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Cross-Equatorial Error Propagation: A Numerical Simulation

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ABSTRACT

The numerical simulations of Baumhefner (1971, 1972) and Miyakoda and Umscheid (1973) have shown that a "wall" placed at or near the equator has a serious effect on Northern Hemisphere forecasts after 10–14 days.

In practice, however, numerical models have available some information from the Southern Hemisphere. The question is posed, "How much information from the Southern Hemisphere is necessary to yield a forecast for the Northern Hemisphere which is more accurate than that obtained by integrating over the Northern Hemisphere alone?"

A simple numerical experiment demonstrates that a global model in which only the largest scales of the Southern Hemisphere are known at initial time yields a more accurate forecast for the Northern Hemisphere than a hemispheric model.

1 Introduction

In recent years there has been considerable interest in the effects of equatorial "walls" on atmospheric numerical prediction models. This interest has been generated by the fact that forecast models, as opposed to general circulation models, have generally been run over a limited spatial domain with boundaries at or near the equator. For Northern Hemisphere forecasting, at least, the use of a restricted domain has been largely necessitated by the lack of data in the Southern Hemisphere.

The imposition of an artificial boundary at or near the equator has two effects. Small distortions in the solution near the boundary propagate away from the boundary, growing in amplitude, until the solution in the interior of the domain is seriously affected. In experiments performed with a general circulation model, Baumhefner (1971, 1972) concluded that Northern Hemisphere mid-latitude prediction was not seriously affected until 12–14 days by a wall placed at or South of the Equator. Miyakoda and Umscheid (1973) using a different general circulation model concluded that the errors generated by a wall at the equator would be appreciable at 8 days and serious at 12 days. This compares with the ultimate limit of predictability of about 3 weeks (Smagorinsky 1969). An equatorial boundary, however, also prevents the large errors, which are present at initial time in the Southern Hemisphere, from propagating into the data-rich Northern Hemisphere. If we possessed absolutely no information about the Southern Hemisphere then the imposition of a wall at the equator would probably be the logical course to follow. However, in the Southern Hemisphere, we do possess, at the very least, climatological information and we can expect to get more and more satellite information in the future. The question might be asked, "How much information from the Southern Hemisphere is necessary to yield a forecast for the Northern Hemisphere which is more accurate than that obtained by integrating over the Northern Hemisphere alone?"

To attempt to shed some light on this question we have performed the following experiment. Firstly, a control run was established by running a high resolution model from real global data for 12 days. Next the model was run over the Northern Hemisphere alone by the imposition of a "wall" at the equator. To simulate the propagation of error from the Southern Hemisphere we have created several global initial fields which are virtually identical to the control in the Northern Hemisphere but have varying degrees of error in the Southern Hemisphere. The global model was then run from those global fields and the effect on the Northern Hemisphere was compared with the global control run and the equatorial "wall" run. The creation of Southern Hemisphere data which contains error is clearly not an objective process and the technique and rationale will be explained in some detail in the next section.

It should be emphasized here that the present experiments are sensitivity experiments; there is no comparison with the real atmosphere. The skill of even the best current (1974) numerical weather prediction model is minimal beyond 4 days. Since the equatorial "wall" effect does not seem to be important for forecasts shorter than one week, the results of this experiment will only be significant in the future when other sources of forecast error have been considerably reduced.

2 Model Description

In one very important aspect this experiment is less realistic than those of Baumhefner (1971, 1972) or Miyakoda and Umscheid (1973). We have used for the experiment a high-resolution, global, free-surface, primitive-equations model. Baumhefner (1972) concluded that the principal effect of placing a wall at the equator was to force the upward branch of the Hadley cell to move North. The position of the downward branch remained largely unchanged and boundary error propagated rather slowly into Northern mid-latitudes. Simulation of the Hadley cell requires a three-dimensional model with forcing terms. The present experiment will not simulate this phenomenon and we would expect the absolute error growth rates to differ from both the atmosphere and previous experiments. However, since our aim is to establish relative error growth rates between different model configurations or initial states the simplicity of our model may not be such a serious drawback.

The particular model used is the spectral model of Bourke (1972). We have used very high resolution ($J = 40$ in Bourke's notation). The model was run with long-wave stabilization by using a mean height for the free surface of 1.5 km.

TABLE 1. Global RMS height difference between two runs, one with raw initial data and one with dynamically balanced initial data.

Time (days)	0	2	4	6	8	10	12
RMS Height Difference (meters)	21.2	14.1	13.0	15.1	14.8	17.6	20.1

The initial conditions for previous experiments were the observed mass fields and geostrophically derived wind fields (Baumhefner, 1971, 1972) or simulated mass and wind fields obtained from a long integration of a general circulation model (Miyakoda and Umscheid, 1973). We have used real geopotential and real wind data for 450 mb for November 1969, objectively analyzed by the method of Robert (1974), as the input to our model. The analyses from Robert's scheme are in the form of Spherical Harmonic coefficients of vorticity, divergence and geopotential analysed to a resolution of $J = 25$.

This method, however, does not produce perfectly balanced winds and geopotentials and there is considerable high-frequency gravity-wave activity during the subsequent integration of the model. Consequently, initial fields were dynamically balanced by running the model backwards and forwards once for 12 hours with a heavy time-filter on the divergence and geopotential fields. After obtaining the new initial state the time-filter was turned off and the model was integrated with no dissipation of any kind.

The dynamic balancing of the initial state removed the high frequency components of the numerical solutions as could be verified by examination of the time evolution of grid-point values of the solution. At the same time, the Rossby wave part of the solution was not affected as can be seen in Table 1. In this Table are plotted the global RMS height differences between two global time integrations performed with raw initial data and with dynamically-balanced initial data out to 12 days.

The difference growth-rates are extremely small, much less than given by the results of predictability experiments.

The initial dynamically-balanced geopotential field is shown in Fig. 1. The high resolution global control run is a 12-day integration from this initial state.

3 The Equator "wall" Run

The simulation of a "wall" at the equator is easily performed with this model by making the initial geopotential and divergence fields symmetric with respect to the equator and the vorticity field anti-symmetric. This condition implies that the meridional wind and the meridional derivatives of the zonal wind and geopotential are zero at the equator throughout the integration.

The initial state for the "wall" run is virtually the same as the initial state for the Northern Hemisphere of the global control run shown in Fig. 1. As the

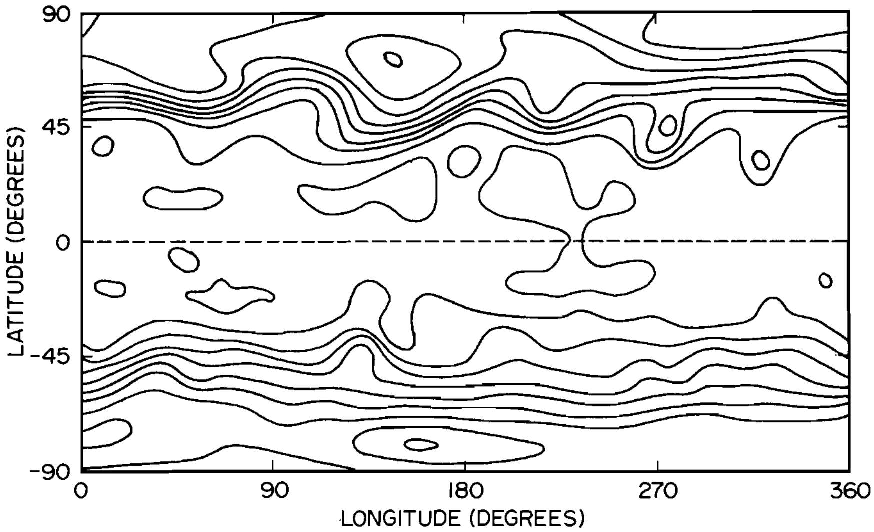

Fig. 1 Initial global 450 mb height field (metres) for control run (after dynamic balancing).

hemispheric integration proceeds, however, the solution departs more and more from the global control solution. In Fig. 2a are plotted the zonally averaged RMS height differences for the Northern Hemisphere between the hemispheric and control runs. The differences at 2, 8 and 12 days are plotted and as expected the errors grow most rapidly around 50°N, near the jet stream. In Fig. 3, curve (a), is plotted the RMS height difference between 30°N and 90°N for the control and equator "wall" cases. If we assume that the level of no skill is 115 metres, then the hemispheric model still possesses some skill at 12 days. This error growth is lower than that determined by either Baumhefner (1971) or Miyakoda and Umscheid (1973) and is probably due to the use of a one-level model.

4 Error Propagation from the Southern Hemisphere

As stated previously we also attempted to simulate the effect of error propagation from the Southern Hemisphere into the Northern Hemisphere. We wished to create a Southern Hemisphere initial state which would simulate the sampling of the true Southern Hemisphere initial state by a very crude observation network. A simple way to do this was by spectral truncation of the initial Southern Hemisphere fields.

As previously mentioned wind and geopotential data were analysed in the form of Spherical Harmonic coefficients up to $J = 25$, which gives $(J + 1)^2 = 676$ real degrees of freedom per hemisphere for each field. (Note that the model was run at still higher resolution).

