MEASUREMENTS OF THE PROPERTIES OF HIGH ELEVATION FOG IN QUEBEC, CANADA

Robert S. Schemenauer
Atmospheric Environment Service
Downsview, Ontario M3H 5T4
Canada

Peter H. Schuepp and Selim Kermasha
MacDonald College, McGill University
Ste. Anne de Bellevue, Quebec H9H 1C0
Canada

Pilar Cereceda
Pontificia Universidad Catolica de Chile
Casilla 114-D, Santiago, Chile

ABSTRACT. The Chemistry of High Elevation Fog (CHEF) programme is operational twelve months a year on two mountains (Mt. Tremblant and Roundtop Mtn.) in Quebec, Canada and for four months on a third mountain (Mt. Épaule), all having maximum elevations of 970 m. Measurements include: fog water chemistry, precipitation chemistry, ozone concentrations and meteorological observations. Field observations indicate that the summit of Roundtop Mtn. is in cloud about 44% of the time. The mountain (above 457 m) has an estimated forest exposure to acidic fog of 10^5 km^2 h y^{-1}. In autumn 1985 the daily median Roundtop summit fog pH was 3.8 (mean 3.7), and the median precipitation pH 4.55 (mean 4.3). At Mt. Tremblant the values were 3.9 (mean 3.8) and 4.3 (mean 4.25) respectively. In spring 1986 the daily median fog pH on Mt. Tremblant was 4.0 (mean 4.0) and the precipitation pH 4.5 (mean 4.4). The $NO_3^-/SO_4^=$ equivalents ratios in the spring fog water and precipitation were in the 0.4 to 0.5 range with concentrations of NO_3^- and $SO_4^=$ enhanced by a factor of 5 to 10 in the fog water.

1. INTRODUCTION

Concern over the possibility of a major forest decline problem has been slow to develop in Canada. This is not because of any lack of awareness of the nature and extent of the problem in Europe, but rather because field observations supporting a serious health problem with Canadian forests were absent in the early 1980s. Morrison (1984) reviewed the literature on acid deposition effects in forest ecosystems

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and concluded that laboratory and isolated field studies had demonstrated some effects but large scale damage to forests from acid rain was unproven. The situation has changed significantly, however, in the last several years as a result of repeated reports of forest dieback problems at higher elevations in the eastern United States and as a result of a survey of hardwood forest damage (primarily sugar maple, Acer saccharum Marsh) in the province of Quebec in 1985. The survey showed substantial areas of damage in an area (~3 x 10^4 km^2) south of the St. Lawrence river. In some portions surveyed, > 50% of the trees showed a noticeable loss of foliage and dead branches. The impact of this problem on the maple syrup industry has resulted in heightened public and scientific awareness of potential damage to our forests from all causes including atmospheric deposition.

This paper describes results from the Chemistry of High Elevation Fog (CHEF) programme. CHEF was designed to examine the nature and extent of wet and dry atmospheric deposition to high elevation eastern Canadian forests.

Schemenauer (1986) has extensively reviewed the background of CHEF and its close links with the United States Mountain Cloud Chemistry Project (MCCP). The principle objective of MCCP (and CHEF) is to provide air chemistry and meteorological support to studies of the effects of atmospheric deposition on higher elevation forests in eastern North America. A secondary objective is to monitor selected gaseous and particulate air pollutants and the concentrations of pollution related ions in cloud water over an extended period of time in order to estimate time trends in such data.

Cowling (1985) in his comments on the review paper of McLaughlin (1985) states that with the exception of some direct effects of ozone on forests and of the combination of ozone and acid mist "all the presently available evidence indicating a possible role of airborne chemicals in the current 'declines' of forests in Europe and North America is circumstantial". CHEF has adopted the approach of looking first at fog water chemistry (from 1985), then at ozone concentrations (from May 1986) and finally at other atmospheric chemicals as resources permit in keeping with Cowling's conclusions.

