers 7 to 12. The low resolution model only admits variance to wave number 9. Subsequently the variance produced in wave numbers 10 to 12 implies a slightly different transfer of variance in the higher wave numbers. Thus we generate difference variance in all wave numbers (including the zonal flow). Since in the beginning this difference variance is very small, then the spectrum of variance is almost constant, and so the field simply adds more of the same characteristic difference. This explains why the difference spectra have similar shapes. Eventually, of course, the two integrations will be sufficiently different so that subsequent variance transfers are not similar and then the difference spectrum will modify as it does after about 2–3 days. We also notice that the amount of variance generated in the wavelengths shorter than the data resolution is not excessive and in fact, the spectrum of the high resolution model after five days is quite reasonable.

This last observation is significant, because we would not be too confident in estimates of truncation error if in fact that were not the case. As further evidence of the reasonableness of the cascade of variance or energy into the scales of motion not originally present in the data we present in Fig. 9 the energy spectrum at different times during the course of an integration of the data resolution 6 using model resolution 18. We have also plotted a smooth



500MB (13,6) DATA (13,6)RESOLUTION 120HRS AFTER 00Z 6-11-69

Fig. 6 The forecast after 5 days for the initial chart shown in Fig. 5, using wave number 6 resolution for the integration.



500 MB (13,6) DATA (37,6)RESOLUTION 120HRS AFTER 00Z 6-11-69

Fig. 7 Same as Fig. 6, except the integration uses wave number 18 resolution.

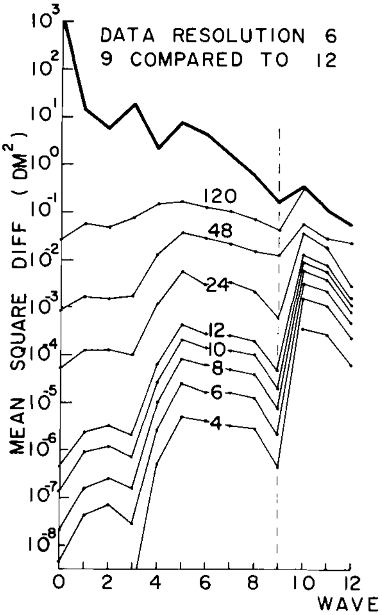


Fig. 8

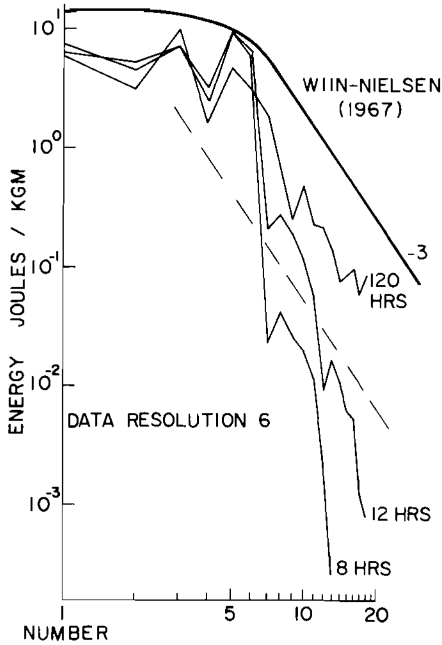


Fig. 9

Fig. 8 The evolution in time of the spectrum of the mean square difference (decameters^2) between an integration with resolution 9 and one with resolution 12. The initial data have a resolution of wave number 6. The heavy solid curve is the spectrum of variance of the integration with resolution 12 after 5 days. The thin curves are labelled in hours after initial time. The short unlabelled curve on the right corresponds to the distribution of error after 2 hours (one time step).

Fig. 9 The evolution in time of the spectrum of kinetic energy for an integration with resolution 18. The initial data have a resolution of wave number 6. The heavy solid curve is the average spectrum for the northern hemisphere taken from Wiin-Nielsen (1967).

representation of Wiin-Nielsen's (1967) kinetic energy spectrum. Note that the energy spectrum remains below that of Wiin-Nielsen at all wavelengths considered, even well within the −3 range. In fairness it must be said that since we have not integrated the model beyond five days, we cannot say for sure that this situation would persist indefinitely.

6 Concluding discussion

In this last section let us firstly reemphasize that the estimates of "spectral truncation error" must be regarded as tentative because of the limited resolution which was used. With that in mind, the results show that truncation error in a spectral model is much less sensitive to resolution than in similar experiments with grid-point models (Chouinard, 1971). Further, these experiments lead one to consider that any model or indeed observing system will suffer from this type of error. This error arises because we simply *do not permit* interactions involving scales which are not within the resolution to affect those scales within the resolution. In that sense we are making an assumption about the *physical* nature of the system rather than a purely mathematical approximation. To that extent, if we can discover what is the net or overall effect of non-linear exchanges involving scales not considered, then we can make more realistic assumptions than the one implied here, namely that the exchanges have *no effect.* In other words, a good parameterization of sub-scale physical processes may further reduce the sensitivity of truncation error to resolution. This in fact has been attempted by Leith (1971), where he has constructed a dissipation function to simulate the effect of truncated resolution.

Acknowledgement

The author is indebted to Dr. A. J. Robert of the Atmospheric Environment Service for providing the barotropic model in working order, as well as for many useful discussions.

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BOOK REVIEW

FUNDAMENTALS OF AERONOMY. By R.C. Whitten and I.G. Poppoff, *Space Science Text Series*, John Wiley & Sons, Inc., New York, London, Sydney and Toronto, 1971, xiv, 439 pages, $14.95 (U.S.).

Although the field of aeronomy is now quite well developed no adequate textbook has been published until 1971. A number of excellent monographs have appeared in recent years, but they are not entirely satisfactory for classroom use. *Fundamentals of Aeronomy* is the book which has finally filled this need.

The authors have tried to develop several topics of aeronomic interest. The treatment of the material is sufficiently fundamental so as to enable any student with a thorough knowledge of mathematics and physics at the undergraduate level to follow the development of the subject matter very easily.

The text comprises 11 chapters. The basic physics is reviewed in Chapter 2. The structure of the neutral atmosphere is discussed in Chapters 3 to 5 and aurora and airglow in Chapter 6. The remaining chapters are mostly concerned with phenomena in the ionosphere including the propagation of electromagnetic waves. One unique feature is the inclusion of relevant problems at the end of each chapter.

A few errors appear to have been overlooked. For example, C_v in equation (3.10) on page 72 should be C_p, specific heat at constant pressure; equation (6.11d) on page 195 seems to have been wrongly used. Some other minor misprints have also occurred.

On the whole, *Fundamentals of Aeronomy* will serve as a good textbook and I would recommend it to students and teachers in aeronomy and allied fields.

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The Environmental Cycle: A Basis for Action

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[Manuscript received 10 November 1971]

ABSTRACT
An analysis is made of the channels by which the environment affects man and man affects the environment. The interactions between the natural environments (land, water, air, plant, wildlife) and the built and social environments are studied. Conclusions are drawn as to how these interrelationships may be used to develop the information that man needs in order to ensure that the environment which results from this complex interplay is to his liking.

