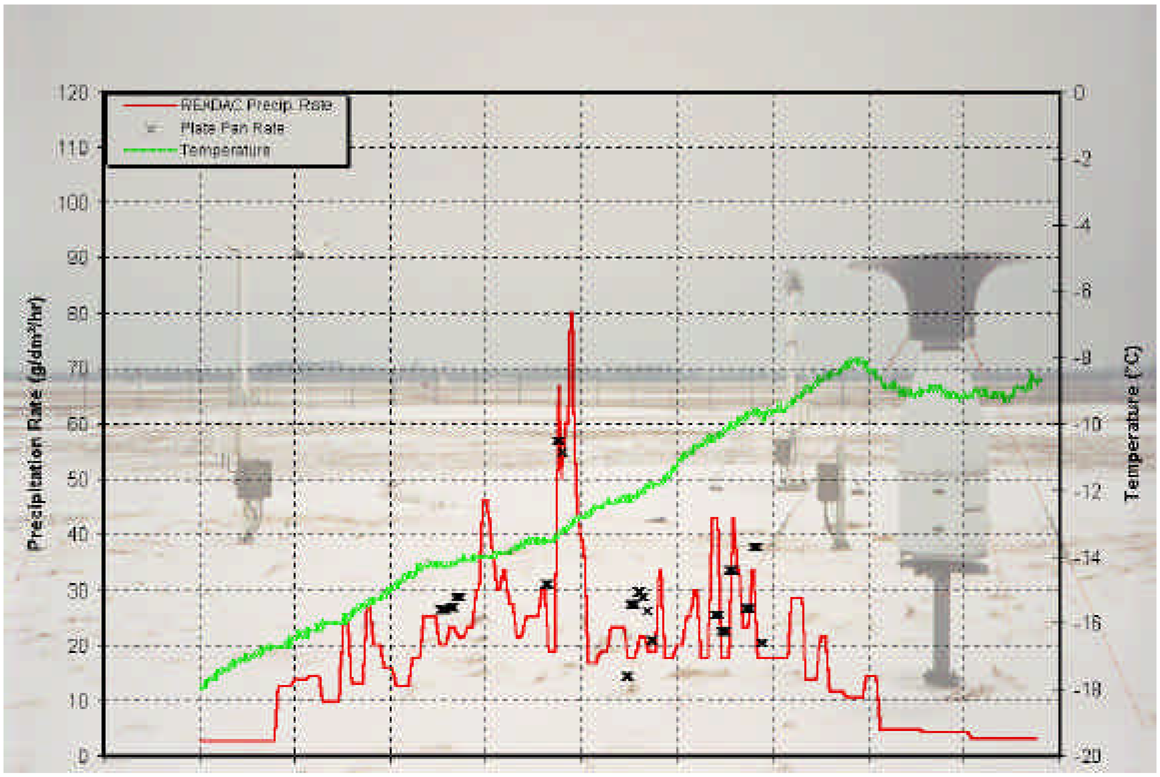
TP 13486E

Evaluation of Snow Weather Data for Aircraft Anti-Icing Holdover Times



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Transport Canada

APS AVIATION INC.

October 1999

Final Version 4.0

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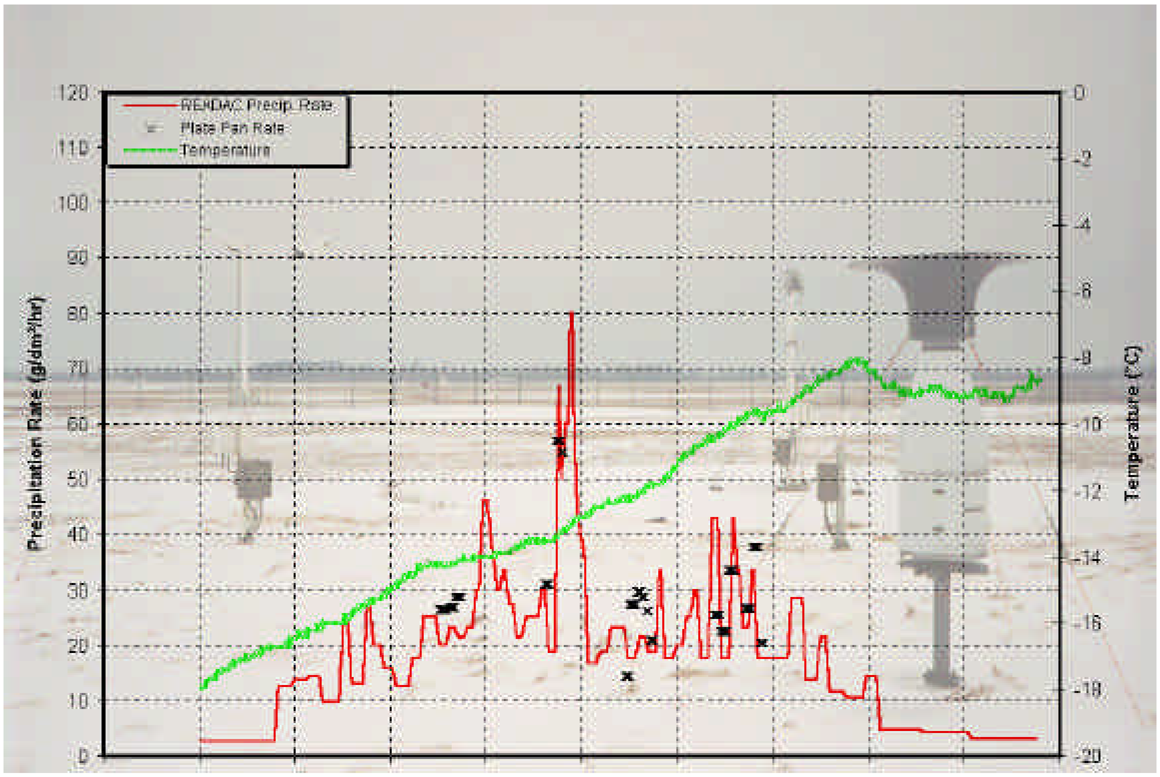

by

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APS AVIATION INC.

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Un sommaire français se trouve avant la table des matières.

PREFACE

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. has undertaken a research program to advance aircraft ground deicing/anti-icing technology. The specific objectives of the APS test program are the following:

- To develop holdover time tables for new anti-icing fluids, and to validate fluid-specific and SAE holdover time tables;
- To gather enough supplemental experimental data to support the development of a deicing-only table as an industry guideline;
- To examine conditions for which contamination due to anti-icing fluid failure in freezing precipitation fails to flow from the wing of a jet transport aircraft when subjected to speeds up to and including rotation;
- To measure the jet-blast wind speeds developed by commercial airliners in order to generate air-velocity distribution profiles (to predict the forces that could be experienced by deicing vehicles), and to develop a method of evaluating the stability of deicing vehicles during live deicing operations;
- To determine the feasibility of examining the surface conditions on wings before takeoff through the use of ice-contamination sensor systems, and to evaluate the sensitivity of one ice-detection sensor system;
- To evaluate the use of warm fuel as an alternative approach to ground deicing of aircraft;
- To evaluate hot water deicing to determine safe and practicable limits for wind and outside ambient temperature;
- To document the appearance of fluid failure, to measure its characteristics at the point of failure, and to compare the failures of various fluids in freezing precipitation;
- To determine the influence of fluid type, precipitation (type and rate), and wind (speed and relative direction) on both the locations and times to fluid failure initiation, with special attention to failure progression on the Bombardier Canadair Regional Jet and on high-wing turboprop commuter aircraft;
- To evaluate snow weather data from previous winters to identify a range of snow-precipitation suitable for the evaluation of holdover time limits;
- To compare the holdover times from natural and artificial snow trials and to evaluate the functionality of NCAR's prototype simulated snowmaking system; and
- To develop a plan for implementing a full-scale wing test facility that would enable the current testing of deicing and anti-icing fluids in natural and artificial freezing precipitation on a real aircraft wing.

The research activities of the program conducted on behalf of Transport Canada during the 1998-99 winter season are documented in twelve reports. The titles of these reports are as follows:

- TP 13477E Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1998-99 Winter;
- TP 13478E Aircraft Deicing Fluid Freeze Point Buffer Requirements for *Deicing Only* Conditions;

- TP 13479E Contaminated Aircraft Takeoff Test for the 1998-99 Winter;
- TP 13480E Air Velocity Distribution Behind Wing-Mounted Aircraft Engines;
- TP 13481E Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks;
- TP 13482E Evaluation of Warm Fuel as an Alternative Approach to Deicing;
- TP 13483E Hot Water Deicing of Aircraft;
- TP 13484E Characteristics of Failure of Aircraft Anti-Icing Fluids Subjected to Precipitation;
- TP 13485E Aircraft Full-Scale Test Program for the 1998-99 Winter;
- TP 13486E Evaluation of Snow Weather Data for Aircraft Anti-Icing Holdover Times;
- TP 13487E Development of a Plan to Implement a Full-Scale Test Site; and
- TP 13488E A Snow Generation System – Prototype Testing.

This report, TP 13486E, has the following objective:

- To evaluate snow weather data from previous winters to establish a range of snow precipitation suitable for the evaluation of holdover time limits.

This objective was met by acquiring and analysing winter weather data recorded by automated weather instruments at meteorological stations from four sites in Quebec. The data collected during the winters from 1995 to 1999 were statistically analysed to determine the cumulative probabilities of high precipitation rates in specific temperature intervals.

ACKNOWLEDGEMENTS

This research has been funded by the Civil Aviation Group, Transport Canada, and with support from the Federal Aviation Administration. This program could not have been accomplished without the participation of many organizations. APS would like to thank, therefore, the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, the National Research Council Canada, Atmospheric Environment Services Canada, Transport Canada, and several fluid manufacturers. Special thanks are extended to US Airways Inc., Delta Air Lines, Royal Airlines, Air Canada, the National Research Council Canada, Canadian Airlines International, AéroMag 2000, Aéroport de Montreal, the Greater Toronto Airport Authority, Hudson General Aviation Services Inc., Union Carbide, RVSI, Cox and Company Inc., the Department of National Defence, and Shell Aviation, for provision of personnel and facilities and for their co-operation on the test program. APS would like also to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data.

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Research reports produced on behalf of Transport Canada for testing during previous winters are available from the Transportation Development Centre (TDC). Twelve reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface.

16. Abstract

APS Aviation Inc. undertook a study to evaluate precipitation rate/temperature data from previous winters to ascertain the suitability of the precipitation rate ranges used for holdover time evaluation.

Data were acquired from Environment Canada from four automated weather stations in the province of Quebec, Canada, located in Dorval (Montreal), Quebec City, Rouyn, and Pointe-au-Père. A total of 1310 hours of snowstorm data recorded between 1995 and 1999 and over 100 hours of freezing rain data were analysed. Included in the data set was over 620 hours of snow data from the 1998-99 winter.

Based on the storm data subdivided by temperature ranges related to holdover time tables, it was observed that the precipitation rate limits used to establish the holdover times are satisfactory. High precipitation rates were found in all of the holdover time temperature ranges, including the –14 to –25°C range. The 95th percentile for precipitation rates was observed to be approximately 22 $g/dm^2/h$ for the total snow weather data. In the –14 to –25°C range, the 95th percentile was 24 $g/dm^2/h$, which is significantly higher than the proposed maximum rate limit of 10 $g/dm^2/h$.

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15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Les rapports de recherche produits au nom de Transports Canada sur les essais réalisés au cours des hivers antérieurs peuvent être obtenus auprès du Centre de développement des transports (CDT). Le programme de la saison hivernale a donné lieu à douze rapports (dont celui-ci). On trouvera dans la préface l'objet de ces rapports.

16. Résumé

APS Aviation Inc. a entrepris l'étude rétrospective de données météorologiques (taux de précipitation, température) pour confirmer la validité des plages de taux de précipitation servant à déterminer la durée d'efficacité des liquides antigivrants.

Les données, transmises par Environnement Canada, provenaient de quatre stations météorologiques automatiques situées au Québec, Canada, soit à l'aéroport de Dorval (Montréal), à Québec, à Rouyn et à Pointe-au-Père. L'analyse a porté sur des données colligées pendant un total de 1 310 heures de tempête de neige, de 1995 à 1999, et sur plus de 100 heures de données de pluie verglaçante. La base de données comportait en outre plus de 620 heures de données de neige, recueillies pendant l'hiver 1998-1999.

Les chercheurs ont d'abord observé une correspondance raisonnable entre les données de tempête, ventilées selon les plages de températures des tables de durées d'efficacité, et les taux de précipitation limites servant à établir les durées d'efficacité. Des taux de précipitation élevés ont été constatés pour toutes les plages de températures, y compris la plage de -14 °C à -25 °C. Pour l'ensemble des données concernant les taux de précipitation neigeuse, le 95e percentile était d'environ 22 g/dm²/h. Dans la plage de -14 °C à -25 °C, le 95e percentile se situait à 24 g/dm²/h, ce qui est beaucoup plus élevé que le taux de précipitation limite proposé, de 10 g/dm²/h.

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EXECUTIVE SUMMARY

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. undertook a study to evaluate precipitation data (precipitation rate/temperature data) from previous winters to ascertain the suitability of the precipitation rate ranges used for holdover time evaluation.

Description and Processing of Data

A total of 1310 hours of storm data points were developed from precipitation gauge logs for natural snow, including 627 hours from the 1998-99 data. Light freezing rain data, based largely on the 1998 ice storm, were used to develop 96 hours of storm data. Data were acquired from Environment Canada from instruments located at Dorval Airport (Montreal, Quebec) and three other stations in the province of Quebec, Canada. The Dorval Airport data were collected over several winters; data from other stations were collected from the winters of 1997-98 and 1998-99. Similar data were collected and analysed by Environment Canada, at Toronto's Pearson Airport, for two winters.

Results and Conclusions

The precipitation rate ranges currently in use in the Transport Canada holdover time tables are satisfactory based on the data from this study. High precipitation rates were encountered in all temperature ranges, from above 0°C to the –14 to –25°C range; the high precipitation rates at cold temperatures were recorded mainly during a few snowstorms in the winter of 1998-99. The 95th percentile for precipitation rates was observed to be approximately 22 g/dm^2/h for snow. In the –14 to –25°C range, the 95th percentile was 24 g/dm^2/h, which is significantly higher than the proposed maximum rate limit of 10 g/dm^2/h for that temperature range. The 95th percentile precipitation rate from the limited freezing rain data was approximately 25 g/dm^2/h.

The data supplied from CR21X, a newer, modified station, require less smoothing and allow more accurate observation of fluctuating precipitation rates. More data of the type available from the CR21X equipment from a greater number of winters is needed to confirm the findings. The study should therefore be extended in upcoming winters to include data recorded from these automated precipitation gauges supported by AES.

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SOMMAIRE

À la demande du Centre de développement des transports de Transports Canada, APS Aviation Inc. a entrepris l'étude rétrospective de données météorologiques (taux de précipitation, température) pour confirmer la validité des plages de taux de précipitation servant à déterminer la durée d'efficacité des liquides antigivrants.

Description et traitement des données

Un graphique des précipitations de tempête de neige a été établi à partir de relevés nivométriques couvrant un total de 1 310 heures, dont 627 heures pendant l'hiver 1998-1999. Les données de pluie légère verglaçante résultaient pour la plupart de 96 heures d'observations faites au cours de la tempête de verglas de 1998. Ces données, obtenues auprès d'Environnement Canada, provenaient de la station météorologique de l'aéroport de Dorval (Montréal, Québec) et de trois autres stations du Québec. Les données de l'aéroport de Dorval couvraient les hivers de 1995 à 1999, tandis que celles des autres stations ne couvraient que les hivers 1997-1998 et 1998-1999. Des données analogues ont été recueillies et analysées par Environnement Canada à l'aéroport international Pearson de Toronto pour deux hivers.

Résultats et conclusions

Selon les données analysées, les plages de températures actuellement utilisées par Transports Canada pour établir ses tables de durées d'efficacité sont satisfaisantes. Des taux de précipitation élevés ont été enregistrés dans toutes les plages de températures, de la plus haute (au-dessus de 0 °C) à la plus basse (-14 °C à -25 °C); les taux de précipitation élevés par temps froid ont surtout été enregistrés au cours de quelques tempêtes de neige, à l'hiver 1998-1999. Pour l'ensemble des données concernant les taux de précipitation neigeuse, le 95^{e} percentile était d'environ 22 g/dm^2/h. Dans la plage de -14 °C à 25 °C, le 95^{e} percentile se situait à 24 g/dm^2/h, ce qui est beaucoup plus élevé que le taux de précipitation limite proposé, de 10 g/dm^2/h. Dans la base restreinte de données de pluie verglaçante, le 95^{e} percentile se situe à 25 g/dm^2/h.

Les données fournies par le CR21X, un nouveau type de station, exigent moins de lissage et permettent une observation plus précise de la fluctuation des taux de précipitation. Mais un plus grand nombre de données telles que celles produites par le CR21X, couvrant un plus grand nombre de saisons hivernales, doit être obtenu pour confirmer les résultats obtenus. L'étude devrait donc se poursuivre encore quelques hivers, pour permettre l'analyse des données enregistrées par ces appareils automatiques utilisés par le SEA.

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GLOSSARY

ADM	Aéroports de Montréal
AES	Atmospheric Environment Services
APS	APS Aviation Inc.
HOT	Holdover Time
OAT	Outside Air Temperature
READAC	Remote Environmental Automatic Data Acquisition Concept
TDC	Transportation Development Centre

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1. INTRODUCTION

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. undertook a study to further advance de/anti-icing technology. This report contains the results of analysis conducted by APS Aviation, in 1998/99, on the evaluation of precipitation data. This study formed part of the winter 1998/99 research program on de-icing, as described in section 5.6.2 of the detailed work statement shown in Appendix A.

Existing holdover times for snow are developed using lower and upper precipitation rates of 10 and 25 g/dm²/h, for all temperatures (0, -3, -14, and –25ºC). These rates have been considered extreme at temperatures of –14ºC and –25ºC, because such high precipitation rates, although they do exist, are perhaps less frequent at lower temperatures. Similarly, for other holdover time table precipitation conditions (e.g. frost), it is believed that the precipitation rates diminish at colder temperatures. A proposal was presented to reduce rate evaluation limits for the new laboratory holdover time procedures in development by the SAE.

The purpose of this study was to evaluate precipitation weather data (precipitation rate/temperature data) from previous winters to ascertain the suitability of data ranges currently in use for the evaluation of upper and lower holdover time limits.

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2. METHODOLOGY

This section describes methods used to evaluate the weather data collected to study the occurrences of high precipitation rates at low temperatures for natural snow and light freezing rain.

Holdover time tables generated from data collected during the 1998/99 winter test season, and descriptions of precipitation types, precipitation rates, rate limits, and the methods used to calculate holdover times, are presented in the Transportation Development Centre report TP 13477E (1).

At the Montreal 1997 SAE Workshop (2) on Laboratory Methods, the holdover time table guidelines were proposed for revision. It was proposed that the upper and lower precipitation rate limits for snow be reduced. This was suggested because there is a natural tendency toward reduced precipitation rates as outside air temperature drops; and it is generally contended that rate limits should reflect natural conditions as closely as possible.

The possibility of maintaining the currently accepted precipitation rate limits for snow, 10 and 25 g/dm²/h, was considered. After much debate, it was decided that the following precipitation rate limits would be adopted for the lowest temperature ranges in the category of snow.

Temperature Range	Holdover Time Evaluation Temperature	Precipitation rate (g/dm²/h)	
		Upper Limit	Lower Limit
-3 to –14ºC	-14ºC	20	10
-14 to –25ºC	-25ºC	10	5
Below –25ºC	(TBD by event)	5	2

The complete set of guidelines for all categories of precipitation that appear in the holdover times is presented in Table 2.1. The remainder of this section describes test sites, equipment, and procedures used to collect data.

2.1 Sources of Data and Test Sites

APS collected data from various sources extending back to the 1990-91 winter season. A summary of these sources is shown in Table 2.2. The precipitation rates analysed in this report were extracted from the following:

- The Dorval READAC log for the years 1995 to 1998;
- The data logs for three CR21X stations 1998 at Rouyn, Pointe-au-Père (Mont Joli), and Ancienne Lorette (Quebec City); and
- The data log from the Dorval Airport CR21X station.

TABLE 2.1

PROPOSED PRECIPITATION RATES FOR HOLDOVER TIMES

Issued on December 16th, 1997

OAT		Precipitation Rates Under Various Weather Conditions, g/dm²/h					
°C	°F	Frost	Freezing Fog	Snow	Freezing Drizzle	Light Freezing Rain	Rain on Cold Soaked Wing
0	32	**.2**		**25 -10**	**13 - 5**	**25 - 13**	**75 - 5**
-3	27	**.2**	**2 - 5**	**25 -10**	**13 - 5**	**25 - 13**	
-7	19	**.2**	**2 - 5**	**25 -10**	10 - 5	25	
-10	14	**.2**	**2 - 5**	25 -10	10 - 5	25	
-14	7	.2	**2 - 5**	20 - 10			
-25	-13	.1	**2 - 5**	10 - 5			
<-25	<-13	.1	2 - 5	5 - 2			

TABLE 2.2

SUMMARY OF WEATHER DATA

PROJECT #	YEAR	PLATE PANS	READAC YUL	CR21X				CITY OF MONTREAL (Fisher/Porter)	OMBROMETER THIES	ETI	TIPPING BUCKET	YYZ
				WUY (Rouyn)	WTQ (Dorval)	WQB (Québec)	WYQ (Pointe-au-Père)					
	1990/91	Test period									X[3]	
	1991/92	Test period						X[6]	X[3]			
	1992/93	Test period						X[6]	X[3]			
C1171	1993/94	Test period						X[1] (Three stations)	X[3] (Shielded)			
CM1222	1994/95	Test period	X[1]									
CM1283	1995/96	15 min	X[2]							X		X[4]
CM1338	1996/97	15 min	X[2]		X[5]							X[4]
CM1380	1997/98	5-15 min	X[2]	X[2]	X[2]	X[2]	X[2]					
CM1514	1998/99	5-15 min	X[2]	X[2]	X[2]	X[2]	X[2]					

[1] Data analysed for Transport Canada in 1996.

[2] Data used for this report.

[3] Unusable data - precipitation rate determined by this gauge was always lower than other instruments.

[4] Analysis completed by AES at YYZ.

