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Tetroon Studies of Diffusion Potential in the Airshed Surrounding the Crowsnest Pass Area

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[Manuscript received 3 March 1973; in revised form 28 May 1973]

ABSTRACT
A series of constant-level balloon flights was made in the Crowsnest Pass area under westerly wind conditions, for the purpose of investigating the diffusion properties of the surrounding airshed. The balloon trajectories showed the existence of large sustained velocities over the mountainous region. The magnitudes of the vertical motions were found to be dependent on wind direction. Under moderately strong wind speeds, they appear to have been insensitive to the vertical temperature gradients which were measured within the first 31 m of the ground.

Diffusion coefficients were calculated from the tetroon data. They were usually found to be about twice as large as the comparable data presented by Pasquill.

1 Introduction

Western Research & Development Ltd. was retained by Westcoast Transmission Co. Ltd. to investigate the diffusion potential of the airshed surrounding its Saratoga Processing Limited plant near Coleman, Alberta. The topography of the region is irregular (see Fig. 2). To the west of the plant, there is a narrow pass (Crowsnest Pass), flanked on either side by mountain ridges which rise almost 1200 m (4000 ft) above the valley floor. This pass opens to the east into a small valley which contains the Saratoga Plant. Steep ridges enclose the valley about 2½ km east of the plant; a narrow gap leads through them into the town of Coleman.

2 Method

Ordinarily, the diffusion properties of an airshed are evaluated with fixed continuous sampling stations and perhaps by surveys in instrumented helicopters. Neither approach is applicable, however, in the rugged terrain which surrounds the Saratoga Processing Plant. The mountain ridges are too steep and inaccessible to allow the use of normal stationary sampling devices; these require shelter, power and convenient access. The winds in the pass are usually very strong and would make a helicopter survey hazardous, especially near the points of interest, which, in this case, lie against the mountain slopes. Western Research & Development Ltd., therefore, chose to study the wind flow by observing the flights of constant-level balloons (tetroons).

A constant-level balloon is made of a relatively inelastic material (usually DuPont Mylar), so that its volume is essentially constant under super pressure (excess internal pressure). The helium-filled balloon seeks a density level at which air displaced by the balloon is exactly equal to the weight of the balloon plus any attachments. The balloon's height is changed from its equilibrium density level by air motion in the vertical plane, or by a change in the volume or mass of the balloon itself. If the balloon retains its mass, it can be expected to follow the trajectory of air originating at a given density level for an indefinite period of time. Ideally, the principle of super-pressure balloons implies a constant volume. In reality, however, every material (including DuPont Mylar) stretches a measurable amount under super pressure (Booker and Cooper, 1965). A certain amount of stretch, however, is desirable if the balloon is to follow the air motions: the effect of elastic stretch and shrinkage reduces the tendency of the balloon to return to its original equilibrium level.

It should be noted that tetroons will not give a perfect description of air flow. Like other measuring devices, they are hindered in their performance by inertial and frictional forces. Reynolds (1973) deduced from observations made at the White Sands Missile Range that, under wave conditions, constant-level balloons with volumes of about 1 m^3 over-estimate isopynic crests and troughs by an average of 6 per cent. Such accuracy is easily tolerable within the context of the present studies. Further questions may arise about the behaviour of tetroons under steady vertical-velocity air motions. Under these conditions, constant-volume balloons could theoretically reach an equilibrium level where the restoring force is balanced by the static drag force. The importance of this objection has never been fully evaluated.

Constant-level balloons have been used for several years to provide estimates of mean air trajectories in a variety of conditions encountered in urban areas (Druyan, 1968), in the stratosphere (Lally, 1970) and over the oceans (Angell and Pack, 1962). Because these balloons tend to follow three-dimensional air trajectories, the information supplied by tracking the divergence of several balloons released at equally spaced time intervals can also be helpful in estimating diffusion statistics (Angell *et al.*, 1971).

The authors launched tetroons in the Saratoga Plant region and followed their trajectories with the aid of double theodolites. The information derived from these flights has been used in estimating ground-level concentrations of SO_2 which might result from the plant effluent.

3 Theoretical considerations

Initially, it is necessary to calculate the elevation at which a constant-level balloon will float. This is the level at which the net upward lift of the balloon is zero. The following equations express Archimedes' principle for conditions at ground level and at the level at which the balloon will float:

$$\rho_0 V = W + L \quad (1)$$

$$\rho_1 V = W \quad (2)$$

where

V = volume of the constant-level balloon (m^3)
W = weight of the balloon, helium and attachments (kg)
L = net upward lift of the balloon (kg)
ρ_0, ρ_1 = air density (kg/m^3). The subscripts "0" and "1" refer to the density at the ground surface and at the floating level, respectively.

Subtracting Eq. (2) from Eq. (1), and making use of the ideal gas law, we have:

$$\frac{P_1}{T_1} = \frac{P_0}{T_0} - \frac{LR}{V} \quad (3)$$

where

P_0, P_1 = atmospheric pressure (mb) at the respective levels
T_0, T_1 = atmospheric temperature (°K)
R = proportionality constant for dry air (287 J/kg °K).

It was assumed for convenience that the atmosphere is characterized by a constant temperature gradient. Thus:

$$h = \frac{T_0 - T_1}{\gamma} \quad (4)$$

where

h = level above the ground at which the balloon will float (m)
γ = temperature gradient (°K/m).

It can now be shown through use of the hydrostatic assumption that:

$$T_1 = T_0 \left(\frac{P_1}{P_0}\right)^{R\gamma/g} \quad (5)$$

where g is the acceleration due to gravity (9.8 m/s^2). Equations (3) and (5) can be solved for T_1, providing P_0, T_0, L and V are known. With the value of T_1, it is then possible to solve for h in Eq. (4).

The tetroons released as part of the Saratoga experiment, made of 2-mil mylar, had free lifts at the ground equal to 5 g and volumes of 1 m^3 when inflated. Fig. 1 shows the theoretical heights to which such tetroons should rise in the absence of vertical air currents, when there is an adiabatic lapse rate, for various ground-level values of temperature and pressure. As may be seen, the maximum elevation gain of the balloon is relatively insensitive to variations in ground-level pressure and temperature. The ground-level pressure during the trials was about 882 mb and the ground-level temperature was approximately 18.0°C, so that the balloons should rise to a height of about 59 m (175 feet).

Fig. 1 was drawn under the assumption that the temperature lapse rate was adiabatic. Calculations showed the equilibrium height to be strongly dependent on the environmental lapse rate. Thus, for twice the adiabatic lapse rate, the floating level is at 90 m (300 feet), while for three times this lapse rate, it is

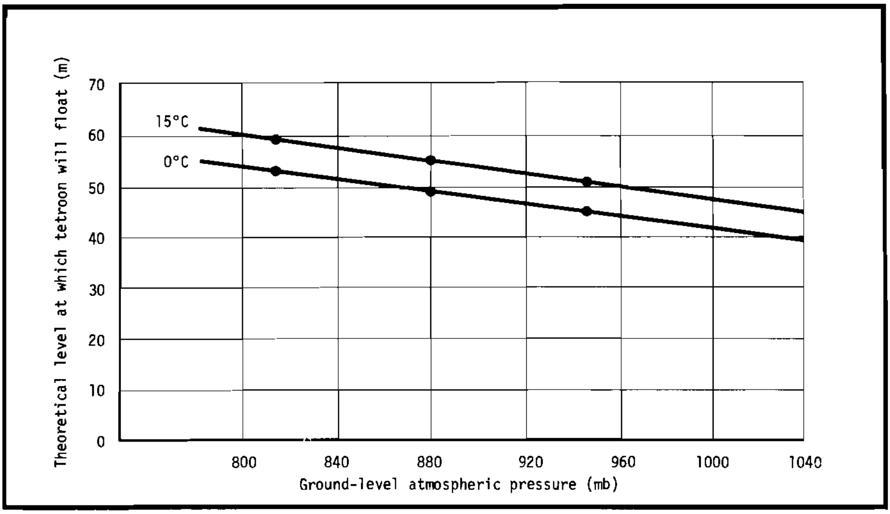

Fig. 1 Height above ground at which 1-m³ tetroons will float in relation to ground level atmospheric pressure, given an adiabatic lapse rate. Balloon lift 5 g. Values have been plotted for ground level temperatures of 0 and 15°C.

near 180 m (600 feet). It is evident that under the influence of large lapse rates, tetroon elevation gain might be considerable.

During the days on which the balloon trials were conducted, the lapse rate should have been close to adiabatic, because wind speeds on these days were quite high (11 m/s) and there was partial or full cloud cover. In the absence of strong solar heating, mechanical turbulence generated by such winds will maintain a near adiabatic lapse rate (Munn, 1966). With strong solar heating, the lapse rate near the ground may be quite large, but will quickly approach the adiabatic value within a few tens of metres above the ground (Webb, 1958; Deardorff and Willis, 1967).

4 Procedures for launching and tracking

Care was taken in determining the free lift of the tetroons. The balloons were fully inflated and then were balanced on a scale to determine their lift capacity. The weighing procedure was conducted inside an unheated van, to avoid any errors created by wind currents. After the initial lift was determined, ballast was added to the balloon in order to attain a controlled free lift of 5 g.

Air temperatures within the van were not recorded. They should, however, have been properly representative of atmospheric conditions. Ventilation was provided by frequently opening the van to the air except for the few minutes surrounding the actual weighing. Solar heating effects on the air temperature within the van should have been minimized by the van's aluminum exterior and wooden paneled interior. The cloudy and occasionally overcast skies combined with the high wind speeds which characterized the trial periods, also would have tended to reduce these solar effects.

Double theodolites, set 1,400 m apart, were used to track the tetroons. Ideally, the method should be very accurate; however, human errors can invalidate the data. Typical errors include failure of the two trackers to take simultaneous readings, or the misreading of the azimuth dial. Errors may be partially assessed by comparing the calculated heights of the tetroon above each observing station. If there are no mistakes, the two heights should be in agreement. For the individual tetroon flights described in this report, the differences between these heights seldom amounted to more than ten per cent of their absolute values.

The tetroons were released about 1½ km to the west of the Saratoga Plant, at one of the two theodolite stations. The observers (who were synchronized by radio contact) took readings every 30 s until a tetroon moved out of tracking range, was obscured by cloud, or was lost against a disorienting background.

5 Description of flights

The tetroon flights were made on both 13 and 14 of September, 1972. During these days, there was a large anti-cyclonic pressure area over southern Alberta, with an accompanying weak gradient wind. There were four trials, each of which lasted for about an hour and a quarter, and consisted of four tetroon flights. The starting and ending times of each trial, together with the average wind, temperature, and temperature-gradient data recorded during the trial period, are given in Table 1. The wind data given in this table were obtained from an aerovane located atop a 91.5-m radio tower which was situated near the plant site. The wind speeds obtained from this instrument were slightly less in magnitude than those indicated by the tetroon flights. The temperature gradient data were obtained from two aspirated temperature sensors positioned 30.5 m apart on the same radio tower. The lower of these two sensors was 4 m above the ground.

TABLE 1. Average atmospheric conditions in the Crowsnest Pass area during tetroon flights.

Trial Number	Time of Trial (MDT) Start	End	Wind Direction	Wind Speed (m/s)	Temperature (°C)	Lapse (°C/100 m)
	13 Sept. 1972					
1	1100	1230	WSW	10.7	16.5	3.00
2	1530	1640	SW	12.5	19.5	2.70
3	1820	1930	SW	11.2	18.3	0.85
	14 Sept. 1972					
4	0940	1100	W	10.7	18.3	1.65

The ground-level wind during the trials was west or southwesterly at about 11 m/s, the atmospheric temperature was about 18.0°C and the temperature lapse near the ground varied from highly superadiabatic (3°C/100 m) to near neutral (1°C/100 m). It will be demonstrated that, at the high wind velocities which characterized the trial periods, air flow is insensitive to the measured

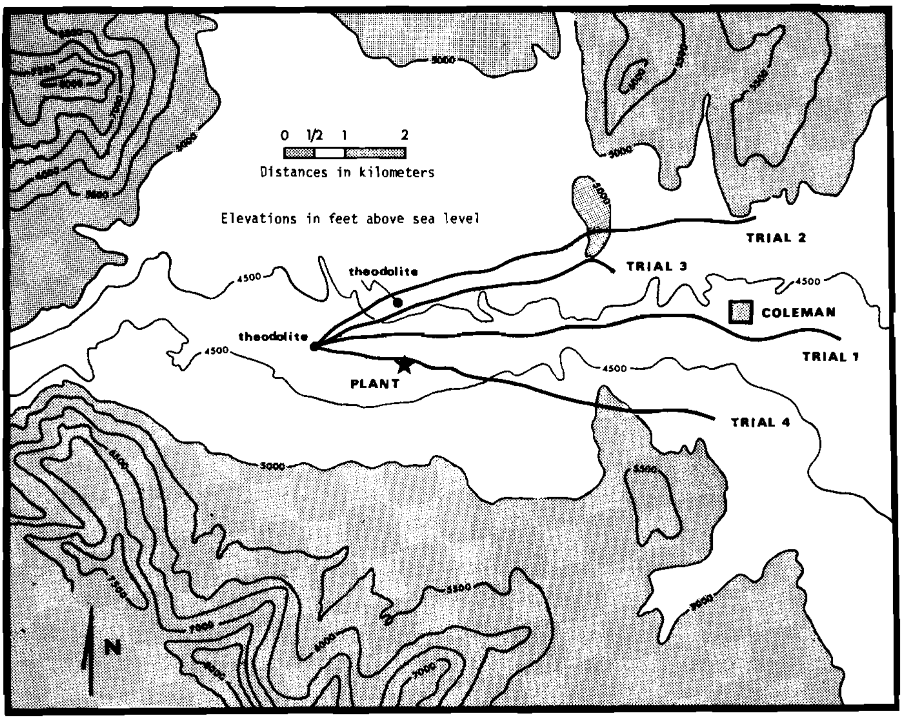

Fig. 2 Horizontal trajectories of balloons released near the Saratoga Plant. Locations of the plant, theodolite stations and the town of Coleman, are shown.

temperature gradients. This was expected in view of the discussion in Section 4, which indicates that under high wind speed conditions, the temperature lapse rate should always be nearly adiabatic, except near the ground. Fig. 2 shows the average horizontal trajectories of the four tetroons which comprised each trial run. The trajectories of Trial 1 balloons fell due east through the mountain gap which leads to Coleman. The tetroons in Trials 2 and 3 went in a northeast direction towards the ridge which flanks the northern side of this gap. The average trajectory for the balloons of Trial 4 was in a southeast direction.

There has been some controversy as to the flow of air with respect to terrain. There have been arguments presented which indicate that the air flow should be parallel to the terrain. The assumption is often employed, for example, in numerical weather forecasting (e.g., Thompson, 1961). On the other hand, calculations of ground-level concentrations of a given pollutant resulting from a point source often use a procedure which effectively assumes that air penetrates the terrain. Because of these controversies, it is of interest to consider what the actual variation of tetroon heights was with respect to terrain. The average longitudinal profiles of the tetroon flights launched for Trials 1 – 4 are displayed in Fig. 3.