1 Introduction

That quality of life is closely related to quality of environment is no longer news. Yet little is known of the mechanisms needed to achieve the desired quality without sacrifice of many past achievements. Traditionally man has been dependent on his environment for his resources. Almost all his ingenuity has been spent in learning how to extract these resources and to mould them to his use. Now that his ability to manufacture on a massive scale has been realized he finds himself confronted by the many problems related to the equally massive return of these same resources to the environment. These are formidable problems indeed and they take many forms. For example, almost all his present systems are designed for the productive side of the cycle; few for the return side. Also, these problems relate to every facet of human life and the question is not simply one of pollution vs. no pollution; it is a question of how much pollution, what kind of pollution and where will it be. The first problem then is how to organize one's thinking to contemplate the problem; the second is how to organize to deal with it. The purpose of this paper is to consider the nature of the environment and its relationship to man, the common denominator to all environmental studies.

In the beginning the environment had the power of death as well as life for man. It still has, but in more subtle ways. As well as air to breathe, the environment provided food, shelter and clothing in increasing abundance and variety, and weapons for his protection. He drew from several rather different environments. There were three physical environments: land, water, and air; and two biological environments: plant and animal. To these he added another, the Built Environment (Hare, 1970) constructed to his liking from resources drawn from the five natural environments. With increased knowledge came increased ability to manage the environment. The goal was always to produce products to improve his safety and enjoyment of life. Struggles took place between nations as

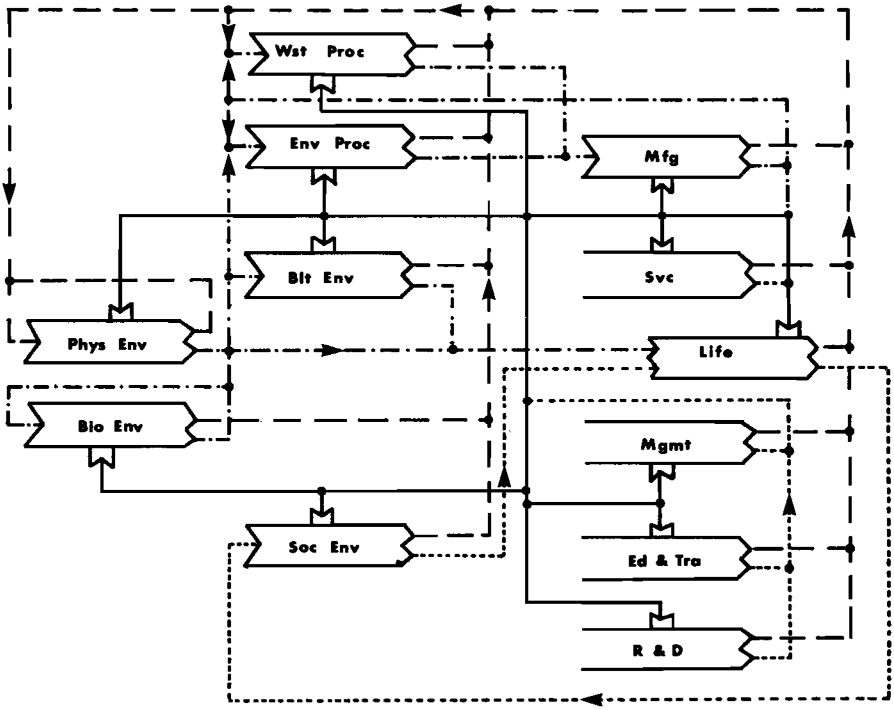

Fig. 1 Diagram of the major environments: physical, biological, built and social, and their support of Life (man's). Also shown are the several supporting systems necessary to the functioning of the rest of the cycle for man's benefit. Desirable material products move along dash-dot lines (— · —); unwanted material products move along long-dash lines (— —); non-material products move along short-dash lines. Detail is given in Section 2 and 3.

they attempted to gain advantage in the form of better or cheaper resources or to protect their possessions and systems. Inherent in these civilizations were other, more subtle environments, cultural environments of a non-material nature. The essence of a civilization was bound up in its cultural beliefs and its cultural developments such as in the arts and politics. Often these were the more complex in that position on the authority scale was as often a social feature as a managerial function.

During most of the period in which these developments took place civilizations were growing faster than was the ability of the environments to affect man. The many changes made by man in the environment turned out to be good for him. All was well. While man had ignored one simple truth, he had evidently done so successfully. The truth: that all resources drawn from the environment eventually return to it. Pollution was known and was accepted as a necessary accompaniment to progress. It had not yet become a problem. It was inevitable that the increasing tempo of the production side of the cycle should lead to increasing tempo in the return side. Unless the return side is as well managed as the production side the resources on which man depends will become contaminated resources and the contaminants will recycle through all his environments and all his systems.

This, then, is the essence of the problem. More knowledge is needed of the nature of the whole cycle, of the processes taking place within the environments, and of the interactions between them. Quantitative information is needed on the nature and volume of elements moving around the cycle. Decision makers and managers are needed and must be trained. New systems for study, research and education are needed. Old-style descipline-oriented structures no longer seem relevant to such broad problems.

2 The environmental cycle

These introductory remarks say something about the nature of the human environment and its relationship to man. They can be summarized as a definition of the human environment which may be useful for later discussion:

> The human environment consists of those systems: physical, biological, built and social, upon which man depends for his physical and cultural well-being and which he, in turn, affects through his activities.

It is helpful at this point to portray the features of the environmental cycle and their interrelations. These are shown in the schematic diagram in Fig. 1. A word of explanation is necessary to understand the figure. Each component is shown as a system identified by a name which is abbreviated in the figure. Arrowheads inward show input to the system. Arrowheads outward show output. Lines beginning at an output arrowhead and ending at an input arrowhead depict transfer of a product from one system to another in which it is used. For example, iron ore is drawn from the environment to be processed in another system. Lines ending on the side of another system indicate that the product becomes a resource to be used in the work of the recipient system rather than a product to be processed by it. An example would be machines produced in one system for use in the work of another.

Life is the starting point. The four classes of environment: physical, biological, built and social, provide what is necessary and what is desirable for life. The importance of the nature and the quality of each of these environments should be evaluated in terms of their ability to feed the life system. These environments also interact with each other through transfer of material or living products. For example, deer eat grass, and grass requires soil, water and air. When the deer die their remains return to the physical environments. Environmental Processing (Env Proc) and Manufacturing (Mfg) supply the material needs to support the environments as well as all systems. These are dispensed through a support network shown by the full line. Desirable material products are shown by dash-dot lines. All material returns ultimately to the physical environment along the long-dash lines. There are also non-material products produced by Life and other systems and these move along the short-dash lines. The meaning of these relationships will be explored in the following sections.

3 Some related systems

a *The Ecological System*

Consider first the interactions between the five bio-physical environments. This study is known as ecology. The three physical environments (Phys Env) are themselves closely related. Water evaporated from oceans, lakes, and other bodies becomes a constituent of the air. Later it condenses again as rain and falls on land and water. This is the source of both ground water and surface runoff in rivers and lakes to the sea. Climatic regimes in the atmosphere are likewise governed to a considerable extent by the physical features of the land, especially mountains, and proximity to water. These feedbacks are embodied in the circuitry of Fig. 1.