[5] Unusable data - scattered data (gauge was not shielded).

[6] Data archived.

Each site is identified on a map of Quebec, Canada, shown in Figure 2.1. The data are included in Appendix B. Furthermore, two similar studies were conducted in 1995/96, one by APS, using data collected from three weather stations located around Montreal (included in Appendix C), the other by AES (Atmospheric Environment Services) using data collected at Lester B. Pearson International Airport in Toronto (included in Appendix D).

2.2 Equipment

The READAC precipitation gauge consists of a bucket partially filled with an antifreeze compound so that it effectively captures snow. A weighing transducer provides instantaneous displacement values of the bucket in terms of millimetres of precipitation. This shaft displacement is transmitted every 2.5 seconds and averaged every minute in an attempt to eliminate spurious data caused by *wind pumping* and temperature-induced contraction and expansion of the sensor. The READAC instrument has a resolution of 0.5 mm (5 g/dm^2).

The CR21X station operates on the same principle as the READAC station, with an accuracy of 0.1 mm (1 g/dm^2). The station measures precipitation with a Fisher Porter precipitation gauge and the readings are logged with a CR21X data logger.

Precipitation rates tend to fluctuate rapidly during snowstorms. The weight resolution of the READAC stations is less accurate in measuring rapid changes. The data from the CR21X station required less smoothing before it could be interpreted. The increased resolution of the CR21X weighing transducer allows better observation of short periods of heavy precipitation.

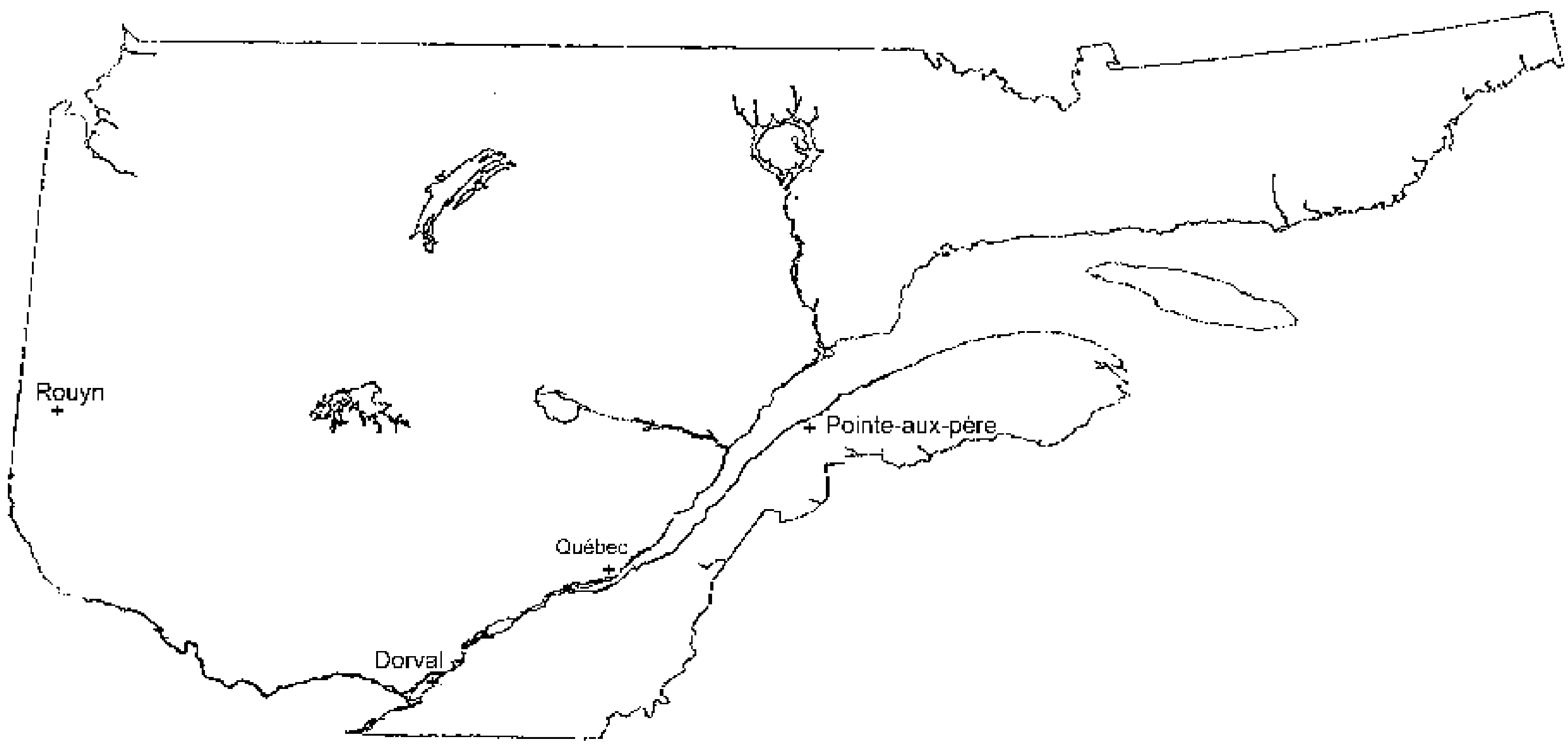
2.3 Description of Analysis Methods

Precipitation rate data were averaged at intervals that correspond to three specified periods typically used in the holdover time tables: 6 minutes for Type I fluids, 20 minutes for Type II, and 35 minutes for Type IV. For natural snow, data were classified into the five temperature ranges: above 0°C, 0 to –3°C, -3 to –7°C, -7 to –14°C and –14 to –25°C. For light freezing rain, data were classified into 2 ranges: 0 to –3°C and –3 to –10°C.

Snowfalls at Dorval were tracked from 1995 to 1999, using the Monthly Meteorological Data provided by Environment Canada. The precipitation and temperature data were then extracted from READAC logs on a minute-by-minute basis, and added to a database. The CR21X data were treated in a similar way. Periods of snowfall were identified, using Environment Canada

Figure 2.1

Map of Precipitation Gauge Locations
Quebec, Canada



summaries, and snow accumulation data were added to the database along with ambient air temperatures. The three CR21X stations at Rouyn, Pointe- au-Père, and Ancienne Lorette, provided temperatures on an hourly basis. The temperatures were then interpolated throughout the hour on a minute-by-minute basis.

Using an algorithm developed by APS, the total precipitation for each snowfall was averaged over time, to produce a smooth curve. Figure 2.1 shows an output from the READAC precipitation gauge and the linearized data for a typical snowfall. The precipitation gauge output, sensitive to 5 g/dm², is plotted versus time to establish the periods of snowfalls. As shown in Figure 2.1, the period when snowfalls were interrupted for a long time was excluded from the analysis. Subsequent snowfalls were treated similarly. The first and last indications of snowfall (first and last 5 g/dm²) were excluded due to uncertainty about the precise start and end of the snowfall.

Periods of low rate snow precipitation might have been overlooked due to long interruptions in bucket weight changes. It is difficult to establish whether these weight changes were due to constant low rate precipitation or long periods with no precipitation and short intervals of higher precipitation near the time of weight changes. The start and end of a snowstorm are difficult to predict because the snow might have started and ended gradually at slow rates or abruptly at high rates.

The READAC and the CR21X stations record the bucket weight at each minute. The precipitation rates are calculated based on the bucket weight and the time between readings. For each time interval the rate is calculated every minute using the following method.

$$Rate_i = \frac{W_i - W_{i-1}}{\Delta time}$$

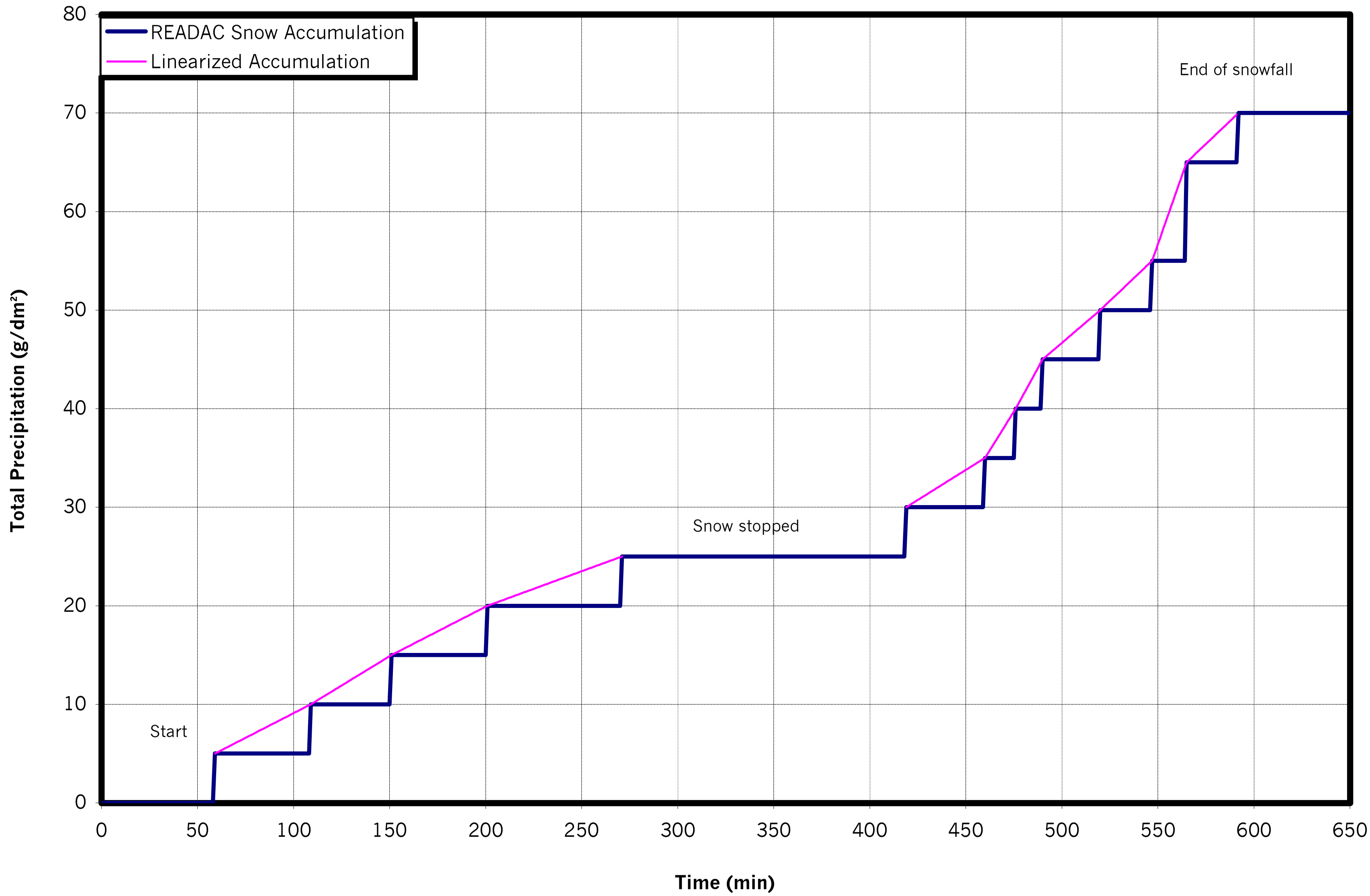
Where:

$Rate_i$	is the rate at a given time
W_i	is the linearized bucket weight at that time
W_{i-1}	is the linearized bucket weight one time interval before the given time
Δtime	is the length of the time interval (6, 20, or 35 minutes)

Once each rate was calculated, a temperature was associated with the rate, based on the time and day at which the rate is measured. All rate and temperature data were added to a database. The database contains all the calculated precipitation rates, classified by ambient temperature, for all sites included in the study. Through statistical analysis, the probability for each precipitation rate, at each temperature, was calculated.

FIGURE 2.2

READAC PRECIPITATION GAUGE
CUMULATIVE AND LINEARIZED PRECIPITATION AT DORVAL



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3. DESCRIPTION AND PROCESSING OF DATA

3.1 Natural Snow

A total of 37 671 data points were developed analytically for natural snow conditions during the 1998/99 season. This represents approximately 625 hours of snowfall and an average of 125 hours of snowfall for each station. Due to improvements in the CR21X stations, all data collected during the past winter at those stations were usable in this analysis. The distribution of new data points, sorted by temperature, is listed below:

Temperature Range	# of Data Points
Above 0°C	2 217
Between 0 and –3°C	7 424
Between –3 to –7°C	10 005
Between –7 to –14°C	13 595
Between –14 to –25°C	4 430

The distribution of data points for 1998/99, by temperature and in histogram format, is shown in Figure 3.1.

A total of 41 029 data points were developed analytically for natural snow conditions prior to the 1998/99 season. This represented, on average, approximately 100 hours of snowfall per year per station, or 15 snowfalls of 6.5 hours each. The distribution of data points collected before 1998/99, by temperature range, is listed below:

Temperature Range	# of Data Points
Above 0°C	2 664
Between 0 and –3°C	10 860
Between –3 to –7°C	12 793
Between –7 to –14°C	11 767
Between –14 to –25°C	2 945

Figure 3.2 shows the breakdown of total data points collected by temperature for

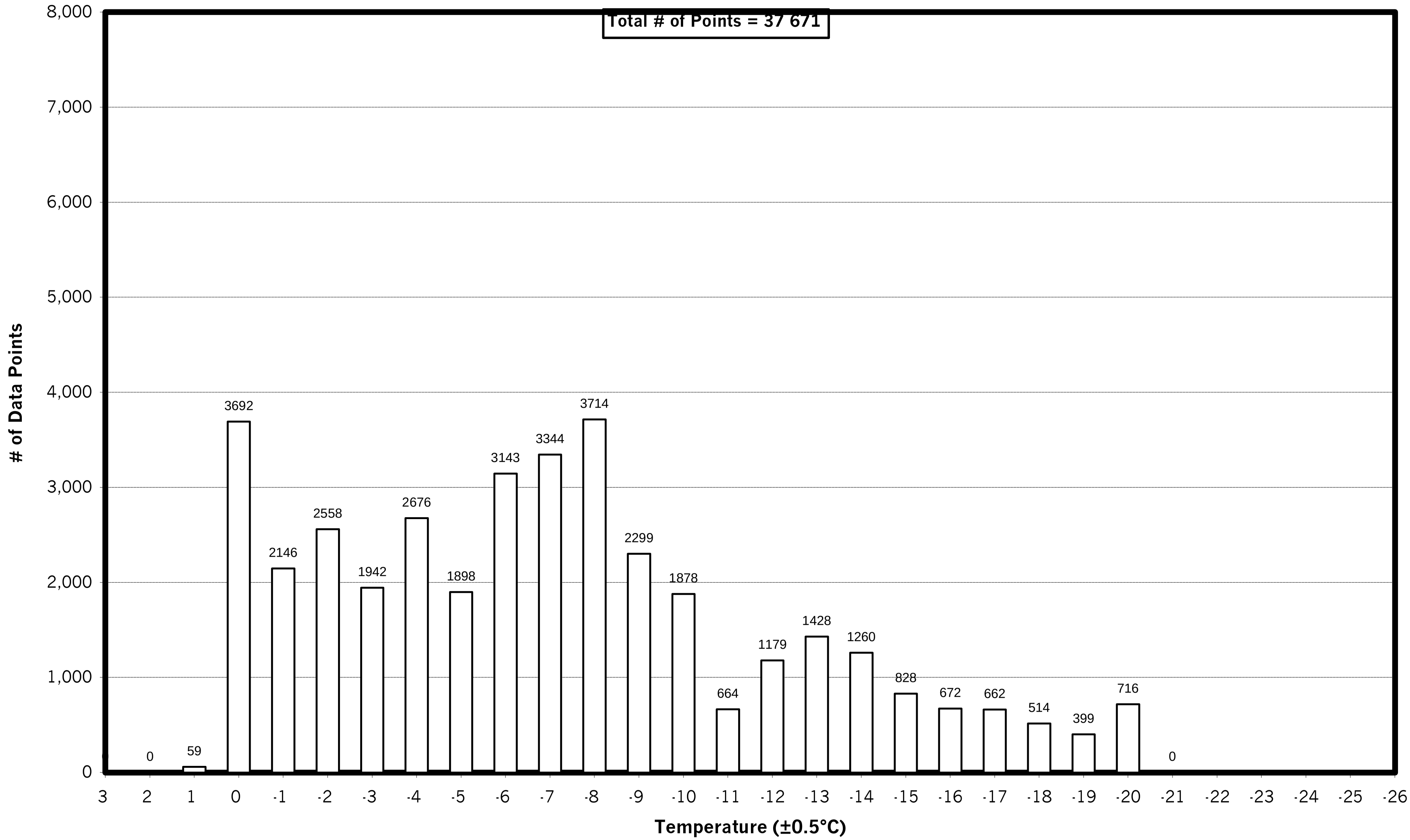
natural snow. The following observations should be noted:

- 23% of the snowfalls occurred within the range of 0 to –3°C;
- 9% occurred between –14 and –25°C;
- 6% occurred above 0°C temperature;
- 29% occurred between –3 and -7°C; and
- 32% occurred between –7 and 14°C.

FIGURE 3.1

TEMPERATURE DISTRIBUTION

Natural Snow - Winter 1998/99

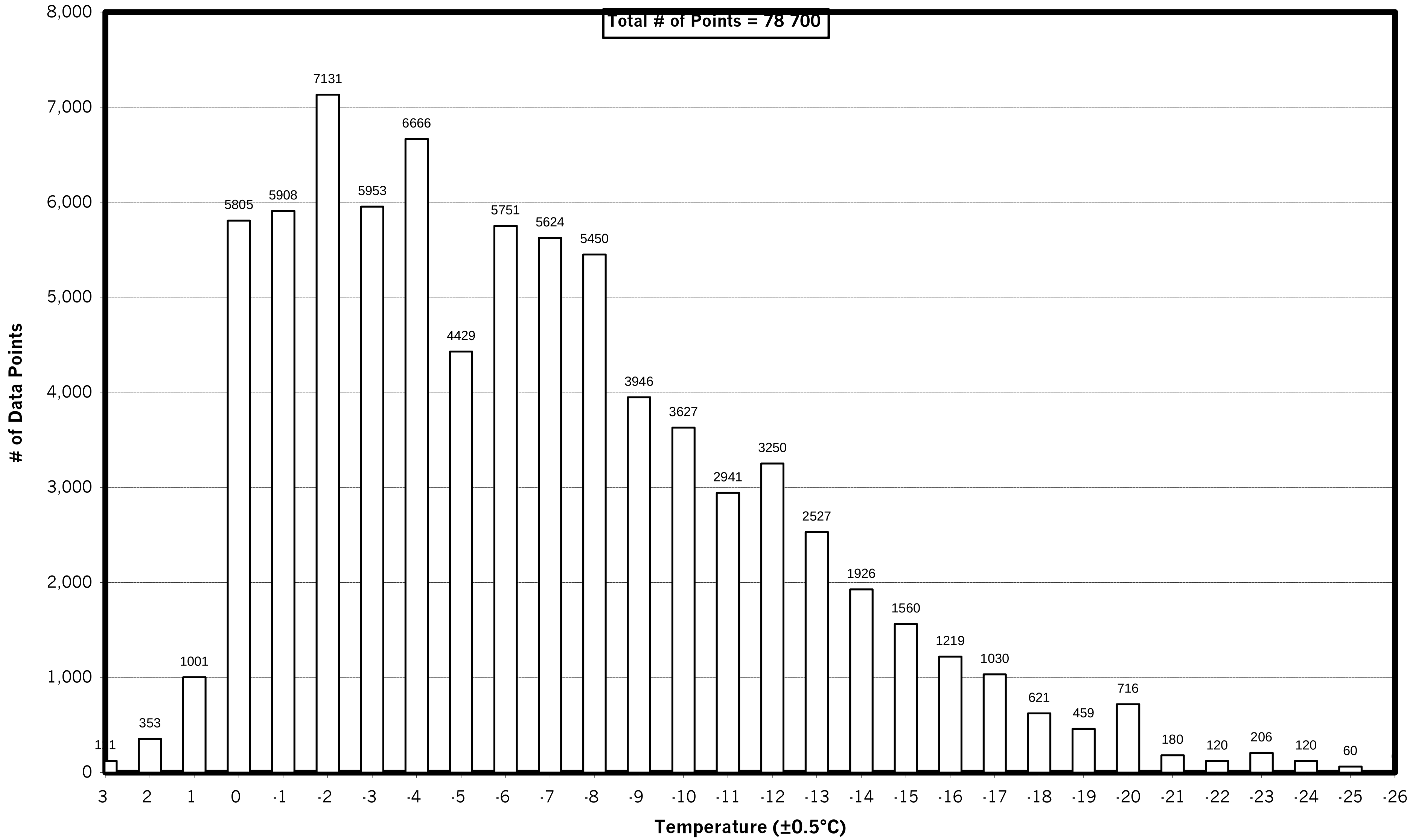


cm1514/report/readac/Tem_dist
At: snow chart99
02/01/01, 4:37 PM

FIGURE 3.2

TEMPERATURE DISTRIBUTION

Natural Snow 1995-1999



cm1514/report/readac/Tem_dist
At: snow chart 95-99
02/01/01, 4:38 PM

3.2 Light Freezing Rain

Data on light freezing rain data were developed from READAC logs, based mostly on the January 1998 ice storm, for a total of 6 367 data points. This represents approximately 106 hours of light freezing rain data. Other occurrences were not used due to a malfunction in READAC instruments. The distribution of these data, by temperature range, is shown in Figure 3.3 and summarized by the temperature ranges below:

	# of Data Points
Above 0ºC	171
Between 0 and –3°C	1 683
Between –3 to –10°C	4 513

The breakdown of freezing rain occurrences by temperature is shown in Figure 3.3. The following observations should be noted:

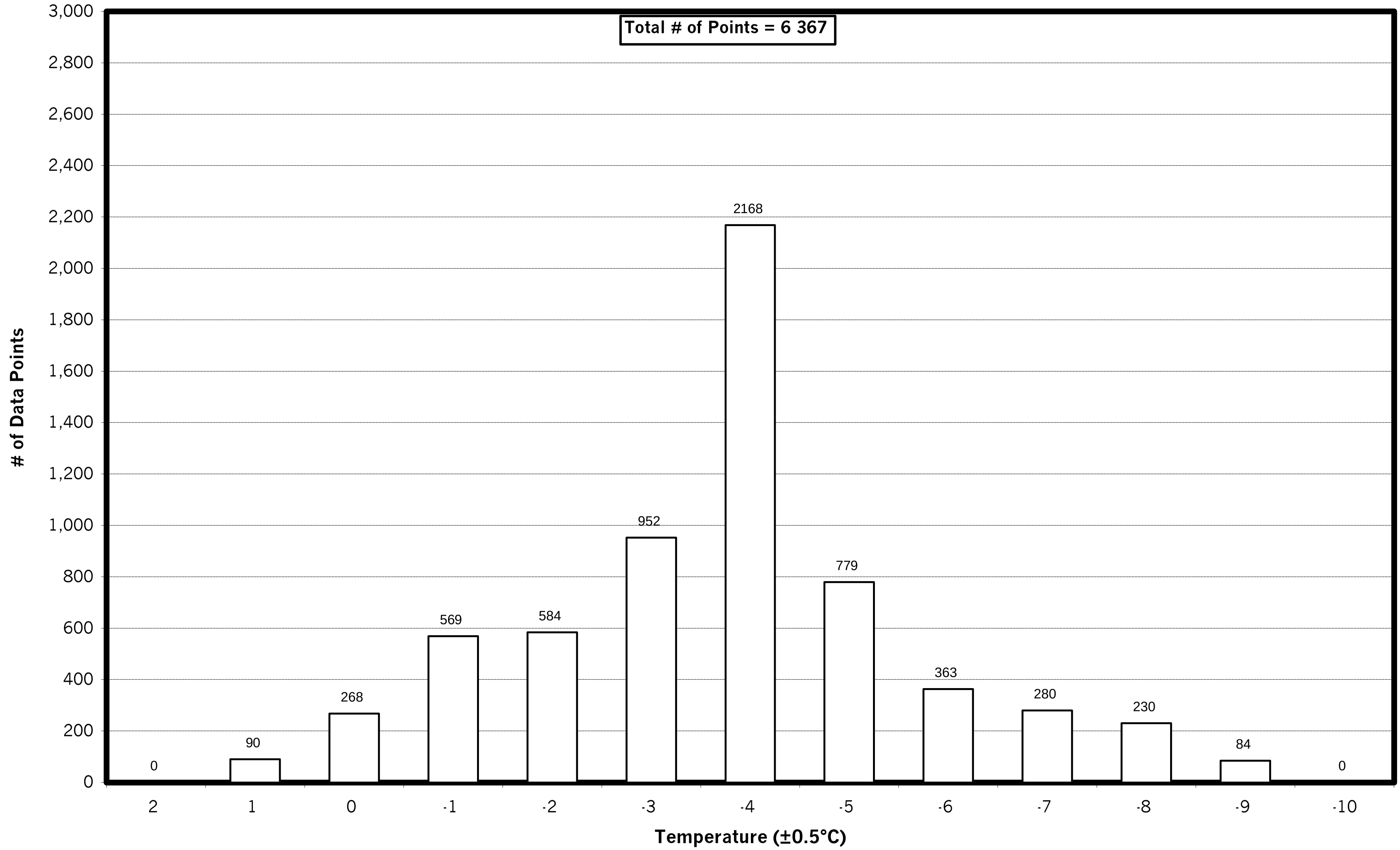
- Freezing rain did not occur at temperatures below –9°C; and
- Over 60% of the freezing rain occurred at temperatures between –3 and –5°C.

These observations should not be used as a generalization of freezing rain occurrences because most of the data were limited to the January 1998 ice storm.

FIGURE 3.3

TEMPERATURE DISTRIBUTION

Light Freezing Rain



cm1514/report/readac/Tem_dist
At: ZR chart
02/01/01, 4:42 PM

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4. ANALYSIS AND OBSERVATION

Precipitation rates were calculated from the weather data using a moving average. Table 4.1 shows minute-by-minute READAC data at Dorval Airport for a 37-minute period on December 14, 1995. Also shown are the 6-minute, 20-minute, and 35-minute averages computed using the linearized accumulation. The average snow rates, used as point data, were calculated by taking the snow accumulation during a specific time interval and dividing this value by the interval. The three intervals used for this analysis are represented in Table 4.1 by brackets in the column next to the "Linearized Total Snow Accumulation" column. The average snow rate was re-calculated every minute by moving the brackets down one time interval (one minute).

The snow weather data were graphed in two formats. In one, the number of occurrences of snow precipitation events was plotted against the precipitation rates for these events (Figure 4.1). The other (Figure 4.2) plots the cumulative probability of snow over all possible precipitation rates. The figures shown correspond to the temperature range of –3 to –7ºC for 20-minute rate calculations. Both plots used the corresponding period to calculate average precipitation rates.

A complete set of plots, for all temperature ranges and rate durations for natural snow and freezing rain, is included in Appendix B.

The histogram in Figure 4.1 indicates that snow events with low precipitation rates occurred much more frequently than those with high precipitation rates for the temperature range shown.

The cumulative probability in Figure 4.2 indicates that over 97% of all the natural snow events in the data records had precipitation rates below 25 g/dm^2/h for 20-minute rate intervals.

The 95th percentile criterion was used in the analysis conducted by AES in 1995 to determine the frequency of occurrence of precipitation rates. The same method was used by APS, and the results are described in the following subsections.

4.1 Natural Snow

The 95th percentile for several temperature ranges for natural snow conditions is shown below:

TABLE 4.1

SAMPLE OF READAC DATA AND ANALYSIS

Location	Date	Zulu Time	Temp (°C)	Type of Precip.	Total Snow Accumulation (g/dm²)	Linearized Total Snow Accumulation (g/dm²)		Average Every Minute (g/dm²/hr)		
								6 min	20 min	35 min
YUL	14/12/1995	21:16	-11.8	S-	40	40.00		9.38	9.38	10.08
YUL	14/12/1995	21:17	-11.7	S-	40	40.16		9.38	[illegible]	[illegible]
YUL	14/12/1995	21:18	-11.6	S-	40	40.31		9.38	[illegible]	[illegible]
YUL	14/12/1995	21:19	-11.6	S-	40	40.47		9.38	[illegible]	[illegible]
YUL	14/12/1995	21:20	-11.6	S-	40	40.63		9.38	[illegible]	[illegible]
YUL	14/12/1995	21:21	-11.6	S-	40	40.78		9.38	[illegible]	[illegible]
YUL	14/12/1995	21:22	-11.6	S-	40	40.94		9.38	[illegible]	[illegible]
YUL	14/12/1995	21:22	-11.5	S-	40	41.09		9.38	[illegible]	[illegible]
YUL	14/12/1995	21:23	-11.6	S-	40	41.25		9.38	[illegible]	[illegible]
YUL	14/12/1995	21:24	-11.6	S-	40	41.41		9.38	[illegible]	[illegible]
YUL	14/12/1995	21:24	-11.4	S-	40	41.56		9.38	9.38	[illegible]
YUL	14/12/1995	21:25	-11.4	S-	40	41.72		[illegible]	9.38	[illegible]
YUL	14/12/1995	21:25	-11.5	S-	40	41.88		9.38	9.38	[illegible]
YUL	14/12/1995	21:26	-11.5	S-	40	42.03		9.38	9.79	[illegible]
YUL	14/12/1995	21:26	-11.4	S-	40	42.19		9.38	10.20	[illegible]
YUL	14/12/1995	21:27	-11.4	S-	40	42.34		9.38	10.62	13.48
YUL	14/12/1995	21:28	-11.4	S-	40	42.50		9.38	11.03	13.57
YUL	14/12/1995	21:29	-11.4	S-	40	42.66		9.38	[illegible]	13.66
YUL	14/12/1995	21:30	-11.4	S-	40	42.81		9.38	[illegible]	13.75
YUL	14/12/1995	21:31	-11.4	S-	40	42.97		[illegible]	12.27	13.84
YUL	14/12/1995	21:31	-11.3	S-	40	43.13		9.38	12.68	13.93
YUL	14/12/1995	21:32	-11.3	S-	40	43.28		9.38	13.10	14.02
YUL	14/12/1995	21:32	-11.4	S-	40	43.44		9.38	13.51	14.11
YUL	14/12/1995	21:33	-11.4	S-	40	43.59		9.38	13.92	14.20
YUL	14/12/1995	21:33	-11.3	S-	40	43.75		9.38	14.34	14.29
YUL	14/12/1995	21:34	-11.3	S-	40	43.91		9.38	14.75	14.38
YUL	14/12/1995	21:34	-11.3	S-	40	44.06		9.38	15.17	14.46
YUL	14/12/1995	21:35	-11.3	S-	40	44.22		10.75	15.58	14.55
YUL	14/12/1995	21:35	-11.2	S-	40	44.38		12.13	15.99	14.64
YUL	14/12/1995	21:36	-11.2	S-	40	44.53		13.51	16.41	14.73
YUL	14/12/1995	21:36	-11.2	S-	40	44.69		14.89	16.56	14.82
YUL	14/12/1995	21:37	-11.2	S-	40	44.84		16.27	16.72	14.91
YUL	14/12/1995	21:37	-11.2	S-	45	45.00		17.65	16.88	15.00
YUL	14/12/1995	21:38	-11.2	S-	45	45.29		17.65	16.62	14.85
YUL	14/12/1995	21:39	-11.2	S-	45	45.59		17.65	16.36	14.71
YUL	14/12/1995	21:40	-11.2	S-	45	45.88		17.65	16.10	14.56
YUL	14/12/1995	21:41	-11.1	S-	45	46.18		17.65	15.85	14.41
YUL	14/12/1995	21:42	-11.1	S-	45	46.47		17.65	15.59	14.26
YUL	14/12/1995	21:43	-11.1	S-	45	46.76		17.65	15.33	14.12
YUL	14/12/1995	21:44	-11.1	S-	45	47.06		17.65	15.07	14.18
YUL	14/12/1995	21:45	-11.1	S-	45	47.35		17.65	14.82	14.25
YUL	14/12/1995	21:46	-11.1	S-	45	47.65		17.65	14.56	14.32
YUL	14/12/1995	21:47	-11.1	S-	45	47.94		17.65	14.30	14.39
YUL	14/12/1995	21:47	-11.0	S-	45	48.24		17.65	14.04	14.45
YUL	14/12/1995	21:48	-11.0	S-	45	48.53		16.79	13.79	14.52
YUL	14/12/1995	21:49	-11.0	S-	45	48.82		15.93	13.53	14.59
YUL	14/12/1995	21:50	-11.0	S-	45	49.12		15.07	13.27	14.66
YUL	14/12/1995	21:51	-11.0	S-	45	49.41		14.22	13.01	14.72
YUL	14/12/1995	21:52	-10.9	S-	45	49.71		13.36	12.76	14.79
YUL	14/12/1995	21:53	-10.8	S-	50	50.00		12.50	12.50	14.86

FIGURE 4.1

READAC AND CR21X ANALYSIS - NATURAL SNOW
-3 TO -7°C
20-MINUTE RATE EVERY MINUTE
1995-1999

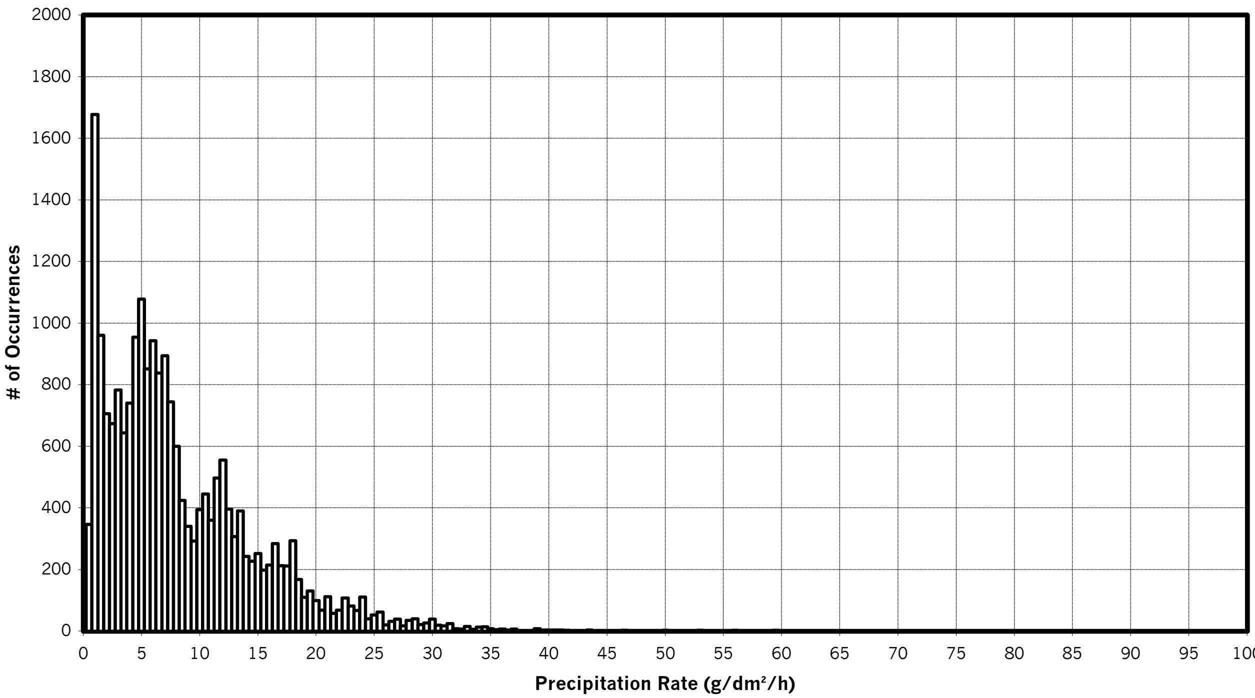
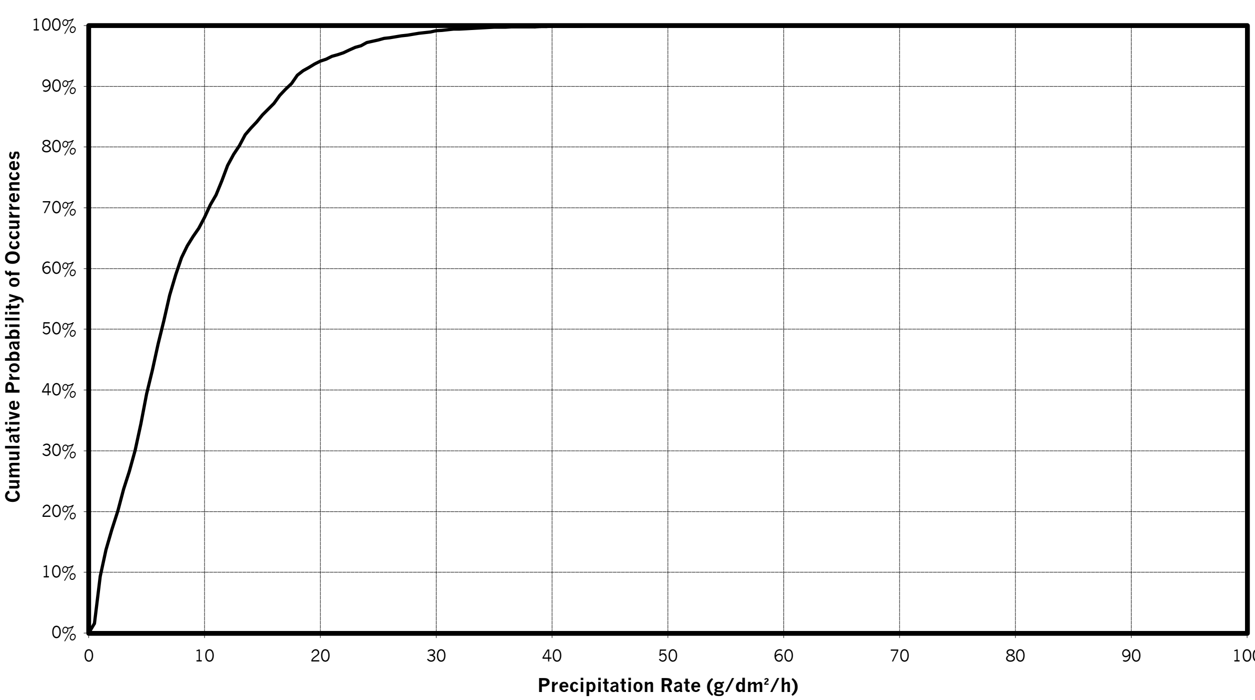


FIGURE 4.2

READAC AND CR21X ANALYSIS - NATURAL SNOW
-3 TO -7°C
20-MINUTE RATE EVERY MINUTE
1995-1999



cm1514/report/readac/Example (-7°C)
At: 2 Charts
02/01/01, 4:52 PM

Temperature Range	95th Percentile Precipitation Rate (g/dm²/h)		
	6 min	20 min	35 min
Above 0°C	21	20	21
0 to –3°C	19	18	18
-3 to –7°C	21	21	21
-7 to –14°C	26	26	26
-14 to –25°C	24	23	24

Each of the rates in the above table represents the rate below which 95% of all snowfalls occurred in a specific temperature range for a given rate duration. For example, in the temperature range of –3 to –7°C and for a duration of 20 minutes, the 95th percentile is 21 g/dm^2/h. This indicates that 95% of the 20-minute rates recorded between –3 to –7°C were equal to or below 21 g/dm^2/h. The percent of occurrences when the precipitation rates were above 25 g/dm^2/h are shown below for all temperature ranges.

Temperature Range	Percent of Occurrences when Rate is above 25 g/dm^2/h		
	6 min	20 min	35 min
Above 0°C	3.0%	3.3%	3.8%
0 to –3°C	1.8%	1.9%	1.5%
-3 to –7°C	2.6%	2.4%	2.3%
-7 to –14°C	5.3%	5.7%	5.7%
-14 to –25°C	3.8%	3.7%	4.4%

The high percentage of occurrences when the rate is above 25 g/dm²/h at low temperatures is attributed mainly to unusually high-rate snowfalls during the 1998/99 winter season.

There were no data available for natural snow conditions below –25°C.

4.2 Freezing Rain

The 95th percentile for two temperature ranges is shown below for freezing rain:

Temperature Range	95th Percentile Precipitation Rate (g/dm²/h)		
	6 min	20 min	35 min
0 to –3°C	29	26	23
-3 to –10°C	25	24	24

In freezing rain, the 95th percentile was near 24 g/dm^2/h for the –3 to –10ºC range and slightly higher, near 26 g/dm^2/h, for the 0 to –3ºC range.

4.3 Snowstorm Analysis

The following section discusses the READAC and CR21X data recorded at Dorval Airport for a single snowstorm. The storm in question occurred on January 15th 1999. The ambient temperature was between –18 and –8 °C. The temperature gradually rose during the snowstorm.

Figures 4.3 to 4.6 show the total accumulations of snow and average rate of precipitation, calculated in 6-minute intervals, for both meteorological instruments. The stepped line on Figure 4.3 represents the data collected from the READAC station. The solid line on the same chart is the smoothed snow accumulation data.

The shapes of Figures 4.3 and 4.5 are very similar, with more detail being represented in Figure 4.5. Due to the increased precision of the CR21X station, it is possible to detect smaller variations in the precipitation rate.

These variations are masked in the READAC data due to the low resolution and the smoothing required to interpret the raw data.

Figures 4.4 and 4.6 show the precipitation rate for a 24-hour period. The 6-minute moving average rates calculated from the CR21X data show much more detail. Higher rates were detected from this station, because the smoothed data from the lower resolution READAC station does not allow detection of rapid increases and decreases in rates.

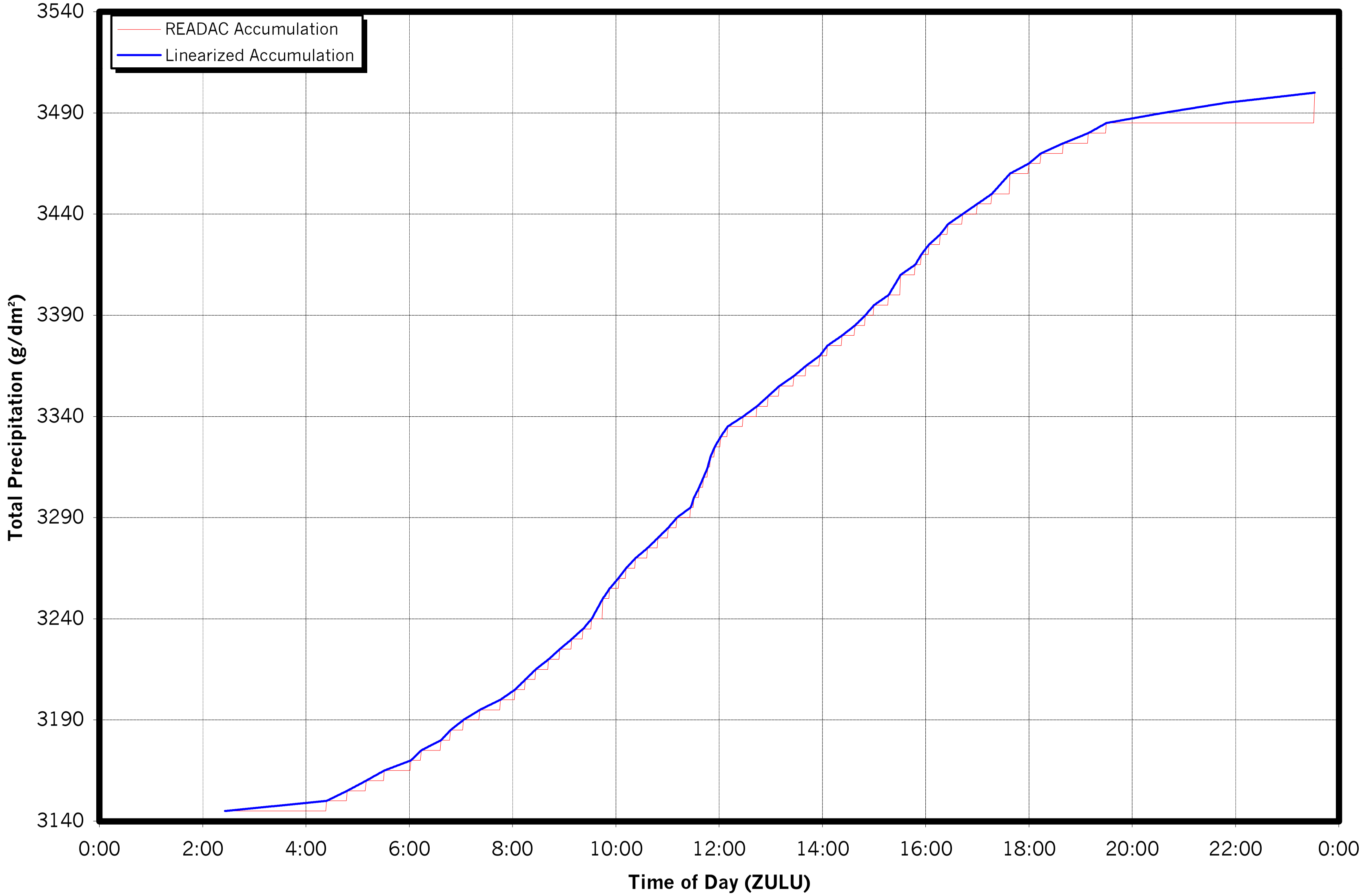
Rate pan data collected from the APS test site located at Dorval Airport are included in Figures 4.4 and 4.6. The pans were placed at a 10º angle on test stands approximately 30 m away from the precipitation gauge. The rates from the pans are based on the weight of snow that collected in the pans during a 10-minute period. The rates are recorded at the end of this time interval. Both the upper and lower rate pans are included in the figures. The data point from the rate pans correlate well with the traces shown in Figures 4.4 and 4.6.