For the purpose of the crude observation-network simulation, the Southern Hemisphere initial wind field and geopotentials were truncated at two different resolutions, $J = 5$ and $J = 10$. In the first case, $J = 5$ there are 36 initial degrees

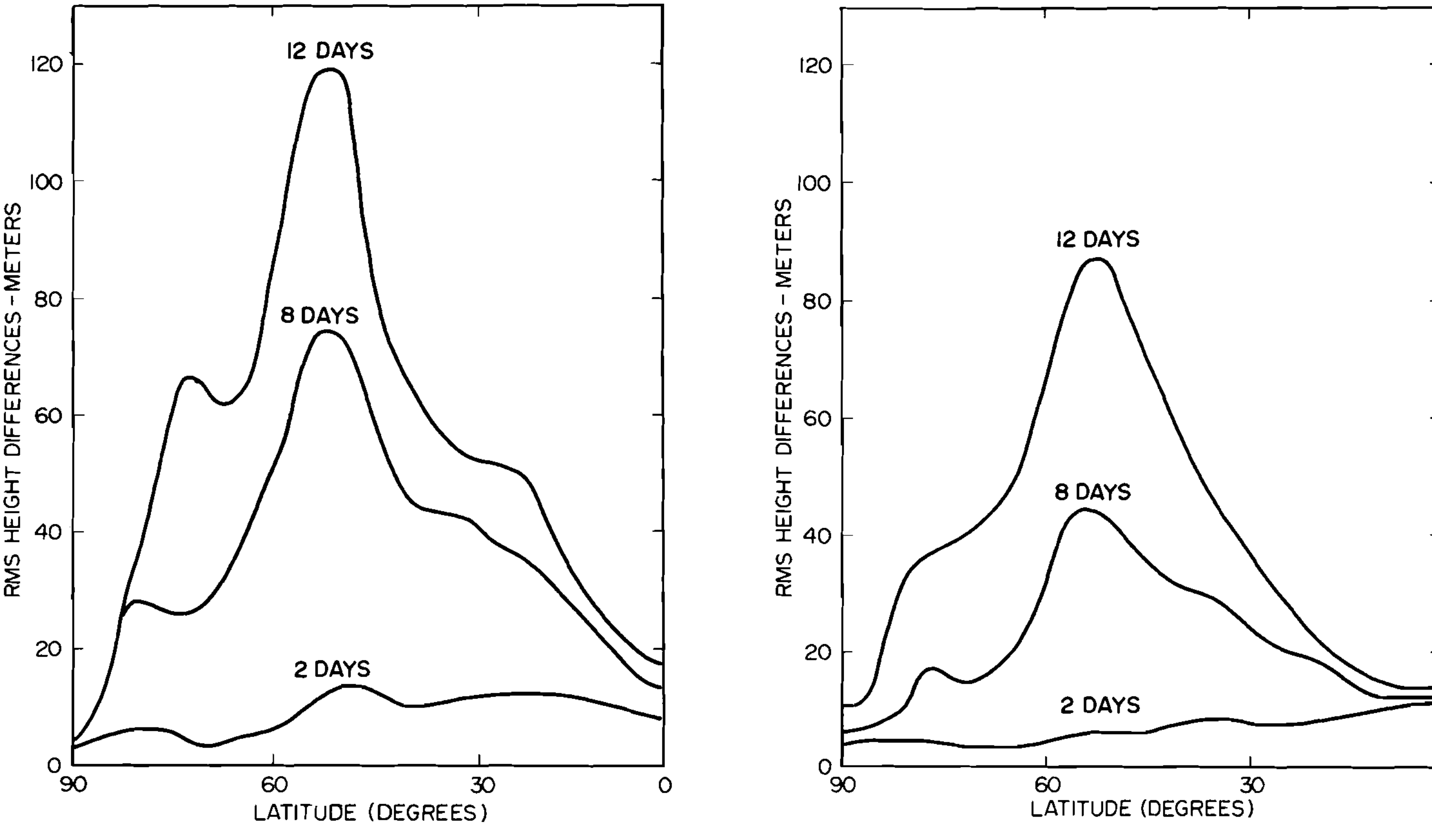

Fig. 2 Root mean square height differences between the control run and two other simulations for the Northern Hemisphere as a function of latitude and time. (Left) is the case with a wall at the equator. (Right) is the case in which the Southern Hemisphere fields are initially analysed only to $J = 5$.

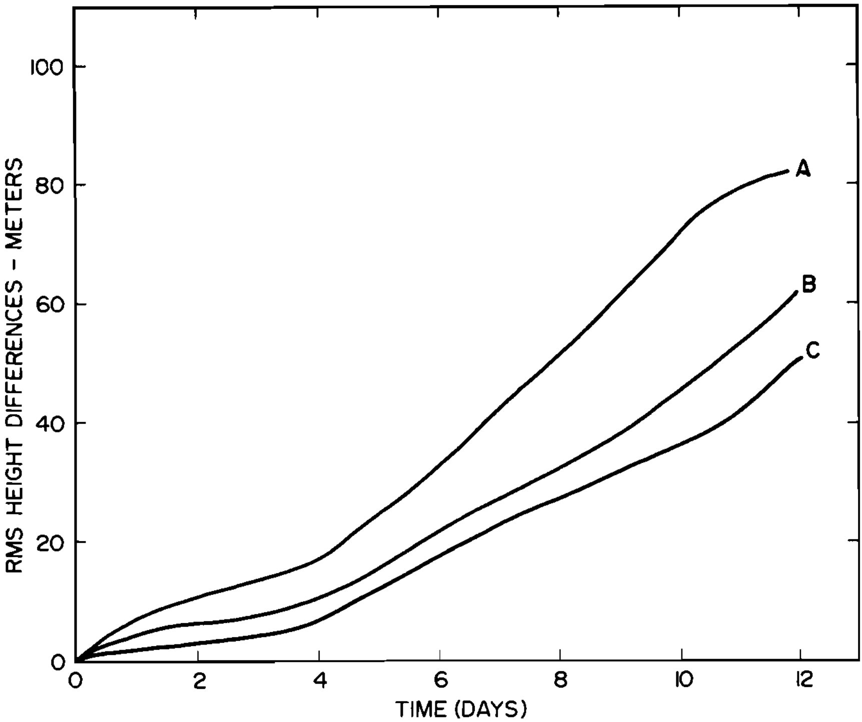

Fig. 3 Root mean square height differences between the control run and three other simulations for the Northern Hemisphere (30°N–90°N) as a function of time. (A) equator "wall", (B) Southern Hemisphere initially analysed to $J = 5$, (C) same as (B) except $J = 10$.

of freedom in the Southern Hemisphere and in the second case 121. The initial height field for the case $J = 5$ is shown in Fig. 4. Waves with an east-west or north-south wavenumber greater than 5 do not appear in the Southern Hemisphere, though the Northern Hemisphere is virtually unchanged from Fig. 1. This type of approximation to the true Southern Hemisphere initial fields could be obtained by a sparse but approximately equally-spaced observation network as might be provided by satellites. There is no short-wave information, but the long-waves are fairly well defined.

This type of simulation of a sparse observation network is not completely realistic because there is no observational error and because the truncation procedure used does not allow the shorter waves to be aliased into the long waves.

In Fig. 2b are plotted the zonally averaged RMS height differences for the Northern Hemisphere between the control run and the case $J = 5$ initially in the Southern Hemisphere. The results are plotted for 2 days, 8 days and 12 days and are similar to Fig. 2a but with lower error growth rates.

In Fig. 3, curves (b) and (c) are the RMS height differences between 30°N and 90°N for the case $J = 5$ and $J = 10$ Southern Hemisphere initial fields,

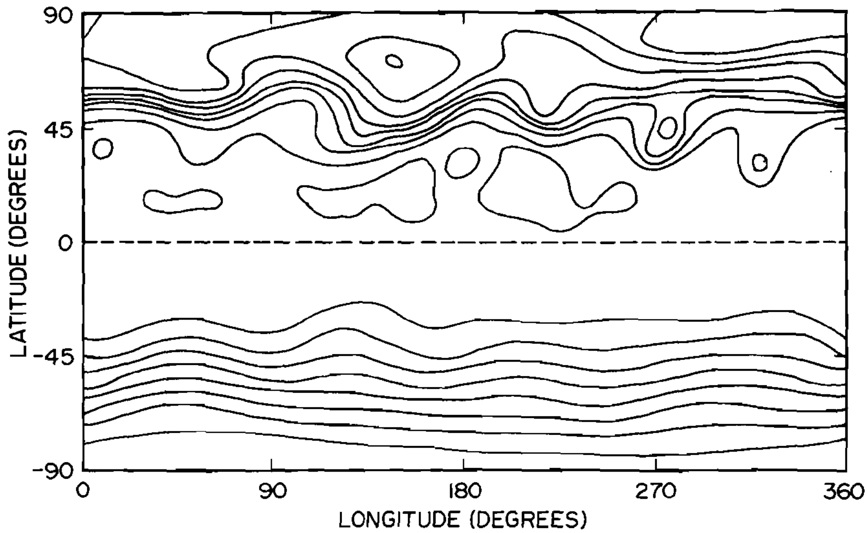

Fig. 4 Initial global 450 mb height field (metres) for case in which the Southern Hemisphere is initially analysed to $J = 5$.

respectively. In both cases the error growth rate is lower than for the equatorial "wall" case.

If "wall" error were the only source of error in numerical models, then knowledge of the largest scales in the other hemisphere would extend the range of forecasts by about 2 days ($J = 5$) and 3 days ($J = 10$). However, this gain will be unrealizable in numerical models until the other sources of error are substantially reduced.

It might be noted that the fractional reduction of "wall" error by knowledge of the largest scales of the other hemisphere is greatest for short-range forecasts and decreases with increasing forecast time. This is consistent with a propagation of error from the smallest scales to the whole spectrum.

5 Conclusions

Given the deficiencies of a barotropic model, it is unfortunately not possible to draw strong conclusions from this experiment. However, the results indicate that even a very low resolution observation network in the Southern Hemisphere can provide information which is useful for forecasting in the Northern Hemisphere and which may be crucial for longer range forecasting (beyond one week). The experiment also indicates that if errors in the Southern Hemisphere initial state are confined to the smaller scales, then these errors do not propagate rapidly across the equator. For short period forecasting (2 days) it appears that the error due to the imposition of a "wall" at the equator can be largely removed by a knowledge of the largest scales of the other hemisphere.