The balance reached by the physical environment controls many features of the biological environments (Bio Env). Different plants require appropriate physical environments to supply their needs. All require some form of soil, water and air. Animals require physical environments plus vegetation and possibly other animal populations for existence. The excrement and the remains of dead animals and plants return to the physical environment and help to determine its characteristics. In addition transpiration from plants and perspiration from animals alter the water vapour balance. The biological environments also affect the chemical composition in the atmosphere. From these few elementary examples it is seen that all five natural environments interact in a complex fashion to reach a balance which in the past has been a stable one.

Man also interacts with these environments. In earlier times he could have been considered as another animal. However, his increasing ability to use and alter the environment necessitates the introduction of the "Life" system in the cycle. This is the key to making decisions about the environment. It is on the basis of man's needs and desires in the Life system that one must now judge the nature and quality of the environments. With the removal of natural balances many species of animals face extinction and man must decide if he wishes this to be, and to take appropriate steps to prevent the disappearance of wanted species.

b *The Modified Ecological System*

Man's early efforts included modification of land to support agriculture and domestic animals. He also constructed shelter, fortifications and villages. Thus began in primitive form a new environment, dubbed the Built Environment (Blt Env) by Hare (1970). As the Built Environment became more sophisticated and tailored to man's needs, it more and more replaced the natural environments. More accurately it took on an importance equal to the bio-physical environments in supplying the immediate material needs of man. The Built Environment now includes homes, buildings, urban and suburban developments and their interlocking services. It includes roads, railways, seaways and airways which are modern counterparts of the paths and river-routes of primitive man. It includes the vehicles which traverse these routes. Depending on one's definition it could be taken to include clothing but this is more a personal and social thing and I prefer to consider this as direct support of life insofar as its relation to weather and climate is concerned and to the social environment insofar as its style is concerned.

c *Manufacturing Support Systems*

To produce the elements of the Built Environment, as well as to produce tools and products used by all systems under full or partial control of man, an elaborate production process is necessary. This is shown in Fig. 1 as Environmental Processing (Env Proc) and Manufacturing (Mfg). By environmental processing is meant the action of extracting needed materials from the bio-physical environments. This includes such operations as mining, or obtaining hides from animals. Its outputs become the raw materials from which articles are made in the manufacturing process. The term manufacturing is here used in the very broad sense of making anything of a material nature which is useful to man, either directly or in the performance of his activities. As with other processes there are two types of product, a useful one and an unwanted one; the latter consists of the unused or waste parts of the input materials as well as the worn out resources (tools, etc.) of the processing system itself. These return to one of the physical environments although not necessarily the one from which they were originally drawn and almost certainly not to the same location.

In our figure we show the useful output of the manufacturing process as entering an all-purpose support channel serving all systems and environments. This is because manufacturing is only one of several systems serving the entire complex. It even serves itself since its own tools and other resources must be produced within the manufacturing process.

Partly through recognition that waste products may be made into useful and profitable products, and partly through realization of the need to minimize pollution, some waste products are removed from the return channel and recycled. In our figure the Waste Processing System (Wst Proc) depicts this function. Here waste materials are removed before returning to the environment and are used as though drawn from the bio-physical environment. It, in fact, serves the same function as Environmental Processing, the only difference being the source of its input. The useful output becomes input to the manufacturing process. This is one strategy of pollution reduction which is receiving much attention today. The reaction against the introduction of non-returnable bottles is a case in point.

d *Non-Material Support*

As with primitive man concern for material things has been a major preoccupation with us. However, the process of development of material systems and environments cannot progress far without development of non-material systems. These can be classified, broadly speaking, into certain categories:

(i) *Services* (Svc). This includes such things as information services, computing services, weather forecasts and so forth.

(ii) *Research and Development* (R&D). This includes the increase of knowledge and understanding of physical and biological processes, some of it being specific to processes which are capable of improvement or engineering to serve man. It should also include the corresponding functions in support of non-material human activity.

(iii) *Education and Training* (Ed & Tra). This includes systems for transferring both general and specific knowledge to people who can use it or appreciate it.

(iv) *Management* (Mgmt). This includes all activities required for decision and control in the operation of all systems. Of primary importance is the establishment of human objectives in the Life system. This is related to international agreements and national legislation.

e *The Social Environment*

Man cannot live by material things alone. He needs a non-material environment not only for the full exploitation of his own potentialities but also as a framework within which decisions are made which affect all of his activities. Here lie his noblest deeds, also his most infamous deeds. This is a most complex environment. In it reside great cultural products: works of art, literature, music, and philosophy. The interrelationships of man to man are here, and his standards of behaviour.

Social decisions are reflected not only in the structure of the social environment but also in the built environment and in various systems: segregation of races, need for armaments, etc. A man's position in a manufacturing firm may represent a social standard as much as a job in the production process.

The output of the Social Environment (Soc Env) is basically non-material and is used in the Life System. The small material output is entirely in the form of waste and represents the fate of worn out resources.

4 The function of management

The more man develops his capacity to use the environment the more is his responsibility for its state and the greater is his need for its management. Management must be based on knowledge, and must be exercised at many levels from that of the concerned individual to that of the international agency. The responsibilities of management fall to a great many groups. Prominent amongst these are the industries, municipalities, countries and the United Nations.

The primary problem is to identify the more important groups, their roles and their responsibilities; this is now rapidly taking place. Objectives must be developed and organizations established to achieve these. Human and organizational rights, insofar as they relate to the environment, must be established. National goals respecting all environments and systems should be set. Laws and standards of conduct must be passed. Regulatory and punitive measures must be decided on.

Decisions must soon be made on the acceptable standards for the human environment. This must include the standards of physical environments needed to support the animal and plant environments desired by man as well as those required to support him directly. Research and education are needed to provide the information on which to determine the standards. Legislation is required to put them into effect. Environmental sampling networks are needed to provide information on the degree to which the standards are being met.

Strategies are needed to minimize the deleterious effects of the return channel of the environmental cycle and to maximize the beneficial effects. There are many classes of strategies: maximize the ratio of desirable to undesirable outputs; recycle undesirable outputs to produce desirable ones (e.g., composting); change strongly undesirable outputs in one medium to less undesirable ones in another (e.g., burning of solid material). Strategies are needed which do not have deleterious effects on other environments. And serious loss of income for large segments of mankind must be avoided.

To support decision-making, indices are required to designate the nature, quantity, quality and rate of flow along the channels in Fig. 1. The GNP is a measure in this category. A more refined and more complete set of indices is needed on which to base the decision-making processes of environmental management.

In short, the immediate problem is the development of organizations, standards and information systems. Simultaneously, improvements in existing operations to reduce their damaging effects on the environment can be carried on. Pollution control measures are mostly now of this type. The long-term problem is more complex and will come into focus as the short-term problems are solved. For the long term a complete redesign of the economic system is probably essential to meet the goal of optimum quality of all aspects of the human environment rather than a goal of maximum production. This has serious ramifications and spells the end of many accepted production policies such as planned obsolescence.