The tetroons of Trial 1 travelled east through Crowsnest Pass over relatively

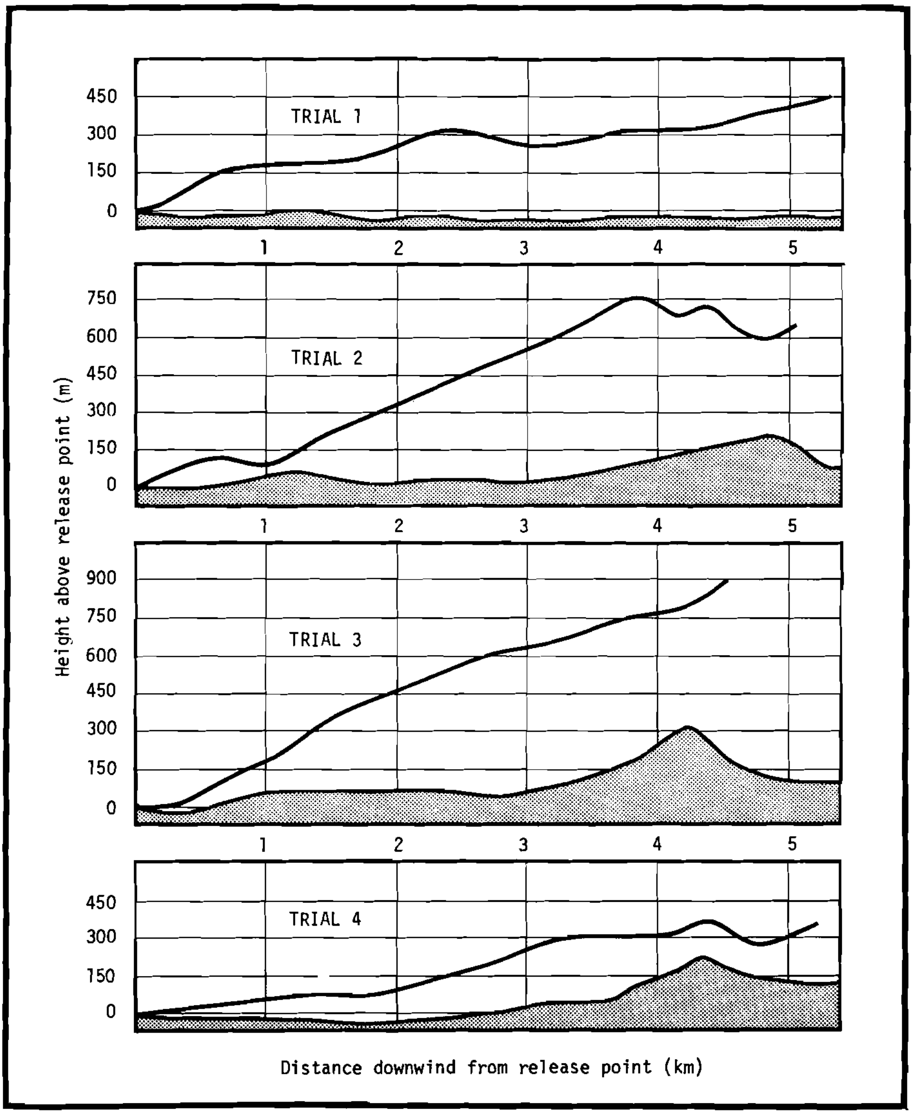

Fig. 3 Variations in height of the average tetroon trajectories.

flat terrain. Within a distance of 1,850 m (6,000 ft) from the launch site they usually rose to a height of at least 305 m (1,000 ft) above the ground. Strong vertical currents must have been present to cause the flights to lie much higher than the theoretical equilibrium level.

The tetroons of Trial 2 rose to average heights above the terrain of over 760 m (2,500 ft). This is more than 10 times the height that would be expected in the absence of updrafts. The average horizontal and vertical variations of the balloons during Trial 3 were similar to those of Trial 2. It is noteworthy that the temperature lapse rate shown in Table 1 was much greater during Trial 2 than during Trial 3 when it was essentially adiabatic. If the attained heights of the balloons were sensitive to near-ground temperature gradients, then tetroons of Trial 2 should have risen higher than those of Trial 3. The fact that this was not the case may be explained in accordance with the theory that under moderate to strong wind conditions, lapse rates quickly change to adiabatic within a short distance above the ground.

The tetroons of Trial 4 tended to remain much closer to the ground than those of previous trials. Up to a distance of 1,850 m from the launch site, the average elevation above the ground did not exceed 100 m (330 ft). As they approached the mountains at downwind distances in excess of 1,850 m, the tetroons tended to rise to greater heights with respect to the terrain.

As mentioned in Section 2, constant-level balloons under steady vertical velocity air motions could theoretically achieve an equilibrium level where the restoring force is balanced by a static drag force. They could thus float at a constant level and yet be in a region of steady upward motion. There is no evidence in Fig. 3 that such a level was attained. Balloons of Trial 3 continued to rise after reaching heights above ground level of 900 m.

6 Calculated diffusion coefficients

The observations presented in the previous section show the presence of strong upward currents in the mean air flow over the mountainous terrain east of the Saratoga Plant. In addition to determining mean air-flow patterns, tetroons can also be used to determine the diffusion properties of the atmosphere (Angell and Pack, 1965).

Gaussian models are usually applied in atmospheric diffusion studies because of the random nature of turbulent motions. Such models require a knowledge of diffusion coefficients; these, in turn, give a measurement of the plume spread. Horizontal and vertical dispersion coefficients were calculated from the tetroon data by determining the mean trajectory direction for each trial and then evaluating the root mean square of the lateral and vertical distances between individual trajectories and the mean trajectory at various downwind distances. The mathematical relation by which the horizontal standard deviation was calculated is thus:

$$\sigma_y^2(x) = \frac{\sum_{i=1}^{n} Y_i^2(x)}{n}$$

where:

$\sigma_y(x)$ = horizontal dispersion coefficient at x,
x = downwind distance from the release point measured along the mean trajectory,
$Y_i(x)$ = lateral distance of the individual trajectory from the mean trajectory,
n = number of trajectories used in the calculation (never less than 3).

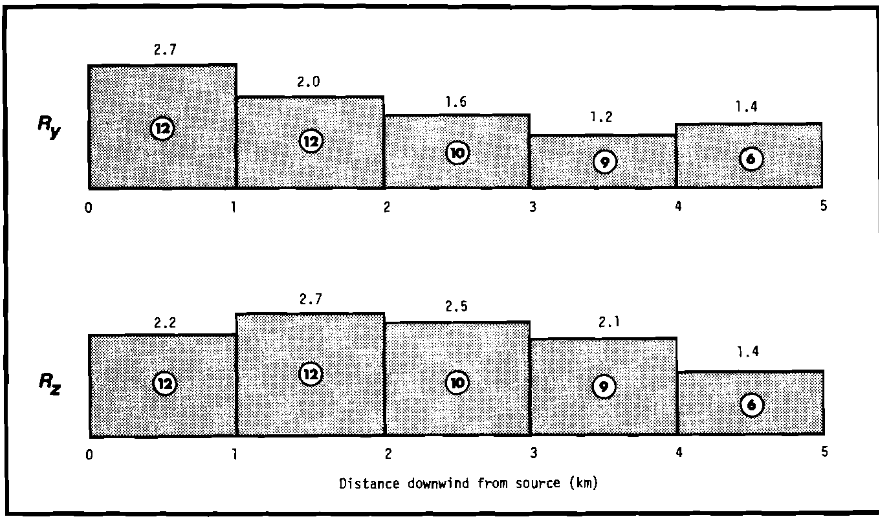

Fig. 4 Median values of R_y and R_z as a function of downwind distance from the release point. The number of observations in each class is shown within the circle.

An equation similar to the above was also used to calculate the vertical dispersion coefficient σ_z.

Usually the coefficients of Pasquill (1961) which were derived from observation made over flat terrain, are used in diffusion calculations. It is therefore of considerable interest to compare the derived coefficients with Pasquill's. For this reason, the following ratio was calculated:

$$R_y = \frac{\sigma_y(x) \text{ as derived from tetroon data}}{\sigma_y(x) \text{ as given by Pasquill}}$$

A similar ratio, R_z, was calculated for the vertical dispersion coefficients.

Values for R_y, and R_z were obtained for each trial at about every 300 m downwind of the launch site. An examination of the data indicated that there were no pronounced differences among the diffusion statistics for the trials. Therefore, the values of R_y and R_z from all trials were grouped together and medians then determined. This grouping means that the median R_y, R_z values were determined from data obtained from all 16 balloon trajectories.

Fig. 4 shows the median values for R_y and R_z as a function of downwind distance from the release point. As indicated in the upper portion of this figure, the derived values of σ_y are about twice as large as Pasquill's, up to a downwind distance of 3 km. Beyond this distance, the derived σ_y values were essentially equal to Pasquill's. It may be significant that the foot of the mountain ridges is at a distance of about 3 km from the release point. The Figure also shows that the derived values of σ_z were usually about twice as great as those suggested by Pasquill.

It should be stressed that the fact that the calculated diffusion coefficients are different from Pasquill's may not be entirely due to terrain influences. A portion of the difference between the statistics is doubtlessly accounted for by the different averaging times. The derived coefficients were obtained from observing tetroons which were launched over a time period of about 1¼ h. Pasquill's coefficients on the other hand, are applicable to about a three-minute time average. Mean wind fields, which may remain essentially constant over a three-minute period, can vary over periods of the order of an hour. Any such unsteadiness in the wind field will be reflected in larger observed diffusion coefficients.

7 Conclusions

The average tetroon flights discussed in this paper show that large upward velocities are associated with moderate westerly winds in the Crowsnest Pass area. These winds are funneled towards the narrow pass which leads into the town of Coleman. Cliffs on either side of this pass effectively act as a block to horizontal air currents causing them to rise abruptly and flow over the terrain.

The strength of the vertical wind is shown to be strongly dependent on wind direction. Tetroons which moved in a northeasterly wind direction (Trials 2 and 3) rose to heights twice as great as those that moved in an easterly direction (Trial 1) and over three times as high as tetroons which went in a southeast direction (Trial 4). This apparent dependence of the vertical velocity on horizontal wind direction was unexpected and remains unexplained.

The heights attained by the tetroons appeared to be insensitive to vertical temperature gradients measured near the ground. This was expected since under moderately strong wind conditions temperature lapses at short distances above the ground should be adiabatic.

Diffusion coefficients were estimated from the tetroon data. These are shown to be generally larger than the well known Pasquill coefficients. Their greater values may be explained as a combination of terrain factors and of factors due to unsteadiness in the wind field.

If the restoring forces on the constant-level balloons were significant, the vertical air motions in the Crowsnest region would be underestimated by the tetroon data. The horizontal diffusion coefficients derived from the trajectory data should continue to be acceptable. The vertical diffusion coefficients, however, may not be representative of the vertical turbulence.

Acknowledgement

The authors wish to express their appreciation to Westcoast Transmission Company Limited for permission to publish the data discussed in this paper.

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ANNOUNCEMENTS

Proceedings: Symposium on the Physical Environment of the Hudson Bay Lowland

The objectives of the symposium which was held March 30, 31, 1973, at the University of Guelph were to:

(a) provide a forum for individuals or groups with planning, development or research interests in the Hudson Bay Lowland;

(b) assess the current level of understanding of the physical environment within the Hudson Bay Lowland.

Seven invitational papers provided the resource material for the symposium and have been reproduced as "Proceedings". These papers dealt with the primary components of the physical environment including geology, surficial deposits, climate, permafrost and hydrology. Contributing authors include R.G. Skinner, S.C. Zoltai, R.J.E. Brown, W.R. Rouse, N.W. Radforth, W. Lammers and W.H. Forman.

Copies of the Proceedings are available immediately upon request to:

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Continued on page 122

Snow Accretion on Power Lines

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[Manuscript received 13 July 1973]

ABSTRACT

The results obtained from an investigation into two damaging snowstorms in the Saskatoon area and the findings of Higuchi indicate that the hazard to power lines from wet snow can be significant even when strong winds accompany the snowfall. Since the incidence of freezing precipitation is low on the Prairies, damage from snow accretion may be of more significance than that from ice accretion.

1 Introduction

Accretion of wet snow has not generally been considered a significant hazard affecting power and communication lines except when the snowfall occurs with light winds. Kuroiwa (1965) investigated icing and snow accretion on electric wires and found that almost all accretion of wet snow in Japan occurred when the wind was less than 3 m/s and the air temperature −1 to +1°C. McKay and Thompson (1969) in a discussion of ice accretion in Canada noted that wet snow is not very adhesive and is easily removed from wires by strong winds. Boyd (1970) reported that, in the protected valleys of British Columbia, winds are particularly light and wet snow frequently accumulates on wires. Elsewhere in the country snow is usually accompanied by winds strong enough to blow any substantial accumulation of snow off the wires. More recently, however, Higuchi (1973) has indicated that on the Island of Hokkaido in Japan accretion of wet snow, frequently accompanied by strong winds, is a much more serious hazard to power lines than is icing from freezing precipitation.

2 Case studies

Investigation of two specific snowstorms which caused significant damage to lines and structures in the Saskatoon area suggests that under certain conditions wet snow accompanied by strong winds, greater than 15 mph, can be a serious hazard to power and communication lines.

A storm on May 3 and 4, 1955, caused severe damage to power, telephone and telegraph lines in Saskatoon and immediate vicinity. Precipitation began as rain, changed to a mixture of rain and snow and finally to snow. Temperatures dropped from the mid-forties to 32°F and remained within a degree of freezing throughout the remainder of the storm. Winds were generally greater than 20

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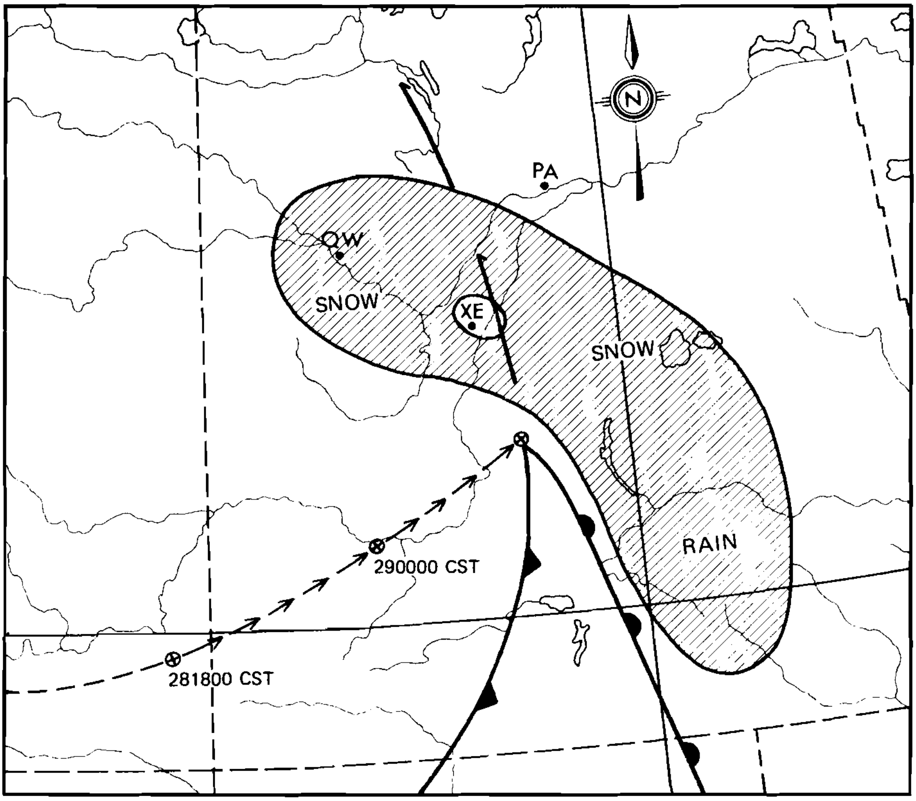

Fig. 1 Low Centre, ⊗, frontal wave and precipitation area, April 29, 1971, 0600 CST. XE – Saskatoon; QW – North Battleford; PA – Prince Albert.

mph and gusted as high as 54 at the height of the storm. According to newspaper reports, damage to power and communication lines and poles was so extensive that for a time much of the city was without power and all communication with the rest of the Province, except via ham radio, was lost.