A more complete answer to some of the questions raised here could be provided by a full general circulation model used in a series of experiments simulating different hypothetical observation networks for the Southern Hemisphere.

Acknowledgement
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References

BAUMHEFNER, D.P., 1971: On the effects of an imposed southern boundary on numerical weather prediction in the Northern Hemisphere. *J. Atmos. Sci.*, **28**, 42–54.

———, 1972: Further experimentation with an imposed southern boundary for large-scale numerical weather prediction. *J. Atmos. Sci.*, **29**, 768–772.

BOURKE, W., 1972: An efficient, one-level, primitive-equation spectral model. *Mon. Wea. Rev.*, **100**, 683–689.

MIYAKODA, K., and UMSCHEID, L., JR., 1973: Effects of an equatorial wall on an atmospheric model. *Mon. Wea. Rev.*, **101**, 603–616.

ROBERT, A.J., 1974: GARP basic data set project (personal communication).

SMAGORINSKY, J., 1969: Problems and promises of deterministic extended range forecasting, *Bull. Am. Met. Soc.*, **50**, 286–311.

BOOK REVIEW

THE PHYSICS OF MESOSPHERIC (NOCTILUCENT) CLOUDS. Proceedings of the Conference on Mesospheric Clouds, Riga, 20–23 November, 1968. J. Ikauneiks, Editor. Israel Program for Scientific Translations, Jerusalem, 1973. $16.00 (US).

A major part of the work on noctilucent (mesospheric) clouds, at least that covering ground based observations and theoretical studies, has been carried out in the Soviet Union which fact may have encouraged the Israel Program for Scientific Translations to profer this collection of papers originally presented at the Conference on Mesospheric Clouds in Riga in 1968 in English. The decision must be regarded as unfortunate.

The study of noctilucent (mesospheric) clouds has had a chequered history, not least so in the years since the Riga meeting. In fact, since that time, rocket experiments to confirm the early Swedish-American sampling probes have reintroduced ambiguities into interpretation of the composition and distribution of the phenomenon. Consequently, several contributions to this collection strongly imply a confident state of knowledge that more recent events would suggest to be unwarranted.

The editor has expressed the hope that the book will be of interest both to professional geophysicists, astronomers and physicists; and to amateurs. Certain weaknesses of the collection suggest that it is less than ideal for either group.

The book fails as a text in that it lacks a sense of unity or consistency and is far from comprehensive in coverage. The Editorial Board might well have minimised these shortcomings by introducing the collection with a review paper similar to that of Bronshten (pp 119–127) and making a preliminary statement underlining those areas of interpretation still equivocal. Within such a context the more specialist papers might better be comprehended by the student or amateur. Regarding comprehensiveness, large omissions

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Changes in the Canadian Definitions of Break-up and Freeze-up

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[Manuscript received 24 July 1974; in revised form 13 January 1975]

ABSTRACT

Canadian definitions of break-up and freeze-up are shown to have changed substantially on several occasions since 1957. This paper demonstrates that because of these changes, great care must be exercised in the tabulation and interpretation of dates of break-up and freeze-up. In part, these changes have been occasioned by historical concerns, so that scrupulous attention to definition is necessary if the Canadian record is to be used for scientific purposes.

1 Introduction

The processes of break-up and freeze-up have a serious impact upon the rhythm of life in Canada and, within the past two decades, there have been vigorous efforts to record and publish their dates of occurrence. In 1970, when all available Canadian dates of break-up and freeze-up were transferred to punched cards, dates were available from 472 locations on water bodies throughout Canada (Allen and Cudbird, 1971). Admittedly, the majority of these yielded short records, but a substantial number spanned several decades. Up to and including the 1969–70 ice season, 54 per cent of the records were of 10 years or less duration, but 87 records of break-up or freeze-up exceeded 20 years, 18 exceeded 50 years and 2 exceeded 100 years duration. The published dates, however, are extremely variable in quality and this is a problem which should be thoroughly appreciated by all users of these records. Although a multitude of factors can influence the homogeneity of records of this nature (Singh, 1973), a major part of the problem lies in the difficulty of defining precise events in the physically complex process of freezing and breaking.

2 Freezing and Breaking

The process of freezing is initiated by the first formation of ice and is completed when the ice cover achieves its maximum extent and thickness. Likewise, breaking begins with the first movement, mechanical fracturing or melting of ice and terminates when the water surface becomes ice free or when it achieves minimum ice coverage. In Canada the mean durations of the break-up and freeze-up processes on approximately 60 rivers is 10.0 days and 18.7 days respectively (Allen, 1964). The mean maximum durations of break-up and freeze-up of these rivers are 19.5 and 36.7 days respectively. These ranges indicate a very considerable latitude for discrepancy among dates observed using different criteria. The dating procedure envisages breaking and freezing as occurring at moments in time whereas in fact they are quite lengthy intervals which, although continuous and accumulative, can be temporarily halted or reversed.

3 Definitions

Inevitably the definition of these moments in time is an arbitrary procedure and, for this reason, no universally satisfactory definitions of break-up and freeze-up have been formulated. Indeed, this problem of definition has not been resolved on a national scale within Canada, notwithstanding considerable effort on the part of the Meteorological Service in a sequence of four publications on break-up and freeze-up issued between 1957 and 1971.

Since 1950 (Canada, Meteorological Division, 1950), the Meteorological Service has been active in standardizing and improving the quality of break-up and freeze-up observations throughout Canada. Although laudable, these endeavours to improve the observational network have led to substantial and frequent changes in the criteria used to define break-up and freeze-up. Since some of these changes identify significantly different moments in the prolonged processes of freezing and breaking, many of the published dates in the Canadian record are for this reason lacking in homogeneity or comparability. Fig. 1 summarizes the essence of these changes. The following elaboration of definitions, however, is essential to convey in specific terms the nature and impact of these changes.

In the first publication (Burbidge and Lauder, 1957) break-up was "... considered to be the date when the ice moves in a river or clears from the shores of a lake." Freeze-up was defined as "... the date when ice forms and begins to grow, but may sometimes be listed as the time when skim ice or slush ice first forms. In the opposite extreme, some observers do not believe that the 'freeze-up' is official until the ice is thick enough to walk on with safety." Thus, in the 1957 publication there were three definitions of freeze-up and one of break-up. There was no tabulation of dates but average dates of freeze-up and break-up were presented on maps.

The second publication (Canada, Meteorological Branch, 1959) afforded the first official tabulation of dates of freeze-up and break-up in Canada, publishing observations from 217 stations. It recognized two dates of break-up and two dates of freeze-up. In the tabulations of dates of break-up, "... two dates are normally given. The first date refers to the first appearance of breaks or movement of ice and the second to the complete clearing of ice from the water." Likewise, in the list of dates of freeze up, "... two dates are normally given. The first refers to the first appearance of ice in the fall, and the second indicates the dates of complete ice coverage." In this publication no attempt was made to reconcile the definitions presented with those published in 1957, but the relationships between the two are illustrated in Fig. 1.

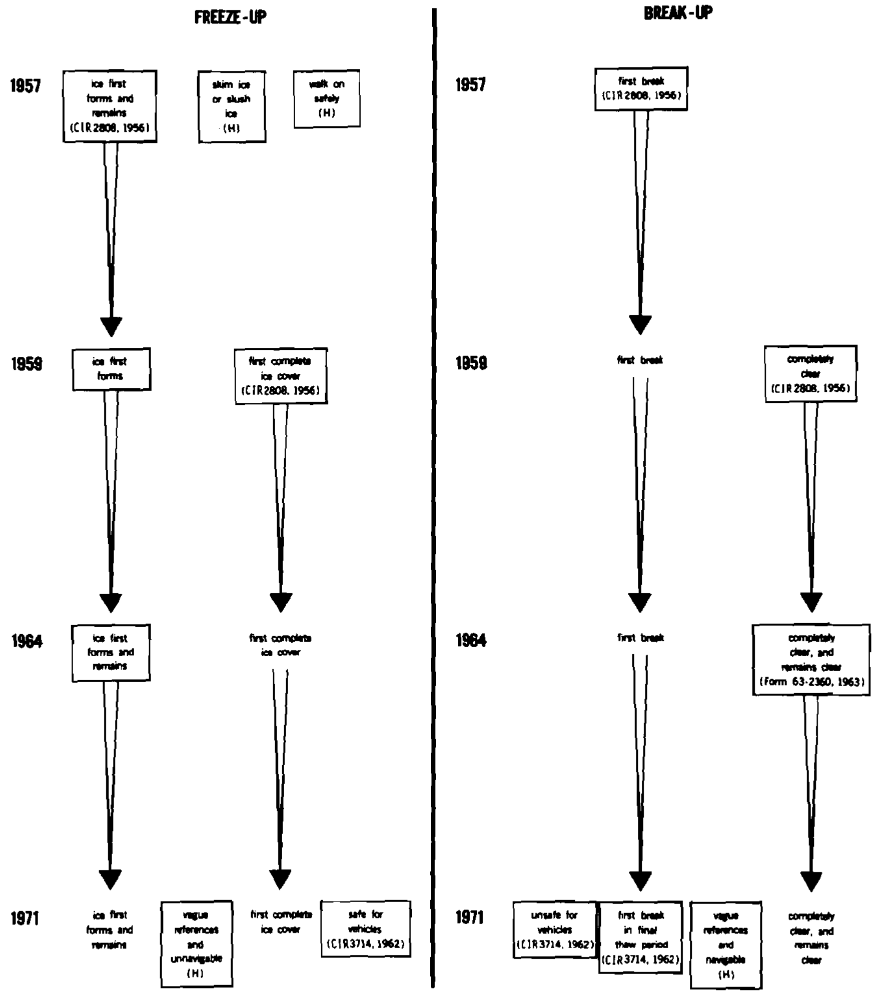

Fig. 1 Definitions of break-up and freeze-up in publications of the Meteorological Service. Arrows link definitions which are similar in class, although not necessarily identical in all their characteristics. New or changed definitions are enclosed in rectangles. When these changes relate to an earlier instruction to observers, the reference to the circular containing that instruction is in parenthesis. H indicates those new or changed definitions which apparently accommodate early, unstandardized observational criteria.