2. SAMPLING PROTOCOLS AND INSTRUMENTATION

CHEF operated two sites in 1985: Mont Tremblant (46°13'N, 74°33'W) with a maximum elevation of 970 m and the main observing location at 860 m; and Roundtop Mountain (45°05'N, 72°33'W) with a maximum elevation of 970 m and the main observing location at 845 m. For the summer of 1986 a third site was added at the Montmorency Forest (47°19'N, 71°10'W) again with a maximum elevation of 970 m which was also the main sampling location. Data discussed here will only be from the first two sites.

Each site has a building equipped for year-around operation. A roof-top platform contains standard instrumentation to measure wind speed, wind direction, temperature, relative humidity, pressure, solar radiation and precipitation amount (in summer). A pair of passive fog water collectors and a pair of passive collectors for precipitation chemistry are also roof-mounted as is the inlet for the ozone analyser. The fog water collector is of the Whiteface Mtn. (ASRC) design. It has ~ 370 vertical Teflon fibres ~45 cm long with a diameter of 0.53 mm spaced ~3 mm apart in two concentric circles resulting in a cross sectional surface area of ~880 cm^2. The precipitation sample comes from a 50 cm diameter plastic container in which a sterile polyethylene bag is placed prior to each precipitation event, rain or snow.

An operator visits the main sampling building and each sub-location on a daily basis. The meteorological and ozone data are recorded continuously on data loggers with a 15 min averaging period. The wet chemistry samples are collected on an event or sub-event basis depending on sample volume and operator availability. During the normal work day sample periods can be as short as one hour. Overnight samples can extend for 16 to 24 hours. CHEF is designed to sample every fog (cloud on the mountain) and precipitation event during the course of the year and at several different elevations at each site if practical. Valley precipitation, at ~250 m, is continuously monitored for comparison purposes.

The data of Schemenauer (1986) indicate that the summit (970 m) of Roundtop Mtn. is in cloud ~44% of the time, the ridge location (845 m) ~38% and a lower ridge (530 m) ~23%. This results in a substantial number of sampling opportunities and as will be seen below a substantial forest exposure to acidic fog.

3. ANALYSIS

The pH measurements on the samples were made in the laboratory with a Corning model 145 pH meter. Measurements were made two weeks (or more) after collection following storage and shipping at ~4°C. The laboratory values agreed well (± 0.1 pH units) with the values measured in the field by the site operator shortly after collection.

The samples were analysed for concentrations of anions (Cl^-, NO_3^-, $SO_4^=$) and cations (Na^+, NH_4^+, K^+, Ca^{++}, Mg^{++}) by High Performance Liquid Chromatography utilizing an IC-PAK Waters column and a Waters pump model 590. The samples were filtered using a Millipore HV 0.45 µm filter and injected with an automatic injector (Waters model WISP 710). The conductivity detector was a Waters model 430 and the chromatograms produced by a Shimadzu C-R3A chromatopac integrator. Detection limits were estimated to be 0.02 ppm for Cl^-, Na^+ and NH_4^+, 0.03 ppm for NO_3^-, $SO_4^=$, K^+ and Mg^{++} and 0.04 ppm for Ca^{++}. The ion chromatograph became operational in late spring of 1986. Only a portion of the analyses from 1986 are available at this time.

Both the fog water samples and the precipitation samples were collected by exposing a pair of identical collectors for the same time interval. This resulted in a set of simultaneous sample pairs which could be screened for possible contamination. In practice, 7% of the samples might be rejected due to notes made by the site operator of possible contamination, usually wind blown material in the precipitation samples. About 3% of the samples are rejected due to a significant difference in the concentration of a major ion between sample pairs. As an example of the agreement in analysis between the accepted sample pairs, the 17 fog sample pairs discussed in the next section had a median difference in $SO_4^=$ concentration of 4 μeq l^{-1} (0.20 ppm) compared to a sample median and median daily median $SO_4^=$ concentration of 199 μeq l^{-1}. The median difference in NO_3^- concentration between sample pairs was 1.9 μeq l^{-1} compared to a sample median NO_3^- concentration of 65 μeq l^{-1} and a median daily median NO_3^- concentration of 119 μeq l^{-1}. The median difference in concentrations between the accepted pairs of simultaneous samples is about 2% of the reported median concentrations for the species.