The second storm, which took place while the author was employed at the Saskatoon Weather Office, was investigated in greater detail. On the night of April 28–29, 1971, a storm centre moved across central Saskatchewan depositing nearly a foot of wet snow in areas northwest and northeast of Saskatoon. Fig. 1 shows the advance of the filling low centre and the associated frontal wave. The precipitation began in the evening as rain, and through the night changed first to a mixture of rain and snow and then to wet snow. By early morning accumulations of snow up to four inches in diameter had built up on the cables of the 138-kV transmission line (Fig. 2) between Saskatoon and North Battleford, in spite of the fact that the winds were relatively strong throughout the night. Reported wind speeds at North Battleford ranged from 15 to 20 mph with a peak gust of 26 while at Saskatoon the speeds ranged between 20 and 30 mph with gusts as high as 37.

At 7:50 CST on the morning of the 29th, a section of the 138-kV line

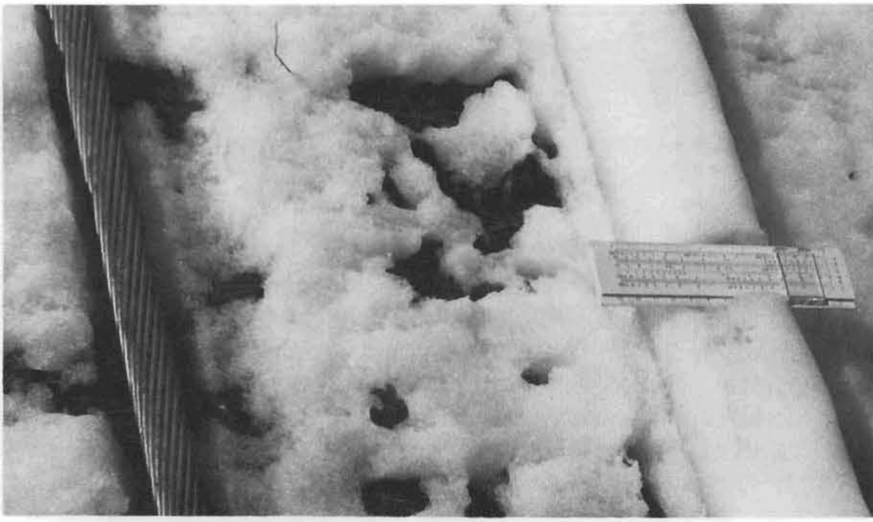

Fig. 2 Snow accumulation on conductor. Cable has a diameter of 0.858 in. Photograph was taken several hours after collapse of the power line and some melting had taken place.

between Saskatoon and the Borden River Crossing went down under the force of the wind and snow causing widespread power failures. Fig. 3 shows the location of this section and a second section farther west which collapsed later in the morning. In all, 96 towers were either damaged or destroyed. In addition, considerable damage to north-south oriented telephone and telegraph lines took place. The main damage area is outlined in Fig. 3. The most extensive damage occurred between Saskatoon and North Battleford. Damage resulted mainly from structural failure in the transmission line towers and the breaking of telephone and telegraph line poles and crossarms. There were numerous breaks in telephone and telegraph lines, but according to Thiele (1971) there was only one break in the 138-kV conductor and that appeared to have been caused by crushing at the time of the tower failure. There was little damage to trees in the area which were not yet in leaf.

3 Data analysis

An analysis of the storm was undertaken in an attempt to determine the meteorological conditions which prevailed during the storm. Since virtually all the damage occurred between the weather reporting stations at North Battleford, Prince Albert and Saskatoon, much of the information had to be obtained from residents of the damage area, power, telephone and telegraph company

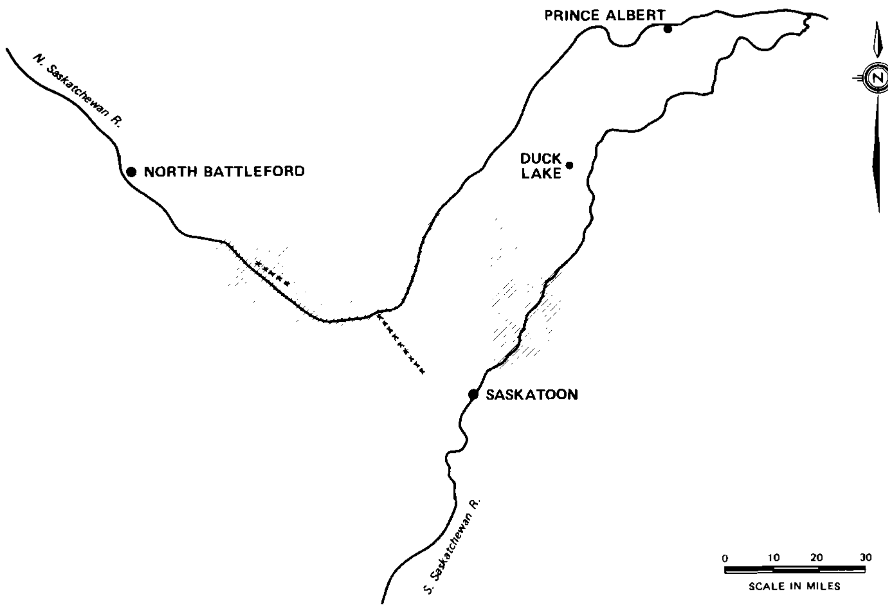

Fig. 3 Area of major damage is shaded. xxx indicates damaged sections of transmission line.

employees and media personnel. Ten residents of the most heavily damaged area were interviewed to obtain information regarding depth of snow on the ground, the amount of accretion on wires and the texture of the deposit. At least six power company employees, one of which was out in the damage area during the storm, provided further information on the texture of the snow, the diameter of the accretion and the nature and extent of the damage. A photographer from the local newspaper and a cameraman from one of the television stations were in the area shortly after the collapse of the first section of transmission line and provided valuable information on the nature and amount of the snow on the line. Regular climatological reports of maximum and minimum temperatures and precipitation were obtained from 4 climatological stations in and near the damage area. In addition to these, detailed descriptions of local damage, snowfall amounts, wind speed estimates, and occurrences of freezing precipitation were received. The Saskatchewan Research Council, Geology Division, maintains an observation well at Duck Lake just north of the damage area. The records of temperature and cumulative precipitation during the storm were made available to the author (Fig. 4).

Data from interviews, climatological stations and regular weather observing stations have been combined in an attempt to outline the areal distribution of the snowfall, Fig. 5. It is interesting to note that some sections northeast and east of Saskatoon received up to 8 inches of snow, but were outside the damage

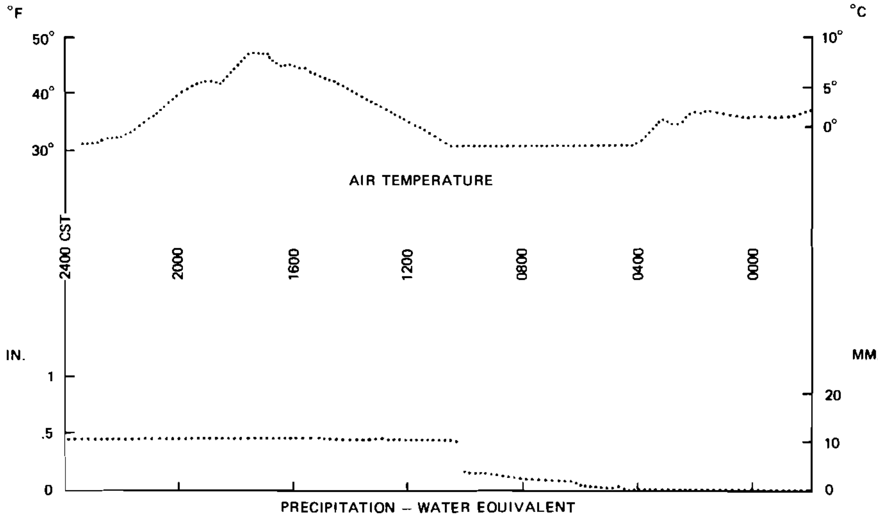

Fig. 4 Temperature and precipitation record from the Saskatchewan Research Council's Duck Lake Observation Well, April 29, 1971. The discontinuity in the precipitation trace at 10:00 CST likely resulted from snow accumulating on the rim of the collector and falling into the weighing bucket.

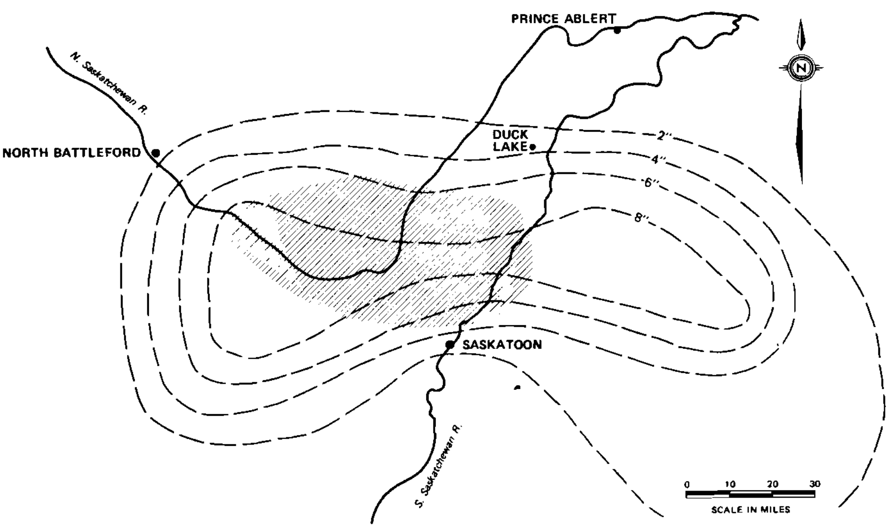

Fig. 5 Storm snowfall (inches).

area. The bulk of the snowfall in these areas appears to have occurred at temperatures slightly above freezing.

As far as could be determined, precipitation throughout the storm was in the form of rain, wet snow or a mixture of the two. The possibility that some freezing rain did occur in the damage area has not been discounted although it

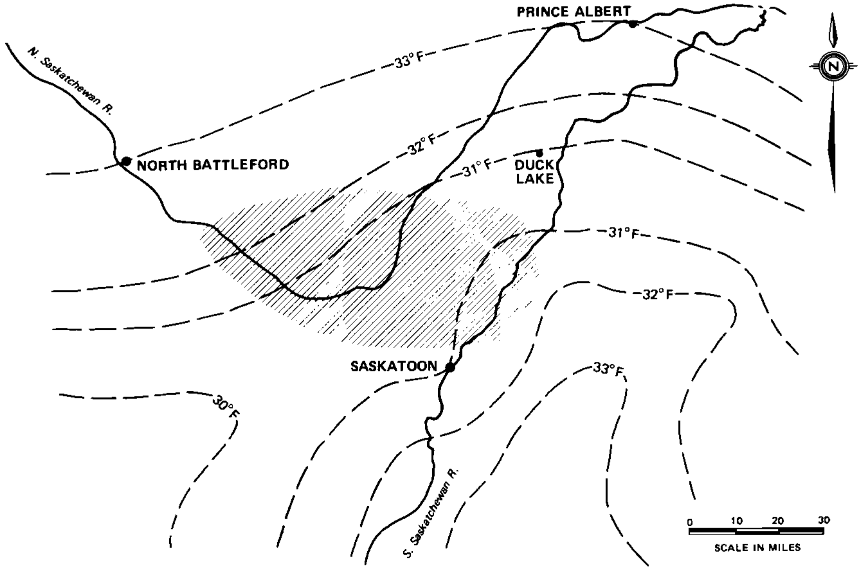

Fig. 6 Minimum temperatures during the storm (°F).

appears unlikely and if it did occur was of short duration. Only one of the persons interviewed mentioned the possibility of freezing rain. Linemen and others who were out in the storm referred to the precipitation as wet snow or a mixture of rain and wet snow. A photographer who examined the accretion on the line shortly after the first section failed, reported it to be packed snow with the consistency of a snowball. He also noted that there appeared to be a thin coating of ice next to the conductor.

Temperatures during the storm were within a few degrees of freezing. Fig. 6 is an isothermal analysis of the minimum temperature distribution on the morning of the 29th. Although the minimum temperature at Saskatoon did get as low as 31 degrees it must have done so only briefly since the lowest hourly temperature reported was 33°F. With low cloud and brisk surface winds it is likely that isothermal conditions existed between ground level and the tops of the towers. As indicated earlier, winds were strong throughout the night. The direction of the wind in the Saskatoon area was east to northeast and nearly perpendicular to the damaged section of power line between Saskatoon and the river crossing.

4 Discussion

Analysis of these two storms has led the author to conclude that under certain conditions wet snow driven by strong winds can be a significant hazard to transmission and communication lines. Table 1 summarizes the weather conditions during the two storms. It is interesting to note the similarity. In both cases the precipitation began as rain, changed to a mixture of rain and snow and

TABLE 1. Weather conditions observed in Saskatoon during two severe storms causing power line damage.

Date		Time (CST)	Precipitation	Temperature (°F)	Wind Speed and Direction	Gusts to
May 1955	03	11:30	R-	38	NNE 32	41
		12:30	R-, S-	36	NNE 36	48
		13:30	S+	32	NNE 40	54
		14:30	S+	32	NNE 25	30
		15:30	S+	32	NNE 24	30
Power failures began		16:30	S+	32	NNE 22	30
		17:30	S-, SG-	32	N 18	25
		18:30	SG-	32	N 24	32
		19:30	SG-	32	NNW 25	30
		20:30	SG-	32	NNW 25	30
		21:30	SG-	32	N 25	30
		22:30	SG-	32	NNW 26	33
		23:30	SG-	32	N 25	30
	04	00:30	SG-	33	NNW 24	35
		01:30	S-	33	NW 15	
		02:30	S-	33	NW 19	
		03:30	S-	34	NW 17	
April 1971	28	20:00	RW-	41	ESE 16	
		21:00	R-	38	E 20	26
		22:00	R-, S--	37	E 21	27
		23:00	R-, S-	35	E 21	
	29	00:00	R-, S-	34	E 20	
		01:00	S-	33	E 20	
		02:00	S-	33	E 18	24
		03:00	S-	33	E 20	30
		04:00	S-	34	E 26	36
		05:00		34	ESE 20	30
		06:00		34	E 18	26
		07:00	R-, S-	34	ENE 15	
Collapse of first section		08:00	SP-	33	NE 20	
		09:00	S-	34	NE 24	31

R: Rain
RW: Rain Shower
S: Snow
SG: Snow Grains
SP: Snow Pellets
Intensity: -- very light
- light
+ heavy

finally just snow. During both storms temperatures fell to near freezing then remained steady and the winds were strong.