In the third publication (Allen, 1964), which contained both tables and maps, and presented dates from 328 water bodies, the definitions of freeze-up and break-up presented in 1959 were elaborated. Break-up was defined as:

"... commencing when the ice in a river or lake begins to move, break, or deteriorate; and ending when the water is completely free of all ice. The first date (1) given in the table, therefore, marks the beginning of the process.

In the case of rivers, it is usually evidenced by a definite breaking or movement of the ice brought about by weakening of the ice due to initial melting, currents, and a rise in water level due to runoff. ... The second date (2) under 'Break-Up' is the date on which the body of water is first observed to be entirely clear of ice and remains clear thereafter."

The 1964 definition of break-up (1) differs from that of 1959 only insofar as deterioration, as well as breaking and movement, is used as a criterion in establishing this date. Therefore, the direct manifestations of thermal as well as mechanical processes are considered to initiate break-up. A much more significant change occurred in the definition of the second date of break-up in the 1964 publication. Where previously break-up (2) was simply the first complete clearing of ice from the water surface, in 1964 it was stipulated that break-up (2) is the date when the water first becomes clear of ice and remains clear thereafter (Fig. 1).

In the same publication freeze-up was:

"... thought of as a process extending over a period of days or weeks. It commences with the appearance of ice crystals on the water surface, and ends when the body of water is completely frozen over. ... The first date (1) given under 'Freeze-Up' is the date on which ice was first observed on the water surface, and remained thereafter. ... The second date (2) given under 'Freeze-Up' is the date of freeze-over, i.e. the date on which the water was first observed to be completely frozen over."

These definitions of freeze-up differ in only one respect from those of the 1959 publication. Freeze-up (1) is further qualified as the date when ice first develops and remains thereafter. Since this criterion of permanence is only applied to freeze-up (1), it is conceivable that in a particular year freeze-up (1) may be recorded on a later date than freeze-up (2), although this does not appear to be the intent of the classification. This inconsistency does not arise in the case of the 1964 break-up dates because the criterion of permanency is applied to break-up (2).

The final publication (Allen and Cudbird, 1971) substantially modified the definition of break-up and freeze-up, and listed new criteria by which breaking and freezing were dated and tabulated. The previous definition of freeze-up (1) was essentially unchanged and given as the date "... on which new ice first formed on the water surface and did not melt completely again until its final deterioration during break-up of the following year." The term freeze-up (1) was abandoned in favour of "first permanent ice." Likewise, freeze-up (2) was renamed "complete freeze-over," although the definition as "... the earliest date on which the water body was reported to be completely covered by ice ..." was essentially the same. Thus, the possible reversibility in the chronological occurrence of the two freeze-up dates was not eliminated in 1971.

Break-up (1) was renamed "first deterioration of ice" and was redefined as: "... the earliest date during the final thawing period of the winter season (if more than one occurred), on which there were definite indications that the ice was beginning to melt. This date marks the beginning of the break-up process, which may be manifested by a definite movement of the ice or the formation of cracks, leads or open water areas in the ice, all the result of weakening of the ice due to melting. On most lakes, where there is very little current to move the ice, initial evidence of melting may be the formation of pools of melt water on the ice surface."

This definition of the first break-up date is significantly different from that in 1964 since the event to be recorded is the first stage in the final break-up of the season. Break-up (2) was renamed "water clear of ice" and given a similar definition to that previously operative as "... the earliest date on which the water was reported to be completely free of all floating ice, and remained so until the following freeze-up."

In addition to these changes, dates relating to trafficability were also tabulated. As is shown in Fig. 1, this generated categories of dates entitled "ice safe for traffic" in the freeze-up period, and "ice-unsafe for traffic" in the break-up period. Two other categories entitled "other date regarding freeze-up" and "other date regarding break-up" were included to accommodate dates of water navigability and dates of freeze-up and break-up described in vague terms which militated against their incorporation into the main break-up and freeze-up categories defined above.

4 Discussion

A scrutiny of these changes in definition indicates that they reflect a desire to reconcile two general groups of influences which can be characterized as historical and scientific respectively.

Prior to the 1950's there were no official efforts to standardize observations of break-up and freeze-up and these operations were conducted by a miscellany of private and public organizations. Consequently, a wide variety of definitions of break-up and freeze-up were operative at many of the early observation sites. It is clear that if the 1959 publication of dates had been restricted to a tabulation of dates which conformed to particular definitions, many of the interesting old records would have been ignored. For example, in the first tabulation of dates (Canada, Meteorological Branch, 1959) only 34 per cent of 217 stations observed break-up, and only 52 per cent of 195 stations observed freeze-up, strictly according to the official definitions in this publication. The earliest published definitions (Fig. 1) appear to have been strongly influenced by historical considerations of this nature. Subsequent changes of definitions reflect a desire to adapt these to scientific needs.

Purely scientific considerations appear to account for the following general changes in observational criteria in the period 1950–71: (1) dates should mainly refer to the final thaw period, and to the final freeze period; (2) dates should refer to the beginnings and ends of these periods, and (3) there should be observation of dates when ice commences and ceases to be trafficable.

Between 1957 and 1971 the published definitions were modified in a piecemeal manner to accommodate these criteria.

The modifications were generally preceded by earlier changes in instructions to observers contained in official circulars. In Fig. 1 changed or new definitions are enclosed in rectangles and, when these changes can be related to an earlier circular, this is identified in parentheses. These modifications are still in progress as witnessed by the fact that the current forms for reporting dates of break-up (Canada, Atmospheric Environment Service, 1972) and freeze-up (Canada, Atmospheric Environment Service, 1973) accommodate information on the trafficability of ice with respect to specified weights of vehicle. This innovation, which first appeared in 1969, has not yet been adopted as a new definition in the published dates.

References

ALLEN, W.T.R., 1964: Break-up and freeze-up dates in Canada. Canada, Dept. of Trans., Met. Br., CIR-4116, ICE-17.

ALLEN, W.T.R. and B.S.V. CUDBIRD, 1971: Freeze-up and break-up dates of water bodies in Canada. Can. Met. Serv., CLI-1–71.

BURBIDGE, F.E. and J.R. LAUDER, 1957: A preliminary investigation into break-up and freeze-up conditions in Canada. Canada, Dept. of Trans., Met. Br., CIR-2939, TEC-252.

CANADA, ATMOSPHERIC ENVIRONMENT SERVICE, 1972: Report on break-up of water bodies. Dept. of the Environment, Atm. Env. Ser., AE0063–2360 (REV 72).

CANADA, ATMOSPHERIC ENVIRONMENT SERVICE, 1973: Report on freeze-up of water bodies. Dept. of the Environment, Atm. Env. Ser., AE0063–2361 (REV 73).

CANADA, METEOROLOGICAL BRANCH, 1959: Break-up and freeze-up dates of rivers and lakes in Canada. Dept. of Trans., Met. Br., CIR-3156, ICE-2.

CANADA, METEOROLOGICAL BRANCH, 1962: Reporting of break-up and freeze-up dates. Dept. of Trans., Met. Br., CIR-3714, OBS-312.

CANADA, METEOROLOGICAL BRANCH, 1963: Report on break-up of rivers, lakes, bays, etc. in Canada. Dept. of Trans., Met. Br., 63–2360.

CANADA, METEOROLOGICAL DIVISION, 1950: Dates of freeze-up and break-up. Dept. of Trans., Met. Br., CIR-1737, OBS-105.

CANADA, METEOROLOGICAL DIVISION, 1956: Reporting of dates of break-up and freeze-up or rivers and lakes. Dept. of Trans., Met. Div., CIR-2808, OBS-255.

SINGH, B., 1973: Break-up and freeze-up dates: a case study of inconsistencies in climatological data. M.A. Thesis, University of Manitoba, Winnipeg.

Low Level Wind Maxima and Temperature Inversions Over the Northern Great Plains

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[Manuscript received 19 August 1974; in revised form 23 January 1975]

ABSTRACT

Discriminant analysis is employed with kite sounding data from Drexel, Nebraska in an attempt to clarify the interaction between the wind shear and temperature inversions in the planetary boundary layer. The mean height of the inversion layer and a measure of the vertical wind shear either above or below the wind maximum combine in a statistically significant function to discriminate between cases when the level of the wind maximum is coincident either with the top or with the base of the inversion near sunrise.

1 Introduction

Nocturnal temperature inversions play a prominent role in the development of the Great Plains low-level jet. Indeed, the widely-accepted explanation for the vertical profile of the horizontal wind (Blackadar, 1957) not only requires the prior formation of an inversion but further specifies that the wind maximum will lie immediately above the inversion top. In support of his thesis, Blackadar draws upon low-level wind and temperature data taken at Drexel, Nebraska between 1916 and 1918. The influence exerted by his interpretation of the Drexel observations suggests that a reexamination of the data is warranted, possibly yielding even more interesting relationships.