5 The functions of R and D and education

The decisions to be made by management must be based on knowledge. Knowledge must be generated by research and development and disseminated, in part, through education and training. In addition, skilled and knowledgeable people are required for the making of decisions and for their implementation. These two products, knowledge and knowledgeable people, imply a need for a wide spectrum of education and training programs, many of which should be associated with R and D programs. In the past such programs have tended to support the decision-making process in the production and economics fields. In the future there will be an increasing emphasis on support to decision-making in the area of environmental quality and in considerations of the workings of the entire cycle. The remarks which follow should be read in relation to research, education and training in the environmental area.

Mission-oriented research and development, and job-oriented training will be closely associated with the work of industries, government and the other groups having management responsibilities as described in Section 4. In support of environmental management much research should be directed to developing standards of environmental quality, to developing test procedures and to providing the kinds of scientific information needed to determine managerial strategies.

The universities have a unique and important role to play in developing and imparting knowledge on the environment. They must study the fundamental natures of the various environments, and the interrelationships between themselves and other systems. This fact has been receiving increasing attention from the universities in recent years as they strive to adjust to their own changing environment. They are faced with a difficult organizational problem. The environmental cycle shows the close interdependence of the several environments and the crucial relationship of man to them. The traditional organization of the universities by discipline seems incapable of adjustment to meet the changing needs. Approaches have been tried, with varying success, to resolve the seemingly opposing organizational philosophies. The apparent solution, to create an interdisciplinary department, is illusory. Such a cross-disciplinary department would be either too large or too diffuse to be effective; and there would be problems with the existing departments specializing in these disciplines.

Probably the solution lies in establishing departments on the basis of objectives associated with particular environments rather than with disciplines or with broad combinations of environments. Thus, there could be a university department with interest in one environment, e.g., air, water, land, plant or animal. If these are too broad, a sub-environment might be chosen, e.g., forest. Such a department would carry out research and education leading to an understanding of the scientific nature of this environment and its interrelationships with man and other systems. This would provide a basis for interdisciplinary study which would remain within reasonable bounds.

Interdisciplinary discussions, symposia, seminars, etc., with groups primarily interested in another environment would be interesting and valuable to both. No doubt also some scientists would become interested in following the chains of cause and effect around the whole cycle and this might ultimately become a discipline in itself – a sort of environmental economy.

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The Contribution Made by Air-Borne Pollutants to the Pollution of Large Bodies of Water

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[Manuscript received 25 January 1972]

ABSTRACT
A brief survey is given of the sources, the methods of injection into the atmosphere, and the mechanisms of deposition into bodies of water for various atmospheric pollutants which contribute significantly to the pollution of large bodies of water. Specific examples of the relative importance of atmospheric sources are included where data are available. Programs of the Canadian Atmospheric Environment Service in this field of research are outlined.

1 Introduction

One of the dominating features of the Canadian environment is the abundance of water resources. Canada's coastline has a length of about 95,500 km, the longest in the world; the country faces three oceans and has a major archipelago in the far north, as well as an immense continental shelf. Canada's freshwater resources comprise about 25 per cent of the world's known volume of fresh water; 7.6 per cent of the country's surface area (about 751,000 km^2) is fresh water. Of the 8,800-km international boundary shared with the United States, almost half traverses common water resources.

In this unique geographical situation, with water resources occupying such a significant role in the country's environment, Canada is very susceptible to the effects of pollution on her water resources. There are many sources which contribute to the pollution of freshwater lakes and oceans: the disposal of wastes through direct outfalls and rivers; run-off from land; dumping, operational discharge, and accidental release from ships; sea-bed exploration for mineral resources; military activities; and transfer from the atmosphere.

It is this last source of water pollution, the contribution made by air-borne pollutants, which will be the subject of this paper. As a better understanding is gained of the transport of atmospheric pollutants over moderate and large travel distances, and the mechanisms operating in the atmosphere which remove air-borne pollutants, it is becoming more evident that air-borne pollutants contribute significantly to the pollution of large bodies of water.

Topics to be considered will be the methods of injection of pollutants into the atmosphere, the mechanisms by which these pollutants are then deposited into the lakes and oceans, examples of important pollutants, and a few quantitative examples where data are available.

2 Methods of injection into the atmosphere

There are numerous methods by which various pollutants may enter the atmosphere. Three of the more important ones are considered below. It is well known that combustion sources of different types are responsible for much of the air-borne pollution. Industrial and home heating which utilize fossil fuels are responsible for significant amounts of sulphur dioxide being injected into the atmosphere; incineration of waste products releases large amounts of various harmful trace substances such as PCB's (polychlorinated biphenyls); and combustion in automobiles is responsible for most air-borne lead.

A second source of air-borne pollutants is the aerial spraying of pesticides. Spraying losses can be significant; sometimes less than 50 per cent of the material reaches the target. Evaporation losses occur during spraying and from the target material; co-distillation with water is significant.

The third important method of injection into the atmosphere is the erosion of soil by wind. Gaseous or liquid materials such as pesticides may become strongly attached to particulate material and be blown into the atmosphere.

3 Mechanisms of deposition of air-borne pollutants into lakes and oceans

The pathways of air-borne pollutants to bodies of water are twofold: there is the direct contribution from precipitation scavenging and dry deposition, and there is the indirect contribution from surface run-off and ground-water. Precipitation is the largest supplier of air-borne materials through the in-cloud process of rain-out and the below-cloud process of wash-out. The processes of dry deposition of particulate matter and direct molecular impaction of gaseous substances are also important deposition mechanisms.

The indirect contribution from run-off and ground water originates from the above processes and from the additional mechanism of leaching, whereby minerals from the soil pass up through plants and are washed from leaves by precipitation. It is difficult to assess the contributions of these indirect processes although the spring run-off would be an example of a substantial source of pollutants which were originally air-borne. This was the cause of the arsenic problem at Yellowknife a few years ago, where high levels of arsenic were found in drinking water during the spring and early summer (Kay, 1959).

4 Sources of water pollution for which the atmosphere is a major transporting mechanism

A recent report (GESAMP, 1971) identified the atmosphere as a means of transport for a number of pollutants which contribute to the pollution of large bodies of water, particularly oceans. Those substances which were most important in this context were pesticides of organochlorine compounds (DDT, for example), and the heavy metals mercury and lead. Significant effects were attributed to pesticides of organophosphorous compounds, herbicides, and PCB's; slight importance was attached to sulphites. There was some uncertainty about the importance of other substances as pollutants including those pesticides containing mercurial compounds and miscellaneous metal-containing compounds, arsenic, and the following petrochemical and organic chemicals: aromatic solvents, aliphatic solvents, and plastic intermediates and by-products.

Although the introduction of inorganic materials into the oceans may not constitute pollution, the introduction of similar amounts into fresh water may certainly do so because of the chemical composition and low buffering capacity of fresh water. Thus sulphates and nutrients, for example, in the amounts that they are now being introduced into freshwater lakes, may certainly be considered as pollutants.