More precipitation collects in the rate pans during high winds, because the stands are always placed facing the wind. The differences between the precipitation gauge trace and the rate pan points could be due to the 10º angle of the test stand.

FIGURE 4.3

READAC SNOW ACCUMULATION

Dorval, January 15, 1999



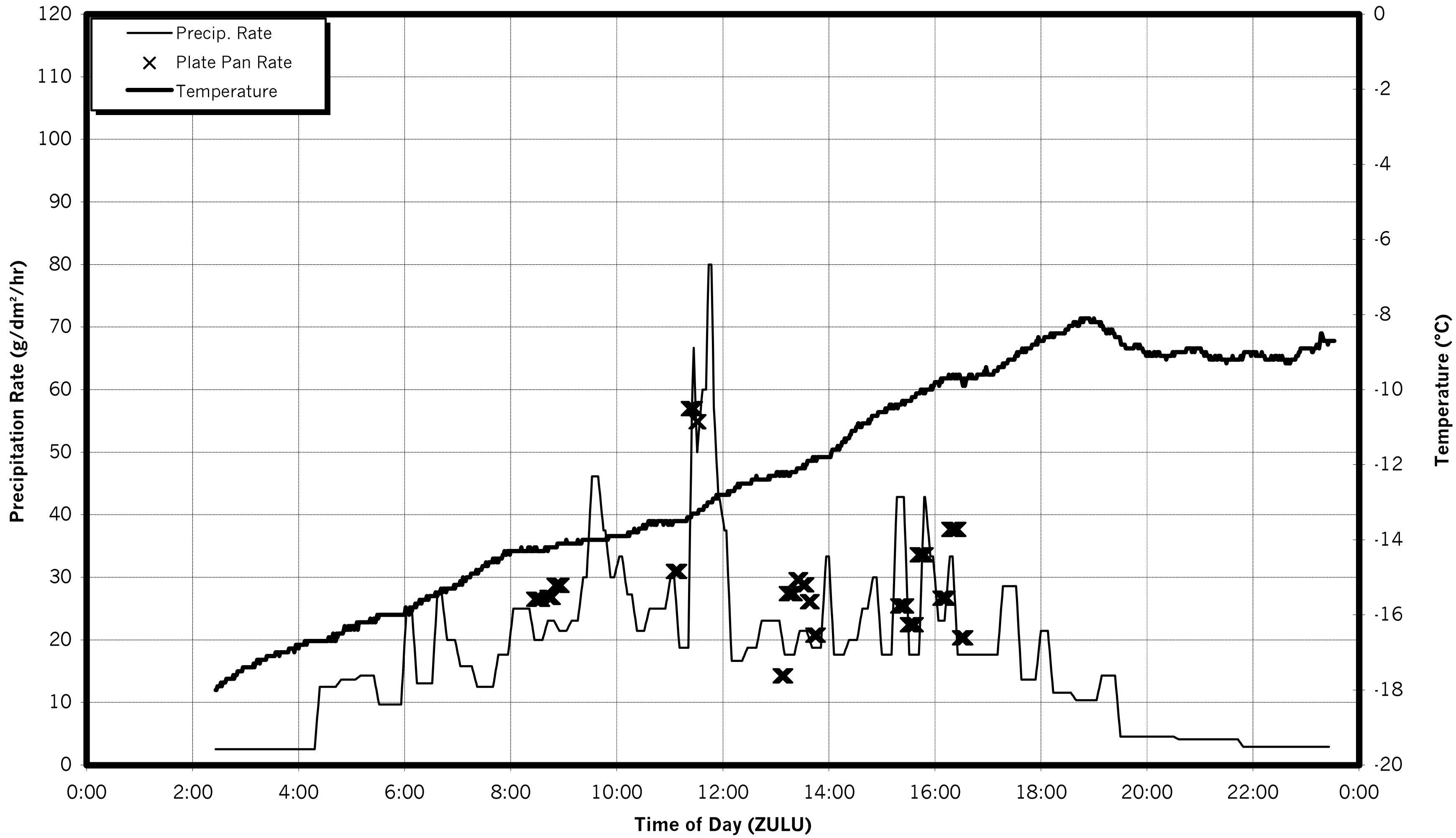
cm1514/report/readac/J15_read
At: ACCUM.
02/01/01, 4:54 PM

FIGURE 4.4

READAC PRECIPITATION RATE

(6-Minute Moving Average)

Dorval, January 15, 1999

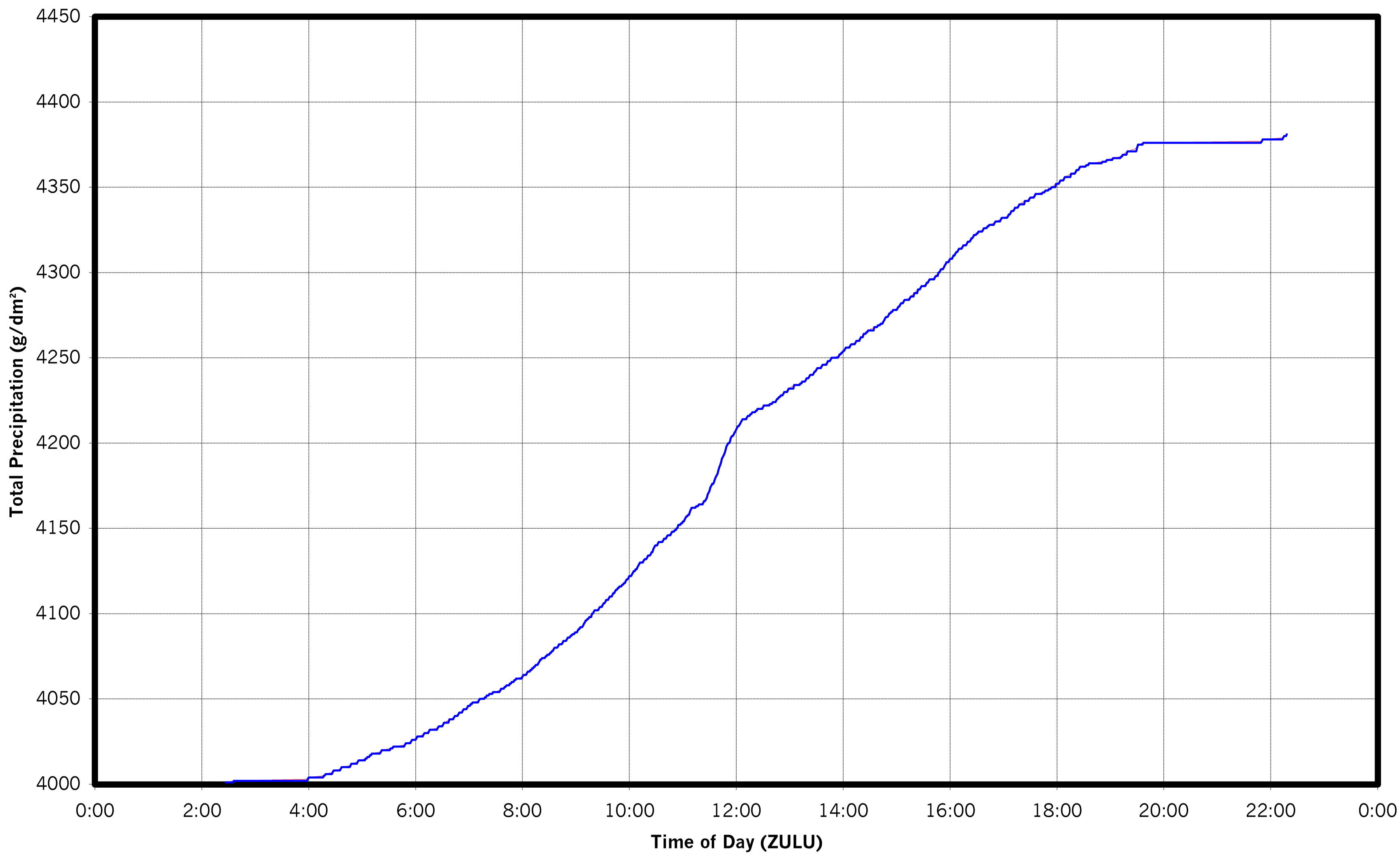


cm1514/report/readac/J15_read
At: RATE
02/01/01, 5:18 PM

FIGURE 4.5

CR21X SNOW ACCUMULATION

Dorval, January 15, 1999



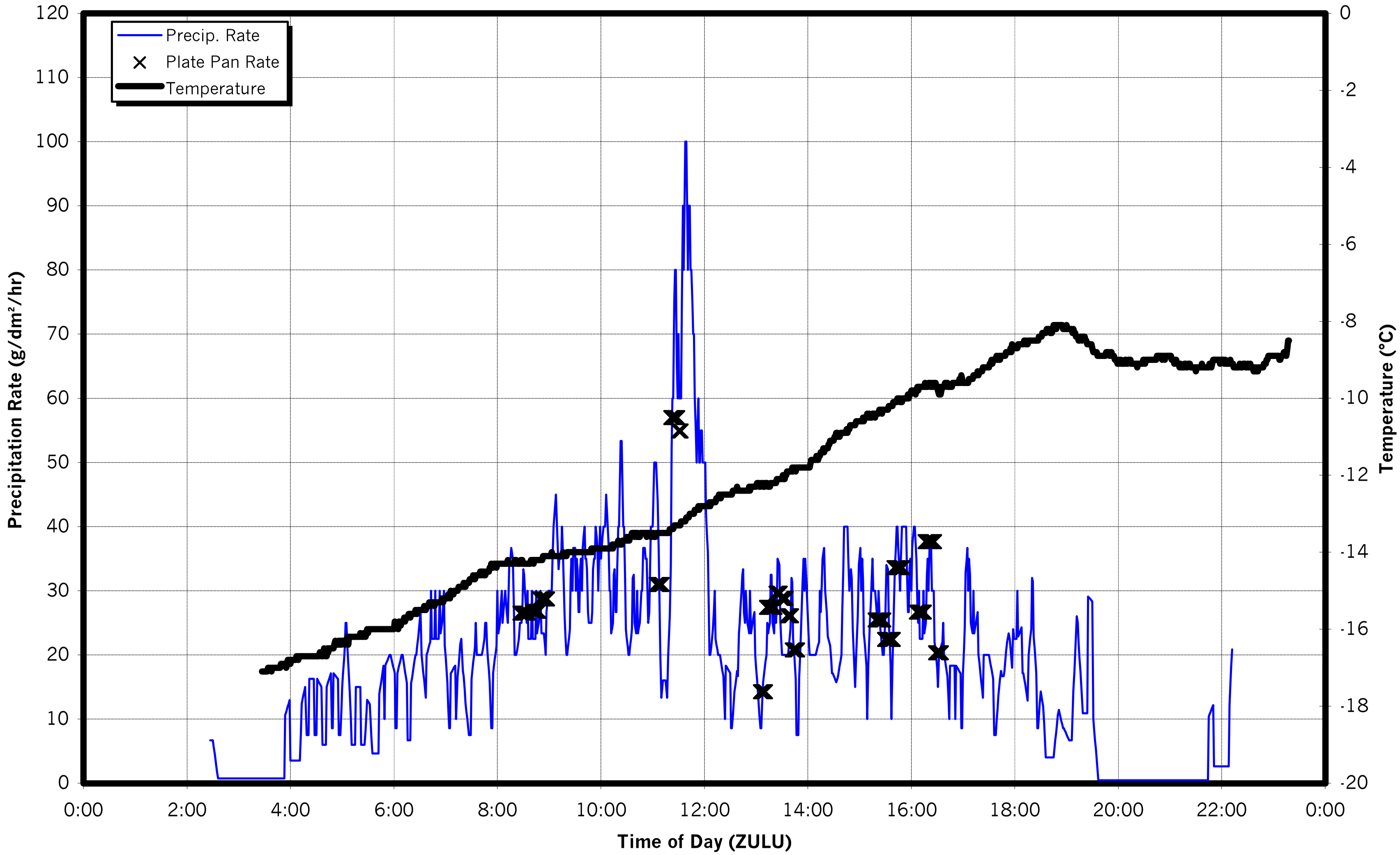
cm1514/report/readac/J15_crx
At: Accum
02/01/01, 4:57 PM

FIGURE 4.6

CR21X PRECIPITATION RATE

(6-Minute Moving Average)

Dorval, January 15, 1999



cm1514/report/readac/J15_crx
At: Rate
02/01/01, 5:22 PM

4.4 Snow at Cold Temperatures

Snow fell at temperatures below –14°C on several occasions during the winter of 1998/99. The following table shows the date for each of these snowfalls and the average temperature during the duration of the precipitation.

Date	Average Temperature during Cold Snowfalls (°C)
December 29, 1998	-18
December 30, 1998	-15
January 3, 1999	-14
January 11, 1999	-15
January 12, 1999	-19
January 13, 1999	-14
January 14, 1999	-16
January 15, 1999	-15

The rates of precipitation are shown in Appendix E for some of the previously mentioned dates. The data from these snowstorms show that rates of precipitation above 10 g/dm^2/h occurred regularly, and rates of precipitation above 25 g/dm^2/h occurred for short periods on most of these occasions.

The general shape of the cumulative probability of occurrence curves at colder temperatures is similar to that of the curves drawn at other temperatures, as shown in Figure 4.7. The two coldest temperature intervals represent the two highest 95th percentile precipitation rates. This indicates that high rates do occur at cold temperatures.

The coldest temperature interval was divided into three smaller intervals (data shown in Appendix B):

- -14 to –18ºC;
- -18 to –22ºC; and
- -22 to –25ºC.

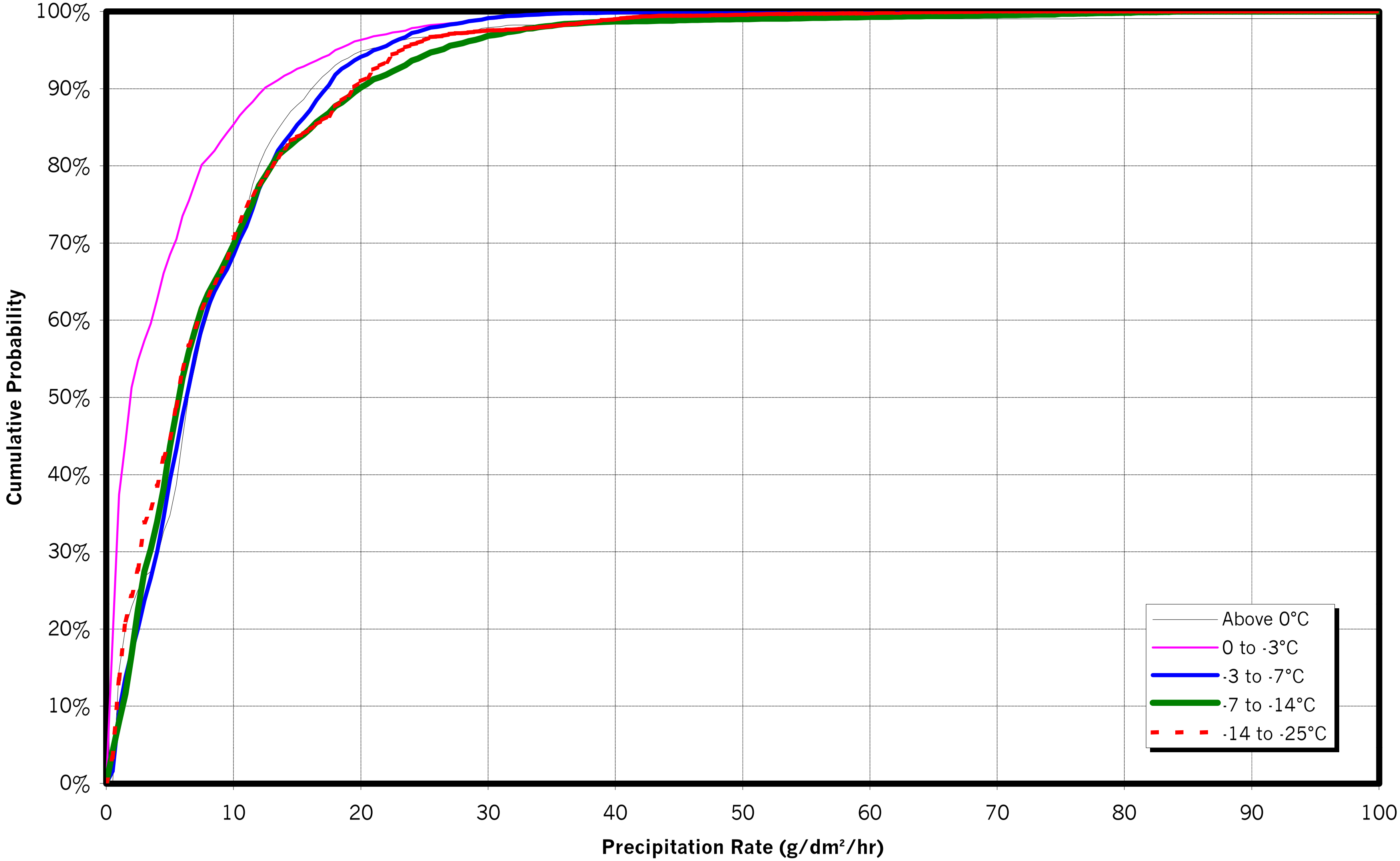
High precipitation rates were more common in the –14 to –18ºC range, but few high rate snow falls were recorded in the other two ranges, as shown in Figure 4.8. It should be noted, however, that the 95th percentile was above 15 g/dm^2/h for all subdivided intervals. The percent of occurrences when the precipitation rates were above 25 g/dm^2/h are shown below for the subdivided intervals:

FIGURE 4.7

READAC AND CR21X ANALYSIS - NATURAL SNOW

20-MINUTE RATE EVERY MINUTE FOR ALL TEMPERATURE RANGES

1995-1999



cm1514/report/readac/All_20mn
At: 20 min Cuml.
02/01/01, 4:59 PM

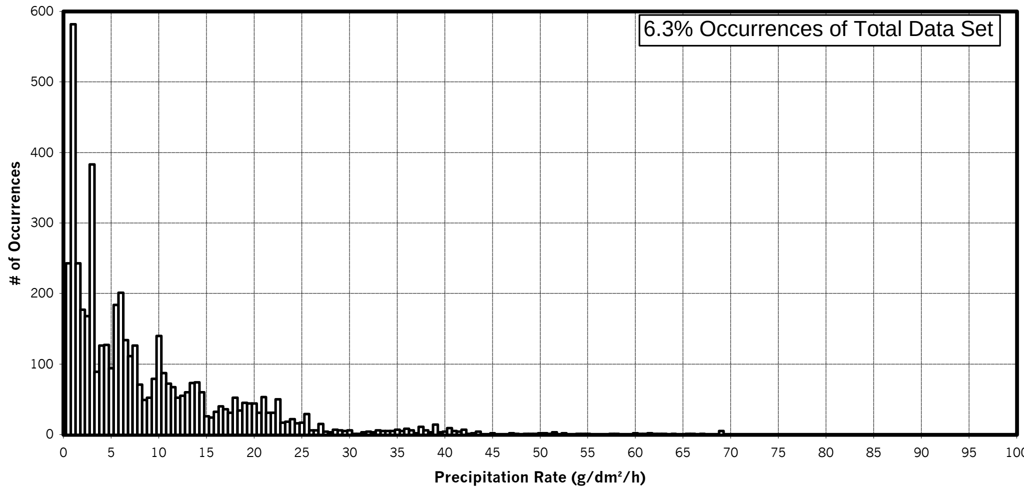
FIGURE 4.8

SUBDIVISION OF -14 TO -25°C SNOW DATA

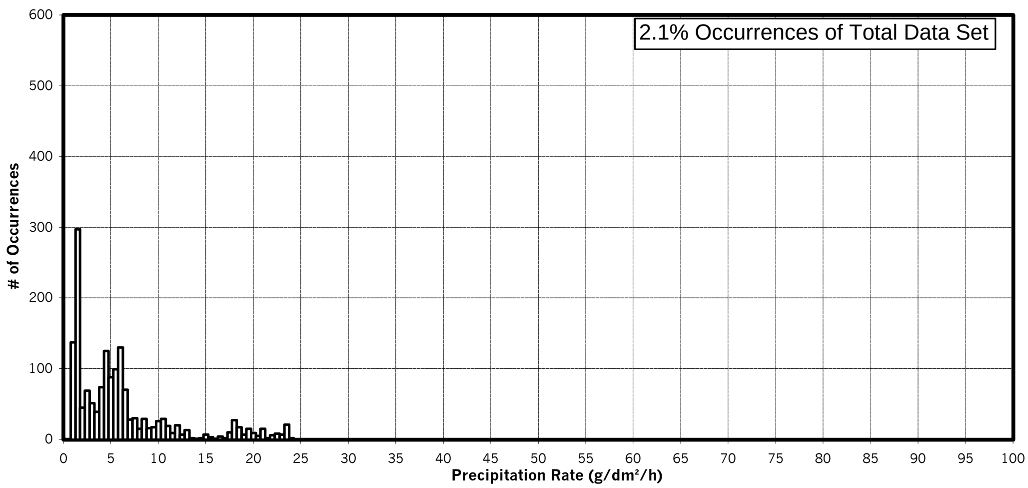
20-MINUTE RATE EVERY MINUTE

1995-1999

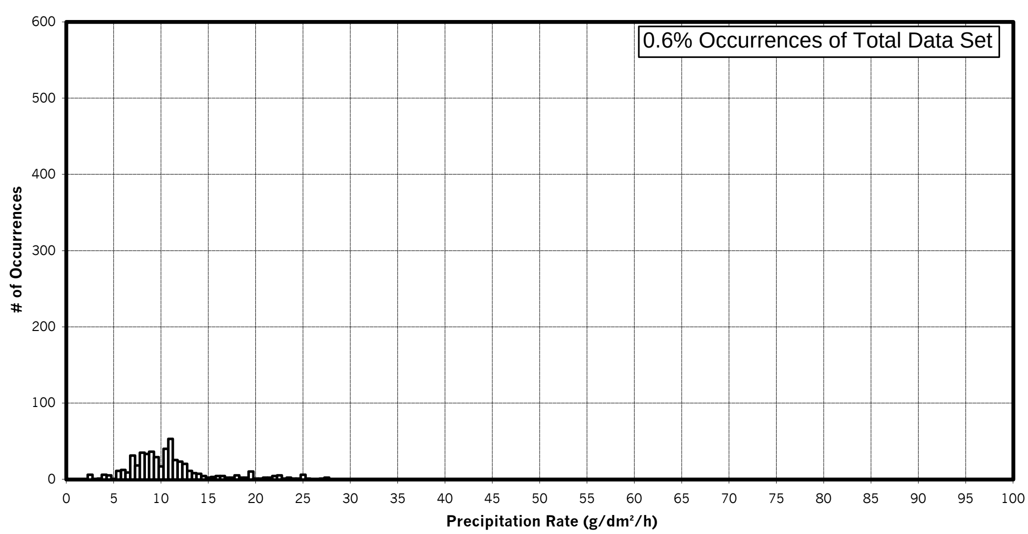
-14 TO -18°C



-18 TO -22°C



-22 TO -25°C



Temperature Range	Percent of Occurrences when Rate is above 25 g/dm²/h		
	6 min	20 min	35 min
-14 to -18°C	5.2%	5.3%	6.4%
-18 to -22°C	0.6%	0.0%	0.0%
-22 to -25°C	1.6%	0.8%	0.0%

4.5 Comparing AES with APS 1995 to 1999 Snow Weather Data

A study of precipitation rate in each holdover time temperature interval was made in 1995 by AES. This study, based on data collected at an experimental site at Pearson Airport is included in Appendix D.