4. FOG AND PRECIPITATION CHEMISTRY

In this section the chemistry of the fog water and precipitation samples from the spring of 1986 at Mt. Tremblant will be compared to measurements from late summer and fall of 1985 at Mt. Tremblant and Roundtop Mtn. In addition, the compatibility of the measurements with those of a detailed aircraft and surface cloud chemistry project in the winter of 1984 will be explored. Only the H^+, NO_3^-, $SO_4^=$ and NH_4^+ concentrations will be discussed at this time.

4.1 Spring 1986 Surface Data

The Mt. Tremblant data from March, April and May of 1986 are given in Table I. The samples are divided into 3 categories: fog; precipitation (almost all rain); and mixed fog and precipitation samples from the Teflon string collector. The data are presented in 3 ways to illustrate the effects of the type of presentation on the data. Mean values are presented in Table Ia), medians of all the samples in Ib) and medians of the daily median values in Ic). Isaac and Daum (1986) argue that the latter presentation is the most reasonable for this type of data since it removes any weighting effect due to some days having more samples than others. The one negative aspect of this approach is that the number of sample days is less than the number of samples which can be a problem in small data sets. The major conclusions from the Table remain unchanged as one moves from Ia) to Ic) but there are some noticeable shifts in emphasis. For example, the difference between fog and precipitation H^+ concentration is similar but the fog plus precipitation category moves closer to the precipitation only value. Also the difference in $NO_3^-/SO_4^=$ ratios between fog and precipitation is increased. In the discussion below we will make use of the values in Table Ic).

The median daily median fog water pH value is 3.98 compared to a summit precipitation pH of 4.49. This represents 3.3 times as much H^+ in the fog water, 104 versus 32 μeq l^{-1}. The valley precipitation has essentially the same pH (4.46) as the precipitation at the summit (4.49). The median daily median mixed fog and precipitation pH value, 4.35, is closer to that of precipitation alone and argues that when

Table I a)

Location	Elevation (m)	Number of Samples	H$^+$ (μeq ℓ$^{-1}$)	pH from H$^+$	$\frac{NO_3^-}{SO_4^=}$	Sample Composition
Pic White	860	17	108 ± 62	3.97	0.52	fog
" "	860	32	93 ± 96	4.03	0.51	fog + precip
" "	860	25	39 ± 38	4.41	0.57	precip
Valley	275	27	48 ± 39	4.32	0.57	precip

Summary of the data collected at the two sampling locations at Mt. Tremblant during March, April and May 1986. Each "sample" is the mean of a simultaneous sample pair. Data are means of all the samples. The equivalents ratio for NO_3^- to $SO_4^=$ is given.

Table I b)

Location	Elevation (m)	Number of Samples	median H$^+$ (μeq ℓ$^{-1}$)	pH	$\frac{NO_3^-}{SO_4^=}$	Sample Composition
Pic White	860	17	113	3.95	0.57	fog
" "	860	32	54	4.27	0.32	fog + precip
" "	860	25	30	4.52	0.41	precip
Valley	275	27	35	4.46	0.43	precip

As for I a) but medians of all the samples.

Table I c)

Location	Elevation (m)	Number of Samples	median day H$^+$ (μeq ℓ$^{-1}$)	pH	$\frac{NO_3}{SO_4}$	Sample Composition
Pic White	860	17 (7)	104	3.98	0.53	fog
" "	860	32 (25)	45	4.35	0.33	fog + precip
" "	860	25 (24)	32	4.49	0.40	precip
Valley	275	27 (27)	35	4.46	0.43	precip

As for I a) but medians of the daily median values. The sample number in parentheses results from grouping the data by day.

rain and fog occur simultaneously the major portion of the water in the passive Teflon string collector is from the rain. This agrees with the conclusion of Schemenauer (1986). A "hat" type cover is not used to shield the fog water collector due to the possibilities of contamination due to blow-off and run-off. A sample is considered mixed when there is evidence during the collector exposure period of rain from the operator's observations, the recording rain gauge or the precipitation chemistry sampler.