5 Examples of atmospheric pollutants reaching bodies of water

a *Results of CCIW Studies*

The Canada Centre for Inland Waters (CCIW) at Burlington, Ontario has been carrying out a study of precipitation and dry deposition sampling and chemical analysis. Monthly samples are collected from 16 selected stations in the Great Lakes Basin and analysed for pH and inorganic constituents. These results suggest, for example, that the atmospheric loading of Lake Ontario is responsible, in the case of total phosphorous and total nitrogen, for about 9 and 12 per cent, respectively, of the total loading of these nutrients. This can certainly be considered a significant input.

b *Recent Swedish Studies*

In a report (Sweden, 1971) prepared for submission to the United Nations Conference on the Human Environment, Swedish scientists have presented in detail the effect of sulphur on Swedish waterways. Most rivers and lakes in Sweden show an increasing acidity (decreasing pH), which seems to be due mainly to the deposition of sulphuric acid. It is shown in this report that, if the present development continues, about 50 per cent of the lakes and rivers in the areas concerned may have pH-values of 5.5 or even 5.0, which is critical for the survival of most fish, in less than 50 years. This example of the increasing acidity of rain is particularly applicable to areas of freshwater lakes in Canada because they also have a similar low buffering capacity.

c *Transport of Lead*

The global annual supply of lead is about 3×10^6 tons, of which an estimated 2×10^5 tons enters the sea by way of the atmosphere (GESAMP, 1971); the primary source of this lead is the aerosol released from automobile exhausts. It is estimated that at least half of the total amount of lead entering the sea comes from the atmosphere. This fallout of lead has increased lead concentrations in the mixed layers of the oceans of the northern hemisphere by a factor of about five.

d *Transport of DDT*

DDT can reside in the atmosphere in very large quantities, as much as 10^7 tons in vapour form; this is ten to one hundred times the estimated yearly input to the atmosphere. Using measurements of DDT found in rainfall in England and Florida, estimates of the annual contribution of DDT to the oceans by rainfall have been made (SCEP, 1970). This amounts to 2.4×10^4 tons of DDT which is approximately 25 per cent of its estimated annual total production. It is quite plausible that the atmosphere is a major route for DDT residues to reach the oceans.

6 Conclusions

The most important conclusion that may be drawn is that the contribution made by air-borne pollutants to the pollution of large bodies of water is indeed a significant one.

Although few direct measurements have been made to determine the amounts of air-borne pollutants entering large bodies of water by the various processes outlined, indications are that the atmosphere contributes substantially to water pollution. Estimates of the portion of the total amounts of pesticides (e.g., DDT) and heavy metals (e.g., lead) reaching the oceans contributed by atmospheric sources are 25 and 50 per cent, respectively. The nature of freshwater bodies (chemical composition and low buffering capacity) makes them susceptible to more potential pollutants. Thus, such substances as sulphur dioxide, nitrogen and phosphorous become significant air-borne pollutants as far as freshwater bodies are concerned.

The relative importance of various sources of pollutants must be taken into account for differing geographical areas. For example, in mid-ocean, precipitation would be a more significant source of pollutants than would rivers. On the other hand, spring run-off, an indirect atmospheric source, would be more important in a smaller freshwater lake than in the oceans.

The scarcity of direct measurements of atmospheric pollutants' contributions to the pollution of large water bodies makes it difficult to establish pollutant budgets for specific substances and specific bodies of water. However, a recent example of the type of study urgently required to provide such information is that of Winchester and Nifong (1971). They have attempted to construct a budget of major pollutants for Lake Michigan to assess the importance of aerosol fallout as a pollution source for the lake. Their conclusions are that air pollution along the southwestern shore of Lake Michigan can be a significant source of trace element contamination of the lake.

Although it is apparent that the atmosphere is probably as prolific a source as the others outlined, it is essential that further research be done to provide *quantitative* estimates of the contribution of atmospheric sources.

7 AES programs of research

The Atmospheric Environment Service (AES) is currently involved in two major research programs which will contribute directly to our knowledge of atmospheric pollutant input to large bodies of water. Preparations are under way for a study of interface sink mechanisms on Lake Ontario during the International Field Year on the Great Lakes (IFYGL). Vertical fluxes of pollutants such as ozone, carbon dioxide and sulphur dioxide will be measured over the lake, and scavenging contributions under steady state conditions will be examined by means of chemical analysis of precipitation samples.

The AES is also involved in the Gulf of St. Lawrence study, which is to begin in late 1973. Proposed AES programs include the establishment of land stations and use of research vessels to collect precipitation samples for chemical analysis, and the determination of the fluxes of pollutants through the air-sea interface.

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ANNOUNCEMENT

International Water Resources Association

The International Water Resources Association (IWRA) has recently been founded as a non-governmental, not-for-profit organization. One of the major factors in establishing IWRA was the need for a society to provide an international forum for the interdisciplinary discussion of all aspects of water resources science and technology. IWRA is the culmination of the efforts of internationally prominent administrators, engineers and scientists representing many disciplines in the field of water resources. For further information about IWRA objectives, membership application forms (institutional or individual), or for any other reason contact:

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Snow Devils — A Meteorological Oddity

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[Manuscript received 4 June 1971]

1 Introduction

The dust devil has been studied by many authors and a comprehensive summary is given by Geiger (1965). They are the visible result of the entrainment of dust and other light debris in the vortex created by the overturning on a large scale of super-heated layers of air near the ground. They may rotate either cyclonically or anti-cyclonically. Carroll and Ryan (1970) found a correlation between the direction of rotation and the sense of the vertical component of the vorticity feeding the dust devil. Although snow devils (Fig. 1) are visually similar to dust devils, it is unlikely that they are caused by the same process, but no references to them can be found in the available literature.

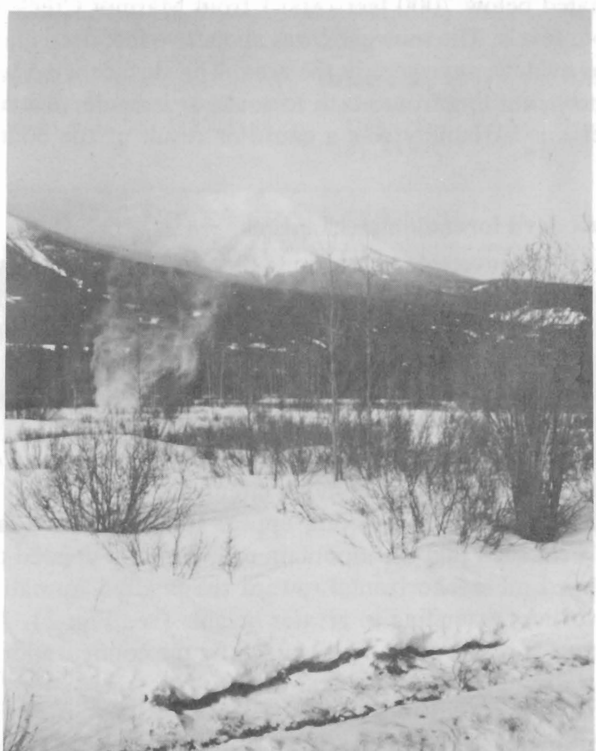

Fig. 1 One of several snow devils observed in the Kananaskis Valley, January 22, 1971.