The graphs (Cumulative Probability versus Precipitation rate) were reasonably similar in overall curve shape but not necessarily in exact values. For the temperature range of 0 to –3°C, the results of the AES study are very similar to those in this report. The 6-, 20-, and 35-minute rates are nearly identical in both studies. The 95th percentile was 16 g/dm^2/h in the AES report and 18 g/dm^2/h according to this report.

In the range of –3°C to –7°C, the general shapes of the curves are not as similar as those previously mentioned. The findings of this study show that only 68% of precipitation is expected to be below 10 g/dm^2/h, the findings of the AES study suggest that 87% of precipitation will be at a rate lower than 10 g/dm^2/h. The curves from the APS and the AES studies show very little change in precipitation rate for the various time intervals, although a slight tendency toward higher rates is shown for shorter time intervals.

The 95th percentile rates, based on data collected from the READAC and CR21X stations, are 26 g/dm^2/h for the –7 to –14°C range. The 95th percentile precipitation rates for this temperature range are significantly higher than the AES study due to very high rates recorded during a least two specific snowfalls during the winter of 1998/99.

The range of –14 to –25°C presents the largest variation in results between the two studies. The AES graphs indicate that snow precipitation rates in that temperature range are much lower than the other ranges. These finding do not match the results of this report. The data from the READAC and CR21X stations show very little difference in the probability versus precipitation rate curves for various temperature ranges. A slight increase in the 95% rate was detected at lower temperatures.

Overall, these two data sets (AES and Snow Weather Data for 1995/98) are similar enough to compare with each other for temperature ranges above –7°C. Below that temperature, the AES data does not contain any high rate precipitation points. The data collected by AES were recorded in Toronto. The average temperature is warmer in that region than in the regions where the APS data were collected. This resulted in colder ambient temperatures in the data analysed for this study.

4.6 Comparison of 1993 to 1995 with 1995 to 1998 Snow Weather Data

Preliminary analysis of these two sets of data revealed that numerous data conversions are needed to help make substantial conclusions. Variations in scales between the two data sets can present other difficulties. The data presented in the 1993 to 1995 analysis were not separated into temperature ranges. The following 95th percentiles were approximated from the graphs presented in Appendix C.

From this data it can be observed that very high snowfall rates were recorded during the 1993/1994 winter. The 95th percentile for the entire temperature range from 1993 to 1995 was 21 g/dm^2/h.

TABLE 4.2

SUMMARY OF 1993 TO 1995 SNOW WEATHER DATA

Date	Ambient Temperatures (°C)	95th Percentile Snowfall Rate (g/dm²/h)
1993/1995	N/A	26
1993/1994	N/A	37
21-Dec-93	0.5	37
01-Apr-94	-13	61
08-Jan-94	-18	11
14-Jan-94	-10	5
23-Jan-94	-16	13
27-Jan-94	-9	27
12-Feb-94	-8	17
23-Feb-94	-9	31
10-Mar-94	-5	19
27-Mar-94	0.2	31
07-Apr-94	-1.3	16
1994/1995	N/A	21
07-Jan-95	-3	17
12-Jan-95	-14	20
04-Feb-95	-8	9
11-Feb-95	-9	14
16-Feb-95	-1	28
24-Feb-95	-0.2	11
27-Feb-95	-12	13
06-Mar-95	-7	25
08-Mar-95	-5	17

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5. CONCLUSIONS

The data required and analysed in this report encompass four acquisition sites. Increasing the number of data collection sites increases the range of temperatures observed and provides a better interpretation of generalized weather conditions.

Few freezing rain data were detected from the weather station logs. The majority of the data on freezing rain were centred in the -3 to -5ºC interval. The 95th percentile precipitation rate from the limited freezing rain data was approximately 25 g/dm^2/h.

Preliminary analysis indicates that the current holdover time rate evaluation limits for snow are satisfactory. High rate snow precipitation in cold weather was observed during some of the snowstorms documented during the winter of 1998/99. High rates occur for short periods during snow precipitation for all ambient temperature ranges.

In the -14 to -25°C range, the 95th percentile was 24 g/dm^2/h, which is significantly higher than the proposed maximum rate limit of 10 g/dm^2/h for that temperature range. The subdivision of this temperature range indicated that precipitation rates below -18ºC were significantly lower and occurrences were less frequent. Based on the data analysed for this study, the precipitation rate limits could be reduced if the coldest temperature range was -18 to -25ºC.

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6. RECOMMENDATIONS

More data should be collected and analysed from the four weather stations in Quebec. Data, if available, from additional stations should be included to increase the range of temperatures observed. Stations further north and south could provide data from warmer and colder regions.

The temperature ranges used to establish holdover times should be re-evaluated according to the weather data collected. Ranges could be based on the frequency of precipitation in each range.

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REFERENCES

1. D'Avirro, J., Chaput, M., Hanna, M., Peters, A., *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1997/98 Winter*, APS Aviation Inc., Montreal. December 1998, Transportation Development Centre report, TP 13477E, 200.

2. *Workgroup on Laboratory Methods to Derive Holdover Time Guidelines (Minutes)*, SAE Aerospace International, Warrendale, PA, November 20 and 21, 1997, 21.

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APPENDIX A

TERMS OF REFERENCE – WORK STATEMENT

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 98/99

(December 1998)

1. INTRODUCTION

Following the crash of a F-28 at Dryden in 1989 and the subsequent recommendations of the Commission of Inquiry, the Dryden Commission Implementation Project (DCIP) of Transport Canada (TC) was set up. Together with many other regulatory activities an intensive research program of field testing of deicing and anti-icing fluids was initiated with guidance from the international air transport sector through the Society of Automotive Engineering (SAE) G-12 Committee on Aircraft Ground De/Anti-icing. As a result of the work performed to date Transport Canada and the US Federal Aviation Administration (the FAA) have been introducing holdover time regulations and the FAA has requested that the SAE, continue its work on substantiating the existing ISO/AEA/SAE Holdover Time (HOT) tables (TC research representing the bulk of the testing).

The times given in HOT Tables were originally established by the Association of European Airlines based on assumptions of fluid properties, and anecdotal data. The extensive testing conducted initially by the DCIP R&D Task Group and subsequently by its successor Transport Canada, Transportation Development Centre (TDC) Aviation Winter Operations R&D (AWORD) Group has been to determine the performance of fluids on standard flat plates in order to substantiate the times or, if warranted, to recommend changes.

TDC has undertaken most of the field research and much other allied research to improve understanding of the fluid HoldOver Times. Most of the HOT table cells been substantiated, however low temperatures have not been adequately explored and further tests are needed.

The development of ULTRA by Union Carbide stimulated all the fluid manufacturers to produce new long lasting anti-icing fluids defined as Type IV. All the Type IV fluids were upgraded in early 1996 and therefore all table conditions need to be re-evaluated and the table revised if necessary. Certain special conditions for which advance planning is particularly difficult such as low temperatures with precipitation, rain or other precipitation on cold soaked surfaces, and precipitation rates as high as 25 $gm/dm^2/hr$ need to be included in the data set. All lead to the need for further research.

Although the Holdover tables are widely used in the industry as guides to operating aircraft in winter precipitation the significance of the range of time values given in each cell of the table is obscure. There is a clear need to improve the understanding of the limiting weather conditions to which these values relate.

An important effort was made in the 94/95 and 95/96 seasons to verify that the flat plate data were representative of aircraft wings. Airlines cooperated with DCIP by making aircraft and ground support staff available at night to facilitate the correlation testing of flat plates with performance of fluids on aircraft. An extension of this testing was to observe patterns of fluid failure on aircraft in order to provide data to assist pilots with visual determination of fluid failure, and to provide a data to contamination sensor manufacturers. The few aircraft tests made to validate the flat plate tests were inconclusive and more such tests are needed. Additional tests testing with hot water for special deicing conditions were not completed. All these areas are the subjects for the further research that is planned for the 98/99 winter.

The primary objective of 97/98 testing was the performance evaluation of new and previously qualified Type IV fluids over the entire range of conditions encompassed by the holdover time tables. The effect of different variables on the fluid holdover time, in particular the effect of fluid viscosity, was examined and deemed to be significant. As a result, any future Type IV fluid holdover time testing will be conducted using samples representative of the manufacturers lowest recommended on-wing viscosity. Current methods for establishing holdover times in snow involve outdoor testing, which has been the source of industry concern for some time. It is recommended that a snowmaking device in development need to be evaluated for the future conduct of snow holdover time tests in controlled conditions. The study of fluid buffers was also continued in 97/98 and identified several industry concerns which will be addressed in further research. The adherence of contaminated fluid to aircraft wings was also evaluated in a series of simulated takeoff runs without aircraft rotation. Further research in these areas is needed.

2. PROGRAM OBJECTIVE (MCR 16)

Take an active and participatory role to advance aircraft ground de-icing/anti-icing technology. Develop international standards, guidance material for remote and runway-end de-icing facilities, and more reliable methods of predicting de-icing/anti- icing holdover times.

3. PROGRAM SUB-OBJECTIVES

3.1. Develop reliable holdover time (HOT) guideline material based on test information for a wide range of winter weather operating conditions.

3.2. Substantiate the guideline values in the existing holdover time (HOT) tables for fluids that have been qualified as acceptable on the basis of their impact on aircraft take-off performance.

3.3. Perform tests to establish relationships between laboratory testing and real world experience in protecting aircraft surfaces.

3.4. Support development of improved approaches to protecting aircraft surfaces from winter precipitation.

4. PROJECT OBJECTIVES

4.1. Develop holdover time data for all newly qualified de/anti-icing fluids.
4.2. Develop holdover time data for Type IV fluids using lowest qualifying viscosity samples.
4.3. Develop supplementary data for a reduced buffer 'de-icing only' Table.
4.4. Determine whether recycled, recovered fluid can be used as a 'De-icing only' fluid.
4.5. Determine whether the extreme precipitation rates used for laboratory testing of de/anti-icing fluids are in fact encountered in practice.
4.6. Obtain equipment for laboratory production of artificial snow which most closely reproduces natural snow.
4.7. Assess the limiting conditions of wind, precipitation and temperature under which water can be used as the first step of a two-step de-icing procedure.
4.8. Determine the patterns of frost formation and of fluid failure initiation and progression on the wings of high-wing turbo-prop and jet commuter aircraft.
4.9. Assess the practicality of using vehicle-mounted remote contamination detection sensors for pre-flight (end-of-runway) inspection.
4.10. Provide base data on the capabilities of remote sensors.
4.11. Provide pilots with reference data for the identification of fluid failure. Quantify pilot capabilities to identify fluid failure
4.12. Provide support services for the conduct of tests to determine under what conditions contaminated fluid adheres to aircraft lifting surfaces.
4.13. Assess whether pre-warming fuel at time of re-fuelling will help to eliminate the 'cold soaked' wing problem.
4.14. Develop a low-cost test wing which can be used in the laboratory in lieu of field testing full scale aircraft.
4.15. Establish the safe limits for de-icing truck operation when de-icing aircraft with the engines running.
4.16. Provide general support services.
4.17. Disseminate test findings

5. DETAILED STATEMENT OF WORK

5.1. General

5.1.1. Planning and Control

Develop a detailed work plan, activity schedule, cash flow projection, project management control and documentation procedures (as specified in Section 9,"Project Control") within three weeks of effective commencement date, confirming task priorities, suggesting hardware and software suppliers, broadly identifying data needs and defining the roles of subcontractors, and submit to TDC for review and approval.

5.1.2. Safety and Security

Particular consideration will be given to safety in and around aircraft on the airport and deicing sites In the event of conflict between access for data gathering to obtain required test results and safety considerations, safety shall always govern.

5.2. Holdover Time Testing and Evaluation of De/Anti-icing Fluids

5.2.1. Newly Certified Fluids

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and to develop individual Holdover Time Tables based on samples of newly certified or re-certified fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate tests for one new fluid. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests will be performed in the laboratory. All testing shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

5.2.2. Low Viscosity Type IV Anti-icing Fluids

Fluid holdover time testing of Type IV fluids will be conducted using procedures established during past test seasons but using fluid with the lowest operational use viscosity.

5.2.2.1.Flat Plate Tests for New Type IV Fluids

Conduct flat plate tests under conditions of natural snow and artificial precipitation to record the holdover times, and develop individual Holdover Time Tables based on samples of new Type IV fluids supplied by Fluid Manufacturers under as wide a range of temperature, precipitation rate, precipitation type, and wind conditions as can be experienced. Anticipate for four new fluids using samples with one viscosity. Snow tests shall be conducted outdoors, and ZD, ZR-, Zfog, and CSW tests shall be performed in the laboratory using methodology applied in past years.

5.2.2.2.Effect on Holdover Time of Viscosity

Conduct tests aimed at determining the effect of fluid viscosity on holdover time. Tests shall be conducted in light freezing rain and freezing drizzle conditions at various temperatures in the National Research council (NRC) Climatic Environment facility (CEF) using low and high viscosity samples

representing production limits of three anti-icing fluids: a propylene, an ethylene and the Fluid X (which will become the benchmark for laboratory based HOT testing).
Anticipate a total of approximately 100 tests to be conducted under ZR- and ZD at -3 and -10 Celsius at low and high rates.

5.2.3. Recycled Fluids as Type I Fluids

5.2.3.1.Holdover Times

A complete set of holdover time tests shall be conducted using two fluid test samples of recovered glycol based freezing point depressant fluid which have been recycled and exhibit nominal conformance to Type I de-icing fluid performance characteristics. The objective of this series of tests is to establish a sound base of data sufficient to establish valid holdover time tables for these fluids.

5.2.3.2.Compatibility with Type IV Fluids

Fluid compatibilty trials shall be conducted using various combinations of the recycled fluids and commercial Type IV fluids. Determine how the Inland fluids perform when used in conjunction with a Type IV fluid overspray.

5.3. Supplementary Data for Deicing Only Table

Evaluate the test conditions used in establishing the deicing only table by undertaking the following test series at sub zero temperatures but with no precipitation.

5.3.1. Establish Quantity of Fluid for Field Tests.

Conduct a series of comparative laboratory tests with 0.5, 0.25 and 0.1 litre per plate. Consider the case of spraying for frost with a fan shape to cover a wide area with a small amount of fluid compared with a stream as used to remove snow or ice. Examine typical fluid quantities representing frost removal spray. Conduct some tests on aircraft piggybacking on other testing if feasible.

5.3.2. Establish Temperature of Fluid for Field Tests

Laboratory tests will be performed with fluids initial temperatures at the spray nozzle of 60ºC, 50ºC, and 40ºC initial temperature.
Field tests on aircraft will be designed to measure the loss of fluid temperature and to measure fluid evaporation and enrichment during the air transport phase between spray nozzle and wing surfaces, for various distances and shapes of spray pattern (3 distances; 2 spray patterns).

5.3.2.1.

Examine the effect on the final freeze point of sprayed fluids on the wing, resulting from variations in the temperature of the fluid (60ºC, 50ºC, and 40ºC).

5.3.2.2.

Examine the effect on wing heat and fluid evaporation of removing contaminant from the wing surface. Various degrees of ice depth shall be deposited using a hand-held rainmaker, including a very light coating to simulate frost. The amount of fluid sprayed shall be controlled by the operator, spraying until a clean surface results**.**

5.3.3. Perform tests at current buffer limit as baseline.

Perform a series of comparative tests using buffers at 3ºC and 10ºC to compare to the new data and the data collected last season with buffers at 0ºC .

5.3.4. Simulate High Wind Conditions

Tests shall be performed using NRC fans producing winds up to 30 kph for comparison with the earlier series of tests with speeds up to 20 kph

5.3.5. High Relative Humidity

Perform a series of plate tests at 90% RH to compare results to those already gathered. Review the condition with weather services to determine typical RH values during deicing only conditions.

5.3.6. Cold Soaked Wings

Perform a series of tests on cold soak boxes to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT. These tests can be run in conjunction with high humidity tests when deposition of frost on cold soaked surfaces would normally be expected.

5.3.7. Effect of Snow Removal on Fluid Heat Input

Perform tests to establish whether removal of snow results in extesive amounts of heat being carried away and insufficient heat being transferred to the wing during deicing.

Expose flat plates to snowfall (either natural or as simulated by approved equipment) and protect snow catches of various thicknesses. Tests shall be run in an area protected from further snowfall. Fluid shall be applied with a hand sprayer, until the plate is cleaned, measuring the amount of fluid applied. The final fluid concentration on the plate shall be measured. The heat lost in fluid run off shall be measured. Parallel tests will be conducted on bare surfaces.

A carefully calculated heat balance shall be determined for each experiment based on the temperatures of the applied fluid, the plate and the collected run-off material.

5.3.8. Effect of Composite Surfaces on Evaporation

Evaluate the effects of the use of composite materials in wings on the heat transfer from deicing fluid to the wing. Conduct a series of laboratory comparative tests on a several samples of composite surfaces.

Identify an appropriate aircraft having a wing surface composed of new technology composite material as well as aluminium, determining the thermal pathways connecting the composite surfaces to the main wing structure.

Conduct field tests on a sample aircraft.

5.3.9. Unpowered Flight Control Surfaces

Field trials will be conducted on DC9 aircraft to assess the impact of fluids of various buffers on the freedom of operation of the unpowered elevator control tabs to establish whether the natural buffer provided by evaporation would be sufficient to provide protection if the wing were in a cold-soaked condition, with wing temperature several degrees below OAT

5.3.10.Field Tests on Aircraft

Three overnight test sessions shall be planned for these tests. Tests shall be conducted on aircraft types including the McDonnell Douglas DC-9 and Canadair RJ, with a minimum of one night for each type. Testing on a third aircraft type would be useful to improve confidence and to confirm the universality of the results. Use an ice detector sensor system to provide a separate source of data.

5.3.11.Laboratory Tests

The number of proposed tests shall be controlled by limiting tests to the minimum number of ambient conditions that will support conclusions on the significance of the issues raised while maintaining a good level of confidence. As a minimum, this encompasses about 230 plate tests and would require about 8 days at the NRC CEF Facility or other suitable facility.

5.4. Flow of Contaminated Fluids from Wings during Takeoff

5.4.1. Requirement

Evaluate anti-icing fluids for their influence on adherence, in particular, propylene based Type IV fluids which were observed during fluid failure

A test plan shall be developed jointly with NRC.

Two days of testing at Mirabel Airport shall be planned.

Use an ice contamination sensor to assist in documenting contamination levels to provide valuable assistance in data gathering. A contingency allowance to fund sensor company participation shall be included.

Data collected during these trials shall include:

- type of fluid applied;
- record of contamination level prior to take off runs,;record of level of contamination following takeoff runs;
- observations, photography and video taping, and ice sensor records; and
- specifics on aircraft takeoff runs obtained from NRC personnel.

5.4.2. Conduct of Trials and Assembly of Results

Coordinate all test activities, initiating tests in conjunction with NRC test pilots based on forecast weather. Analyse results and document all findings in a final technical report and in presentation format.

5.5. Aircraft Full-Scale Tests

5.5.1. Purpose of Tests

Conduct full-scale aircraft tests:

- To generate data which can be used to assist pilots with visual identification of fluid failure;
- To generate data to be used to assess a pilot's field of view during adverse conditions of winter precipitation for selected aircraft; (See item 5.11)
- To compare the performance of de/anti-icing fluids on aircraft surfaces with the performance of de/anti-icing fluids on flat plates;
- To examine the pattern of failure using Type IV fluid brands not tested in the past; and
- To further investigate progression of failure on the two wings in crosswind conditions.