2 Data Source

From the latter part of 1915 through 1918 the atmosphere above Drexel, Nebraska was observed through the use of kites. Nominally, flights were made each day near sunrise; from beginning to end a flight reaching several thousand meters altitude would last three or four hours. For various reasons this was not always achieved. In some instances later flights were substituted; on other occasions one flight followed on the heels of another for a period of 36 hours or so. As a result the observations of the lowest few thousand meters are scattered throughout the day. Temperature, pressure, horizontal wind speed and direction as well as ambient vapor pressure were recorded with the time for every 250 m and selected crucial heights. During the flight, surface conditions were recorded every 15–30 minutes. The original data are compiled in

TABLE 1. Occurrence of simultaneous low-level wind maxima and temperature inversions for Drexel, Nebraska (and, in parentheses, the percentage based on the occurrence of wind maxima)

	July	August	September	Total
1916	27 (42)	52 (70)	47 (56)	126 (57)
1917	38 (58)	34 (63)	58 (74)	129 (66)
1918	30 (45)	42 (57)	35 (53)	107 (52)
total	95 (48)	128 (63)	139 (61)	362 (58)
soundings	228	250	273	741

TABLE 2. Percentage of wind maxima with inversions, cumulative by criterion, for each of four times of day.

Criterion	midnight	6 a.m.	noon	6 p.m.
0	100	100	100	100
1	52	46	19	20
2	41	26	7	10
3	31	14	3	4

Monthly Weather Review Supplements nos. 5, 7, 8, 10–15 and summarized in no. 20.

3 Data Selection

Since nocturnal wind maxima are most common over the Great Plains during the summer (Bonner, 1968), the months July, August and September have been selected for study. Table 1 reveals that the occurrences of low-level wind maxima and temperature inversions within the same 250 m height interval are rather evenly divided between the chosen months.

The observed wind maxima were classified according to criteria (slightly modified) established by Bonner (1968):

0: wind maximum in the first 2000 m above ground
1: wind at level of maximum at least 12 m s^{-1}, decreasing by 6 m s^{-1} before the next minimum or below 3400 m
2: wind at least 16 m s^{-1}; decreasing 8 m s^{-1} etc.
3: wind at least 20 m s^{-1}; decreasing 10 m s^{-1} etc.

The individual wind maximum observations were placed into four time intervals consisting of the three hours either side of midnight, 6 a.m., noon and 6 p.m. The usual observational procedure was to make soundings at sunrise and occasionally conduct sequential launchings around the clock for 1–1½ days; consequently, most of the observations fall into the 6 a.m. time period.

Consistent with theory, the greatest relative frequency occurs around midnight, with the hours immediately following showing a strong residual intensity. Since the occurrence of criterion 1, 2, and 3 maxima in the 6 a.m. interval is similar to that at midnight, and especially in view of the much larger sample for this interval, the subsequent discussion is confined to this group.

Eliminating a few instances of multiple wind maxima and choosing the observation closest to 6 a.m. (in the event the same maximum was present on a succeeding sounding), the height of the wind maximum is found to coincide exactly with the level of the inversion top in 99 cases; further, the wind maximum coincides with the inversion base on 22 occasions. The latter phenomenon does not appear to have been mentioned previously. In the following the former phenomenon will be denoted as "+1"; the latter as "−1".

4 Application of Discriminant Analysis

In the absence of a specific physical theory underlying the occurrence of both phenomena "+1" and "−1", it is of interest to begin sorting out the factors which characterize the two; in this respect, the technique of discriminant analysis first employed by Fisher (1936) – and elaborated on by many others – is most suitable. Choosing two characteristics which may be of importance to the phenomena in somewhat different respects, a linear function Z of the observations is sought which significantly discriminates between the two phenomena "+1" and "−1":

$$Z = b_1x_1 + b_2x_2 \text{ or } Z = b_1x_1 + b_3x_3$$

where x_1, x_2 and x_3 are the observed characteristics.

Two possible forms were considered:

a x_1 = mean height of inversion layer
$= \frac{1}{2}(h_t + h_b)$ where h_t is height of inversion top
h_b is height of inversion base
$x_2 = V_m - V_s$ where V_m is wind at maximum
V_s is surface wind

b x_1 = mean height of inversion layer
x_3 = Criterion (0, 1, 2, or 3)

According to Tintner (1952), with the assumption that the x's are normally distributed within each group ("+1" and "−1") an F statistic may be formed to test the hypothesis that $R = 0$, where

$$R_2 = (mn/(m+n))\ (b_1d_1 + b_2d_2) \text{ or } (mn/(m+n))\ (b_1d_1 + b_3d_3)$$

is a kind of multiple correlation coefficient; m and n are the numbers of individuals in each group, and the d's are the differences in the means of the x's between groups. Thus, we wish to test the hypothesis that there is no ability to distinguish the two groups wtih the discriminant function obtained, using

$$F = \frac{m+n-p-1}{p}\left\{\frac{R^2}{1-R^2}\right\}$$

where p is the number of characteristics (two).

5 Results

a Group "+1" is characterized by a low mean inversion height (~240 m) and $V_m - V_s \sim 11$ m/sec; "−1" has a high mean inversion height (~540 m) and somewhat lower wind shear (~9.5 m s^{-1}). The critical F for 2 and 119 degrees of freedom at the 0.995 level is 5.5; the computed $F = 52$. Therefore the hypothesis that there is no ability of the characteristics to distinguish the two groups is rejected with a probability 0.005 of error.

Inserting the means of the characteristics, the individual discriminant functions are

$$x_1 = 688 + 2.46x_2 \qquad \text{for "+1"}$$
$$x_1 = 910 + 2.26x_2 \qquad \text{for "−1"}$$

Since the two groups are of different size, the group means cannot be used to obtain a single discriminant function; inserting the arithmetic means instead yields

$$x_1 = 759 + 2.36x_2$$

b Group "+1" again has a lower mean inversion height, but also a lower mean value of the criterion (0.86 vs. 1.14 for group "−1"). The computed $F = 70$, and thus the null hypothesis is once more rejected in favor of the alternative hypothesis; i.e., a statistically significant discriminant function has been determined. The individual functions are

$$x_1 = 658 - 26.6x_3 \qquad \text{for "+1"}$$
$$x_1 = 943 - 26.6x_3 \qquad \text{for "−1"}$$

and using the arithmetic means of the characteristics

$$x_1 = 996 - 26.6x_3$$

6 Conclusions

The coincidence of a low-level wind maximum with the top of a temperature inversion may be distinguished from coincidence with the base of the inversion by means of a linear function of the mean height of the inversion and the vertical shear of the horizontal wind either above or below the maximum.

A slight improvement of the above study might be obtained by restructuring the Criterion 0 somewhat. Also Johnson (1950) has illustrated a technique for maximizing the information from scores (such as the Criterion classification) in discriminant analysis. In fact Suzuki (1964, 1966, 1969) has apparently independently devised methods along the same lines and applied them to meteorological problems. Certainly this approach should be implemented in the second case here.

Furthermore, the relation of the wind maximum height to the inversion characteristics could be investigated more closely in several respects. By and large, the data is tabulated at 250 m intervals; as a result, the wind speed maximum may appear to occur at the base or the top of an inversion — or in between in the case of a deep inversion. Additionally, occasional soundings include data for intermediate levels. Together, these would allow for a distribution of wind maximum height between the inversion base and top, rather than a dichotomous separation; the data selected however included few maxima between the base and top.

Finally, it is perhaps of importance that the mean height of the inversion is greater for the "−1" phenomenon than for the "+1" case. However, a physical theory which not only explains the "−1" phenomenon but encompasses this observed difference is not presently available.

Acknowledgements
The encouragement from Dr. James McQuigg of the University of Missouri – Columbia is greatly appreciated.

References

BLACKADAR, A.K., 1957: Boundary layer wind maxima and their significance for the growth of nocturnal inversions. *Bull. Amer. Meteor. Soc.*, **38**, 283–290.

BLAIR, W.R., *et al.*, 1916: Free-air data at Drexel Aerological Station. *Mon. Wea. Rev. Suppl.*, nos. 5, 7.

BONNER, W.D., 1968: Climatology of the low-level jet. *Mon. Wea. Rev.*, **96**, 833–850.

FISHER, R.A., 1936: The use of multiple measurements in taxonomic problems. *Ann. Eugen.*, **7**, 179–188.

GREGG, W.R., 1922: An aerological survey of the United States. *Mon. Wea. Rev. Suppl.*, no. 20.

GREGG, W.R., *et al.*, 1916–18: Free-air data at Broken Bow, Okla., Drexel, Nebr., Ellendale, N. Dak., Groesbeck, Tex., Leesburg, Ga., and Royal Center, Ind. Aerological Stations. *Mon. Wea. Rev. Suppl.*, nos. 8, 10, 11, 12, 13, 14, 15.

JOHNSON, P.O., 1950: The quantification of qualitative data in discriminant analysis. *J. Amer. Stat. Assoc.*, **45**, 65–76.

SUZUKI, E., 1964: Categorical prediction schemes of rainfall types by discriminant analysis. *Pap. Meteor. Geophys.*, **15**, 119–160.

———, 1966: Correlation analysis containing discrete variables used in certain meteorological problems. *Ibid.*, **17**, 10–30.

———, 1969: A discrimination theory based on categorical variables and its application to meteorological problems. *J. Meteor. Soc. Japan*, Ser. II, **47**, 145–158.

TINTNER, G., 1952: *Econometrics*. Wiley (New York), 80 pp.

Plume Convection Over an Urban Area as Observed by Acoustic Echo Sounding

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ABSTRACT

An acoustic echo sounder situated in downtown Toronto has been used to detect convective plumes in the planetary boundary layer and to measure, by means of the Doppler effect, the vertical air motions associated with them. The plumes observed were the order of 390 m in horizontal extent, were detectable to a height of about 400 m, and were characterized by peak upward velocities in excess of 1 m s^{-1}. The sounder measurements are shown to be consistent with surface meteorological parameters, and suggest that free convection over an urban area of considerable surface roughness and non-uniformity is not greatly different from that over uniform land surfaces or water.