2 Description

The snow devils were first observed about 1100 MST, January 22, 1971 from the trail leading to Marmot Creek Watershed, forming in the Kananaskis Valley about 300 feet below. The valley runs north and south with peaks to over 10,000 feet above MSL on both sides. The valley floor is about half a mile wide at an elevation of 4,800 feet. From this distance the snow devils frequently appeared to rise in the lee of a small ridge from a diffuse mass of blowing snow, take the characteristic shape of a dust devil, and move north or northeast along the valley. Forming at irregular intervals they had a life span of 30 seconds to two minutes. From closer range, it was estimated they averaged 15 to 30 feet in diameter and 40 to 50 feet in height, but a few were two to three times as tall as the average. Two were noted above timberline, and one over a pine forest on Marmot Watershed. All those seen from close range had a cyclonic rotation. About 30 were seen in a two-hour period, and occasionally, two at once.

3 Weather conditions

Warm air advection in a strong westerly circulation aloft was creating typical chinook cloudiness – high broken cirrus with patches of altocumulus or stratocumulus. The warm air however had overpassed the valley, and valley temperatures were between 15 and 20°F. A stable lapse rate of 3 to 4°F/1000 feet has been estimated below 7000 feet (MSL) from Marmot Creek temperatures measured at four levels. The snowpack was about two feet deep and well settled. No melting was evident anywhere in the area. The surface wind was extremely variable and gusty, shifting from north to south at irregular intervals. It is not known whether this variability was a cause or result of the concurrent snow devil activity.

4 Possible snow devil formation mechanisms

If it is assumed that convective overturning did not cause the snow devils, they must have been caused by mechanically induced vortices in the wind flow, but the exact process is a matter for conjecture. Because many formed in the lee of a small ridge, it is possible that they were visible evidence of downstream eddies created by the ridge. However, it seems unlikely that whirls would extend to heights greater than the ridge under stable conditions.

One snow devil has been seen since January 22 and it occurred also in the Kananaskis Valley under a strong chinook circulation. Thus either the topography or the weather conditions or both, appear to be causative factors. If the wind direction were such that the mountain configuration created a rotor cloud with its axis tipped off the horizontal toward the favored formation area, this could explain vortices extending to greater heights (see Fig. 2). Alternatively, the horizontal vortex of the rotor cloud, aided by the configuration of the ridge and the valley walls, may induce vertical vortices below it.

5 Application

If the snow devils are indeed caused by strong, subsiding winds flowing over a narrow valley, pilots of light aircraft attempting to fly at low levels through

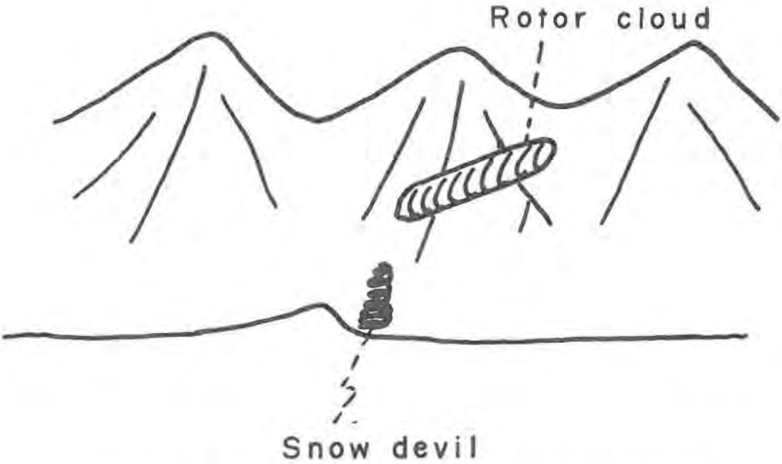

Fig. 2 Diagram to illustrate hypothesis for snow devil formation.

mountainous areas should be warned of possible severe turbulence. This can apply to all seasons of the year. If the snow is crusted, or if no dust is available, the vortices may be invisible and therefore more dangerous.

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NOTES FROM COUNCIL

The following were accepted as members by Council:

January 27, 1972

Member	Paul Erik Carlson	
Student Member	Jerry Tadeusz Broszkowski	Robert Gordon Humphries

February 21, 1972

Member	Patricia G. Murray Leonard E. Parent	Roddy R. Rodgers
Student Member	Yong S. Chung	Mindaugas John Kezys

From the President

The President wishes to bring to the attention of the members of the Society, that the Executive is prepared, through its established committees or through the formation of ad hoc committees, to adjudicate or examine matters of professional or scientific concern brought to its attention by a member or members.

AES Headquarters Opened

On October 29, 1971, under cloudless skies an outdoor ceremony was held in Toronto at which the new headquarters building of the Atmospheric Environment Service (formerly Canadian Meteorological Service) was officially opened in front of a large gathering of invited guests. A special platform was set up at the front of the new building at 4905 Dufferin Street where, flanked by two scarlet-coated RCMP constables, the official party and special guests assembled.

The main speaker, the Honourable Jack Davis, Minister of the Department of the Environment, was introduced by the Honourable Arthur Laing, Minister of the Department of Public Works. Mr. Davis, in his remarks, drew attention to the vastness of Canada and the excellent work carried out by the national weather service in obtaining observations and providing services across the country. In the future, increasing emphasis, he said, would be placed on measuring and monitoring the quality of the air in order to ensure the protection of the atmospheric environment.

Mr. J.R.H. Noble, the Honourable Jack Davis and the Honourable Arthur Laing.

Other highlights of the program were an official ribbon cutting and plaque unveiling by the two Ministers; the presentation of the Ceremonial Scissors to Mr. Davis by Irving Boigon representing the consulting architects; and musical numbers provided by the North York Concert Band. A presentation of two

Centennial Plaques was made by Mr. J.R.H. Noble, Assistant Deputy Minister, Atmospheric Environment Service, to Mr. Davis and to Mr. George Brown, one of the most senior employees of the AES, who joined the Service in 1930. Mr. Brown accepted the plaque on behalf of all former and present employees of the Atmospheric Environment Service. A tour of the building and a reception followed the ceremony.

The official opening and dedication of the building was one of several events held during the week of October 24, in conjunction with the opening of the building and the 100th anniversary of the "Met" Service. In addition there was a three-day international scientific symposium on October 26–28, a banquet on the evening of October 27, and an "Open House" for the general public on October 30 and 31. The latter event was an outstanding success during which an estimated 10,000 people toured the building viewing the displays and equipment which had been set up for the occasion.

Alberta Centre

On Wednesday December 8, a meeting of the Alberta Centre was held in Edmonton at the University of Alberta. The speaker was Dr. Madhav L. Khandekar, and the subject, "Discrete Vortex Representation of Atmospheric Motion with Possible Applications to Tropical Cyclone Forecasting". Dr. Khandekar, who is a Research Associate at the University of Alberta (Department of Geography), described a 2-layer discrete vortex model developed by himself and Dr. Shabbar while on a National Research Council Fellowship in Toronto. The basis of the model is the motion of discrete vortices governed by a system of differential equations and allows extension of a barotropic model to a baroclinic atmosphere. The model was tested on tropical cyclone data for Barbados and the possible application to long-range forecasting was discussed. Dr. Khandekar's talk was accompanied by several slides. The time and care taken by the speaker in the preparation of his paper was much appreciated by those in attendance.