Higuchi (1973) has found that when there is sufficient moisture in the snow, accumulations of snow tend to slide around the conductor, as shown in Fig. 7, eventually forming a cylinder around the cable. Examination of the photographs of the snow-covered conductor in the April, 1971 storm shows evidence of a similar process. It is likely that the conductor was at a temperature near 32°F when the snow began. As the snow, or rain and snow mixed, impinged on the conductor it slid around the cable and pushed by the strong wind eventually

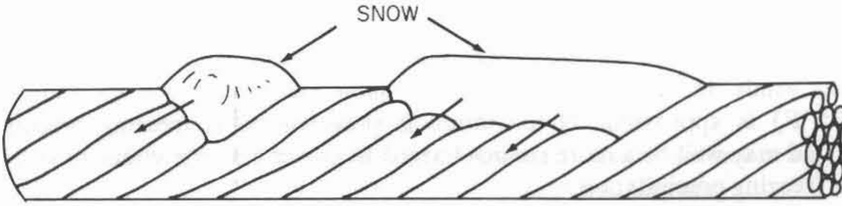

Fig. 7 Snow sliding in the direction of the strand twist (after Higuchi, 1973).

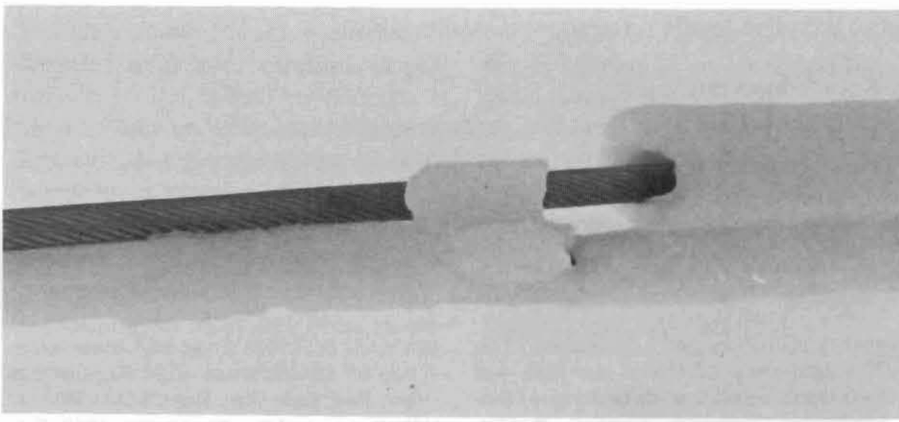

Fig. 8 Photograph of the fallen conductors showing cylindrical accretion of snow. (Courtesy of the *Saskatoon Star Phoenix*.)

formed an insulating coating of snow around the conductor. Slight heating of the conductor inside this cylinder of snow could have caused some melting resulting in what appeared to be a thin layer of ice next to the conductor as noted by one of the photographers. As the wind-driven snow continued to accumulate on the outside of the cylinder it rotated thus allowing for a more or less uniform accumulation. One may observe in Fig. 8 that the snow around the conductor is not attached to it but rather that it has formed a loose fitting cylinder around the conductor which would be free to rotate as the snow accumulated on the windward side. Strong winds would have a tendency to pack snow against this so it would not dislodge easily.

It is likely that on the Prairies, where the incidence of freezing precipitation is low, damage to lines from the accretion of wet snow is as great or greater than that from freezing precipitation. Examining precipitation that occurred while the air temperature was within the 30 to 35 degree range, Bergsteinsson and Maybank (1973) found that in the 18-year period, 1953 to 1970, during the months of October through March the number of hours with wet snow was nearly ten times as great as the hours with freezing precipitation. Snow was reported on 1,004 hours while freezing rain and/or freezing drizzle were reported on only 108 hours.

5 Conclusion

Wet snow can cause significant damage to lines even when accompanied by strong winds. In the Saskatoon area, wet snow (temperature in the range 30 to 35°F) is approximately ten times as prevalent as is freezing precipitation and may well be a more serious hazard to power and communication lines than freezing precipitation.

Not all occurrences of wet snow, however, result in damage and further study is therefore required to determine precisely the critical meteorological conditions which result in snow accretion on lines. Once those conditions have been identified climatological analyses can be undertaken to provide probable snow accretion loadings for transmission line design.

Acknowledgements

The author wishes to express his gratitude to the many persons who provided information, data, suggestions or comments. Special thanks are due to H.A. Thompson of the Atmospheric Environment Service whose interest, encouragement and assistance were greatly appreciated.

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NOTES FROM COUNCIL

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Lidar Study of Atmospheric Particulate Over the City of London

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[Manuscript received in final form 13 September 1973]

ABSTRACT

The laser radar (lidar) is capable of detecting weak concentrations of particulate in the lower atmosphere at ranges up to several kilometres. Through this technique, models of thermal convection and theories of particulate diffusion may be studied by observing the spatial and temporal changes in particulate concentration. A pulsed ruby lidar has been assembled at this University, with scanning optics located at an elevated position overlooking the city. Criteria have been evolved here for deriving profiles of extinction coefficient, and particulate number and mass concentration from the lidar signatures. Sample profiles of particulate concentrations are given for comparison with the design prediction of lidar sensitivity.

1 Introduction

Transfer by thermal convection in the lower atmosphere is the subject of this research project. This may involve the natural transfer of heat and water vapour between the ground and the air up to a few hundred metres above ground, or the transfer of particulate from stacks and other man-made sources. There is growing acceptance of the thermal plume as the physical model in natural transfer (see, for example, Fanaki 1971). This model in turn has been inspired by the visible plume commonly observed in the effluent from stacks.

Current theories on thermal plumes are either in the elementary formative stage or are applicable in the relatively simple environment of the open countryside. Examples of the natural plume are discussed by Kaimal and Businger (1970), while Turner (1970) and Briggs (1969) refer to the visible plumes from stacks and similar sources. The urban area introduces new boundary conditions into the plume model. Pasquill (1972), Egan and Mahoney (1972) and others discuss some of the analytical problems of diffusion prediction in the urban environment.

One method of studying thermal diffusion in the lower atmosphere uses the laser radar (lidar). In principle, the lidar is similar to the weather radar that is familiar to radar meteorologists. In essence, an outward travelling pulse of energy from a transmitter irradiates the atmosphere, while an adjacent receiver detects scattering of this radiation by components of the atmosphere. The lidar may operate at wavelengths in the ultraviolet, visible or infrared region, where scattering is due mainly to atmospheric molecules and particulate matter. In particular, Raman scatter and scatter by resonance re-radiation permit identification of the scattering molecules, but the laser power currently available for these applications is relatively small and a very high degree of frequency selectivity is necessary in the receiver. On the other hand, elastic Rayleigh and Mie scattering do not provide for identification of the scattering molecules, but high laser power is available and the requirement for frequency selectivity in the receiver is modest. At the present time, lidars observing Raman scatter and resonance re-radiation are limited in practice to ranges of a few hundred metres. Lidars observing Mie and Rayleigh scattering, however, may probe the atmosphere horizontally at ranges up to about 10 km. Comprehensive discussions on these lidar principles are presented by Derr and Little (1970) and by Kildal and Byer (1971).

The present project uses a lidar operating in the visible region to observe Mie scattering by atmospheric particulate. The lidar, located on the U.W.O. campus, is equipped with special optics that permit scanning in the horizontal over the City of London. The next section will describe the physical arrangement of this lidar and its design sensitivity. This will be followed by a discussion on the technique of analysis, including improvements developed by the writers. Finally, some preliminary results of these observations will be presented to illustrate the sensitivity of the lidar in detecting atmospheric particulate.

2 The lidar and field of view

a *Location*

The roof-top position of the scanning optics provides a wide field of view over the city. This includes not only the city proper but also the northern suburbs and rural area. Only a 90-degree sector to the west is excluded by local buildings. From this observing point, the whole of the city lies within a radius of 10 km. With its population of 223,200, the city possesses many of the characteristics of urban areas frequently mentioned in diffusion studies elsewhere, including multiple heat islands and katabatic flow along the river valleys (Thomas, 1967). Although the city's air quality generally is acceptable, London nevertheless has many point sources of industrial stack effluent and line sources along traffic arteries and the river. Upwind rural areas apparently also contribute to the general particulate concentration in the urban air.

b *Lidar*

Fig. 1 shows a block diagram of the lidar. The components in the lower half are located in the laboratory, while the optics in the upper half are on the laboratory roof. The transmitter signal originates from a pulsed ruby laser at wavelength 0.6943 μm. This signal is conditioned and re-directed to the transmitter optics by a beam expander telescope. A precision turntable[1] controls

[1]Alignment of this turntable requires critical adjustment, through a technique involving optical reflection from the surface of an oil pool (Hay *et al.* 1973).

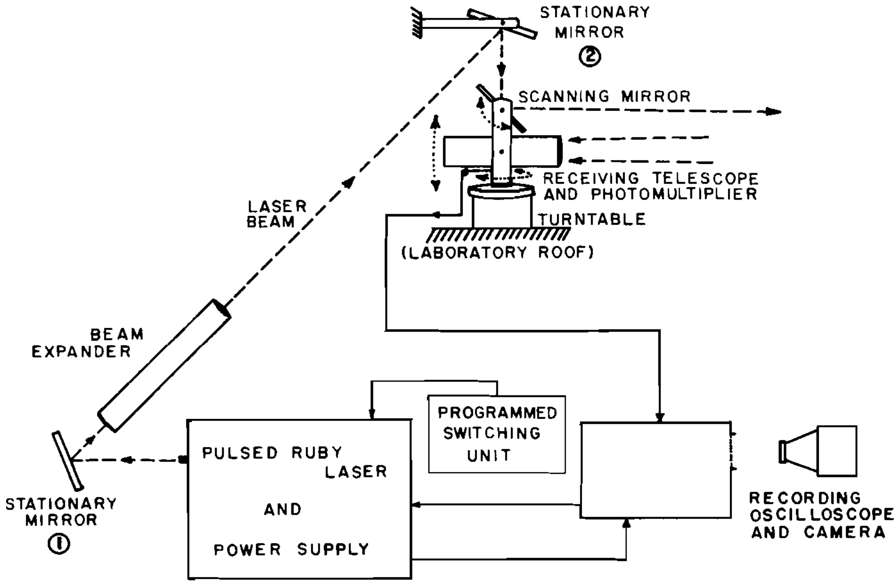

Fig. 1 Basic components of the research lidar.

the transmitting mirror and the receiving telescope, whose axes intersect along the observing path. A photomultiplier at the receiving telescope responds to the scattered signal, and transmits this information to a recording receiver in the laboratory. At a range of 3 km, the spatial resolution of the lidar is a cylindrical volume approximately 10 m in length and 5 m in diameter. Additional details on the lidar are found in Hay *et al.* (1973).

c *Reference Aerosol*

We now define a "reference aerosol" as a means of assessing the lidar sensitivity. In general, suspended particulates in the air have chemical compositions that depend upon their sources, the history of the conveying air mass, and upon ambient humidity. Through a study of numerous air samples, Barrett and Ben-Dov (1967) and Bethke *et al.* (1970) have described a representative particulate. Its density is 1.8 g cm^{-3}, refractive index is 1.5, diameter has a Junge-type number/size distribution of exponent −4 within the range 0.04 to 10 μm, and mean particle mass is 8×10^{-9} μg. The mean back-scattering cross-section (σ_R) for this representative particulate at the lidar wavelength is 3.9×10^{-16} m^2 sr^{-1} (McCormick *et al.* 1968). The "reference aerosol", then, is a unit volume of dry air containing the number concentration ρ of particles with these characteristics.

These characteristics of the reference aerosol may be related to the calibration of the lidar through two parameters of the basic lidar equation. One is the volume back-scattering coefficient of the reference aerosol, β_R. Assuming single scattering by each particle, this is defined by Eqs. (1) and (2):

$$\beta_R = \rho(\text{particles m}^{-3})\ \sigma_R(\text{m}^2\ \text{sr}^{-1}) \tag{1}$$

$$= \frac{m(\mu\text{g m}^{-3})}{8.0 \times 10^{-9}}\ \sigma_R(\text{m}^2\ \text{sr}^{-1}) \tag{2}$$

where m is the mass concentration of the aerosol particulate.

The second parameter is the extinction coefficient, α_R, of the reference aerosol. This describes the depletion of energy from the progressing lidar wave through scatter in all directions by the suspended particulate. There is no simple, theoretical relationship between β_R and α_R for aerosol particles, but in the mean they may be related semi-empirically through the form of Eq. (3) (Collis, 1969):

$$\beta_R = \left(\frac{k_1}{4\pi}\right) \alpha_R^{k_2}. \tag{3}$$

The constant k_1 is 0.485 according to Mie scattering theory for the reference aerosol at the lidar wavelength (McCormick *et al.*, 1968). On the other hand, k_2 appears to depend upon system variables in a manner that has not yet been fully explored. Numerous experimental trials in the writers' laboratory suggest that $k_2 = 1.0$ is acceptable for a limited range of lidar observations (Houston 1971; Hay *et al.*, 1973).

d *Visibility*

One method of describing the atmospheric environment in which lidar observations are made is through reference to the optical visibility. Here, visibility (V) is defined in the conventional meteorological sense as the maximum range at which a dark target may be discerned against the horizon sky by a trained observer. Horvath (1971) has demonstrated that the Koschmieder formula

$$V = \frac{3.91}{\alpha} \tag{4}$$

(where α is the extinction coefficient of the atmosphere[2]) is valid within close tolerances for specified conditions on the type of target and the sky illumination of the observing path. In addition, α is interpreted as the mean value over the length of the observing path. Thus, if the particulate loading of the air is uniform along a path observed by the lidar, the environmental extinction coefficient of Eq. (3) may be assigned a value through an auxiliary estimate of visibility and Eq. (4).

e *Maximum Range*

We next enquire about the ability of the lidar to observe a local concentration of particulate within an otherwise homogeneous environment. This is the

[2]For the present study, particulate loading of the air is interpreted relative to the reference aerosol. Hence α in Eq. (4) becomes α_R.

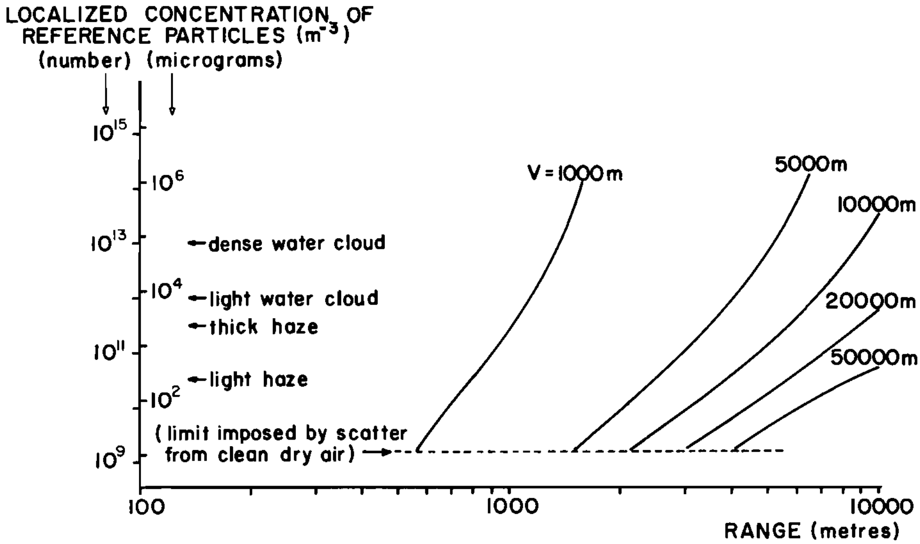

Fig. 2 Range dependence of minimum detectable concentration of particulate in the lower atmosphere, for various horizontal visibilities at the lidar.

idealized case of a plume from a point source rising in well-mixed air. For this purpose, we specify the environmental background through its visibility (V), and assume that V is not affected by the superimposed local plume.