1 Introduction

The operation of the acoustic echo sounder (also known as sodar, acdar, and acoustic radar) depends on the scattering of acoustic energy from fluctuations of temperature and wind speed in the atmosphere. The nature of this scattering has been described by Tatarski (1961) and Monin (1962), and observed in the atmosphere by Kallistratova (1961) and in the laboratory by Baerg and Schwarz (1966). It is sufficient to note that the intensity of sound backscattered from clear air is dependent only on the fluctuations of air temperature in the volume insonified, and not on the fluctuations of air velocity. The sound interacts constructively only with a scale of turbulence equal to one half of the wavelength of the incident sound.

If the turbulence in the scattering volume has a mean velocity radial with respect to the antenna, the frequency of sound scattered will differ from that transmitted by an amount given to first order in $|\mathbf{v}|/c$ by

$$\Delta f = -2wf/c$$

where Δf is the difference between the transmitted frequency f and the mean received frequency $(f + \Delta f)$, w is the mean radial velocity of turbulent structure in the scattering volume, $\mathbf{v}$ is the air velocity vector and c is the speed of sound. Various second order corrections to this simple Doppler formula, resulting from wind and temperature variations with height, are discussed by Georges

TABLE 1. Operating Parameters of the Acoustic Echo Sounder

Peak Power	40 W (electrical)
Pulse Width	150 ms
Pulse Repetition Period	4 s
Carrier Frequency	2000 Hz
Antenna Area	1.45 m^2
Beam Direction	Zenithal
Receiver Bandwidth	100 Hz
Number of Periods Timed in a Frequency Measurement	100
Duration of Frequency Measurement	~ 50 ms

and Clifford (1972). However, since wind speeds encountered in the lowest 500 m of the atmosphere are generally less than 0.05 *c*, first order theory is quite adequate.

Published work by several research groups has demonstrated the value of the backscattered sound amplitude in delineating atmospheric structures, and in complementing observations made with conventional meteorological instruments (Cronenwett *et al.*, 1972; Emmanuel *et al.*, 1972; McAllister *et al.*, 1969). Some observations have been published relating Doppler-derived winds and acoustic backscattering structures (Beran *et al.*, 1971; Mahoney *et al.*, 1973), but the major effort in acoustic Doppler work has been directed towards developing an operational wind and wind shear sensing system (Beran, 1974) where little attention is paid to the structures causing the scattering. The turbulence merely acts as a tracer of atmospheric motion.

2 Equipment

The acoustic echo sounder used for these observations is described in detail by Bennett (1975), while its immediate predecessor is discussed by List *et al.* (1972). Operating parameters are variable, but those used in this work are listed in Table 1. The system is monostatic and the antenna is vertically directed, so that the received sound is scattered by temperature fluctuations alone and any Doppler shift in frequency is a result of vertical air motion. The amplitude of the received signal was recorded as an intensity-modulated trace on a facsimile recorder as a function of the height of the scattering volume and time. The gain of the preceding amplifier was adjusted so that at the height at which echo frequency was being measured, an echo with a signal-to-noise ratio of 10 just exceeded the threshold sensitivity of the recording paper.

Echo frequency was measured at a fixed delay after transmission of the acoustic tone burst using a digital frequency counter. The counter was operated in the period measurement mode to time the duration of a specified number of positive zero crossings of the input waveform. Because the input signal was strongly filtered by several bandfilters in the receiver electronics, high frequency noise did not cause significant triggering errors. However, the scattered sound received at the antenna is the superposition of a large number of randomly-phased sinusoidal components with frequencies determined by the radial motion of the associated scattering centre. The waveform is thus very similar to that of narrowband noise, having a well-defined carrier frequency and an amplitude which varies over a wide range, often falling to near the level of background noise. Because of these amplitude fluctuations, it was necessary to ensure that the frequencies being measured were representative of the signal rather than of the background noise. Accordingly, the signal-to-noise ratio was monitored while the period measurement was being made. A signal-to-noise ratio of greater than ten was determined to be necessary for an accurate period measurement. As explained above, an adjustment of the facsimile recording system enabled a simple test for adequate signal-to-noise ratio to be made.

To obtain a velocity resolution of $\pm$ 15 cm s^{-1} when operating at 2000 Hz, the frequency must be measured accurate to $\pm$ 2 Hz. Such an accuracy requires a data sample of the order of 250 ms in duration, or 500 cycles of a 2000 Hz waveform. This amount of data may be accumulated in one measurement, but it is preferable to average shorter data samples from successive pulse interrogations to obtain the required accuracy while retaining useful space resolution in the vertical. In processing the vertical velocity data discussed in this paper, a weighted average of exponential form with an *e*-folding time constant of 60 seconds was used.

The acoustic antenna of the sounder is located at a height of 58 m above ground level, on the balcony of the McLennan Physical Laboratories. It is shielded against background noise by a 3-meter high plywood enclosure lined with acoustic foam.

Wind data for the experiment came from an anemometer mounted at 70 m above ground on the rooftop of the laboratory. Temperature was measured using a thermocouple and a calibrated chart recorder. The probe extended 1 m from the north side of the laboratory, 30 m above ground.

3 Geography of the Toronto Area

The McLennan Laboratory is in downtown Toronto, about 3.5 km north of the Lake Ontario shoreline, which runs from north-east to south-west in the Toronto area. The land slopes gently towards the lake from an area of low hills about 20 km back from the shoreline. A bluff about 35 m high which runs east-west about 2.6 km north of the laboratory is cut by several ravines in the Toronto area. The area surrounding the observing site is heavily built up for at least 17 km in all directions, barring those where the lake is closer. Within the 180° sector centered about south-east and to a distance of 2 km is the business and commercial district, where there are many buildings of over 10 stories. The area for several kilometres in the opposite sector is residential, with buildings of two to three stories, and occasionally a small park or high-rise apartment. Area topography and the extent of urbanization are shown in Fig. 1.

4 Observations and Discussion

While the observations discussed below were being made (November 23, 1973), Toronto was under a ridge of high pressure which extended northwestward from a large high pressure cell centered near Bermuda. Lightly over-

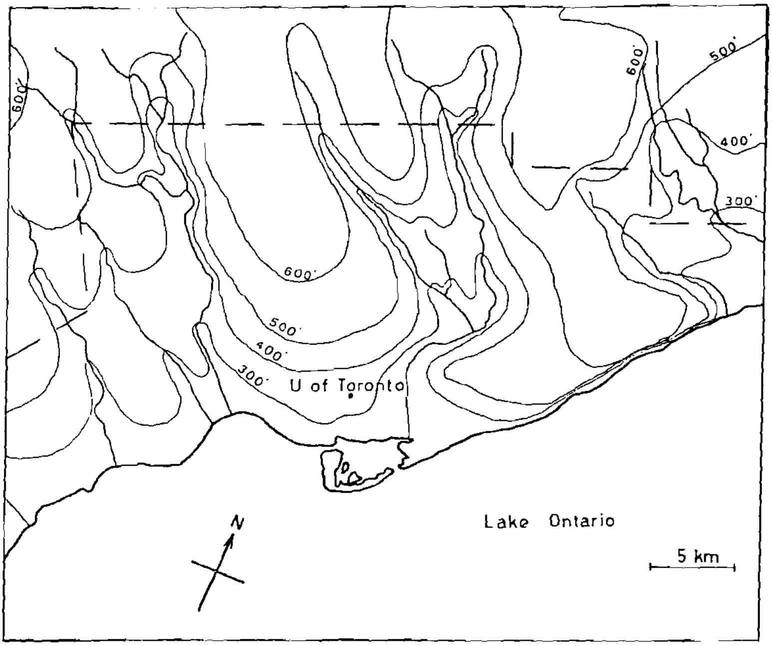

Fig. 1 Topographic map of the Toronto area showing the location of the University of Toronto antenna site and the approximate extent of the built-up area (dashed line).

cast skies present during the morning cleared for several hours in the early afternoon. Winds were from the north at about 2.5 m s^{-1}, and the temperature fluctuated about a mean value of 13°C. Barometric pressure was steady.

The facsimile record for the period of observation is shown in Fig. 2. A layer echo which may be associated tentatively with a nocturnal inversion (McAllister *et al.*, 1969), began to lift at about 1015 EST (eastern standard time). Direct evidence of weak convection penetrating to the 130 m level appeared about 30 minutes later. This conjecture is based on the familiar acoustic echo pattern associated with convective plumes which has been investigated by several authors (Beran *et al.*, 1971; Kjelaas *et al.*, 1974; McAllister *et al.*, 1969). It has been shown to be an alternation of vertically-oriented regions of strong acoustic scattering with regions of little or no scattering. Individual plumes became more distinct about 1230 EST as the sky cleared. The period of time during which vertical velocity measurements were made extended from 1505 EST to 1545 EST. The height of measurement was centered about 150 m above ground level.

Fig. 3a is an enlarged portion of the facsimile record to be compared with the near-surface air temperature in Fig. 3b, the Doppler-derived vertical velocities in Fig. 3c and the horizontal wind speed in Fig. 3d.