A.F.I.

Symposium – A History of Meteorological Challenges

The elegant new auditorium of the Atmospheric Environment Service (AES) was put into full use during the centennial celebrations of the Canadian Meteorological Service at Toronto (reported above). Internationally renowned scientists reviewed their own disciplines covering the whole range of meteorology within the program (except for two changes) as published in *Atmosphere* (**9**, p. 67).

The concept of the symposium was to emphasize meteorological challenges met, attacked and to a degree overcome, but in such a way that challenges for the future would be clearly outlined. Thus the accounts would show a living history rather than just a record of a series of events. Overall, each speaker in his own characteristic style tried to fulfil this objective. Even though the ideal may not have been reached in every presentation, the papers were intrinsically interesting on their own merits.

Dr. B.J. Mason in action.

Several speakers were united in pointing out that many of the challenges in meteorology resulted from the need to provide services (aviation forecasting, pollution potential forecasting) or to prevent future disasters (hurricanes, storms on the Great Lakes, etc.). Others reiterated at length the continuing need to make many more measurements and to collect more data in order to verify theoretical models and to monitor environmental quality.

An excellent summary of the symposium sessions has been published elsewhere* and the reader is referred to this article. The highlights reported below are intended as a résumé of the challenges to be met by meteorology in the future.

Dr. P.D. McTaggart-Cowan, Executive Director of the Science Council of Canada, maintained that the challenges of the Seventies are here now, and the chief of these is concern with the environment. There is a need for predictive climatology using computer models. Meteorology must fully cooperate with agencies dealing with renewable or non-renewable resources as well as biometeorology. Universities must be given more resources to help expand their efforts in environmental studies.

In his discussion about the General Circulation of the Atmosphere, Dr. J. Smagorinsky (NOAA) reminded those in attendance that computer models of the atmosphere were not new, only their operational use for practical forecasting. Even though many refinements are being made in these models to include

Bull. Amer. Meteorol. Soc., **52**, 1207–1212.

ocean-atmosphere and hydrological interactions at continental surfaces, albedo variations, etc., they still cannot explain the impact of the last 100 years of man's industrial activities. For further progress it has become imperative to be able to predict man's effect on the atmosphere.

More measurements of radiation in the atmosphere are required according to Prof. F. Möller (University of Munich): dust absorbs a large amount of the incoming radiation; cloudy skies are of special interest since they are so complex; the radiation balance of the atmosphere must be studied in detail.

A five-star performance was given by Dr. B.J. Mason, Director-General of the British Meteorological Office. He reviewed thoroughly the entire field of the Physics of Cloud and Precipitation. To advance this field of study even more, it is essential that two independent research groups should be brought together: scientists engaged in microphysical laboratory studies and meteorologists involved with the dynamics, sizes and shapes of clouds. He also noted that controversial theories and techniques have helped to stimulate scientific thinking (e.g., meteoritic dust theory and weather modification).

According to Dr. R.J. Murgatroyd (British Meteorological Office), Upper Atmosphere Meteorology can only develop if measurements are made as high as possible. However, balloon measurements must be standardized. Satellites yield better values (than rockets) for cold and warm thicknesses. Atmospheric constituents (even minor ones) should be measured in greater detail for air pollution studies, and to investigate ozone layer destruction. Radar networks must also be expanded.

Professor B.J. Bolin (University of Stockholm) discussed Atmospheric Chemistry and Environmental Pollution. At present the turbulent diffusion of pollution is not considered to be a major problem. Meteorologists must become involved with biometeorology and chemistry to learn how man affects the cycles of natural atmospheric constituents. The carbon cycle must be studied in detail (CO_2 increases 4%/annum from industrial activity). Residence time of SO_2 must be determined since it can move 1500 miles in 2½ days and cross international boundaries. N_2 cycle is not well known. Meteorological research is essential in the study of air pollution which is also a problem in other areas of scientific research: because meteorologists have experience with computer modelling; atmospheric transport is a crucial link; and some constituents result from meteorological processes.

Dr. R.W. Stewart (Canadian Water Management Service, Vancouver) categorically stated that there was only one challenge in the field of the Atmospheric Boundary Layer – to parameterize turbulence. Even though turbulence theory has developed from the Reynolds stresses through Lagrangian processes and correlations and Richardson Numbers to modern similarity theory, there was a real need to direct theory and observation to parameterize models correctly (especially with the help of computers). The results will be used to provide service to scientists who must solve air pollution problems.

Professor V. Suomi (University of Wisconsin) gave a graphic example of how technological advances in other fields helps meteorology. The GHOST system, which employs better balloons to allow practical soundings of the stratosphere to be carried out, got Dr. J.G. Charney interested in GARP and as a result theoretically-oriented scientists were brought into mutual cooperation. The age of the satellite is revolutionizing the whole system of data acquisition.

Even natural disasters have helped to foster development in Dynamic Weather Prediction according to Dr. G.P. Cressman, Director, National Weather Service (NOAA). Storms in 1950 and 1953 were missed by forecasters but caught by early computer models. As more physics has been input into the forecast models the predictions have advanced significantly. By 1980 the practical limit of predictability should be reached; however, a short-range forecast of 6 hours will require a resolution of 25 km and a computer power 200 times that of current CDC machines. He gave an encouraging note to forecasters since he could envision that they would still be needed over the next 100 years (at least) to weigh the ensemble of forecast products for short-range forecasts.

Dr. J. Clodman (AES, Toronto) listed a whole host of mesoscale problems that need to be attacked to solve practical environmental problems, including: land/sea breeze, lake effect storms, mountain valley winds, squall lines, tornadoes and CAT. However, NWP techniques are very difficult to apply to numerical prediction of mesoscale effects except for terrain-induced phenomena where pre-existing mesoscale fields are not important. If interactions with the terrain can be understood then a lot of these phenomena can be reasonably well predicted.

In the domain of Applied Meteorology and Environmental Utilization, Dr. R.E. Munn (AES, Toronto), stressed that interfacing with the consumer is absolutely essential in the modern world. The information explosion has forced all scientists to engage in interdisciplinary dialogue which can be achieved by interdisciplinary symposia, reviews and institutes, for example. Ironically consultants must become specialists since user needs are changing rapidly with time. In biometeorology more studies of human stress must be made; urban monitoring networks must be expanded. Decision makers, managers and planners should routinely use cost/benefit analyses with the appropriate weather input parameters.

Dr. R.E. Hallgren (NOAA) spoke in place of Dr. Robert M. White on the Winds of Change. He pointed out that the human race usually meets challenges which are caused by crises of their own making. It is becoming important to organize in order to meet new challenges arising in the environment. The atmospheric sciences must be concerned with the total environment but this necessitates integration and cooperation if the goals of environmental management are to be achieved. For effective integration, service activities must be coordinated in the highest type of organization (e.g., NOAA in a new Dept. of Natural Resources). Linkages must be formed between agencies and competent interested persons. Research cannot be carried out under only one umbrella but interactions must be on a lateral basis especially since only specialists should be employed to solve particular problems.