The maximum range at which a plume of given concentration may be detected is found by combining Eqs. (1), (2) and (4) with the lidar equation. Details on the latter may be found elsewhere (see, for example, Collis (1969) and Hay *et al.* (1973)). The spectral radiance of the sky in the lidar field-of-view presents the minimum-signal limit at the lidar. Fig. 2 illustrates the minimum concentration of reference particles that may be detected at various ranges for visibilities from 1000 m to 50,000 m. In each case, the lidar signal scattered by aerosol particles must exceed that scattered from air molecules. In addition, the particle concentration within a localized plume must be greater than that of the environment in which it is embedded. For reference, the particle concentrations in representative clouds and hazes are noted on the ordinate scale. Measurements reported below indicate particle number concentrations within plumes in the range 5×10^{10} to 5×10^{11} m^{-3} ("light haze" to "light water cloud"). Fig. 2 shows that these will be detectable by the lidar at ranges 6–12 km when the environmental visibility is 20 km.

3 Initial observations on particulate concentration

A lidar "signature" is recorded photographically for each transmitted laser pulse. This signature is essentially a graph indicating the change in atmospheric scattering of the laser pulse with distance from the lidar. The analysis of a

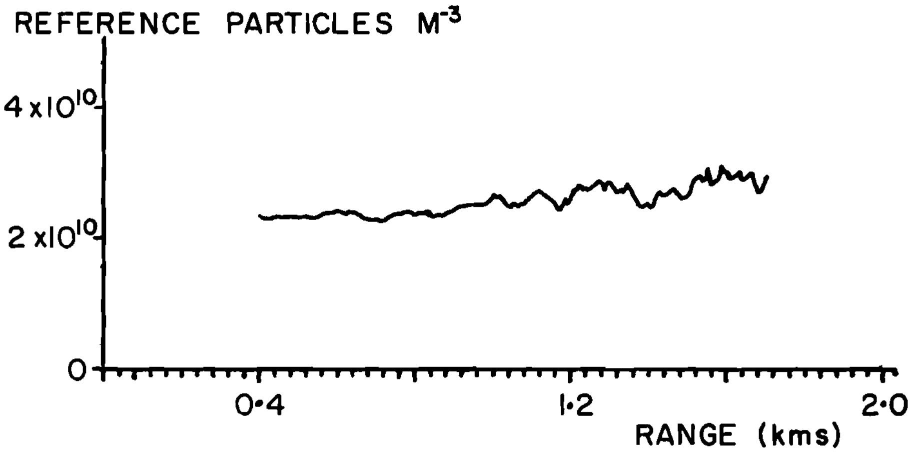

Fig. 3 Concentration profile through a well-mixed atmosphere. (3 Jan. 1973, 1300 h. Visibility 10 mi., temperature 34°F, humidity 82%, wind E 15–20 mph, area of low pressure approaching.)

signature follows in three steps: manual tracing of the photographic record onto a standard format, photoelectric scaling of this tracing to digitize its coordinates, and computer analysis of the scaled coordinates to derive the profile of extinction coefficient or reference particle concentration from the lidar equation.

Several aspects of the analysis have been examined by the writers during the development of the computing procedure. These include the accuracy of hand tracing of the lidar signature, and the evaluation of the atmospheric extinction coefficient at a nearby reference range. Hitschfeld and Bordan (1954) have pointed out the need for accuracy in the latter, for the analogous case of weather radar observations on rainfall. For example, a 2-km error in estimating visibility at 16 km yields a 10 percent error in derived particle number concentration; the latter increases to 30 percent for the same error in visibility at 4 km. The application of Eq. (4) near the lidar with the aid of an optical visibility meter provides a means of reducing this error to an acceptable level. Other reports on this project give details of this analysis.

Lidar observations over the city were initiated in the Fall of 1972. A first analysis of these has demonstrated some noteworthy features of the concentration profiles. Fig. 3 shows an approximately uniform concentration of particulate during an interval of good visibility and mixing by moderately strong winds over the city. A rapid change in concentration profile is illustrated in Fig. 4, where the two soundings were taken about one minute apart as a front with snow squalls approached the city. An invisible plume as detected by the lidar is shown in Fig. 5; this apparently is associated with the river in the city, since no other sources could be identified in the upwind direction. Fig. 6 indicates the extreme sensitivity of the lidar to particulate in visible plumes. Here, the source is a stack whose effluent concentration is of a magnitude seen commonly

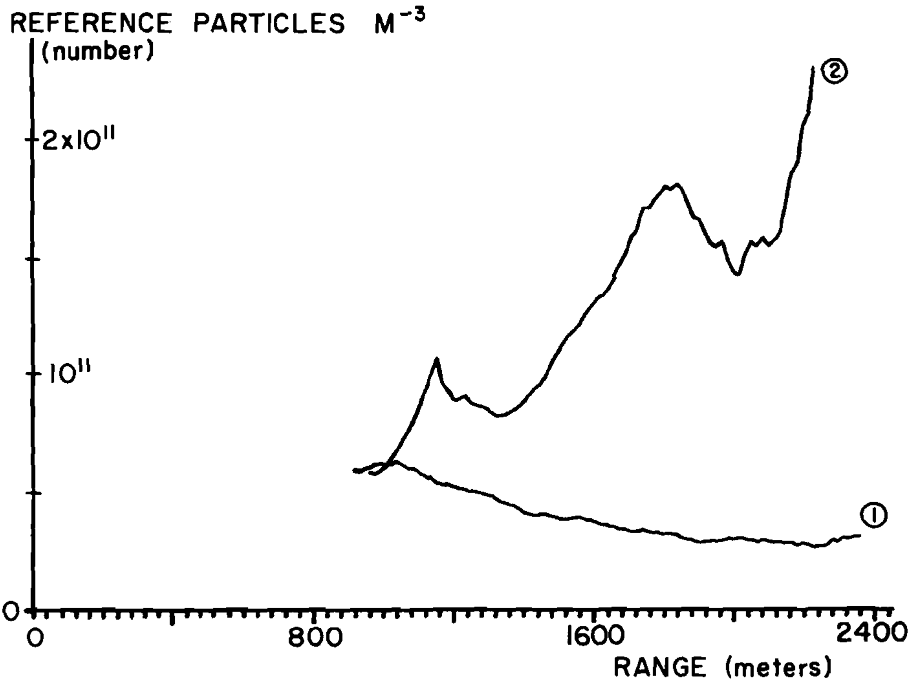

Fig. 4 Two profiles of particulate concentration along the same radial from the lidar, as observed one minute apart. (11 Jan. 1973, 1800 h. Visibility 2–4 mi., temperature 14°F, humidity 72%, wind W 15 mph, local snow squalls.)

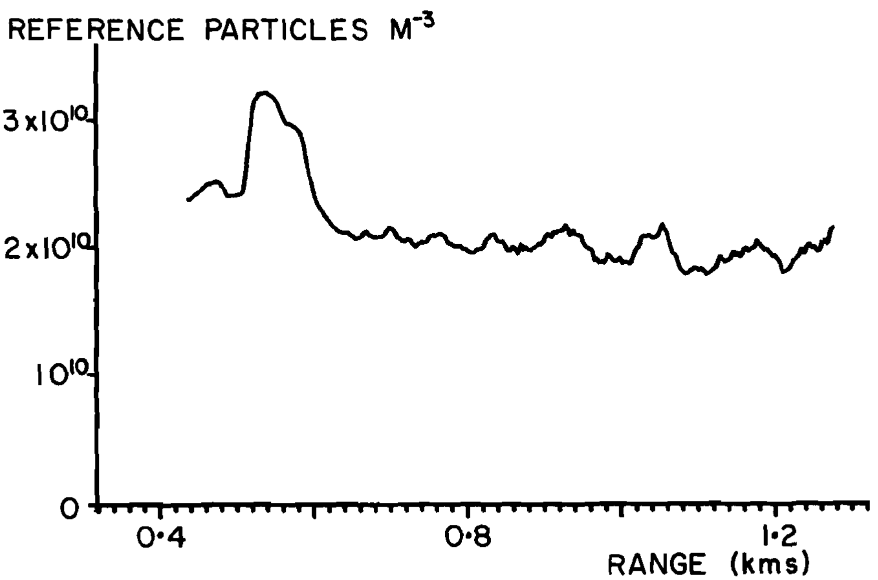

Fig. 5 Invisible plume as detected by the lidar. (27 Oct. 1972, 1605 h. Visibility 10 mi., temperature 57°F, humidity 50%, wind SE 8 mph, altocumulus cloud at 14,000 ft.)

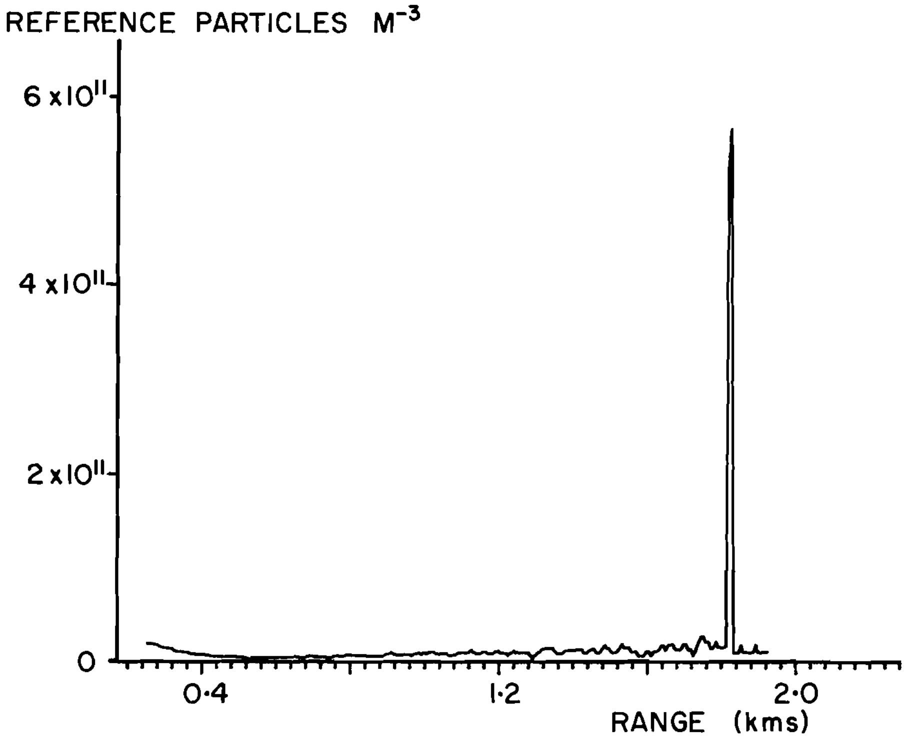

Fig. 6 Particulate concentration at the plume of an incinerator stack. (12 Jan. 1973, 1050 h. Visibility 10 mi., temperature 20°F, humidity 73%, wind WSW 20 mph, thin cirrus cloud cover.)

over the city. Comparison between Fig. 6 and Fig. 2 suggests that this plume could be detected at a range of 10 km when atmospheric visibility is 20 km.

4 Conclusions

It is clear from these preliminary soundings that the lidar is capable of observing ambient particulate concentrations and localized plumes over much of the city. These will support a study of thermal convection involving natural aerosol at closer ranges, and of particulate diffusion from point or extended sources at larger ranges.

Acknowledgements

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The Canadian Meteorological Society held the Seventh Annual Congress at St. Mary's University, Halifax, Nova Scotia, from May 30 to June 1, 1973. Sessions on the opening day were focussed on the theme *The Atmosphere and the Oceans* and were succeeded by many others devoted to principal areas of meteorological research. In particular, three sessions had papers dealing with remote sensing, showing the increasing importance of special techniques to probe the atmosphere and the earth's surface from a distance.

The oceanographic flavour of the Congress proved popular not only because of the east coast location of the meetings but also because of the local scientists who were deeply committed to studying the oceans and marine meteorology. The Bedford Institute in Dartmouth is one of the outstanding oceanographic institutions in the Western Hemisphere. Military interest in Halifax also is centred on the sea, with fifty per cent of the Canadian Forces Weather Centre's (METOC) effort there directed towards oceanographic ends.

The 1973 Congress was opened with a warm welcome from Dr. Owen Carrigan, President of St. Mary's, and further greetings were extended by G.A. McKay, CMS President.

The Atmosphere and the Oceans

R.V. Dexter, Chairman of the first session, introduced Dr. William L. Ford, Director of the Bedford Institute of Oceanography, who presented the keynote address, "Meteorology and Oceanography, as Environmental Sciences". In the near future there will be intense activity to explore air/sea interactions on every scale, information essential for forecast meteorology and dynamical oceanography. BOMEX in 1969 with only 5 ships and several aircraft yielded so much data it was a formidable task just to process these. Planning for GARP therefore did not reap the full benefits expected from BOMEX. GATE, scheduled for 1974, will involve 12 countries with 30 ships, 10 aircraft and 4 satellites over a 3-month period in the region from the equator to about 20°N extending from Africa to S. America. The meso-scale convective characteristics about the Intertropical Convergence Zone will be studied to help develop longer-term atmospheric models. Oceanographers will investigate the direct forcing of the ocean over scales to a few hundred kilometres. In 1976 or 1977 the First GARP Global Experiment will be undertaken as an even larger effort to understand long-term global-scale atmosphere-ocean coupling. This could lead to more realistic predictions of climatic change.

Meso-scale research is also being carried out to determine wave generation, and the vertical fluxes of heat, material and momentum, especially at high wind speeds.

Dr. Ford stressed the importance of preserving the quality of the atmosphere and the hydrosphere, both of which are fundamental to the well-being of mankind. This must be of key concern to oceanographers and meteorologists.

Problems have arisen from the fact that we live in a closed system (except for radiation in and out) subjected to man-induced stresses, exponentially increasing. The extra load of pollutants not abated through regular programs will have to be borne, absorbed, dispersed and transformed by the environment. Scientific attention is turning away from fluxes of energy to fluxes of marine chemistry for major and minor atmospheric gases, halogens, halides, metals (Cu, Pb, Hg) and organics. (Meteorologists have been interested in salt nuclei for the formation of water drops.) Giant pulse lasers may be available soon to obtain profiles of the chemical content of air and the upper 2 m of water through Raman backscattering. Of central concern will be the fluxes of substances generated by man (many of which are toxic and long-lived). However, the background natural fluxes still need to be determined. At present some surprising figures have emerged: 438×10^6 tons/yr of plant products (terpins, pinines, isoprenes – the blue haze over forests or natural smog) pass from the atmosphere mainly to the sea; 9×10^6 tons/yr CO go from ocean to atmosphere, about 5% of total amount produced by fossil fuels; 200×10^6 tons/yr of Cl_2 are produced in the atmosphere from marine-derived chloride. Particulate matter injected from the ocean into the atmosphere is perhaps the most significant process by which the ocean affects the biosphere. Man-made influences are already on a significant scale, e.g., CO_2 is $\sim 1/10$ of that fixed into organic matter through photosynthesis on land and sea – 15×10^9 tons/yr in 1970, and doubling within 20 years. The question remains whether these can be absorbed by the atmosphere/ocean system. Other chemicals present a challenge as well, e.g., oxides of nitrogen and sulphur along with organic and inorganic dusts. Lead measured in the Greenland Ice Cap has increased to 500 times the natural level, and correlates well with the increased use of leaded gasolines; this applies to ocean waters also (off Greenland at least). Metals (Cr, Cu, Fe, Pb, Zn) may be enriched many orders of magnitude in the surface films of ocean water.