5.5.2. Planning and Coordination

Planning and preparation for tests including provision of facilities, personnel selection and training, and test scheduling shall be the same as provided to TDC in previous years

5.5.3. Testing

All tests and dry runs shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

Test planning will be based on the following aircraft and facilities:

Aircraft	Airline	Test Locn.	Deicing Pad	Deicing Crew
Canadair RJ	Air Canada	Dorval	Central	Aéromag 2000
ATR42	Inter Canadian	Dorval	Central	Aéromag 2000

5.5.4. Test Measurements

Make the following measurements during the conduct of each test:

- Contaminated thickness histories at selected points on the wings. The selection of test points shall be made in cooperation with the Transportation Development Centre,
- Contamination histories at selected points on wings (selected in cooperation with the Transportation Development Centre),
- Location and time of first failure of fluids on the wings,
- Pattern and history of fluid failure progression,
- Time to failure of one third of the wing surface
- Concurrent measurement of time to failure of fluids on flat plates. The plates will be mounted on standard frames and on aircraft wings at agreed locations,
- Wing temperature distributions,
- Amount of fluid applied in each test run and fluid temperature,
- Meteorological conditions, and
- For crosswind tasks, effects of rate of accumulation on each wing.

In the event that there is no precipitation during full-scale tests, the opportunity shall be taken to make measurements of fluid thickness distributions on the wings.

These measurements shall be repeated for a number of fluid applications to assess the uniformity of fluid application.

5.5.5. Pilot Observations

Contact airlines and arrange for pilots to be present during the tests to observe fluid failure and failure progression, and to record pilot observations from the cockpit and the cabin for later correlation with aircraft external observations.

5.5.6. Remote Sensor Records

Record the progression of fluid failure on the wing using RVSI and/or Cox remote contamination detection sensors if these sensors are made available.

5.6. Snowmaking Methods and Laboratory Testing for Holdover Times

5.6.1. Evaluation of Winter Weather Data

5.6.1.1.Snow Rates

Collect and evaluate snow weather data (precipitation rate/temperature data) during the winter to ascertain the suitability of the data ranges used to date for evaluation of holdover time limits.

Obtain current data from Environment Canada for three sites in Quebec: Rouyn, Pointe-au-père (Mont-Joli), and Ancienne Lorette (Quebec City), in addition to Dorval (Montreal).

5.6.1.2.Fog Deposition Rates

Devise a procedure and conduct fog deposition measurements outdoors on at least two occasions to determine the range of fog deposition rates which occur in natural conditions.

5.6.1.3. Frost Deposition Rates

Frost deposition rates shall be collected at various temperatures in natural conditions in order to determine a deposition range for this condition. Consideration shall be given to collecting deposition rates in cold temperatures (for example in Thompson, Manitoba). A total of five sessions shall be planned.

5.6.2. Snowmaking Methods

Acquire a version of the new snow generation system recently developed by the National Centre for Atmospheric Research (NCAR).

Evaluate the NCAR system for the future conduct of holdover time testing in simulated snow conditions. Tests shall be conducted in a small climatic chamber at Concordia University, PMG Technologies, or at NRC. Tests shall also be conducted with one Type IV fluid over a range of temperature and snowfall rates to compare the SAE holdover times for this fluid in natural and simulated conditions.

A further series of tests shall be performed with the system in order to assess the holdover time performance of the reference fluid (as described in the proposed SAE test procedures).

A total of 8 days of climatic chamber rental shall be planned for the conduct of the proposed tests.

5.7. Documentation of Appearance of Fluid Failure for Pilots

Current failure documentation deals largely with freezing drizzle and freezing rain conditions

5.7.1. Documentation of Failures

Finalise documentation of failure through limited further research as follows:

5.7.1.

provide similar documentation for fluids exposed to snow conditions, taking advantage of the availability of a snow making device for laboratory use;

5.7.1.2.

provide documentation for a propylene based Type IV fluid at typical delivered viscosity, for precipitation conditions tested previously, to determine characteristics at its operational limits and the nature and mechanisms of failure. Conduct selected comparison tests with a second fluid to test commonality of responses. Data from this activity will be cross-analysed with data from proposed research to examine the flow of similar fluids at different levels of contamination from aircraft wings during a simulated takeoff; and

5.7.1.3.

examine and document the appearance and nature of failure of propylene base fluids at cold temperatures (-10 C).

5.7.1.4.

Conduct tests at the National Research Council Climatic Environmental Facility based on last years' procedures, with enhancements as necessary and available. Snow documentation may be conducted in a different laboratory facility. Documentation under outdoor snow conditions will be conducted for comparison purposes to laboratory conditions.

5.7.2. Conduct of trials/assembly of results

Coordinate all test activities, scheduling tests with NRC CEF in conjunction with other test activities. Analyse results and document all findings, recommendations and conclusions in a final technical report and in presentation format. Provide timely updates of schedule revisions to TDC.

5.7.3. Pilot Observations

Contact airlines and arrange for pilots to be present during tests to observe fluid failure and failure progression. Record pilot observations for later correlation with aircraft external observations.

5.8. Feasibility of Performing Wing Inspections at End-of-runway

5.8.1. Requirement

Examine the feasibility of scanning aircraft wings with ice contamination sensors just prior to aircraft entering the departure runway using Dorval airport as an example scenario.

Explore ways of positioning sensors at agreed locations on an airport.

Composition and conduct of tests shall be adapted as information is gained on the practicality of this activity.

5.8.2. Planning

A Project Plan shall be prepared which will include:

a) activities to determine the parameters, operational issues and constraints related to the proposed process, and

b) a test plan for operational trials to examine the capabilities of the contamination sensors to determine the feasibility of their operational use.

The test plan for operational trials (three sessions) shall include:

- establishing test locations with airport authorities,
- establishing operational procedures with airport authorities,
- arranging equipment for scanning; vehicle, sensor installation and radios,
- collecting and coordinating information from the deicing activity at the deicing centre,
- test procedures with detailed responsibilities for all participants,
- control of the confidential data gathered on wing condition, and
- notification to all concerned in the project, including aircraft operators, that scanning activities will take place.

5.8.3. Coordination

Coordination all activites with authorities from Aéroports de Montréal and arrange support from Cox and/or RVSI

5.8.4. Field Trials

Conduct trials to further evaluate the feasibility of integrating such a process within current airport operations management, as well as to gather information on wing condition, just prior to takeoff, during deicing operations. These trials shall be based on the use of mobile equipment currently available. A “truthing” test pannel shall be present at each trial to demonstrate the validity of the wing readings on an ongoing basis

The trials shall be designed to address issues such as:

- equipment positioning versus current runway clearance limitations,
- time delay between inspection and start of take-off
- system capabilityto meet its design objectives in severe weather
- suitability of mobile equipment or fixed facility.
- need for rapid extension and retraction of sensor booms,
- airport support needed, e.g. snow clearance, provision of operating locations,
- accommodating scanner limitations for distance, light, angle of incidence.

- communications needed to support scanning operation,
- recording data from the sensors, and
- communicating results of the scanning to pilots and regulatory authorities.

5.8.5. Test Personnel and Participation

Initiate all tests based on suitable weather conditions. The individual test occasions shall be coordinated with Aéroports de Montréal and Aéromag 2000.
Coordinate the provision of a suitable vehicle and the installation of an ice detection sensor. Monitor the test activity, ensuring the collection and protection of all scanning data, as well as the collection of data related to weather conditions and previous aircraft deicing activities. Ensure that the instrument providers deliver data and an objective measure of wing contamination based on scanner information in a timely and reproducible manner.

5.8.6. Study Results

Results from the feasibility study shall be presented in technical report format which shall include comments pertinent to long term implementation.
Results from the scanner tests shall be provided in technical report format and shall include analysis of wing contamination data cross-referred to the deicing history of individual aircraft scanned.

5.9. Ice Detection Sensor Certification Testing

5.9.1. Minimum Ice Thickness Detectable in Tactile Tests

Prepare procedures and conduct tests to establish human limits in identifying ice through tactile senses. These tests shall use the NRC or equivalent test facilities acceptable to TDC and a test setup equivalent to that planned for sensor certification. Several ice thicknesses and textures shall be tested to establish tactile sensing limiting thickness for smooth ice and for roughened ice.
The experiment shall involve sufficient participants and test conditions such as to provide reliable results usable in approving sensors to replace human tactile testing.
TDC shall assist in the experimental design
Tests shall be conducted with both contractor personnel and a selection of pilots as subjects.
A professional human factors scientist shall be used to establish testing parameters such as:

- what proportion of plates should be bare
- whether subjects should be blindfolded to eliminate visual cues.
- whether the same plate should be judged more than once
- how to ensure that subjects do not compare plates
- what should be the minimum time between plate touching

Results of the tests shall be analysed statistically to establish confidence limits for the findings

5.9.2. Field Tests for Sensor Distance and View Angle Limits

Develop a detailed test plan with a matrix of all test parameters, required coordination of equipment detailing the responsibilities of all participants.
Collect test data, including photo and video records of all tests.
The areas of ice contamination used for sensor evaluation shall be quantified by size, location and thickness. Angles of incidence, sensor heights and distances shall be verified independently. In concert with the sesor manufacturer, data from sensor readings and observer data shall be collated and analysed to reach conclusions on sensor limitations for distance and angle of incidence in various weather conditions.

5.10. Planning a Wing Deicing Test Site

Develop a plan for implementing a deicing test site, centred on an aircraft wing and supported by current fluid and rainmaking sprayers.
The plan shall include the acquisition of a surplus complete wing, from either a scrapped or an accidented moderate sized aircraft or an outboard section of a larger aircraft. The wing section should if possible include ailerons and leading edge slats
The design of the test site shall include a test area that could contain and recover sprayed fluids. Installation of the wing should entail a mounting designed to allow the wing to be rotated relative to current winds. The site must be secure yet allow ease of access and ability to install inexpensive solutions to control sprayed fluid.
Costs shall be estimated for the main elements of the development of a wing test bed site including:
wing purchase and delivery,
site lease and development, and
wing mount design and fabrication.

5.11. Evaluation of Hot (and Cold) Water Deicing

Investigate unheated and hot water deicing/defrosting, to determine under what meteorological conditions and temperatures these procedures are safe and practicable.
Unheated water deicing shall be evaluated at air temperatures above 1 degree C(34 degrees F).
Hot water deicing shall be evaluated at air temperatures below 1 degree C and include temperatures below –3 degrees C (27 degrees F).
These experiments shall establish how long it takes for the water to freeze on the surface under these conditions.
This is to be the first step of a two step procedure. From these data, a safe and practical lower limit shall be established considering the three-minute window required for second step anti-icing in the two-step deicing procedure.
Precipitation rates, as utilised in the generation of holdover time tables, shall be considered. Environmental chamber tests shall be correlated with outdoor aircraft tests. All laboratory test procedures and representative test results shall be recorded on videotape, including failure modes where applicable. The video shall depict a

recommended full-scale aircraft hot water deicing procedure. A written report shall include the laboratory test results and a recommended aircraft unheated/hot water deicing procedure, including the limitations of precipitation, OAT and wind.

5.12. Evaluation of Warm Refuelling

Conduct a feasibility study of the suitability of refuelling with warm fuel to reduce susceptibility to “cold-soaked wing” icing, and to improve holdover times.
Coordinate activities to support testing the “warm fuel” concept using operational aircraft, including arranging;

- Participation of interested airlines, along with provision of aircraft for test purposes;
- Participation of local refueller;
- Arrangements with the equipment supplier (Polaris) to deliver the equipment to the selected airport along with the required technical support.

Testing will be conducted at Dorval on three occasions, one of which will include snow or freezing precipitation. Test aircraft selected should include a representation of both “wet” and “dry” wings if possible.
Wing surface temperatures of test wings will be monitored at several points over a period of time, to assess the influence thereon of warmed fuel. A reference case based on fuel boarded at the normal local temperature will be conducted.

5.13. Engine Air Velocity Distributions near Deicing Vehicles

Measure air velocity distributions in the vicinity of a de-icing truck when de-icing a large aircraft whose engines are running.
Tests shall be conducted during a period of no precipitation, either frost deicing or following snowfall, on two separate occasions at the Dorval International Airport deicing facility. Aircraft with engines mounted on the wing (e.g. B737) as well as rear engines mounted aircraft (e.g. DC-9 and RJ) will be sampled during live deicing operations, the precise type to be agreed by TDC. The tests shall be coordinated with Aéroport de Montréal and Aéromag 2000.
Wind velocity shall be measured from an Elephant-mu de-icing truck at locations recommended by TDC around the tail of the aircraft at different elevations and distances from the engines depending on the aircraft type, and the de-icing procedure followed by Aéromag 2000.
Photograph and video record the conduct of all tests.

5.14. Provision of Support Services

Provide support services to assist TDC with testing, the reduction of data and presentation of findings in the activites identified below which relate to the content of this work statement, but are not specifically included.

5.14.1.Re-Hydration

Conduct a series of exploratory trials on flat plates at the Dorval site or NRC to observe the behaviour of re-hydrated Type IV fluids and to help determine how re-hydration affects the flow- off characteristics of a Type IV fluid exposed to frost conditions.

5.14.2.Frost Tests on a Regional Jet

Conduct a series of tests to determine the roughness of frost deposition on the wings of a Regional Jet aircraft. Conduct tests on three overnight occasions.

5.14.3.Ice-Phobic Materials Evaluation

Conduct a series of tests on flat plates to determine the effects of ice-phobic materials on the film thickness and on holdover time of de/anti-icing fluids.

5.14.4.Evaluation of Infra-Red Thermometers

Evaluate use of infra-red technology as a method of determining accurate skin and fluid temperatures during operational conditions. Conduct tests in conjunction with full-scale and holdover time testing.

5.14.5.Frost Self-Elimination

Examine the self-elimination of frost on several test surfaces under variable weather conditions. Conduct test in conjunction with frost deposition trials on flat plates.

5.14.6.Environmental Impact Assessment

Assess the environmental issues related to the use of glycol-based products for aircraft de-icing purposes. Examine the waste fluid collection and disposal procedures for several deicing facilities in relation to current and future environmental legislation.

5.14.7.An Approach to Establish Wing Contamination

Document an approach to determining operational limits for levels of contamination on aircraft wings. This approach will include consideration of the location of contamination on the wings and the area contaminated. The levels of contamination on aircraft wings prior to takeoff as determined during the scanning trials prior to takeoff will be factored in.

The approach will discuss how the limits (when defined) could be used in software routines to enable sensor systems to provide Go/No-Go indications to the aircraft pilot and regulatory authorities.

5.14.8. Accident/incident Database Analysis

Provision of database manipulation and support aimed at establishing problem areas and their significance.

5.14.9.Other activities

Other activities, such as the evaluation of forced air technology, the evaluation of alternate (zero glycol) deicing methods, and the evaluation of frost removal equipment at gates, or others may emerge as issues during the course of the winter season.

APPENDIX B

WINTER WEATHER DATA 1995/96 TO 1998/99

APPENDIX B

WINTER WEATHER DATA

1995 TO 1999

The following charts include the complete rate data analysis, subdivided by temperature ranges for both snow and freezing rain. A histogram of points and a cumulative probability chart are included for each rate calculation interval in all temperature ranges.

The lowest holdover time temperature range for snow conditions was subdivided into three ranges. The charts for this analysis are also included.

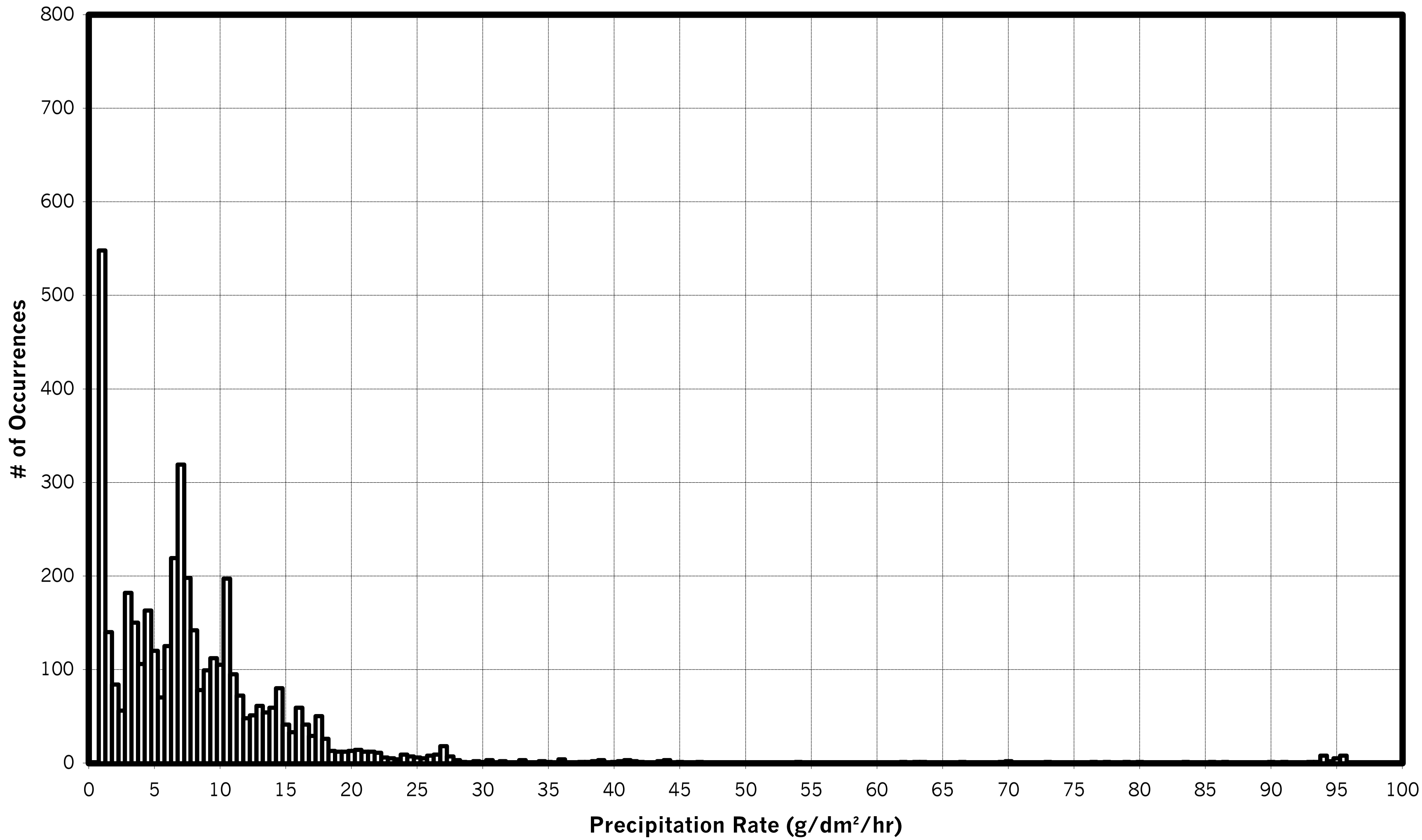
INDEX

READADC AND CR21X ANALYSIS - NATURAL SNOW

ABOVE 0°C

35-MINUTE RATE EVERY MINUTE

1995-1999



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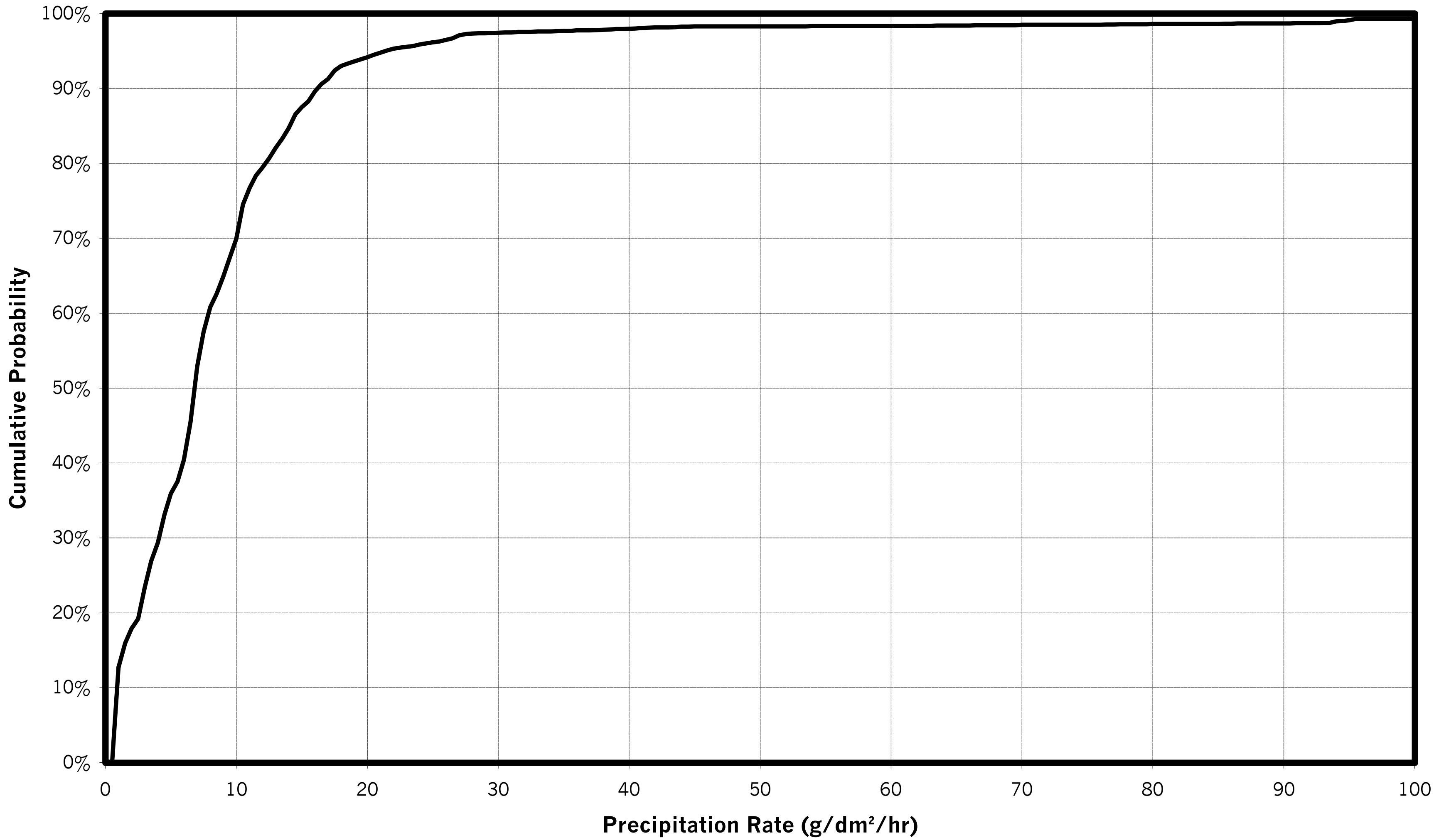
At: 35 min Hist
02/01/01, 5:48 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