The final impression resulting upon the sessions was that the symposium was an outstanding success. The participants after three days of active dialogue were grateful and exhilarated. The organizers of the symposium did a superb job – unfortunately this seems only to occur once in a blue moon (or at least only once each century).

Of course all that could be said was not delivered by each speaker in the allotted time. The Proceedings of the symposium are therefore awaited with increasing interest and are expected to be published during the summer of 1972.

C.E. STEVENS
1916–1971

The unexpected death of Elmer Stevens, in Moncton on December 4th, was a shock to the scientific community of Canada. Mr. Stevens was Atlantic Regional Director of the Atmospheric Environment Service (AES), Department of Environment. He had a leading role to perform in the organizing of the newly formed Department in the Atlantic Region and his loss is most premature and untimely.

He was born in Moncton, received his early schooling there, and attended Acadia University and the University of Toronto. He joined the Meteorological Service in September 1939, serving on the staff of the newly opened Halifax District Public Weather Office which was under the direction of Mr. J.R.H. Noble, the present Assistant Deputy Minister, AES. During the war he served at several Air Force stations across Canada, including Trenton, Prince Albert and Summerside, providing instruction and forecast service to many Commonwealth pilots-in-training under the Joint Air Training Plan.

Following the war, he joined the District Aviation Forecast Office at Moncton Airport and then proceeded to the Goose Bay Main Meteorological Office in 1947 for his tour in isolation. He was appointed Officer-in-Charge there in 1951 and directed a staff of Canadian and American Meteorologists in the provision of forecast services to the military forces of Canada, the United States and Great Britain, as well as to a growing volume of civil oceanic traffic, and the public and marine community of Labrador.

He was promoted to Superintendent of Operational Requirements, Forecast Division, in Meteorological Headquarters in 1958 but before taking up his duties there, served for a year in an advisory and liaison capacity to the Assistant Deputy Minister, Air, Department of Transport in Ottawa.

Upon continuing at Meteorological Headquarters in Toronto in 1959 he performed his new duties with skill and understanding. He was largely responsible for the development of a career plan for Meteorological Technicians in the aviation briefing field throughout Canada and this proved most successful. Among his duties was the deployment of professional forecast staff throughout Canada to isolated and non-isolated offices. To satisfy both the offices and the individuals concerned demanded rare tact and judgment, both of which he exhibited to a high degree.

His promotion to Regional Meteorologist of the Atlantic Region followed in

1963. All forecast offices, weather observing programs, research and operational services pertaining to meteorology in that Region came under his jurisdiction. He was advanced to Regional Director, AES, Atlantic earlier in 1971 with the transfer of the Service from the Ministry of Transport to the Department of Environment.

Mr. Stevens was selected for attendance at the National Defence College course for senior military and civil officials held in Kingston Ontario in 1966–67. Throughout his career he participated in many management seminars and courses, and scientific gatherings sponsored by both Canadian and United States organizations.

He was a Fellow of the Royal Meteorological Society, a member of the Canadian Meteorological Society, and of the American Meteorological Society. He had been a president of the local unit of the Professional Institute of the Public Service for some years before the advent of collective bargaining, and was an executive member of the Moncton Branch of the Federal Institute of Management.

When he departed Goose Bay, the U.S.A.F. Detachment Base Commander, Colonel Beck, presented him, in a military ceremony, with a plaque in recognition of meritorious service to the U.S Armed Forces. His other honors included the Centennial Medal of Canada and letters of citation from ranking government officials of Canada. He was respected throughout Canada for his ability, his industry and his pride in the work which his staffs and himself accomplished.

While he enjoyed gardening, curling, and bridge, he took little time off from his work to take part in outside activities. He was a member of the First United Baptist Church of Moncton, and a most capable chairman of its Finance Committee.

He was devoted to his wife, Doris, and most proud of his three daughters, Lynne (Mrs. John Fudge) now in Montreal, a graduate of Acadia University and the University of New Brunswick; Laurie, a Registered Nurse presently furthering her education at the University of New Brunswick; and Lee, who is presently pursuing her studies at Acadia University.

Those of us who knew Mr. Stevens will identify with his family and other friends in our sorrow over his passing. While his career progress in the Meteorological Service was rapid it is certain that he would have had much more to contribute and would have risen to higher positions in the new organization.

He was a friendly, comfortable person whose empathy with others was readily established. His dedication to the Service will always be remembered for he served with distinction, driving himself with a will toward the high standards he set for himself and his organization. He expected similar loyalty to the Service from his staff.

Elmer's work is his memorial. His loss to the Public Service of Canada is a most untimely one. His family, his colleagues, and his friends can view with pride his accomplishments and this is the measure of consolation which remains to them.

C.H.S.
Moncton, N.B.

INFORMATION FOR AUTHORS

Articles may be contributed either in the English or French language. Authors may be members or non-members of the Canadian Meteorological Society. Manuscripts for *Atmosphere* should be sent to the Editor, *Atmosphere*, P.O. Box 41, Willowdale, Ontario. After papers have been accepted for publication, authors will receive galley proofs along with reprint order forms.

Manuscripts for *Atmosphere* should be submitted in duplicate, typewritten with double-spacing and wide margins, each page numbered consecutively. Headings and sub-headings should be clearly designated and distinguished. Each article should have a concise, relevant and substantial abstract.

Tables should be prepared on separate sheets, each headed with a concise explanatory title and number.

Figures should be provided in the form of two copies of an original which should be retained by the author for later revision if required after review. A list of legends for figures should be typed separately on one or more sheets. Authors should bear in mind that figures must be reduced for reproduction, to be printed alone or with other figures. Labelling should be made in a generous size so that characters after reduction are easy to read. Line drawings should be drafted with India ink at least twice the final size on white paper or tracing cloth, and adequately identified. Photographs (halftones) should be glossy prints at least twice the final size.

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

Footnotes to the text should be avoided.

Literature citations should be indicated in the text by author and date. The list of references should be arranged alphabetically by author, and chronologically for each author, if necessary. Forms of abbreviation may be obtained by studying past issues of *Atmosphere*.

Italics should be indicated by a single underline.

The Canadian Meteorological Society
La Société Météorologique du Canada

The Canadian Meteorological Society came into being on January 1, 1967, replacing the Canadian Branch of the Royal Meteorological Society, which had been established in 1940. The Society exists for the advancement of Meteorology, and membership is open to persons and organizations having an interest in Meteorology. There are local centres of the Society in several of the larger cities of Canada where papers are read and the discussions held on subjects of meteorological interest. *Atmosphere* is the official publication of the Society and is distributed free to all members. Since its founding, the Society has continued the custom begun by the Canadian Branch of the RMS of holding an annual congress each spring, which serves as a National Meteorological Congress.

Correspondence regarding Society affairs should be directed to the Corresponding Secretary, Canadian Meteorological Society, P.O. Box 41, Willowdale, Ontario.

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