The median daily median $NO_3^-/SO_4^=$ ratio is higher (0.53) in fog than in rain (0.40) at the same altitude. This difference is larger than if one examines the means, 0.52 versus 0.57 and in the opposite direction. The valley precipitation values are similar (slightly higher) to those on Pic White. The median daily median fog plus precipitation value of 0.33 is lower than that of fog or precipitaton alone. It is difficult to draw conclusions regarding these differences due to the natural variability of the fog and precipitation events. Castillo (1984) also found this for summer cloud water $NO_3^-/SO_4^=$ values at Whiteface Mtn., N.Y. The variability is well illustrated by Table II in which all of the fog samples are listed for this period. Fog samples from March and April are few in number because most were mixed with precipitation. Since airmass origins can change seasonally and annually it points to the value of having a long record in order to state median values with some degree of confidence. The alternative is to take the case study approach and examine one episode in depth in order to try to understand the processes active at the time. An example might be 23 May 1986 where 5 consecutive fog samples were obtained and the pH dropped from 4.80 to 3.95 while the $NO_3^-/SO_4^=$ ratio seemed to rise and then fall.

A summary of the July to December 1985 data from the Mt. Tremblant and Roundtop Mtn. sites is given in Table IIIa) (mean values) and Table IIIb) (medians of daily medians). Most of the fog only values are from September and October. The median pH (3.88) of the autumn fog samples at Pic White on Mt. Tremblant is slightly lower than that for the spring of 1986 discussed above (3.98). The median values for the small number of samples at the summit (3.80) and the high elevation ridge (3.96) of Roundtop Mtn. in the autumn also fall in the same range. The Mt. Tremblant precipitation values for the autumn at the summit (4.30) and the valley (4.17) are also slightly lower than the corresponding values for the spring (4.49 and 4.46). The Roundtop Mtn. values for autumn 1985 at the summit (4.55) and valley (4.21) locations are again comparable to the spring data.

This look at the data from the two sites in the autumn of 1985 and the Mt. Tremblant site in two seasons (autumn 1985 and spring 1986) shows that the fog water acidity is consistently about 3 times higher than precipitation acidity on the upper part of the mountains. In addition, the autumn data in particular suggests lower pH values for precipitation in the valley as opposed to near the summit. This may be largely due to evaporation but scavenging may play a role. The $NO_3^-/SO_4^=$ ratios for the spring data fall in the 0.4 to 0.5 range. The general agreement in fog water (and precipitation) acidity levels in the autumn and spring is perhaps understandable in terms of an almost

Table II

Date 1986	Sample #	pH	H^+ ($\mu eq\,\ell^{-1}$)	$\frac{NO_3^-}{SO_4^=}$	Comments
March 4/5	5/6	3.69	205	0.53	24 h
April 7/8	7/8	3.98	104	0.75	24 h
May 6	21/22	3.76	174	0.33	1100-1200 EST
6	23/24	3.70	200	0.36	1200-1400
6	25/43	3.83	147	0.49	1400-1500
6	26/27	3.93	118	0.61	1500-1530
7	39/40	4.24	58	0.77	1300-1400 EST
7	41/42	3.90	125	0.66	1400-1500
8	46/51	4.10	79	0.23	1130-1300 EST
8	52/53	3.76	172	0.21	1300-1400
8	54/55	3.79	164	0.19	1400-1530
23	120/121	4.80	16	0.57	0930-1030 EST
23	122/123	4.59	26	0.70	1030-1130
23	124/125	4.36	44	0.78	1130-1230
23	126/127	4.17	67	0.76	1230-1400
23	128/129	3.95	113	0.69	1400-1515
24	138/139	4.54	29	0.18	
		3.97	108.3± 62.2	0.52± 0.22	N=17

Listing of the fog samples collected at Mt. Tremblant during March, April and May 1986. Each value in columns 3, 4 and 5 is the mean of a simultaneous sample pair. The mean pH is from the mean H^+ concentration. The $NO_3^-/SO_4^=$ ratio is from concentrations in $\mu eq\ \ell^{-1}$.