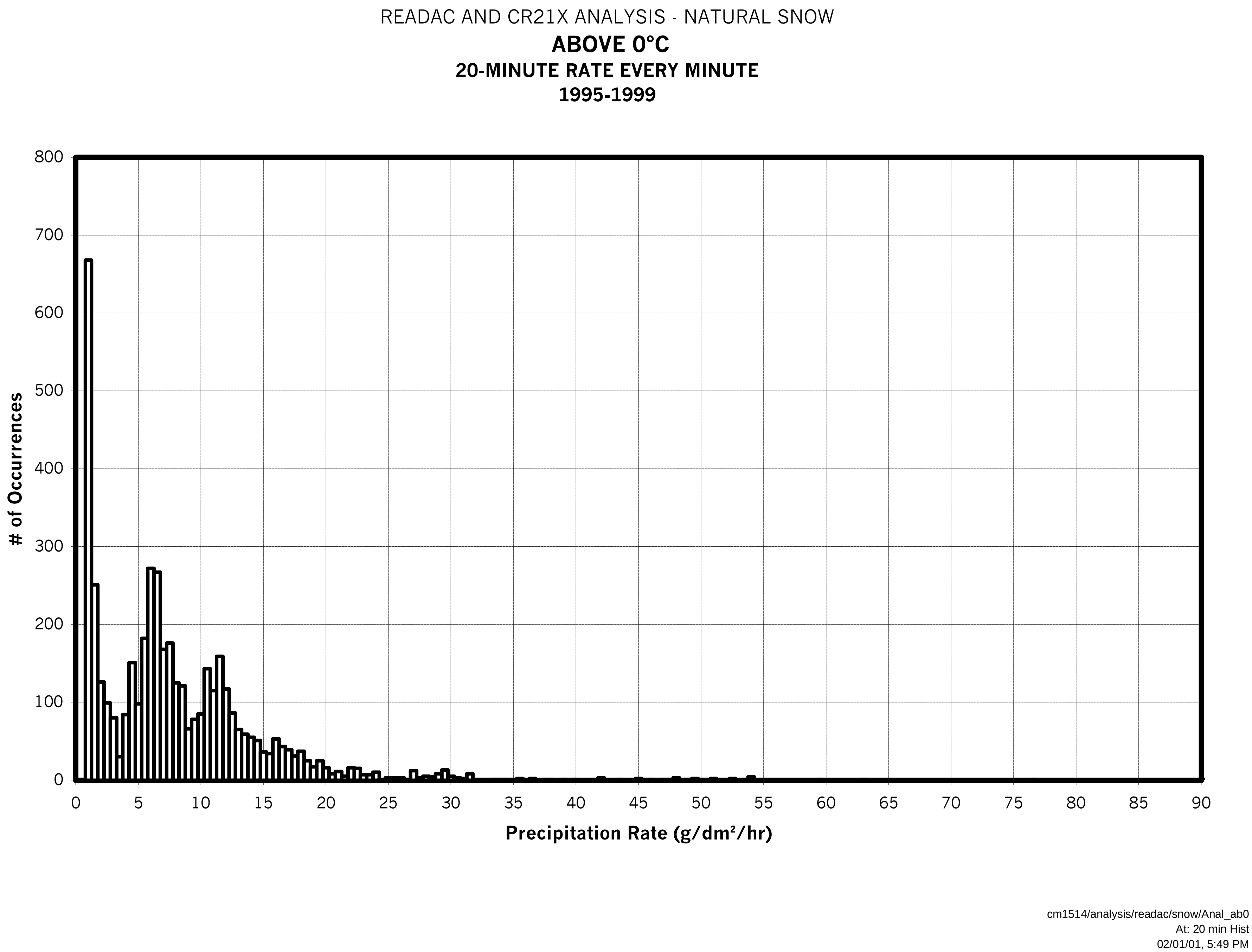
ABOVE 0°C

35-MINUTE RATE EVERY MINUTE

1995-1999



cm1514/analysis/readac/snow/Anal_ab0
At: 35 min Cuml.
02/01/01, 5:49 PM

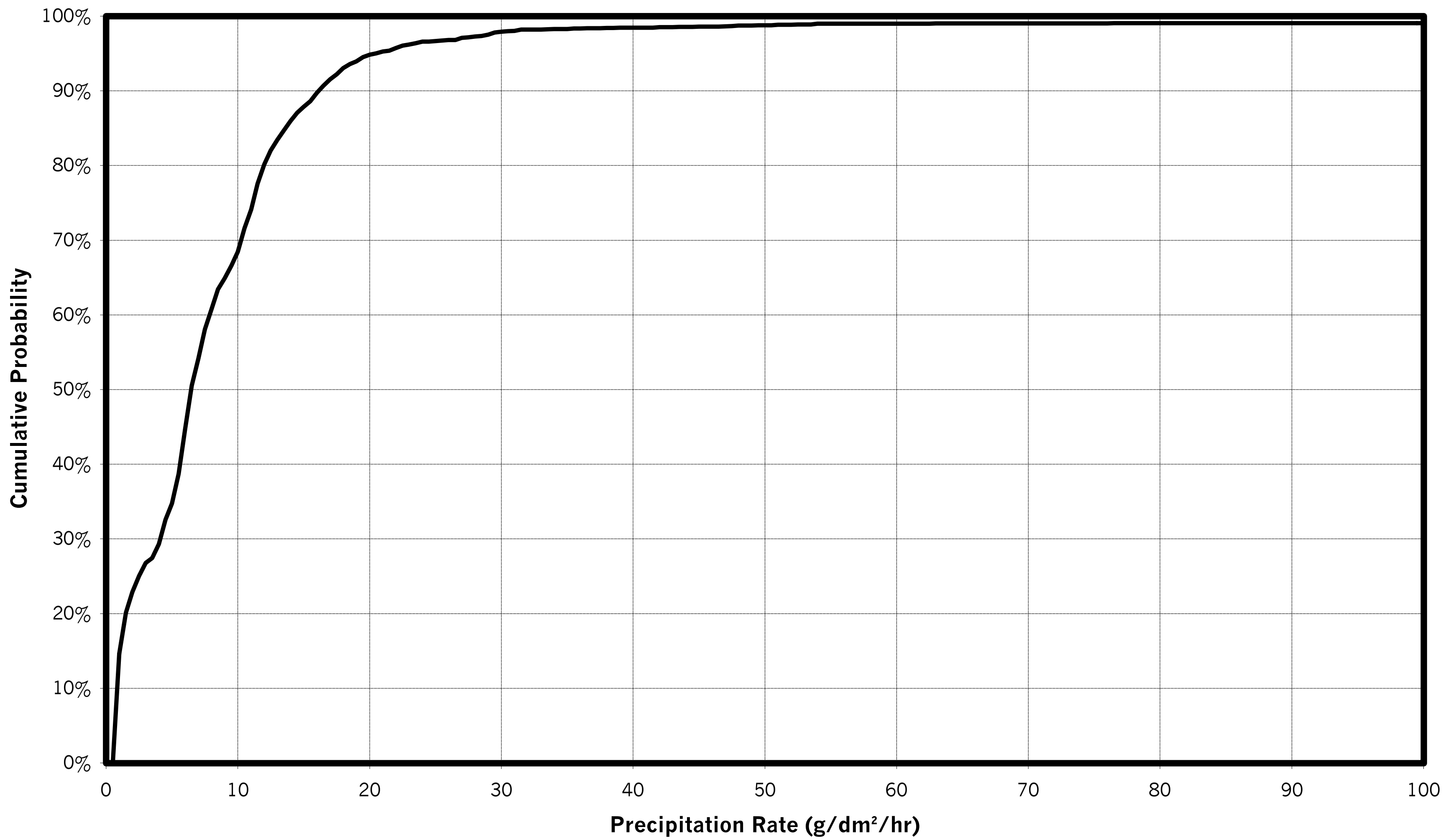

READADC AND CR21X ANALYSIS - NATURAL SNOW
ABOVE 0°C
20-MINUTE RATE EVERY MINUTE
1995-1999
# of Occurrences
0
100
200
300
400
500
600
700
800
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Precipitation Rate (g/dm²/hr)
cm1514/analysis/readac/snow/Anal_ab0
At: 20 min Hist
02/01/01, 5:49 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

ABOVE 0°C

20-MINUTE RATE EVERY MINUTE

1995-1999



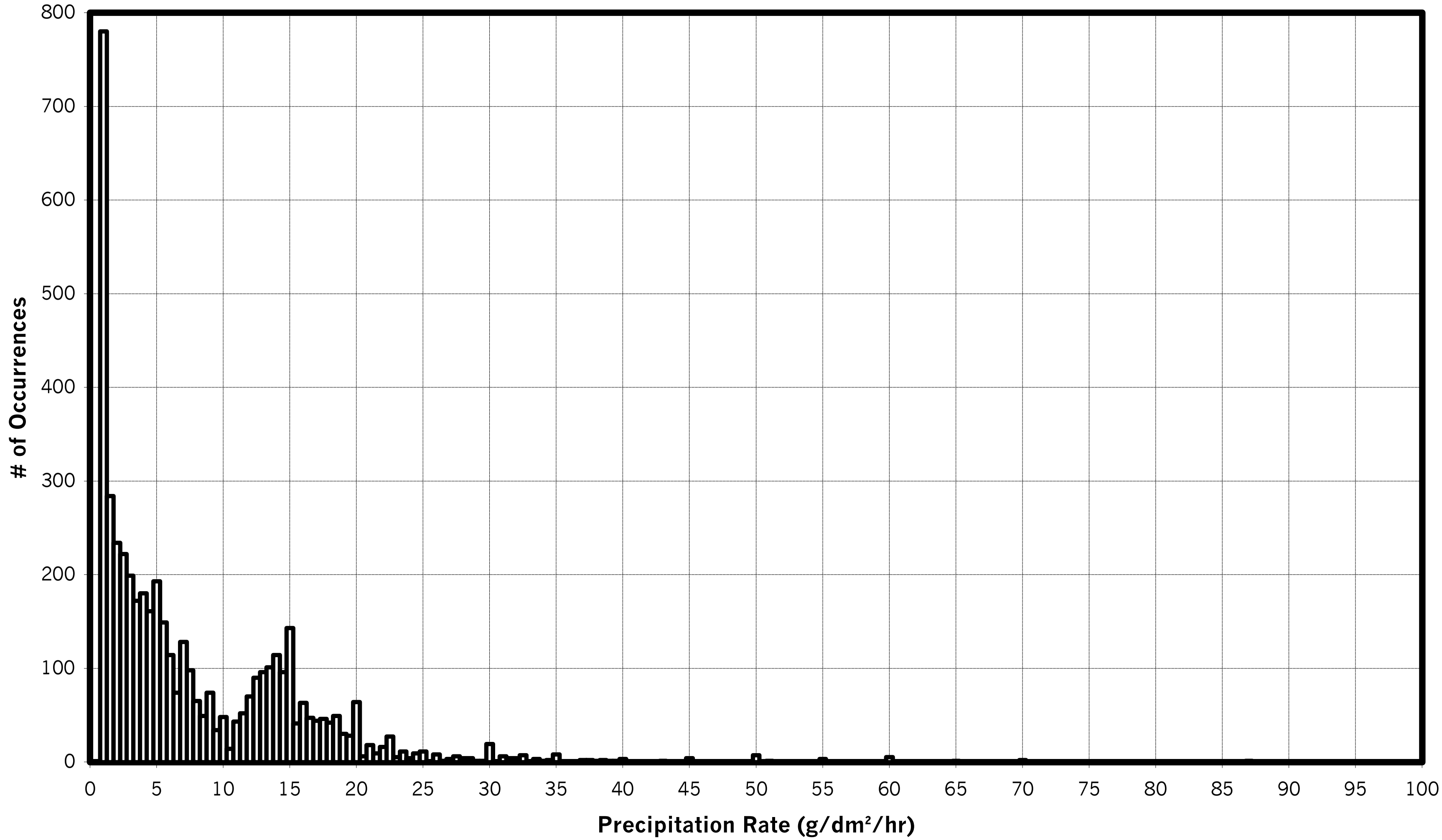
cm1514/analysis/readac/snow/Anal_ab0
At: 20 min Cuml.
02/01/01, 5:49 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

ABOVE 0°C

6-MINUTE RATE EVERY MINUTE

1995-1999



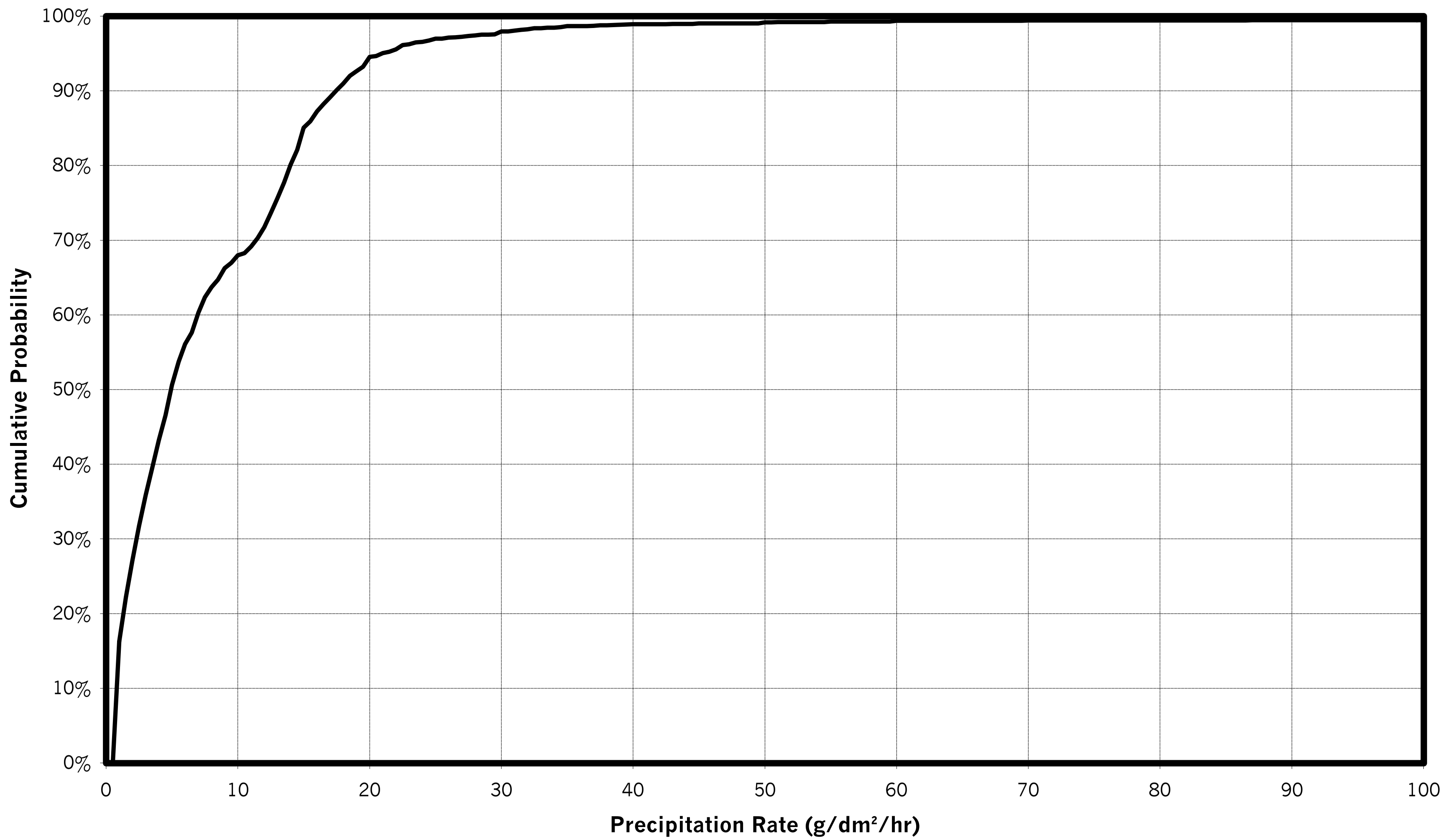
cm1514/analysis/readac/snow/Anal_ab0
At: 6 min Hist
02/01/01, 5:50 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

ABOVE 0°C

6-MINUTE RATE EVERY MINUTE

1995-1999



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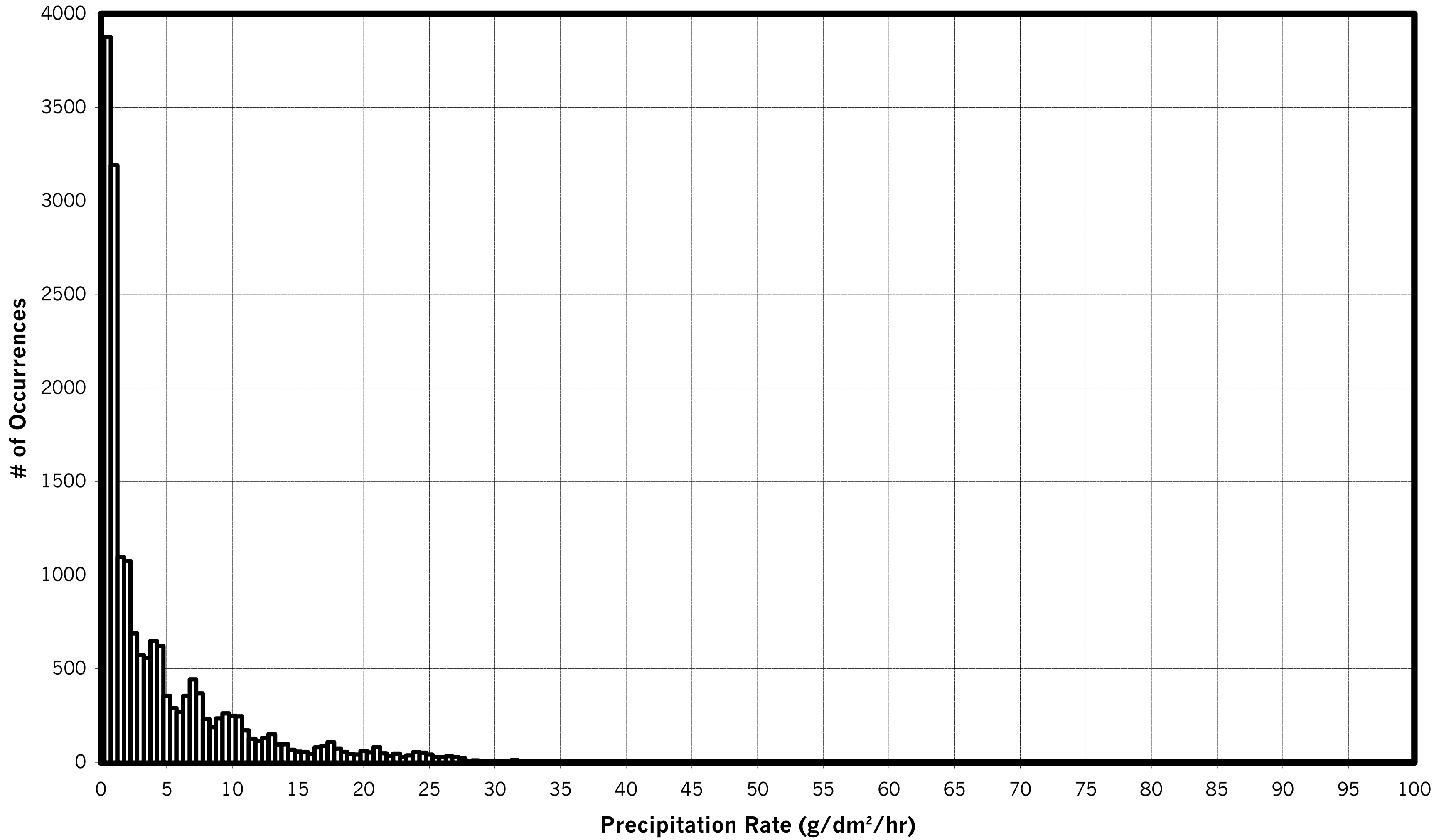
At: 6 min Cuml.
02/01/01, 5:50 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