The data show the thermal plumes observed to be very similar to those observed over uniform flat land surfaces (McAllister *et al.*, 1969; Cronenwett *et al.*, 1972) and over water (Ottersten *et al.*, 1974). By contrast, however,

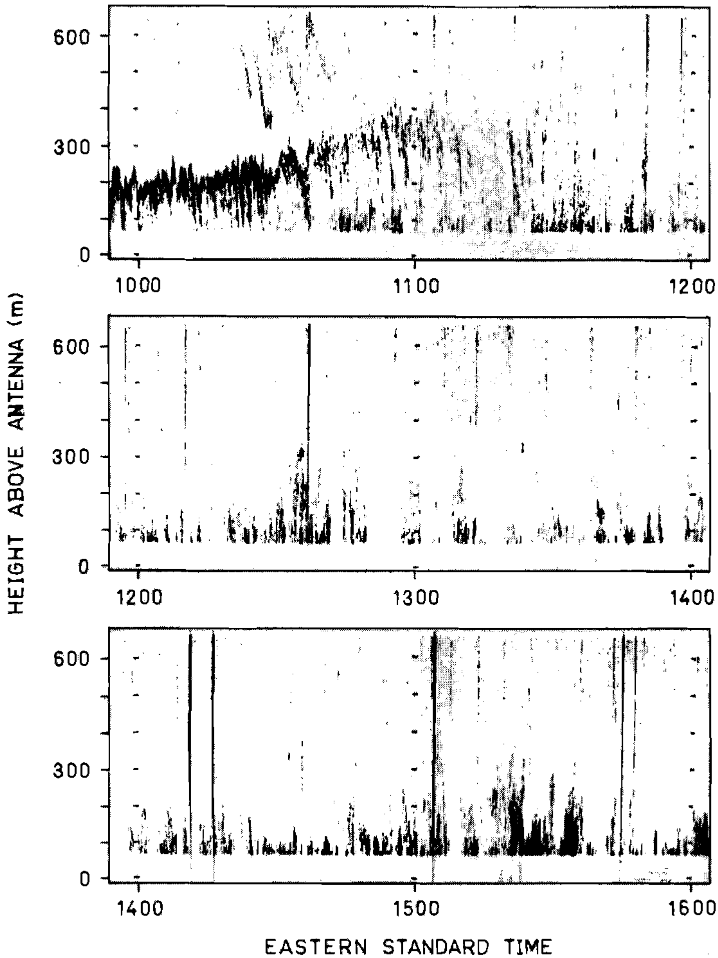

Fig. 2 Facsimile record for November 23, 1973 obtained using a vertically-directed monostatic acoustic sounder. Regions of strong thermal turbulence appear dark. The vertical scale gives the height of the scattering volume above the antenna, itself 58 m above ground level. The slanted structure evident between 1000 and 1115 EST is associated with the lifting nocturnal inversion, while the vertical structures visible throughout most of the record are due to thermal plumes. The period during which vertical velocity measurements were made is between 1505 and 1545 EST. (Dark vertical lines are caused by the noise of passing aircraft.)

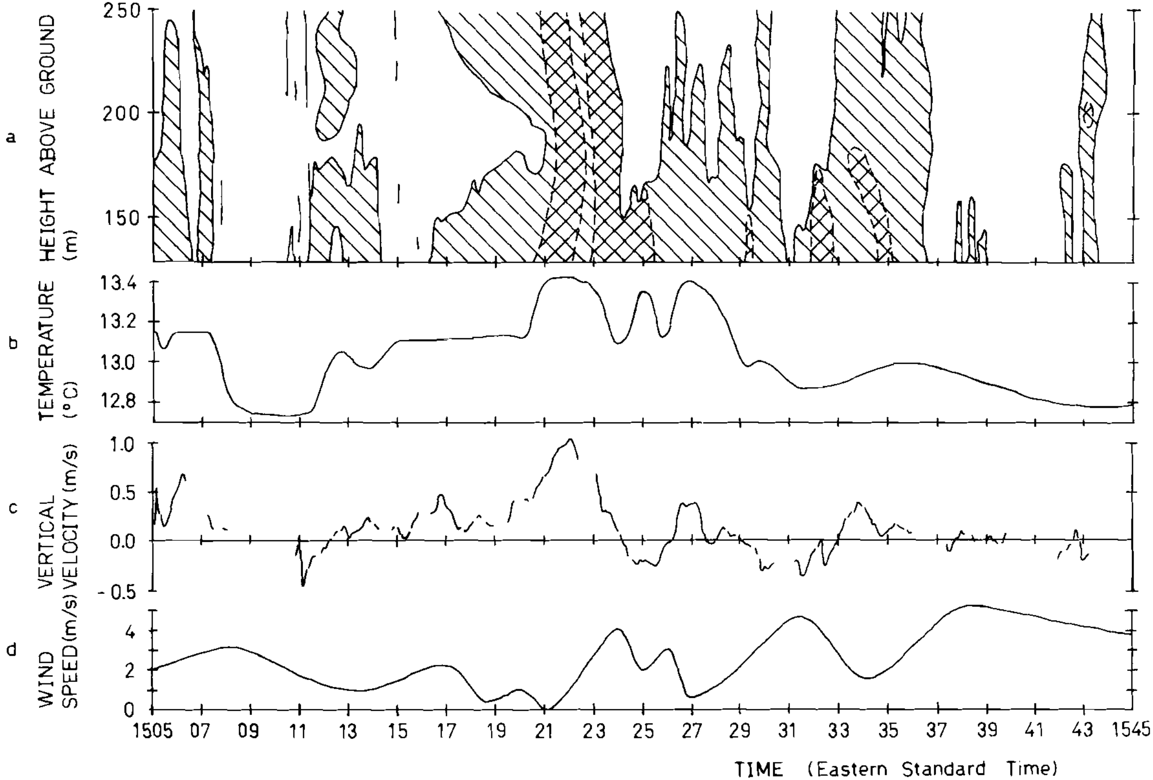

Fig. 3a. (top) Simplified version of the facsimile record in Fig. 1 for the period 1505 to 1545 EST. Plumes are indicated by the hatched areas. The vertical scale gives the height above street level. b. Air temperature measured at 30 m above street level for the period 1505 to 1545 EST. c. Vertical velocity of air at a height of 150 m above street for the period 1505 to 1545 EST, deduced from the Doppler shift experienced by backscattered sound. No velocities were plotted for those periods during which there was insufficient signal-to-noise ratio for echo frequency measurement. d. (bottom) Horizontal wind speed at a height of 70 m above street level for the period 1505 to 1545 EST.

the plumes observed on this and many other occasions at the Toronto site had formed over an extensive fetch of a non-uniform nature, with numerous local sources of heat (roads, buildings) and considerable surface roughness.

The plumes were vertical, having no consistent tendency to slope upwind or downwind. This is in agreement with the observations of Beran *et al.* (1971), who took this fact as an indication of the lack of wind shear at the levels of observation. If it is assumed that there was no wind shear on November 23, 1973, then the mean width at 150 m of the thermally turbulent regions traversing the antenna during the period of observation was 390 m, and the mean width of the thermally quiescent regions was 340 m. This can be compared to scales deduced from aircraft observations of temperature in a convective field by Warner and Telford (1967). They found the temperature pulses (plumes) to average from 200 m to 300 m across, while the quiescent regions averaged 20% larger. Although the agreement is quite good, the sample of sounder-observed plumes is too small for a detailed comparison. Moreover, estimation of the plume dimension from the facsimile record is quite difficult, as the plumes show considerable small scale structure. Blobs of thermally-turbulent air appear to become separated from the main body of the plume, and the plume itself divides into several vertically-oriented scattering regions near the upper limit of detectability.

Acoustic scattering is obtained from much greater heights in some plumes than in others. Whereas Warner and Telford (1963) noted that the temperature pulses identifying plumes were not discernible above 500 to 700 m, acoustic scattering from plumes was not detectable above 400 m in our observations. Konrad and Robison (1973) suggest that the height of the minimum intensity of temperature fluctuations is the order of 0.5 Z_{max}, where Z_{max} is the maximum height reached by plume air in overshoot. Thus the height at which the temperature pulses become indiscernible should be scaled by the mixing depth at the time of observation. As this depth was not determined for our data, direct comparison with scaled aircraft data was not possible. It should also be kept in mind that in the case of the aircraft observation, maximum plume height was determined on the basis of the plume being indistinquishable from the background; whereas in the sounder observation, maximum plume height was that at which the sound scattered from the plumes dropped below the sensitivity of the receiver.

The temperature measured at 30 m (Fig. 3b) did not show the very distinct pulse structure discussed by Warner and Telford (1967). This fact suggests that the probe was located at a height at which plumes had not totally disassociated themselves from the forced convection layer. Nonetheless, there is a definite correlation between the appearance of scattering regions at higher levels observed using the sounder and the occurrence of positive temperature fluctuations at 30 m. The magnitude of these fluctuations was from 0.3 °C to 0.6 °C relative to the base level temperature. This range is quite consistent with Warner and Telford.

Vertical velocity data are shown in Fig. 3c. The trace is not shown where there was insufficient signal for reliable frequency measurements. Computed vertical velocities tended to fluctuate quite markedly from one pulse interrogation to the next, so that longer period trends were not easily assessed without data averaging. Thus the observed time series has been smoothed using a digital average of exponential form with a time constant of 60 seconds. Warner and Telford (1967) also noted the masking of average plume vertical velocities by fluctuations of higher frequency.

In our observations there was a definite correlation between the observation of upward vertical motion and the presence of acoustic backscattering at 150 m. Thus the thermally turbulent air with a positive temperature excess was rising. This is consistent with aircraft observations and plume theory. There appears to be a tendency for the themally quiescent air between plumes to have the expected descending motion, but because of the frequent lack of acoustic backscatter from these regions, this deduction cannot be made with certainty.

The horizontal wind speed near the antenna site, and 70 m above ground is shown in Fig. 3d. This data has been smoothed to be comparable with the vertical velocity data. The wind tends to reach a maximum after the passage of an updraft over the antenna, and to fall to a minimum just before. This phase relationship is to be expected, for the updraft must be fed by a horizontal convergence near ground level. This is discussed by Coulman (1970). Coulman noted that at 6 m above ground the maximum in wind speed after plume passage was quite noticeable, while the preceding minimum was often not present.