Table III a)

Location		Elevation (m)	Number of Samples	$\overline{H^+}$ (μeq l^{-1})	$\overline{pH}$ from $\overline{H^+}$	Sample Composition
Mt.Tremblant	Pic White	860	20	153.2± 95.9	3.82	fog
" "	Mid-level	590	2	73.4± 3.6	4.13	fog
" "	Pic White	860	35	87.3± 83.6	4.06	fog + precip
" "	Mid-level	590	16	80.1± 62.5	4.10	fog + precip
" "	Pic White	860	49	55.9± 37.9	4.25	precip
" "	Valley	275	25	74.1± 45.2	4.13	precip
Roundtop	Summit	970	4	196.2±182.1	3.71	fog
"	Ridge	850	2	110.4± 43.8	3.96	fog
"	Summit	970	8	84.3± 33.8	4.07	fog + precip
"	Ridge	850	3	46.5± 26.7	4.33	fog + precip
"	Summit	970	24	48.1± 47.4	4.32	precip
"	Ridge	850	9	92.3± 22.7	4.04	precip
"	Valley	245	49	77.3± 64.8	4.11	precip

Mean values of H^+ concentration for the data collected at the different sampling locations at the Mt. Tremblant and Roundtop Mtn. Sites from July to December 1985. Each precipitation sample is the mean of a simultaneous sample pair; most fog samples were single samples. From Schemenauer (1986).

Table III b)

Location	Elevation (m)	Number of Samples	median H$^+$ (μeq l^{-1})	pH from med. H$^+$	Sample Composition
Mt.Tremblant Pic White	860	20 (15)	132	3.88	fog
" " Mid-level	590	2 (2)	73	4.14	fog
" " Pic White	860	35 (32)	73	4.14	fog + precip
" " Mid-level	590	16 (16)	69	4.16	fog + precip
" " Pic White	860	49 (48)	50	4.30	precip
" " Valley	275	25 (25)	68	4.17	precip
Roundtop Summit	970	4 (4)	160	3.80	fog
" Ridge	850	2 (2)	110	3.96	fog
" Summit	970	8 (8)	82	4.09	fog + precip
" Ridge	850	3 (3)	48	4.32	fog + precip
" Summit	970	24 (24)	28	4.55	precip
" Ridge	850	9 (9)	98	4.01	precip
" Valley	245	49 (48)	61	4.21	precip

As for Table IIIa) except the H$^+$ concentrations are medians of the daily median values. The sample number in parentheses results from grouping the data by day.

constant molar ratio of SO_x to NO_x emissions throughout the year in the northeastern United States (Summers and Barrie, 1986), and an approximate equivalence in autumn and spring in the incoming solar radiation which in part controls the production rates of NO_3^- and $SO_4^=$.

4.2 Comparison with Aircraft Data

Isaac and Daum (1986) report on the results of an extensive aircraft and surface observation study conducted near North Bay, Ontario during January and February 1984. This location is about 400 km due west of Mt. Tremblant. Both locations are in areas which are 100 km or more from major pollution sources. Table IV compares some of the winter data from North Bay to the autumn and spring data from Mt. Tremblant.

Table IV

Species	Season	Cloud/Fog Water	Precipitation High Elevation	Precipitation Low Elevation
pH	autumn	3.88	4.30	4.17
	winter	3.59	4.55	4.22
	spring	3.98	4.49	4.46
$SO_4^=$	autumn	-	-	-
(μeq l^{-1})	winter	255.0	22.5	44.0
	spring	199	32	39
NO_3^-	autumn	-	-	-
(μeq l^{-1})	winter	164.0	22.4	91.0
	spring	119	16	22
$NO_3^-/SO_4^=$	autumn	-	-	-
	winter	0.70	0.62	1.40
	spring	0.53	0.40	0.43

Median daily median values for three seasons of the year. The autumn and spring CHEF project values are for Mt. Tremblant, Quebec. The winter values are from Isaac and Daum (1986) for the North Bay, Ontario aircraft and ground data.