Pathways of pollutants through air/sea/land cycles must be traced by air/sea interaction models developed by the physical-meteorologist and -oceanographer. This will enable reliable estimates of the capacity of the atmosphere/ocean to carry the waste products of our civilization. Results from ever-increasing research activities will permit Society to control and manage its output stresses within the ability of the total environment to absorb these safely and continually.

Following the theme address, Dr. H.C. Martin (AES, Toronto) described a study to measure energy transfer over Lake Ontario near the mouth of the Niagara River, as part of the AES contribution to the IFYGL program. Instruments were installed on a barge with a 12-m tower to measure directly the fluxes of sensible and latent heat. These measurements agreed well with values calculated by more indirect methods.

Continuing on the topic of air-water interaction, Dr. K.L. Denman (Fisheries Research Board, Halifax) discussed wind mixing in the upper ocean. Three storms in June 1970 were investigated using data from Ocean Weather Station PAPA (CCGS Vancouver). Mixing occurred throughout a depth of about 50 m.

There was a resultant cooling of 1°C at the surface which is quite large if compared to the annual variation of 8°C.

The next paper, delivered by Bryan Adamson for the author E.C. Jarvis (AES, Toronto), dealt with the utilization of VTPR (vertical temperature profile radiometer) data, a subject of increasing interest to operational meteorologists. He explained how the 1000 to 500-mb thickness data observed over the northeastern Pacific were used in the AES regional update (forecast) model. It appeared that some increase in forecast accuracy could be expected whenever the VTPR data were added to the regular synoptic data from the surface ships.

The attention of the participants was returned to the east coast of Canada during the presentation of Dr. J.L. Walmsley (AES, Toronto), an outline of his PH.D. work at McGill. He had constructed an air-water boundary-layer model for the Gulf of St. Lawrence region. Results suggest that advection of cold water in this area is an extremely important factor in determining the date of freeze-up.

The final paper of the morning session, by Professor S. Orvig of McGill, concerned synoptic influences on air-sea interaction in the Sable Island area. As expected, the heat flux is downward from May to August; however, the pronounced winter deficit which occurs for continental regions does not occur for Sable Island. This can likely be explained by the persistence of relatively warm low clouds throughout the winter season. Wintertime sea-surface cooling in this area is apparently achieved largely by the bodily export of heat to the south rather than by radiative heat losses.

The afternoon session, chaired by Dr. S.D. Smith of the Bedford Institute, although continuing on the same theme as that of the morning, was remarkable for its variety of fare and therefore produced a stimulating afternoon for all.

M.R. Morgan, DND Meteorological and Oceanographic Centre (METOC) in Halifax, gave two papers which represented well the dual function of this weather office. In the first he discussed the analysis of sea surface temperature for 10 years of observations of the Atlantic south of Nova Scotia. Persistent features of the thermal distribution are controlled more by the shape of the ocean floor than by local weather patterns. For example, stationary warm and cold tongues were found to be perturbations in the Gulf Stream caused by the underwater topography. The thermal patterns themselves also influence the marine meteorology. The tongues explain well the patchy nature of fog occurring over the Canadian Continental Shelf around the Maritime Provinces. Other weather features which are strongly influenced by the temperature distribution are paths of tropical storms and the formation of thunderstorms. In conclusion, Mr. Morgan stated that climatic changes could perhaps be forecast from predictions of the sea surface temperature.

Moving into the forecast field in his second presentation, he spoke about sea-wave forecasting for the Atlantic based on the analysis of ship wave reports received at METOC. Persistence of waves on the sea surface fortunately serves two purposes: historical data can play a large role in the analysis of the current charts; and successful forecasts can be made with a largely extrapolative technique (since wave patterns can be moved with the predicted wind field). This mainly manual method is outperforming the U.S. NWS technique (computer produced) for periods up to 36 h, with 6-m waves being correctly predicted 70% of the time. Extension of the forecast method into inland seas, such as the Gulf of St. Lawrence, requires consideration of shallow water effects (refraction and focussing of waves) as well as the open-water fetch (dependent on wind direction). The wave data also serve as a base for the compilation of a wave climatology for ocean regions.

The analysis of sea surface temperatures was again discussed by Dr. Max Dunbar (McGill University and the Bedford Institute) in an invited paper dealing with the response of marine biology to the changes in the marine (hydrospheric) climate. A cyclic temperature variation with a 20- to 30-year period in subarctic waters was related to biological phenomena. There is strong evidence that several species of fish (notably cod and salmon) and the whale are very sensitive to these changes, since they are found farther north following climatic temperature maxima. This may be a key factor in the disappearance of salmon from the west Greenland region. Marine species have also become adapted to "ecological signals", such as, light intensity, current velocity, phases of the moon, turbidity and areas of local productivity. The biological behaviour will adjust to changes in these signals whether produced by natural or man-made climatic changes. Migration of Atlantic salmon is believed to be controlled by a navigational signal, e.g., a chemical or electrical stimulus. In the future it may be possible to predict the locations of marine harvests by monitoring temperature, salinity and water transport in particular oceanic areas.

One of the most entertaining and engaging presentations of the Congress was delivered by Professor A.B. Fraser of Pennsylvania State University, on the subject of mirages over the ocean. Since these optical phenomena are caused by different over-water temperature profiles they may be used in conjunction with explicit mathematical equations to solve for the temperature in the lower atmosphere. A series of beautiful and detailed colour slides (which unfortunately cannot be reproduced here) of mirages were shown to illustrate this procedure.

Colour slides were also used by Allen Penney of the School of Architecture, Nova Scotia Technical College, to help demonstrate the gap which exists between the engineer/architect and the climatologist/meteorologist in the field of building design. For example, buildings may be well-designed individually, but when erected in groups are not structurally sound due to interactions with wind eddies. These eddies very often give rise to a "suction" effect which appears to be an important factor in causing windows in high-rises to "pop out" rather than blow in. The heat-island effect is also expanding because tax relief for new structures is provided for higher heating costs and this is aggravated for buildings constructed cheaply with minimum insulation. Urban meteorologists and architects should work together to prevent design errors and to minimize the adverse climatological changes which are inevitable with higher and larger buildings.

Al Bealby presented a progress report on behalf of D. Bellows and R. Jessup (AES, Toronto) on the prediction of cloud and precipitation areas. APT satellite photographs are analysed to identify regions of large-scale cloudiness which are then advected with the 500-mb wind pattern from CMC forecasts. The cloud regions may be transformed by translation, rotation and deformation, the extent of which is updated with the latest available data. The system is not operational yet; an objective verification scheme is in the planning stage.

In the final paper of the day, W.R. Smith (AES, Toronto) outlined recent improvements in the AES transmissometer presently used. Reduction in size and simplification of the electronic components are achieved through the use of integrated circuits and solid state circuitry. There should be a drop in costs when this system becomes operational in about two years' time.

Hail and Cloud Physics

On Thursday morning the first part of the sessions devoted to this subject was chaired by Professor R.H. Douglas, Macdonald College. Dr. P.R. Kry described work that he and Professor List had carried out at the University of Toronto to understand hailstone growth. In a theoretical study of the gyration of spheroidal hailstone models they derived the equations of motion for freely falling rotating oblate spheroids incorporating wind-tunnel values for coefficients of aerodynamic forces and torques. A symmetric gyration about the minor axis allows the shape symmetry of the growing spheroidal hailstones to be preserved. The majority of hailstones in nature exhibit this shape symmetry.

Professor List next reported on the planning and instrumentation for an important series of experiments in the Swiss hail tunnel by research groups from the Swiss Federal Snow and Avalanche Institute and the Universities of Alberta and Toronto. They started out to study the icing of spheroidal hailstone models under various rotational conditions (including the one mentioned in the preceding paper). Environmental conditions were varied as follows: relative velocity, equal to calculated terminal velocity; liquid water content, 3–40 g m^{-3}; air temperature, –5 to –30°C; pressure, as related to the air temperature as found on the average for Colorado hailstorms. The growth collision efficiency was equal to 1 but the collection efficiency was as low as 0.05. The fact that most experiments were performed at high liquid water contents (~30 g m^{-3}) was questioned during the discussion. Dr. List said that these were chosen because they appeared to give the proper growth rates in the absence of any other good measured values which could serve as a guide. Also little time was available for lower values to be studied. Several persons questioned whether electric fields could affect the experimental results, e.g., fields due to spray for producing droplets. In reply it was explained that all the models had been grounded; furthermore the energy from the inertial forces involved should be much larger than that from any electrical force that could be conceived as applying.

In a second paper elaborating still further on these experiments, Dr. E.P. Lozowski (University of Alberta) showed slides of the hailstone models: oblate spheroids with a major axis of 2–3 cm, and axis ratio 1:0.67:0.5. Typical gyration rates were 400–1600 Hz. Results were reproducible, since models of the same size under similar environmental conditions yielded very similar hailstones.

A Monte Carlo technique was used by Dr. D. Robertson of McGill to investigate the growth of drops by accretion of smaller droplets. He employed the best available data on measured fall speeds and collision efficiencies to determine the capture efficiencies. Compared with previous theory, more realistic cloud conditions were incorporated for water content and distribution of droplet sizes. It was shown that idealistic models which assumed a continuous growth mechanism of accretion underestimate the expected growth rate and this becomes very serious for a few statistically "fortunate" drops. A member in the audience pointed out that this new model may still not be very realistic.

In the final presentation of the morning, Dr. H. G. Leighton explained a cloud droplet growth model which he and Dr. R.R. Rogers had developed at McGill. Growth by coalescence was calculated stochastically; growth by condensation, by assuming simple diffusion theory along with adiabatic liquid water contents. Computations were made for various cloud conditions, (strong) updraft speeds and initial droplet distributions. Results indicated that sufficient droplets could grow to precipitation size, and become radar-detectable upon reaching 7 km above cloud base if they had been assigned a realistic droplet spectrum at the base along with suitable initial conditions. It was emphasized that growth by condensation plays a vital role in determining the time before the onset of rapid growth by coalescence. During the discussion it was remarked that the computational technique might have some effect on the model's results.

An afternoon session continued the same topic under the Chairmanship of Dean H.F. Hitschfeld of McGill. R.G. Lawford, also from McGill, delivered the first paper which described the initial stages of radar-detectable precipitation in cumuloform clouds. In contrast to earlier studies in each of which only one storm was analysed, the author investigated over 85 echoes which evolved within the range of the Alberta Hail Studies radar on July 9, 1971. The effects of the synoptic field and topography on the geographical and temporal distributions of the heights, thicknesses, rates of growth, durations and trajectories of initial echoes were examined. New echoes forming were affected by the stages of development of older, already existing echoes. A descriptive model of the evolution of radar-detectable precipitation was advanced and helped account for the variations of initial echo heights in the same space/time domain.

Next, C.R. Girard of the University of Toronto gave a paper, co-authored by Professor List, dealing with particle kinetics in the physics and dynamics of clouds. It was shown how cloud microphysics could be introduced, with a limited amount of parameterization into dynamic cloud models. The cloud particle spectrum could be mathematically described by means of one additional independent variable, such as droplet or crystal mass, besides space and time coordinates. Processes such as nucleation, condensation, sedimentation, coalescence and breakup can be considered. The role of electrification could also be estimated if electrical charges are specifically related to particle size or mass.

Following this, T.B. Low (University of Toronto) reported on a project with Dr. J.D. McTaggart-Cowan under the supervision of Dr. List. They investigated the effect of water drops (~ 4.9 mm), falling at close to 80% of their terminal velocity, colliding with free falling radar chaff fibre, 25 μm by 10.7 cm. Such chaff has been used extensively as a tracer material for weather radars. In 1 hour of intense rain the chaff fibres would fall 20–40 m farther than they would in clear air, i.e., rain pushes the chaff earthward at a rate which can probably be neglected for most tracer studies. These measurements were in general agreement with results from actual studies. The Chairman suggested that the curl-up of chaff due to drop collision, as shown by Mr. Low, might appreciably affect its ability to be detected by radar.

R.G. Lawford had the honour of closing the session with a further analysis of the radar echo data presented in his opening paper of the afternoon. PPI data were digitized for computer evaluation of storm parameters including maximum echo top, echo duration and vertically integrated rain mass (VIR). The maximum value of VIR in an echo may be useful as an indicator of the time when hail is falling at the surface. Radar data were objectively analysed and examined for short-lived showers as well as severe storms. These techniques, if associated with a radar linked to a data acquisition and computer system, could provide for a real-time analysis of radar data.

Agrometeorology and Micrometeorology

The first two papers in this session chaired by Dr. R.E. Munn were presented by research scientists from Macdonald College; the last two, by those from AES, Toronto. Professor N. Barthakur reported on his work in conjunction with Dr. P.H. Schuepp to measure temperatures of externally irradiated leaves inside a wind tunnel as functions of surface wetness for low ambient temperatures. Two different techniques have been tried for prevention of freezing in plants: spraying the foliage with water, depending on the high specific heat and latent heat of fusion to maintain temperature; and irradiating with microwave energy at a frequency of 2.45 GHz. (S band) with a power density, 0.73 cal cm^{-2} min^{-1}. The spray method is generally effective down to a temperature of about -6°C, but the irradiation method appears to be much preferable. A development program is under way to achieve a practical system for irradiating grape vines. By prolonging the growing season the sugar content of the fruit should be increased to at least 20%.

In the next paper Professor R.H. Douglas described his studies on vertical temperature distributions in corn crops. Daily maximum and minimum temperatures were measured at five levels, from 6 inches to 6 feet. Where the foliage was lush, as in the 1972 crop, daytime maximum temperatures were a little higher (at least 2°F) than at the same level over grass; this difference in effect followed the growth of the corn, rising in height as the plants become taller. Night-time minima were essentially the same either in the crop or over grass. The presence of the crop kept the soil cool and moist, the foliage warmer than its surroundings – the "forest effect". A significant difference in the diurnal temperature behaviour in corn and over grass was also revealed by continuously recorded data for eight levels. Orientation of a corn plot with respect to incident solar radiation apparently made little difference in the temperature distribution.

In the succeeding presentation concerning diffusion of pollution from motor vehicles, Dr. F.H. Fanaki first commented on the magnitude of the problem. In the Toronto area, motor vehicles generate 97% of the CO, 68% of the hydrocarbons and 18% of the oxides of nitrogen. Diesel engines produce smaller amounts of gaseous pollutants than gasoline engines. In work with J. Kovalick, road tests were made on a passenger car and a station wagon; wind tunnel tests, on models. The exhaust plume exhibited three separate regions: the first was the eddy system due to the vehicle itself acting as an obstruction; the second region was a vortex rising to the height of the vehicle; the behaviour in the third region was as if the vortices were coming from a line source moving with the vehicle. The height to which the plume eventually rose depended on both the vehicle size and the degree of temperature instability in the surrounding atmosphere. The paper emphasized the need for back-up of wind-tunnel measurements by field work on moving vehicles.

Dr. Bhartendu's paper described a problem which, it seems, has been only partially solved at this time. Large oscillations in the large-ion count were observed at Woodbridge Meteorological Research Station, of period ½ to 1 hour, being most pronounced in winter. Generally the amplitudes were larger for the negative than for the positive ions. The Aitken nuclei count did not show these oscillations, but the evidence is inconclusive, since the sensitivity of the latter measurement is much lower. The cause of the oscillations was traced to the electrical heating of the building, but the mechanism involved apparently is still not clear.

Remote Sensing

Three sessions in the Congress formed a separate symposium (almost a mini-Congress) and were held on Thursday and Friday concurrently with other sessions. E.G. Morrissey chaired a session with only one paper. He expressed regret that the invited paper by Drs. Harold M. Woolf and William L. Smith (National Environmental Satellite Service, NOAA) on "Satellite Sounding of the Atmosphere" would not be given because of travel-fund difficulties. (Another paper by a U.S. author was not presented later in the program for the same reason.) The keynote paper had been eagerly anticipated by many of the participants.