5 Conclusions

Plumes observed in the urban boundary layer during early winter were characterized by strong thermal turbulence relative to the surrounding air, a temperature excess of the order of 0.5°C at 30 m above ground, upward air motion of the order of 1 m s^{-1} at 150 m above ground, a horizontal extent averaging 390 m at 150 m above ground, a separation averaging 340 m and a vertical extent of greater than 400 m. The passage of a plume over the observing site was preceded by a minimum in horizontal wind speed and followed by a maximum. The fluctuation in wind speed was the order of ± 1.5 m s^{-1}.

The acoustic backscattering patterns typifying plumes in the urban boundary layer are indistinguishable from those observed over flat uniform surfaces; the plume sizes, separations and maximum heights are comparable and near-surface temperature and wind speed show the expected behaviour during plume passage overhead. This suggests that free convection is not strongly influenced by surface roughness or non-uniformity.

The sounder observations show that individual plumes possess considerable small-scale structure, both in vertical velocity and in the intensity of thermal turbulence.

The accuracy of velocity measurements made with the sounder is estimated to be ± 15 cm s^{-1}. The corresponding resolutions in height and in time are 30 m and 60 s respectively, though the time resolution can be improved if some deterioration in height resolution can be tolerated.

At present, the only demonstration of the accuracy of the Doppler determinations of air motion made in this laboratory is their consistency with concurrent measurements of related parameters, and with measurements, both remote and in situ, made by other observers (Beran *et al.*, 1971; Mahoney *et al.*, 1973; Warner and Telford, 1967). Work is now progressing towards increasing the reliability of Doppler velocity determinations. A major part of this effort is directed towards the development of instrumentation to sample and record amplitude and frequency data digitally for computer processing.

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References

BAERG, W. and W.H. SCHWARZ, 1966: Measurements of the scattering of sound from turbulence. *J. Acoust. Soc. Am.* **39**, 1125–1132.

BENNETT, R.C., 1975: Acoustic radar studies of planetary boundary layer structures associated with gravity waves, fronts and lake breezes. Ph.D. thesis, University of Toronto. 308 pp.

BERAN, D.W., C.G. LITTLE, and B.C. WILLMARTH, 1971: Acoustic Doppler measurements of vertical velocities in the atmosphere. *Nature* **230**, 160–162.

BERAN, D.W., 1974: *Remote sensing wind and wind shear system.* Report No. FAA-RD-74-3, available through National Technical Information Service, Springfield, Virginia 22151.

COULMAN, C.E., 1970: Fluctuations of horizontal wind speed near ground in convective conditions. *Quart. J. Roy. Meteor. Soc.* **96**, 529–534.

CRONENWETT, W.T., G.B. WALKER, and R.L. INMAN, 1972: Acoustic sounding of meteorological phenomena in the planetary boundary layer. *J. Appl. Meteor.* **5**, 1351–1358.

EMMANUEL, C.B., B.R. BEAN, L.G. MCALLISTER, and J.R. POLLARD, 1972: Observations of Helmholtz waves in the lower atmosphere with an acoustic sounder. *J. Atmos. Sci.* **29**, 886–892.

GEORGES, T.M. and S.F. CLIFFORD, 1972: Acoustic sounding in a refracting atmosphere. *J. Acoust. Soc. Am.* **52**, 1397–1405.

KALLISTRATOVA, M.A., 1961: Experimental investigation of sound wave scattering in the atmosphere. *Trudy Inst. Fiz. Atmos., Atmos. Turbulentnost, No. 4*, 203–256, USAF FTD transl. TT–63–441.

KJELAAS, A.G. and G.R. OCHS, 1974: Study of divergence in the boundary layer using optical propagation techniques. *J. Appl. Meteor.* **13**, 242–248.

KONRAD, T.G. and F.L. ROBISON, 1973: Development and characteristics of free convection in the clear air as seen by radar and aircraft. *J. Appl. Meteor.* **12**, 1284–1292.

LIST, R., R.C. BENNETT, and U.W. RENTSCH, 1972: Acoustic echo soundings in urban Toronto, *Atmosphere* **10**, 73–79.

MAHONEY, A.R., L.G. MCALLISTER, and J.R. POLLARD, 1973: The remote sensing of wind velocity in the lower troposphere using an acoustic echo sounder. *Bound. Layer Meteor.* **4**, 155–167.

MCALLISTER, L.G., J.R. POLLARD, A.R. MAHONEY, and P.J. SHAW, 1969: Acoustic

sounding – a new approach to the study of atmospheric structure. *Proc., I.E.E.E.* **57**, 579–587.
MONIN, A.S., 1962: Characteristics of the scattering of sound in a turbulent atmosphere. *Soviet Phys. – Acoust.* **7**, 370–373.
OTTERSTEN, H., M. HURTIG, G. STILKE, B. BRÜMMER, and G. PETERS, 1974: Shipborne sodar measurements during JONSWAP II. *J. Geophys. Res.* **79**, 5573–5584.
TATARSKI, V.I., 1961: *Wave propagation in a turbulent medium.* McGraw-Hill Book Co., New York (transl. by R.A. Silverman).
WARNER, J. and J.W. TELFORD, 1963: Some patterns of convection in the lower atmosphere. *J. Atmos. Sci.* **20**, 313–318.
WARNER, J. and J.W. TELFORD, 1967: Convection below cloud base. *J. Atmos. Sci.* **24**, 374–382.

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exist, there being no discussion of the related aeronomy near the mesopause, no discussion of nucleation and particle growth theories so germaine to noctilucent cloud interpretation, nor is the dynamics of the mesospheric-thermosphere interaction given token consideration as was so effectively done at the Tallinn meeting two years previously. The collection must be acknowledged to be almost exclusively comprised of papers on interpretation of ground-based observations of noctilucent clouds and related phenomena and these not of uniformly high quality.

On a purely technical level, a major reservation must be expressed about the unnecessary difficulty introduced in interpreting the figures due to the absence of suitable figure legends. The alternative method used of describing the figures directly in the text confused and irrated this reviewer.

If not then a good book for the amateur what value has it for the professional? Again little! The professional is interested in current information particularly in areas open to equivocal interpretation and, as already noted in this regard, the timing of the translation could hardly be less fortunate. The interpretation of noctilucent cloud particles as comprising an ice shell on a condensation nucleus of cosmic or volcanic dust must again be held as unresolved pending further studies not, at this time, imminent. The papers of Eerme (pp 65–79) and Willmann and Sergeevich (pp 56–64) relating to the feasibility of measuring noctilucent cloud from satellite are among the better papers in the collection but their predictions that such observations would not take place in the near future has already been confounded by the results reported on by Donahue and co-workers from horizon measurements from OGO 6 more than two years ago.

Finally one might quibble about the inadequacy of referenced material which lays very heavy emphasis on publications within the Soviet Union and fails to acknowledge the influence of similar work by colleagues in the West.

The quality of translation is good, with few editorial errors, though there are a few lapsi calami which change the sense of a phrase (e.g. p. 4 line 11: for thermosphere read troposphere; p. 16 line 4: for altitude read latitude) but these are minor indeed.

One must inevitably conclude that this book is unlikely to be referred to as a definitive work on mesospheric clouds and that it is more likely to adorn the shelf of a bookseller than that of the discriminating scientist.

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Atmosphere

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Figures in italics refer to 8th Annual Congress Issue.

Section A: Index of Contributions by Author

Section B: CMS Subject Index

Section C: General Subject Index

ERRATA

In some copies of Volume 12 Number 3, on page 114, Fig. 7 was inadvertently inverted.

INFORMATION FOR AUTHORS

Editorial policy. *Atmosphere* is a medium for the publication of the results of original research, survey articles, essays and book reviews in all fields of atmospheric science. It is published quarterly by the CMS with the aid of a grant from the Canadian Government. Articles may be in either English or French. Contributors need not be members of the CMS nor need they be Canadian; foreign contributions are welcomed. All contributions will be subject to a critical review before acceptance. Because of space limitations articles should not exceed 16 printed pages and preferably should be shorter.

Manuscripts should be submitted to: the Editor, *Atmosphere*, West Isle Office Tower, 5th Floor, 2121 Trans-Canada Highway, Dorval, Quebec H9P 1J3. Three copies should be submitted, typewritten with double spacing and wide margins. Heading and sub-headings should be clearly designated. A concise, relevant and substantial abstract is required.

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

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

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

Footnotes to the text should be avoided.

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

RENSEIGNEMENTS POUR LES AUTEURS

Politique éditoriale. *Atmosphère* est un organe de publication de résultats de recherche originale d'articles sommaires, d'essais et de critiques dans n'importe lequel domaine des sciences de l'atmosphere. Il est publié par la SMC à l'aide d'une subvention accordée par le gouvernement canadien. Les articles peuvent être en anglais ou en français. Il n'est pas nécessaire que les auteurs soient membre de la SMC; les contributions étrangères sont bien-venues. A cause des limitations d'espace les articles ne doivent pas dépasser 16 pages dans le format final. Tout article sera soumis à un critique indépendant avant d'ètre accepté.

Les manuscrits doivent être envoyés à : le Rédacteur, *Atmosphère*, West Isle Office Tower, 5e étage, 2121 route Trans-canadienne, Dorval, Québec H9P 1J3. Ils doivent être soumis en trois exemplaires dactylographiés à double interlignes avec de larges marges. Les titres et sous-titres doivent être clairement indiqués. Chaque article doit comporter un résumé qui soit concis, pertinent et substantiel.

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

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

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

Les notes de renvoie au texte doivent être évitées.

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

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

Correspondence regarding Society affairs should be directed to the Corresponding Secretary, Canadian Meteorological Society, c/o Dept. of Meteorology, McGill University, P.O. Box 6070, Montreal, P.Q. H3C 3G1

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Toute correspondance concernant les activités de la Société devrait être adressée au Secrétaire-correspondant, Société météorologique du Canada, Département de Météorologie, l'Université McGill, C.P. 6070, Montréal, P.Q. H3C 3G1

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