The aircraft cloud water samples were collected at a median altitude (1.2 km) comparable to that on the mountain (0.9 km) but the aircraft precipitation samples were collected somewhat higher (1.9 km).

The basic agreement between the data sets is very good. Cloudwater pH values are lower than in precipitation, and precipitation aloft (CHEF Pic White) has higher pH values than that at low elevation (ground surface North Bay; valley CHEF). Sulphate and nitrate concentrations are 5 to 10 times higher in cloudwater than in precipitation, and concentrations at low elevations are higher than those aloft. The equivalents ratio of $NO_3^-/SO_4^=$ is lower in spring than winter for cloud/fog water and the spring precipitation values are lower both aloft and at low elevations. At North Bay most of the precipitation fell as snow while at Mt. Tremblant almost all of the precipitation was rain. If snow is an efficient scavenger of HNO_3 (which is present in high concentrations at the ground in winter, Anlauf et al. 1986) then this would explain the high NO_3^- concentration in low level precipitation in winter as well as the high $NO_3^-/SO_4^=$ value.

Banic et al. (1986) looked at the problem of whether cloud water chemical composition reflects the aerosol and gas composition of the air below cloud base or whether in-cloud aqeuous phase reactions significantly modify cloud water composition. This was done in part by examining ratios of certain primary soluble ions. Table V compares some of the North Bay aircraft and ground data from summer 1982 and winter 1984 to the spring 1986 Mt. Tremblant CHEF data. The spring $NO_3^-/SO_4^=$ and $H^+/SO_4^=$ ratios are similar to but generally not quite as high as for the summer and winter data. Leaitch and Strapp (1987) have argued that in the winter NO_3^- was dominant in the determination of cloud water acidity and that the NO_3^- and acidity levels in cloud water were higher than could be accounted for by simple dissolution of ground aerosol and acidic gases, perhaps the result of in-cloud HNO_3 production mechanisms. The quick look at the aircraft and CHEF data sets presented here suggests that when fully analysed the CHEF data will be able to shed considerable light on these processes on an annual basis.

5. FOREST EXPOSURE

The survey of sugar maple damage symptoms published as a map by the Quebec Ministry of Energy and Resources in 1985 includes the area of the province surrounding the CHEF Roundtop Mtn. site. We have taken a preliminary look at the influence topography might play in determining where the damage areas are located. The hypothesis is that if the dieback of sugar maples and other deciduous species in mountainous areas is related to the input of some atmospheric pollutant such as acidic fog/cloud water or ozone then the dose received by the trees should depend on such parameters as altitude, wind direction, wind speed, slope orientation and perhaps solar exposure. Indeed, these parameters will determine to a large degree the weather related stresses on the trees even in the absence of significant pollutant concentrations. It may be very difficult to partition the two contributions without a careful look for episodic (pollutant and meteorological) damage within the canopy.

A study area of approximately 165 km^2 was chosen around the Roundtop Mtn. site. It extends from 45°00'N to 45°10'N and 72°30'W to 72°40'W. The percentages of land area in various elevation ranges are shown in Table VI. Only areas above 457 m (1500 ft) are shown. This

Table V

Species	Season	Cloud/Fog Water	Precipitation High Elevation	Precipitation Low Elevation	Surface Air
$NO_3^-/SO_4^=$	summer	0.9	0.5	0.7	0.3
	winter rain	0.7	0.8	0.9	0.3
	winter snow	0.8	0.8	2	0.5
	spring	0.5	0.4	0.4	-
$H^+/SO_4^=$	summer	0.8	1	1	0.5
	winter rain	0.8	1.7	1	0.6
	winter snow	1	0.8	2	0.8
	spring	0.5	0.8	0.7	-
$NH_4^+/SO_4^=$	summer	0.5	0.3	0.4	0.9
	winter rain	0.3	0.6	0.2	0.8
	winter snow	0.5	0.4	0.4	0.6
	spring	0.6	0.5	0.4	-

Ion ratios (equivalents) in cloud/fog water and precipitation for the summer and winter (from Banic et al., 1986) at North Bay, Ontario and for the spring (this paper, median daily median values) at Mt. Tremblant, Quebec.