Mr. Joseph MacDowall described the organization, facilities and programs of the Canada Centre for Remote Sensing. Up to the present there have been two main thrusts to CCRS programs, namely the airborne remote-sensing program and the program for receiving and processing imagery from the U.S. Earth Resource Technology Satellite (ERTS). A smaller financial outlay, which may later pay extra dividends, has involved the contract support of the development of remote-sensing devices by industrial and university groups in Canada. More recently an Applications Division has been created to assist the remote-sensing consumer by developing more products and new methods for looking at these products. The speaker's illustrated examples (including colour slides from ERTS) clearly demonstrated the power of remote sensing as applied to a wide variety of resource and environmental problems. The lengthy question and discussion period showed equally clearly the wide-ranging and keen interest of the audience.

The next session on this subject was chaired by Dr. C.L. Mateer. In the lead-off paper Dr. M.M. Millan (AES, Toronto) described the principles of the correlation spectrometer, an instrument which has been touted by some as the wünder instrument for remote sensing of atmospheric pollutants. He emphasized the problems of data interpretation and evaluation caused by uncertainties in the spectral composition of the light source, spectral reflection properties of the earth's surface, and interference by other atmospheric gases. He suggested that the use of four spectral masks in place of the customary two might improve the interpretation accuracy, as has proven to be the case in the double-difference method used in ozone observations. It was perfectly clear that equally careful attention must be paid to data interpretation/evaluation problems as to instrument design when considering remote-sensing experiments.

Dr. J. Howard Shafer (University of New Brunswick) reported on his current research program with Professor Charles Young (UNB) to determine experimentally molecular parameters for NO_2 and SO_2, taking proper account of the influence of the wings of distant lines of CO_2 and H_2O. Such determinations were necessary so that infrared remote-sensing measurements of these atmospheric pollutants could be interpreted and evaluated. In particular, one of the problems has been that CO_2 lines appear to have a sub-Lorentzian wing profile and detailed line-by-line calculations of transmittance in the NO_2, SO_2 bands overestimate the absorption. The present program is aimed at resolving these problems.

The use of LIDAR in remote-sensing measurements on the atmosphere was described by Dr. S.R. Pal on behalf of a group working at York University, including Dr. A.I. Carswell, J.D. Houston and W.R. McNeil. He outlined the features of the York LIDAR system which permits measurements of the four Stokes parameters of the backscattered radiation. He presented illustrative results for clear and hazy urban air, for the effect of multiple scattering in clouds, and for differentiating between the ice and water phases in clouds. By looking at depolarization ratios for the long (6943Å) and short (~3472Å) ruby laser wavelengths, it is possible to estimate the backscattering contribution by non-spherical particles in the atmosphere.

A laboratory project for determining the atmospheric propagation of CO_2 laser radiation at 9.6 and 10.6 μm was reported on by R.E. Chapman (University of New Brunswick) who is working with Professor Young. The project, which is just getting underway, uses a tunable CO_2 laser source to measure rotational line strengths, collision-broadened widths (for both self- and N_2-broadening) and the variation of the widths with rotational quantum number for the 9.6- and 10.6-μm CO_2 bands.

Dr. J.B. Kerr (University of Toronto and AES, Toronto) presented some results of his research, with Professor A.W. Brewer, on the measurement of total atmospheric ozone in the presence of clouds. Since total ozone measurements utilize the sun as a radiation source and the absorption of solar ultraviolet radiation as the measure of the amount of ozone, clouds have always presented a serious interference problem. By measuring the zenith-scattered light polarized parallel to the solar plane for a triplet of wavelengths, the effects of clouds were found to be eliminated. Evidently, for a double intensity ratio derived from a triplet measurement, all sky conditions appear to be the same as those for thick clouds. This kind of measurement will undoubtedly become standard for routine ozone measuring programs around the world within the next few years.

In the final paper of the session, Professor Young discussed the possible use of CO_2 laser radiation for remote sensing of atmospheric ozone. The first step in an investigation of this possibility is the comparison of laboratory measurements of transmittance with calculated values. For the 9.6-μm band of ozone, these comparisons suggest that the individual rotational lines in this band have super-Lorentzian wings. Adjustments have been made in the calculation model to take account of this difference.

Professor Young also was Chairman of the final session on Remote Sensing. E.G. Morrissey (AES, Toronto) presented results from a pilot project aimed at utilizing aerial stereo-photography of early-morning smoke (or condensation) plumes to "observe" the meso-scale wind field over a city. This would be especially valuable for periods with inversions or high pollution potential. He mentioned the problem of seeing the condensation plume against the snow background on the roofs and the solution of this problem by proper choice of photographic film. From sample results obtained on flights over Ottawa, it appeared that the method could be used although further tests should be carried out before a larger scale program is started.

Dr. J.B. Kerr in his second presentation on the same day reported on some short-lived fluctuations in total ozone which he had observed in Toronto and Jamaica. These variations, which usually lasted about half an hour and were always observed as an increase above background, sometimes amounted to 30% of the background ozone. The variations were of two types: those associated with clouds and those associated with clear skies. For the variations associated with clouds, their amplitudes did not appear to be related to the presence of lightning. For the clear-sky variations, their occurrence at different times in the direct-sun and zenith-sky measurements suggested an advected phenomenon. The need for an automated meso-scale network to investigate the nature of these disturbances was suggested. In the discussion, it was pointed out that ozone is produced in silent discharge and that it did not necessarily follow therefore, that the lack of variation in amplitude with lightning was inconsistent with the extra ozone being produced by cloud electrical effects.

In the final paper of the session, Mr. H.G. Hengeveld (AES, Toronto) described the objectives and nature of the AES ice reconnaissance remote-sensing program. He stressed the limitations of visual observations: limited areal coverage, daylight observations only, cloudiness, etc. Illustrative examples of data records along with their interpretation, were shown for the various sensors, including the aerial cameras, the laser profilometer, the infrared line scanners, and the side-looking airborne radar. Data applications include: real-time use for provision of information about ice in navigable water, accumulation of data for ice climatology, and utilization in special studies.

Weather Forecasting Research

The first session on Friday morning had J.M. Leaver of the Canadian Meteorological Centre as Chairman. Dr. I.D. Rutherford also of the CMC opened this series of papers by discussing a method to update forecasts with real wind and height data in a hemispheric, single-level, P.E. model. The process is that basically used in objective analysis with a trial field, but in this study both the winds and heights were "cross-coupled" for the updating. Unfortunately the method is somewhat prodigal of computer time for operational use, but it yields improved results in objective analysis.

Parameterization of surface friction in a short-range atmospheric prognostic was outlined by Pierre Benoit in a summary of his McGill M.SC. thesis. Turbulence in the planetary boundary layer generated by the surface friction drains energy of the flow and reduces vorticity aloft. This turbulence is of a much different scale than the prognostic model grid-length, and hence is not detected in numerical models unless introduced in parametric form. Benoit's model is superior to Cressman's drag coefficient model, giving better agreement with climatological averages for mid-latitudes. New features added are a locally variable drag coefficient and computations of the cross-isobaric component of the surface stress. Changes in the empirical constants for this "resistance law" model or in the roughness length do not seem to affect prognostic results of the P.E. model used to simulate the atmosphere.

Gerard Piette (CMC, Montreal) spoke on the computation of mixing heights and transport for forecasting air pollution potential. Radiosonde and pibal information are utilized. However, some subjective interpretation of the radiosonde reports by a meteorologist is still required, especially to help define the inversion which caps the mixing layer.

Great emphasis is being placed by the AES Forecast Research Division at Toronto to develop a Regional Update System. In a progress report on this effort Dr. A.L. Bealby indicated that the latest available surface observations are used to update the existing numerical forecast; previously, new input could only be incorporated every 12 hours. The system produces an analysis and a 24-h mean sea level pressure prog each hour. The prog is completed about 40 min after data time, with execution time after data cut-off running to about 5 min. The quality of the results is comparable to that associated with the subjective progs from the Toronto Weather Office.

Applied Meteorology

Professor Roland List as Chairman of the second morning session introduced Ron Robinson of the CMC, Montreal who discussed the tailoring of statistically-produced forecasts to meet user requirements. Usually the standard forecasts which are based on regression analysis are produced under the constraint of minimum rms error. The numerical forecast values of maximum and minimum temperatures are somewhat conservative: 60–70% are correct for near-normal temperatures; only 20%, for more extreme temperatures. If an "inflation factor" is used, 40% accuracy across the board can be achieved. Furthermore, by "hedging" an even higher accuracy can be obtained for near-normal conditions. Thus, it is suggested that the "inflation factor" should be used by local weather offices to tailor forecast products for the benefit of their consumers.

The ultimate in automated-public weather forecasting was described by I.B. Findleton, also of the CMC, Montreal. Worded forecasts of weather conditions are generated for Montreal by pattern recognition techniques (statistical approach) applied to the CMC operational forecast model (dynamic approach). Five 12-h periods (0–60 h) are covered. Input consists of 1000-, 850-, 500-mb height and thickness progs twice daily, plus surface weather reports. The output covers four categories: clear, cloudy, rain and snow. This system which has been running operationally since December 1972 should be extended to the Provincial area during 1974.

The evolution of a numerical weather prediction program in a regional weather office (AES) was described by Don McGeary who presented a paper by S.V.A. Gordon, O.I.C. of the Prairie Weather Central. Some problems tackled by the H/P 2100A computer are: severe instability storms, winter weather (blizzards, snow), forecast output, climatological data, verification and office administration. About 5% of the office budget is devoted to computer operation. This resident system is more convenient than a commercial time-share facility. It is now being expanded to the executive-level to allow for real-time operation.

It would be difficult to categorize the final presentation, since it dealt with meso-meteorology, pollution and remote sensing. However, Professor P.M. Strain (University of New Brunswick) spoke mainly on the latter subject in a paper co-authored with Dr. R.W. Gamble (N.B. Dept. of Fisheries and Environment) and G.P. Semeluk (UNB). He described the portable gas climatograph developed to study atmospheric pollution produced by a pulp mill complex at Nackawic, N.B. in the St. John River valley. The speaker noted that advances in instrumentation for measuring pollutants lag far behind developments in analytical chemistry.

General Meteorology

K.F. Harry was Chairman of the final session of the 1973 Congress. Dr. R.E. "Ted" Munn, this year's recipient of the Patterson Medal, led off by discussing the methodologies of environmental impact studies – studies which should include both environmental *and* economic considerations. He stressed that we must have both jobs *and* a clean environment. "Environmental Impact Assessments" must be a scientific appraisal of a problem rather than just a mere list of objectives. Such reports are often far too lengthy and complex to allow for adequate consideration and too many alternative choices are proposed.

Another meteorologically-oriented topic of much public controversy was discussed next as Dr. B.W. Boville (AES, Toronto) commented on the potential role of supersonic transports in atmospheric pollution. Concern has been expressed that water vapour and nitrogen dioxide may, through photochemical reaction, reduce the concentrations of ozone in the stratosphere, causing climatological change. Direct measurement of the constituents of the stratosphere by the SST's themselves, and by satellites in the near future, should add more to our understanding of this process.

Dr. R.C. Murty (University of Western Ontario) presented a paper on finding the location of lightning (sferics) by use of a VHF direction-finder with two antennae separated by 150 m. Measurements on storms up to 60 mi away showed good agreement with radar observations. A third antenna is being added to remove ambiguities which occur in certain cases.

The AERO-MET observational facility installed at the Canadian Meteorological Research Station near Toronto was described by Oscar Koren (AES, Toronto). Wind, cloud height and visibility readings are some of the data on 64 channels input into a PDP 15 computer. Thirteen 33-ft towers are used, eleven of them in-line to simulate a runway.

Some experiments on convective plumes were outlined by Dr. F.H. Fanaki (AES, Toronto). A "plume" model was studied for both free and forced convection using observations from a wind tunnel as well as from the free atmosphere. Previous studies by other workers had examined the plume as a separate entity. A realistic model, as presented here, should include a group of plumes which interact in a complex manner. For example, the air flowing around a plume produces eddies in its wake where a low pressure region develops, so that another plume downstream of the first one moves upstream until both plumes merge. A number of shadowgraphs on slides were shown to illustrate this and other effects including: bent-over plume with a curl or vortex; joined plumes surmounted by a concave cap which has taken the shape of a thermal.

The Congress concluded with a theoretical study by Dr. M. Shabbar (AES, Toronto) dealing with inertial ranges in three-dimensional quasi-geostrophic turbulence. At scales of atmospheric motion shorter than the baroclinic excitation scales, his theory predicts a more realistic shape for the energy spectra than either the two-dimensional turbulence theory of Kraichnan or the quasi-geostrophic theory of Charney.

ANNUAL GENERAL MEETING

On the evening of the first day the Seventh Annual General Meeting of the CMS was convened at St. Mary's University with 53 members in attendance.

Minutes of the 6th Annual Meeting held on May 31, 1972 at Edmonton were approved. The regular Executive Committee reports were presented including the Treasurer's financial statement for 1972 which was also accepted. As usual the most important item debated was the financial status of the Society. In contrast to previous years when the operating budgets were marginal and allowed very little extra for expenditures beyond the printing of *Atmosphere*, 1973 marks the first year that the CMS will have sufficient funds to "do its own thing". The AES will provide grants of $6500 and $10,000 during 1973 and 1974, respectively, and these will be used principally to provide more monetary support to the Centres for their activities, and to the National Executive for their increasing scope of responsibilities to serve the scientific community and the Canadian Public.

In regard to the latter, within the next year the CMS will assume a role formerly occupied by SOMAS of NRC regarding meteorological policies for Canada. This Subcommittee on Matters relating to Atmospheric Science replaces the CMS Subcommittee on Scientific and Professional Matters and in its enlarged role will consider (at least initially) many wide-ranging meteorological problems including: a manpower survey of the Profession in Canada; the exploration of future relations with CAP (mainly the aeronomers); in addition the GARP scientific committee will report to SOMAS.

Future locations for the CMS Congresses were discussed. Toronto Centre's invitation to host the next (1974) Congress was accepted. Vancouver Centre offered to host the 9th Annual Congress. A possibility for a joint meeting with the French Meteorological Society was being explored. Members were favourably disposed to recouple the CMS Congress with the meetings of the CAP or the Learned Societies; this would likely occur in 1976 at Laval with the latter. Some thought was also given to a recommendation for a Weathercaster's Conference to be sponsored by the CMS.

Society Prizes were formally announced. The *President's Prize* was awarded to Professor T.R. Oke (UBC) for his important contributions to urban meteorology; the *Prize in Applied Meteorology*, to Dr. P.W. Summers (Alberta Research Council) for his many important contributions to the design and technological problems of weather modification experiments culminating in the airborne flare system now proven and in use in Alberta and elsewhere; the *Graduate Student Prize*, to L. Ettinger (McGill University) for his M.SC. work on variable static stability as a factor of importance in modelling atmospheric flow; the *Dr. Andrew Thomson Undergraduate Student Prize*, to Carole Dyck, for her paper (with R. List and W.A. Murray) which made a significant contribution to the study of hailstones and their growth through icing.

The CMS National Office for 1973–74 will be located in Montreal, for the first time outside of Toronto. Professor Hitschfeld as incoming President stressed the need to rotate the National Executive about the country. After thanks had been extended to members of the previous Executive for their efforts the meeting adjourned at 9:40 p.m.