Table VI

Elevation Range (m)	Contoured Area (km^2)	Representative Slope (°)	Slope Area (km^2)	Time in Cloud (%)	Forest Exposure (km^{2}h y^{-1})
457-610	23.47	18	24.68	25	54,050
610-686	7.60	20	8.09	30	21,260
686-762	4.77	22	5.14	34	15,310
762-838	2.60	25	2.87	37	9,300
838-970	0.78	28	0.88	42	3,240
			41.7		103,160

Estimated yearly forest exposure to acidic fog water at Roundtop Mountain. The time in cloud is calculated from the data of Schemenauer (1986).

corresponds to terrain that is in cloud 25% or more of the time.

In Table VI, the areas in each altitude range corrected for slope are calculated and combined with the estimated time in cloud to produce an annual forest exposure to acidic fog water. The lowest altitude range 457-610 m has an exposure of 54,050 km^2 h y^{-1} and the highest range 838-970 m an exposure of 3,240 km^2 h y^{-1}. Even though the time in cloud increases with altitude, the decrease in available surface area dominates the calculation. The total forest exposure (above 457 m) in the 165 km^2 study area is 103,160 km^2 h y^{-1}. When one considers the potential multiplying effect introduced by the ~250,000 km^2 area in southern Quebec that the CHEF data might be applied to, the total forest exposure to acidic fog becomes very large. Certainly not all of this area has 25% of the land above 457 m but a large portion does. Also the percentage of time elevated areas are in cloud may vary but based on the three CHEF sites the variation in percentage will not be large. Using the same assumptions as above for the area of Quebec south of Chicoutimi but including the Gaspé gives a forest exposure of ~1.6 x 10^8 km^2 h y^{-1}. Even assuming lower values for areas of elevated land and cloud frequencies would leave one with a value of the order of 10^8 km^2 h y^{-1} for southern Quebec. Using a relatively conservative estimate of fog water deposition rate to a forested area, 0.2 mm h^{-1}, after Lovett (1984), produces an annual water deposition of 2 x 10^{10} m^3 y^{-1}. This is obviously a substantial amount of water. It amounts to ~10% of the annual precipitation in this area. Future calculations making use of the regional and seasonal variability of fog water chemistry from the CHEF data and a detailed look at the provincial topography will attempt to translate these values into annual deposition figures for the major ionic species.

In examining the sugar maple dieback areas at our Roundtop Mtn. study site, except for a small area of moderate (26-50% of the trees affected) damage close to the town of Sutton, the major damage appears to be generally on ridges (at higher elevations) with less severe damage areas occurring in valleys. The relationship of these damage areas to the prevailing wind direction, the steering effects of the main valley, the flow over and around ridge lines, slope, slope solar exposure, etc. are currently being examined.

Detailed calculations of the amount of fog water deposited to a forested mountain slope are very difficult to make. Calculations such as the above based on a deposition value from Lovett's (1984) model are useful approximations. But eventually better ways of transferring measurements of fog liquid water content and fog water chemistry into forest deposition values will have to be found. The model, even if initialised with actual field measurements, will always have great difficulty in dealing with deposition to complex mountainous terrain. Ultimately some form of basin water balance approach may have to be utilized, however, this would be a major effort requiring considerable resources. It may be that an approach that examines the role of a tree as a collector of wet and dry deposition under actual conditions will eventually allow extrapolations from passive fog and precipitation collectors to be made to entire forested areas. Schuepp et al. (1986) examine some aspects of this problem and indicate that the technique shows promise of success.

6. DISCUSSION

The Chemistry of High Elevation Fog (CHEF) programme is still in the initial stages of data collection, analysis and interpretation. The field aspects of the programme ran semi-continuously from July to October 1985 and have operated continuously since that time. This paper has demonstrated that acidity levels in fog and precipitation samples at mountain sites in Quebec, Canada are similar in two seasons, autumn 1985 and spring 1986. In addition, ion analysis of the spring 1986 data has been shown to be consistent with that from a comprehensive aircraft and ground-based field programme in the winter of 1984.

Calculations of forest exposure to acidic fog suggest that the near vicinity of Roundtop Mtn. receives roughly 10^5 km^2 h y^{-1}. Southern Quebec as a whole may receive of the order of 10^8 km^2 h y^{-1}. Translating these values, which indicate how much forest area is in fog, to water and ionic deposition values is a major challenge and is one of the areas in which efforts are continuing. Another related problem, on which work has begun at one site, is an examination of the detailed topography and meteorology to see if a better understanding of these topics will lead to some insight as to why small scale damage patterns appear where they do on the mountain ranges. If the forest decline observed in sugar maples in Quebec is due to atmospheric deposition or to meteorological stresses then some correlation would be expected.

At this time the expectations are that CHEF will operate until the end of 1990 and provide a data base in excess of 5 years in length. This should allow for an assessment of seasonal, annual and geographical changes in fog water and precipitation chemistry, meteorology and gaseous and particulate air pollutants. Continuous ozone measurements began in May 1986 and other parameters will be added as resources permit. Close cooperation with forest scientists will ensure that the data obtained is relevant to current and future forest decline research.

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REFERENCES

Anlauf, K.G., Bottenheim, J.W., Brice, K.A. and Wiebe, H.A. 1986. 'A comparison of summer and winter measurements of atmospheric nitrogen and sulphur compounds'. J. Water Air Soil Poll. **30** , 153-160.

Banic, C.M., Leaitch, W.R., Joe, P.I., Schemenauer, R.S., Strapp, J.W., Tremblay, A. and Isaac, G.A. 1986. 'Airborne studies of chemical and physical processes in clouds in Ontario, Canada'. 2nd Intl. Spec. Conf., Meteorology of Acidic Deposition, March, Albany, New York, 302-316.

Castillo, R. 1984. 'The seasonal comparison of ion concentrations: cloud water and precipitation event samples at Whiteface Mountain, New York'. J. Rech. Atmos. **18** , 167-172.

Cowling, E.G. 1985. 'Critical review discussion paper on "Effects of air pollution on forests". J. Air Poll. Cont. Assoc. **35** , 916-919.

Isaac, G.A. and Daum, P.H. 1987. 'A winter study of air, cloud and precipitation chemistry in Ontario, Canada'. Atmos. Environ. **21**, 1587-1600.

Leaitch, W.R. Bottenheim, J.W. and Strapp, J.W. 1987. 'Possible contribution of N_2O_5 scavenging to HNO_3 observed in winter stratiform cloudwater'. Submitted to J. Geophys. Res.

Lovett, G.M. 1984. 'Rates and mechanisms of cloud water deposition to a subalpine balsam fir forest'. Atmos. Environ. **18** , 361-371.

McLaughlin, S.B. 1985. 'Effects of air pollution on forests - a critical review'. J. Air Poll. Cont. Assoc. **35** , 512-534.

Morrison, I.K. 1984. 'ACID RAIN a review of literature on acid deposition effects in forest ecosystems'. Forestry Abst. **45** , 483-506.

Schemenauer, R.S. 1986. 'Acidic deposition to forests: The 1985 Chemistry of High Elevation Fog (CHEF) project'. Atmos. Ocean **24** , 303-328.

Schuepp, P.H., McGerrigle, D.N., Leighton, H.G., Paquette, G., Schemenauer, R.S. and Kermasha, S. 1986. 'Observations on wet and dry deposition to foliage at a high elevation site'. Accepted, NATO Advanced Research Workshop on Acid Deposition to High Elevation Sites. Edinburgh, Sept. 8-12, 1986. D. Reidel Publ.

Summers, P.W. and Barrie, L.A. 1986. 'The spatial and temporal variation of the sulphate to nitrate ratio in precipitation in eastern North America'. J. Water Air Soil Poll. **30** , 275-283.