In Appreciation

The following persons are gratefully acknowledged for recording the proceedings of the Seventh Annual Congress for this issue of *Atmosphere.*

Bhartendu	J.B. Kerr	C.F. MacNeil	J.C. Pearce
E.F. Caborn	O.Koren	C.L. Mateer	W.R. Smith

G.A. McKay and Dr. P.W. Summers

J.R.H. Noble and Dr. R.E. Munn

ASSOCIATED EVENTS

Members gathered together on Thursday evening for the Annual Society Banquet at the Shore Club, Hubbards Beach, where lobster was the main course. The Maritime flavour was enhanced further by the fog (of the Scotch Mist variety) which persisted during a pleasant and interesting tour of the coast and a visit to Peggy's Cove. However, the weather dampened neither the spirits of the members nor the liveliness of the proceedings when CMS and AES awards were presented.

Drs. Tim Oke and Peter Summers were there to receive Society prizes (see page 119). For the first time, the CMS awarded citations in recognition of outstanding contributions in the increasing national effort to alleviate pollution problems or to develop environmental ethics. Recipients were: Dr. David V. Bates (UBC), Pollution Probe (University of Toronto), and the Ontario Ministry of the Environment Air Management Branch.

Dr. R.E. Munn was presented with the Patterson Medal by J.R.H. Noble, Assistant Deputy Minister, AES, in recognition of his numerous activities in the fields of micrometeorology and the environmental sciences, and in particular for his work on the meteorological aspects of air pollution. "Ted" is currently serving as a member of SCOPE (Scientific Committee on Problems of the Environment) and is Co-Chairman of two Commissions: Simulation Modelling; Environmental Monitoring and Assessment. Recently he was appointed to the Bureau of SCOPE.

AIR POLLUTION AND ATMOSPHERIC DIFFUSION. Edited by M.E. Berlyand, translated from Russian by A. Baruch, Israel Program for Scientific Translations, John Wiley and Sons, Toronto, 1973, 221 pp., $21.50 (U.S.).

This collection of 19 papers includes contributions on many aspects of air pollution meteorology and chemistry. The book is a translation from the Russian (Gidromet., Leningrad, 1971) and the individual papers contain references up to the year 1970. With the rapid advances that are taking place in our understanding of air pollution in the USSR and elsewhere, this volume is therefore already rather dated. Nevertheless, the English translation is welcomed, providing useful insight into the approaches being taken by Soviet meteorologists in their search for practical solutions to a large number of pollution problems. For example, on page 2 mention is made of a 1967 report, "Instructions for calculating the dispersion of harmful substances in the atmosphere (dust and sulfur dioxide) contained in the discharges of industrial enterprises: SN 369–67", which has been "approved by the USSR Gosstroi as *compulsory* specifications in the design and running of plants".

The book contains a large number of typographical errors; on page 1, for example, a "meteorogist" is presumably a meteorologist. For this reviewer at least, however, the text is easier to read than the original Russian.

R. E. Munn
Atmospheric Environment Service
Toronto

WORKSHOP ON MICROMETEOROLOGY. D.A. Haugen (Ed.). American Meteorological Society, Boston, Mass., 1973, 392 pp., $30.00 (U.S.); $24.00 (U.S.), (AMS members).

In August 1972, the American Meteorological Society sponsored a Workshop on Micrometeorology. Its purpose was "... to provide a fairly intense and comprehensive review of current micrometeorological theory and practice ..." and it was aimed at the non-specialist in micrometeorology. During a period of five days, lectures were given by eight specialists in the field. An outgrowth of these lectures is the publication of this book under review.

The first chapter in the book is an introduction to the mechanics of atmospheric turbulence by N.E. Busch. This is followed by two chapters on surface layer turbulence and turbulent transfers by J.A. Businger and J.C. Wyngaard, respectively. The next chapter, by H.A. Panofsky, focuses its attention on the so-called "tower layer". General discussions on similarity laws and scale relations of the whole of the planetary boundary layer are the subjects of Chapter 5 by H. Tennekes. The last three chapters deal with three approaches to numerical modelling of the atmospheric boundary layer. These are by M.A. Estoque, J.W. Deardorff and C. duP. Donaldson. Each chapter corresponded to a lecture given by the author. The Workshop was organized by D.A. Haugen of AFCRL who also edited the book.

As with most books in which each chapter is written by a different author, the quality and depth of coverage varies from chapter to chapter. However, the overall quality is good and no significant errors in treatment were noted. Only a few misprints were found. One example occurs in equation 25 on p. 153 where there should be an exponent of −1 for the bracketted term. Another is the subscripts on the covariance terms in equation 3.7 on p. 7. These errors should be readily apparent to the attentive reader. One of the most important concepts in micrometeorology is that of similarity theory and it is discussed in most of the chapters. However, it is only after the first three chapters have been read that the novice will really begin to understand how the relationships "follow" one another. The last three chapters present a marked contrast on how specialists approach numerical modelling and how they describe their methods to the uninitiated. Chapter 6 by Estoque takes the "cook book" approach and outlines in fair detail the finite-difference equations and methods of computation of his straightforward planetary boundary-layer models. It should be easily understood by the novice but he may be lured into believing that there are no limitations to the approach (which there are). Deardorff, in Chapter 7, also gives some finite-difference equations but his approach is at a much more specialist level. It is unlikely that the novice will be able to follow much of the discussion without additional reading. However, after mastering this chapter the reader will be able to appreciate the advantages, limitations and problems of numerical modelling. In the last chapter Donaldson presents an aeronautical engineering approach to turbulence and diffusion modelling. One gets the impression that the resulting model has so many adjustable "constants" that it can be made to produce any desired result. No finite-difference equations are given but the chapter does have a good discussion of the variance budget equations.

One significant omission from the book is any discussion of the instruments used to collect the all-important data. In micrometeorology the instrumentation used is definitely non-standard and the interpretation of the data must always be tempered with a knowledge of the limitations of the instruments. The only discussion of the limitations of experimental data is that by Wyngaard who points out the problems of obtaining a good statistical average in the real atmospheric boundary layer.

The most important asset of this book is that it is a right-up-to-date account of the field of micrometeorology. The bibliographies of each chapter contain many references from the 70's. Further, since each author was free to discuss what he felt was important, some of the ideas covered had not been published before the book appeared. Two examples are Tennekes' discussion of the log-law and Bussinger's approach to convective velocity scaling. The latter still needs a little more explanation to be completely believable.

It seems traditional in reviews to end with the comments that the price is too high (which in this case is certainly true: $30.00 for non-AMS members, $24 for members) but that the book would be a valuable additon to a library. I think this book will indeed be a valuable addition to a library. Every departmental library should have one and I would recommend it for a spot on the desk of every micrometeorologist. Although the book has its limitations it is an up-to-date account of the state of the art and its scope, as presented by eight of the best in the field, is better than will be found in any single book.

G.A. McBean
Atmospheric Environment Service
Toronto

Bibliography of the Naval Arctic Research Laboratory

Arctic Institute Technical Paper No. 24 is a bibliography of publications which have resulted from work done at the Naval Arctic Research Laboratory at Point Barrow, Alaska, containing data originating from NARL, or, acknowledging assistance from NARL to the author. The bibliography reflects the basic research concerns of NARL over the past 25 years. That is to say that it is firmly based in the physical and technological sciences. The effects of this research are sufficiently broad in scope, however, to make this volume a useful reference tool for the arctic researchers in many other fields; as well as students, scientists, librarians, industrial and government administrators.

The 2,426 entries include scientific and technical reports, graduate theses, journal articles and books. Wade Gunn is technical editor. Orders for the 175-page book may be placed through:

The Arctic Institute of North America
1619 New Hampshire Avenue NW
Washington, D.C. 20009, U.S.A.

Price is $7.50 (U.S.) with no handling charges on prepaid orders.


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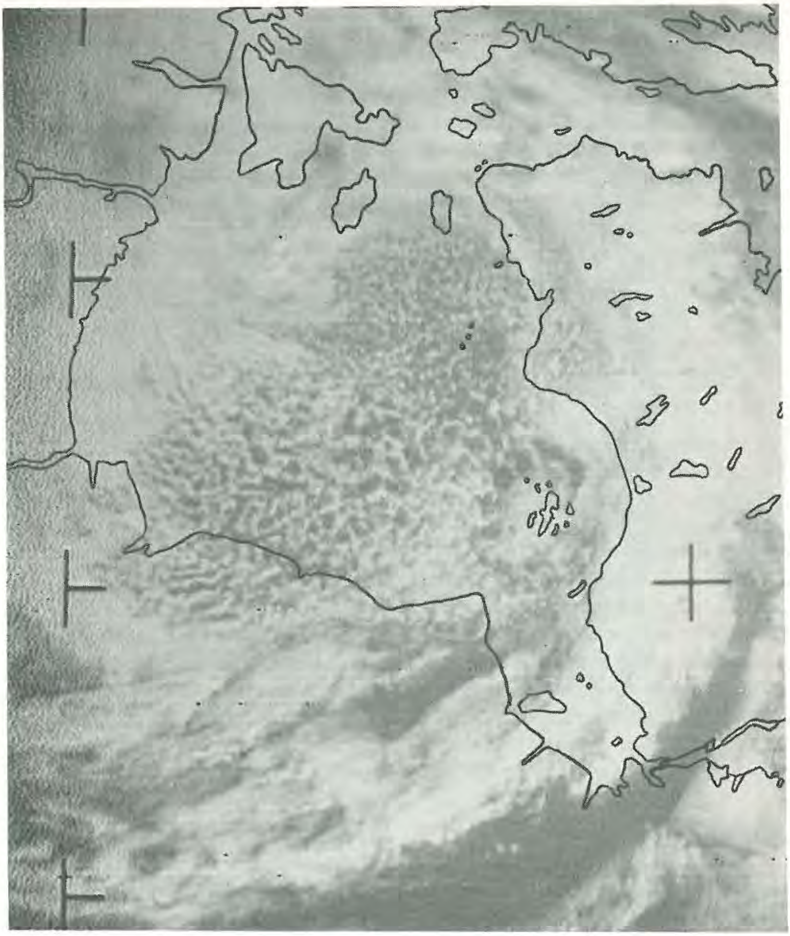
July snow 10''
22° Aug. CLo
Aug. sunshine 46 hr
Aug. sunshine 171 hr
8'' Snow 15-17th/Aug Crop damage
Aug. snow
CLo trace rain July
June 8.5'' rain
101° 15/July Forest fires
Aug. 7'' rain
Aug. rain 1.18'' NMR
June snow 6''
Snow 1/July
Summer drought
CHi 103° NR 10/July
Storm, floods 27/Aug. 3.5'' rain
CHi Aug. sunshine 340 hr
18/Aug. storm damage Wind 76 mph
Aug. mean +8° normal
June 5.8'' rain NMR
July 9.13'' rain mudslides
Summer rain 20''
11-12/Aug. 8''
Rain, floods
Aug. 6.8'' NMR rain
Snow in June
Summer rain 13''
June 8'' rain NMR
Hurricane Alice 6/July
17–18/June Storm – 70 mph winds
CHi June 8.5'' rain
Tornado 13/July
Storm 13/July
Heavy property damage
Aug. 0.2'' rain NR low
98° max. Aug.
Water temp +4° normal
June mean 70°



Hudson Bay As a Heat Source

The first autumn outbreak of cold air across Hudson Bay shows up on this ESSA 8, APT photograph for 17 September, 1973. Open-cell convection pattern over Hudson Bay indicates very rapid heating of the cold airmass through a deep layer in a cyclonically curved flow. Temperatures at Baker Lake were −4°C at the surface and −13°C at 850 mb. Poste-de-la-Baleine reported a surface temperature of 3°C with snowshowers.

W.D. Lawrynuik

NOTICE TO CMS MEMBERS

Membership dues for 1974, as determined at the Seventh Annual Congress of the CMS, stand as follows:

General Member	$15.00
Student Member	$ 5.00
Sustaining Member	$50.00 (min.)

CALL FOR PAPERS – EIGHTH ANNUAL CONGRESS

The Eighth Annual Congress and Annual General Meeting of the Canadian Meteorological Society will be held at York University, Toronto, Ontario, May 29–31, 1974. The theme of the Congress will be *Meteorology and the Community* and it is intended to emphasize the interface between meteorologists and the general public. Papers on weathercasting, urban meteorology and other aspects of the theme topic are particularly invited. Other sessions on cloud physics, dynamic meteorology, micrometeorology and atmospheric electricity are expected.

Members and others wishing to present papers at this meeting should send titles and definitive abstracts (preferably less than 300 words) to the Program Chairman, Dr. G.A. McBean, Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ontario, M3H 5T4, no later than **March 1, 1974.**

Information on registration, accommodation, etc. will be provided in due course. R.A. Miller of the Atmospheric Environment Service is Local Arrangements Chairman for the Congress.

CALL FOR NOMINATIONS – 1973 AWARDS

Nominations are requested from members and Centres for the 1973 Society Awards to be presented at the 1974 Annual Meeting. Four awards are open for competition: 1) the President's Prize for an outstanding contribution in the field of meteorology by a member of the Society; 2) the Prize in Applied Meteorology for an outstanding contribution in the field of applied meteorology by a member; 3) the Graduate Student Prize for a contribution of special merit by a graduate student; and 4) the Dr. Andrew Thomson Undergraduate Student Prize for a contribution of special merit by an undergraduate student. The awards will be made on the basis of contributions during the 1973 calendar year. Nominations should reach the Corresponding Secretary not later than March 1, 1974.

NEW EDITORIAL ADDRESS

Editorial correspondence and manuscripts for *Atmosphere* should be sent to the following address:

Dr. I.D. Rutherford
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Dorval, P.Q. H4Y 1A8

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. At nine local centres of the Society, meetings are held on subjects of meteorological interest. *Atmosphere* as the official publication 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, P.O. Box 160, Ste-Anne-de-Bellevue, P.Q. H9X 3L5

There are three types of membership – Member, Student Member and Sustaining Member. For 1973 the dues are $15.00, $5.00 and $50.00 (min.), respectively. The annual Institutional subscription rate for *Atmosphere* is $10.00.

Correspondence relating to CMS membership or to institutional subscriptions should be directed to the University of Toronto Press, Journals Department, Front Campus, Toronto, Ontario, Canada M5S 1A6. Cheques should be made payable to the University of Toronto Press.

La Société météorologique du Canada a été fondée le 1er janvier 1967, en remplacement de la Division canadienne de la Société royale de météorologie, établie en 1940. Cette société existe pour le progrès de la météorologie et toute personne ou organisation qui s'intéresse à la météorologie peut en faire partie. Aux neuf centres locaux de la Société, on peut y faire des conférences sur divers sujets d'intérêt météorologique. *Atmosphère*, la revue officielle de la SMC, est distribuée gratuitement à tous les membres. À chaque printemps, la Société organise un congrès qui sert de Congrès national de météorologie.

Toute correspondance concernant les activités de la Société devrait être adressée au Secrétaire-correspondant, Société météorologique du Canada, C.P. 160, Ste-Anne-de-Bellevue, P.Q. H9X 3L5

Il y a trois types de membres: Membre, Membre-étudiant, et Membre de soutien. La cotisation est, pour 1973, de $15.00, $5.00 et $50.00 (min.) respectivement. Les Institutions peuvent souscrire à *Atmosphère* au coût de $10.00 par année.

La correspondance concernant les souscriptions au SMC ou les souscriptions des institutions doit être envoyée aux Presses de l'Université de Toronto, Département des périodiques, Campus Front, Toronto, Ontario, Canada, M5S 1A6. Les chèques doivent être payables aux Presses de l'Université de Toronto.