0 TO -3°C

35-MINUTE RATE EVERY MINUTE

1995-1999



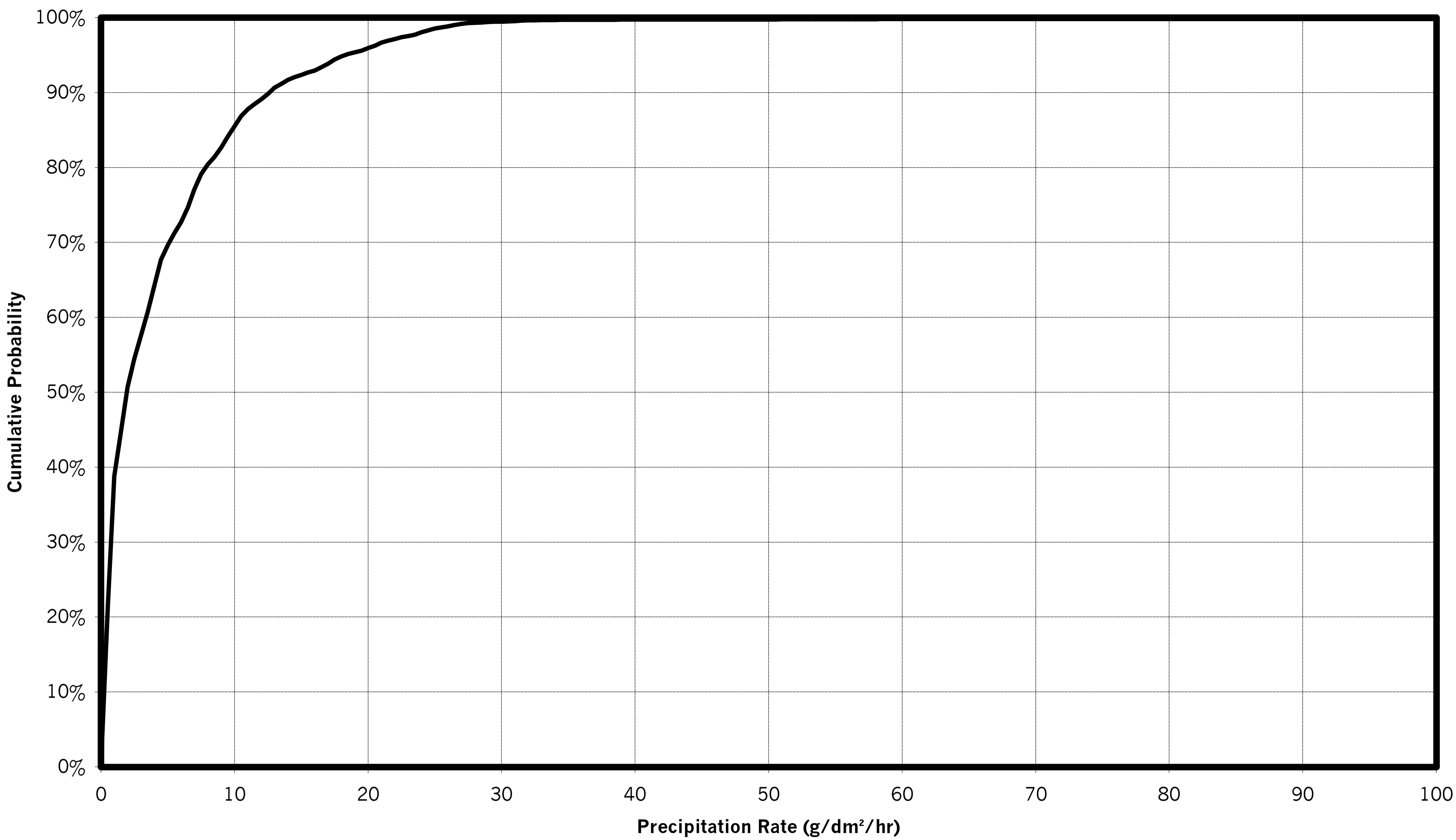
cm1514/analysis/readac/snow/Anal_-3
At: 35 min Hist
02/01/01, 5:52 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

0 TO -3°C

35-MINUTE RATE EVERY MINUTE

1995-1999



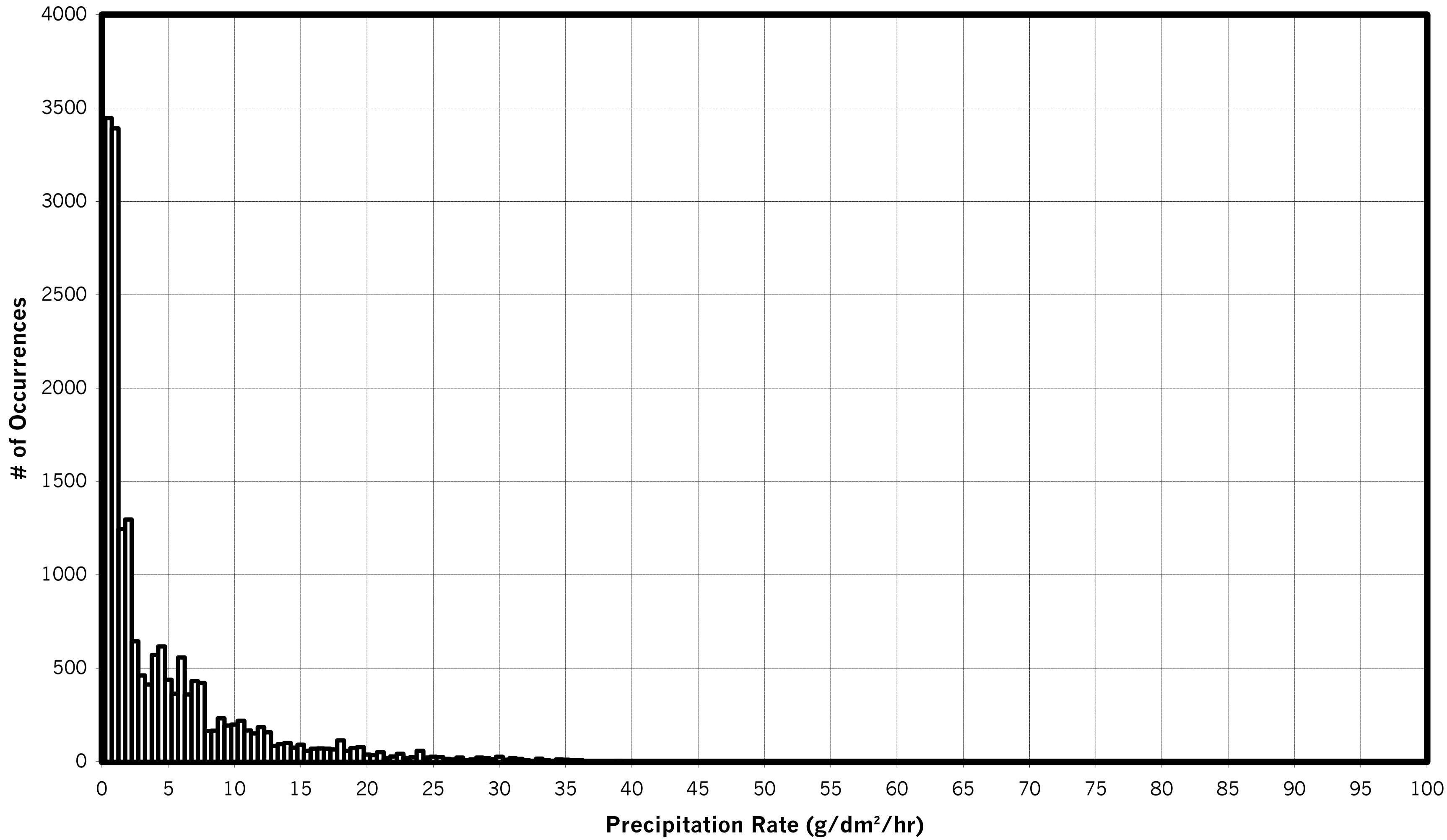
cm1514/analysis/readac/snow/Anal_-3
At: 35 min Cuml.
02/01/01, 5:52 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

0 TO -3°C

20-MINUTE RATE EVERY MINUTE

1995-1999



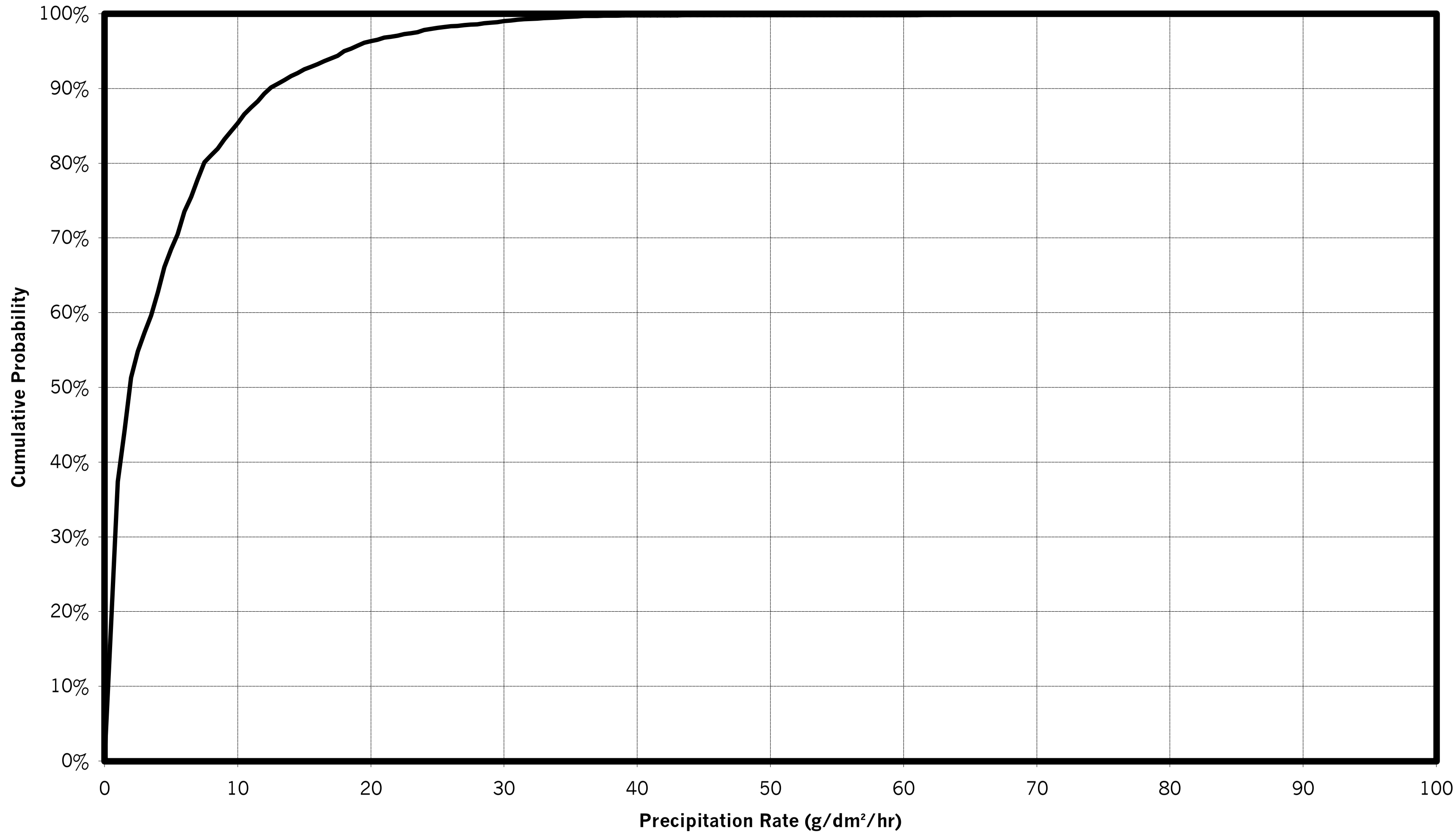
cm1514/analysis/readac/snow/Anal_-3
At: 20 min Hist
02/01/01, 5:53 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

0 TO -3°C

20-MINUTE RATE EVERY MINUTE

1995-1999



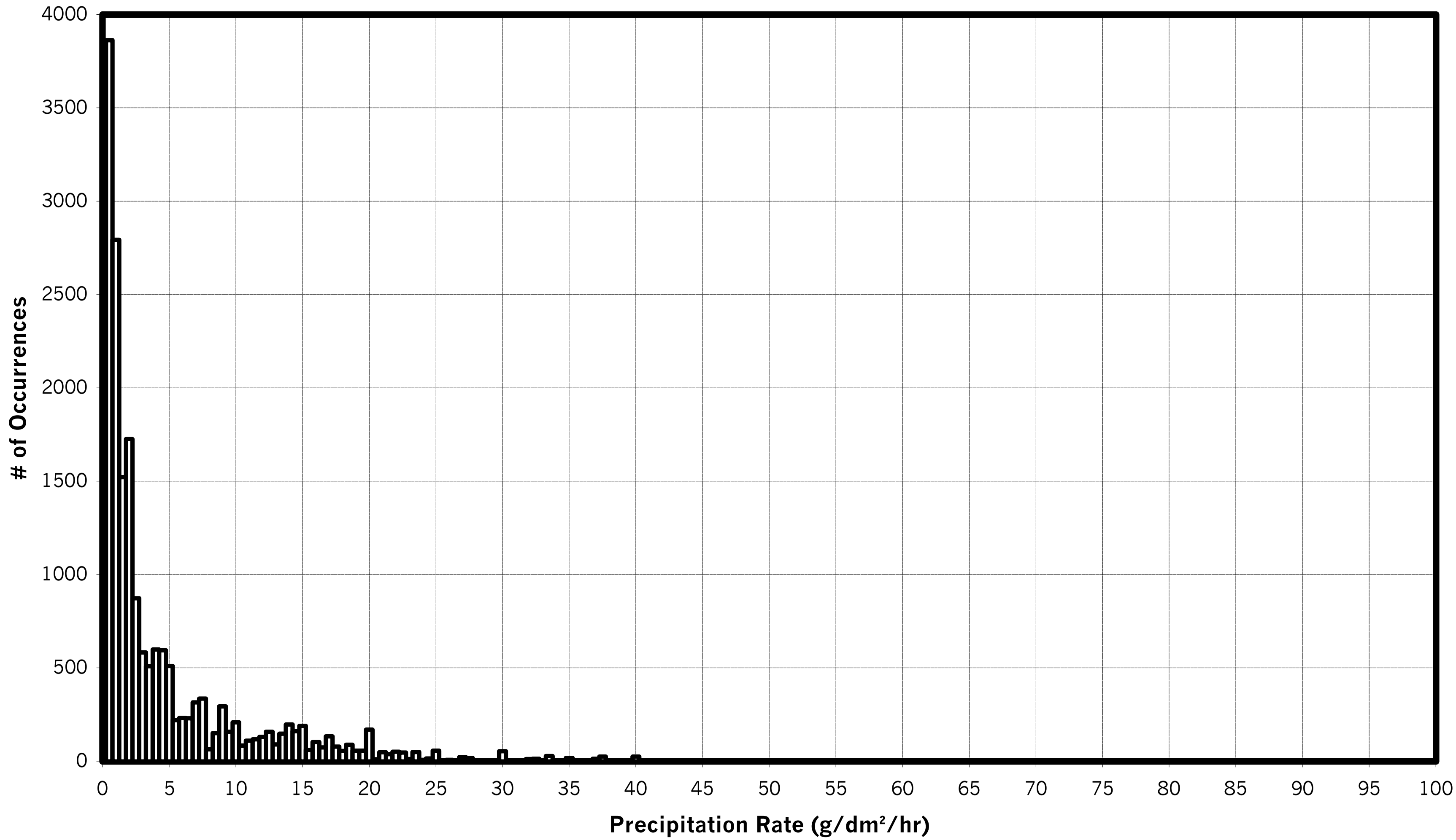
cm1514/analysis/readac/snow/Anal_-3
At: 20 min Cuml.
02/01/01, 5:53 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

0 TO -3°C

6-MINUTE RATE EVERY MINUTE

1995-1999



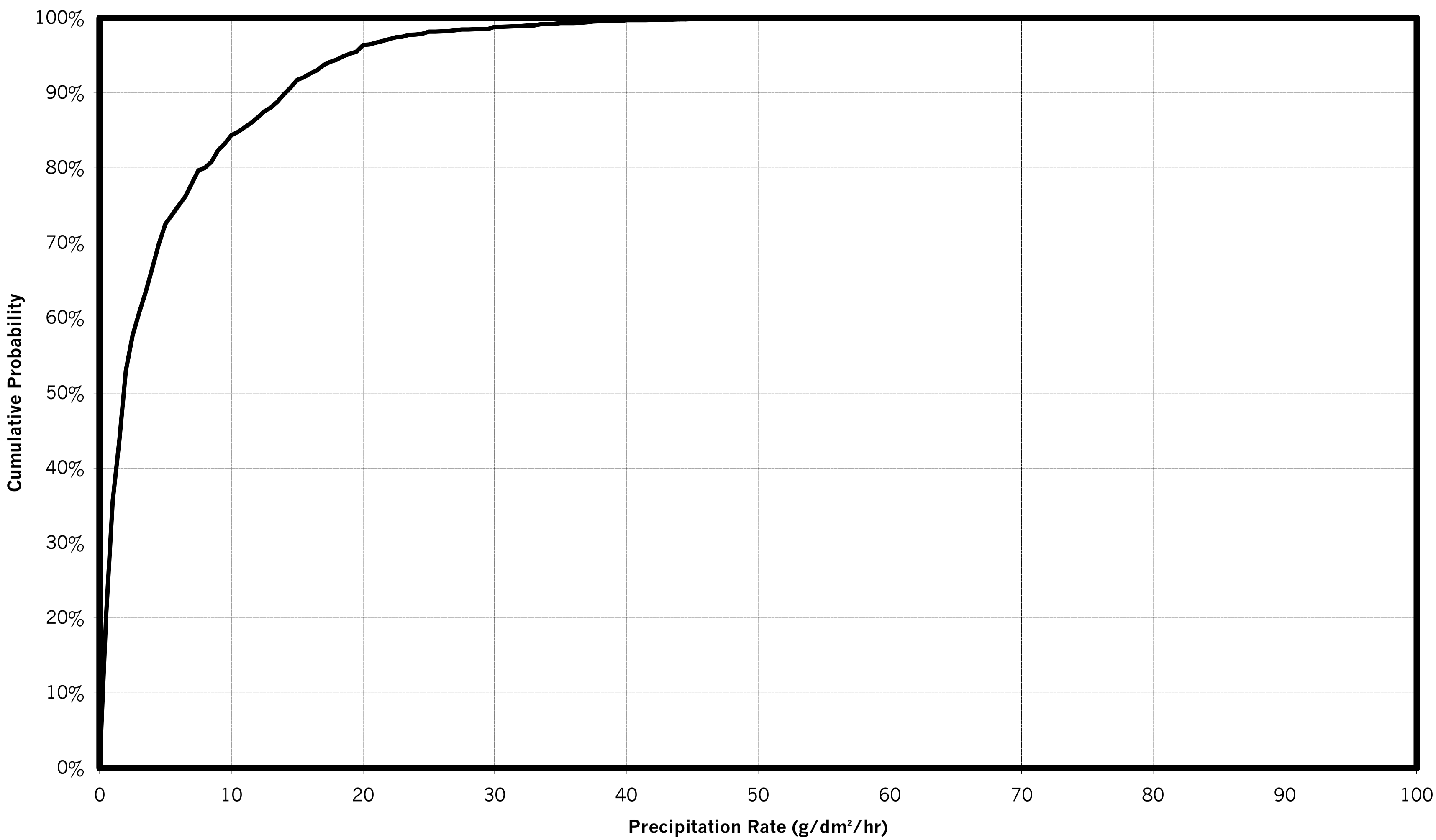
cm1514/analysis/readac/snow/Anal_-3
At: 6 min Hist
02/01/01, 5:53 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

0 TO -3°C

6-MINUTE RATE EVERY MINUTE

1995-1999



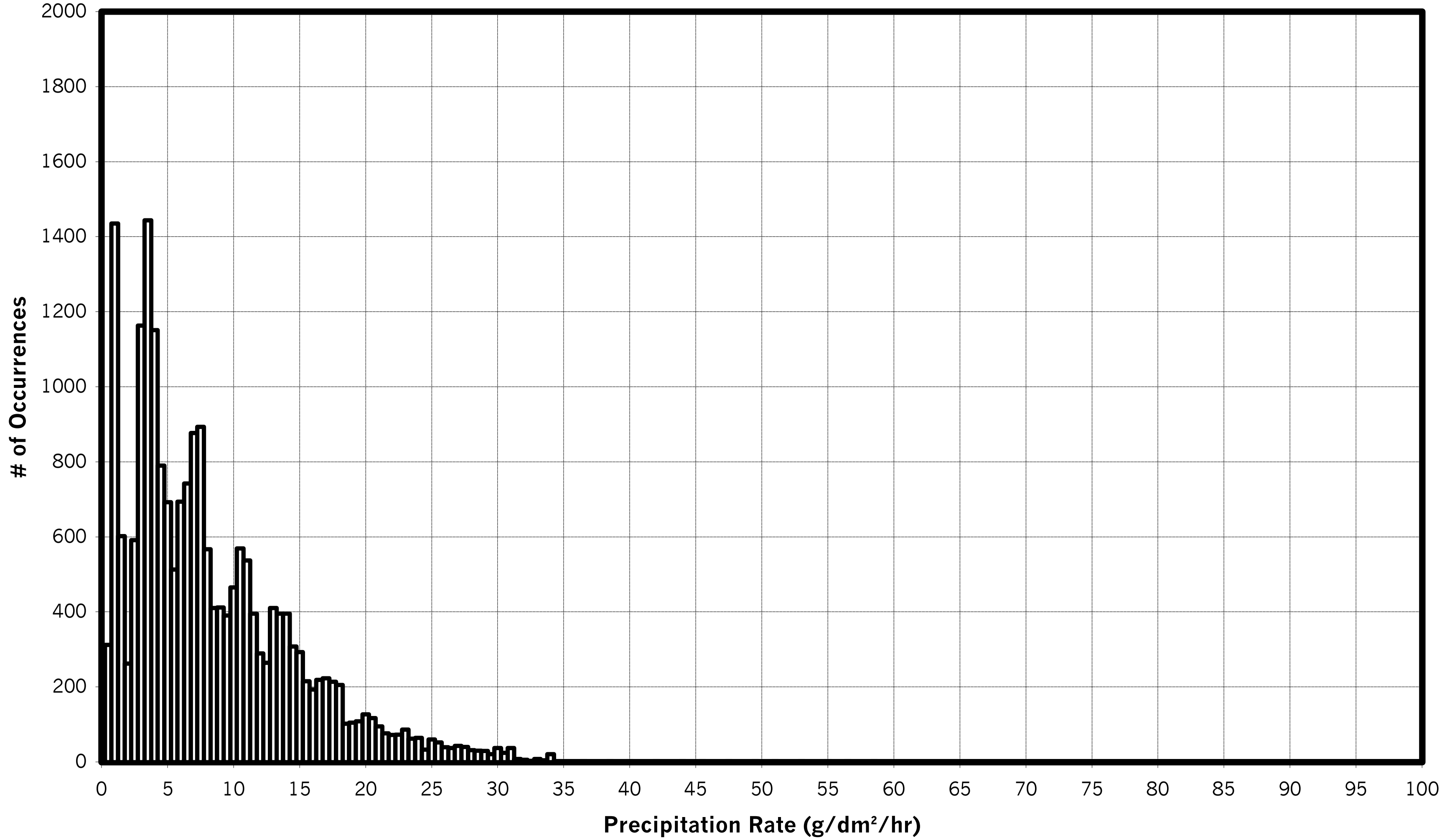
cm1514/analysis/readac/snow/Anal_-3
At: 6 min Cuml.
02/01/01, 5:54 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-3 TO -7°C

35-MINUTE RATE EVERY MINUTE

1995-1999



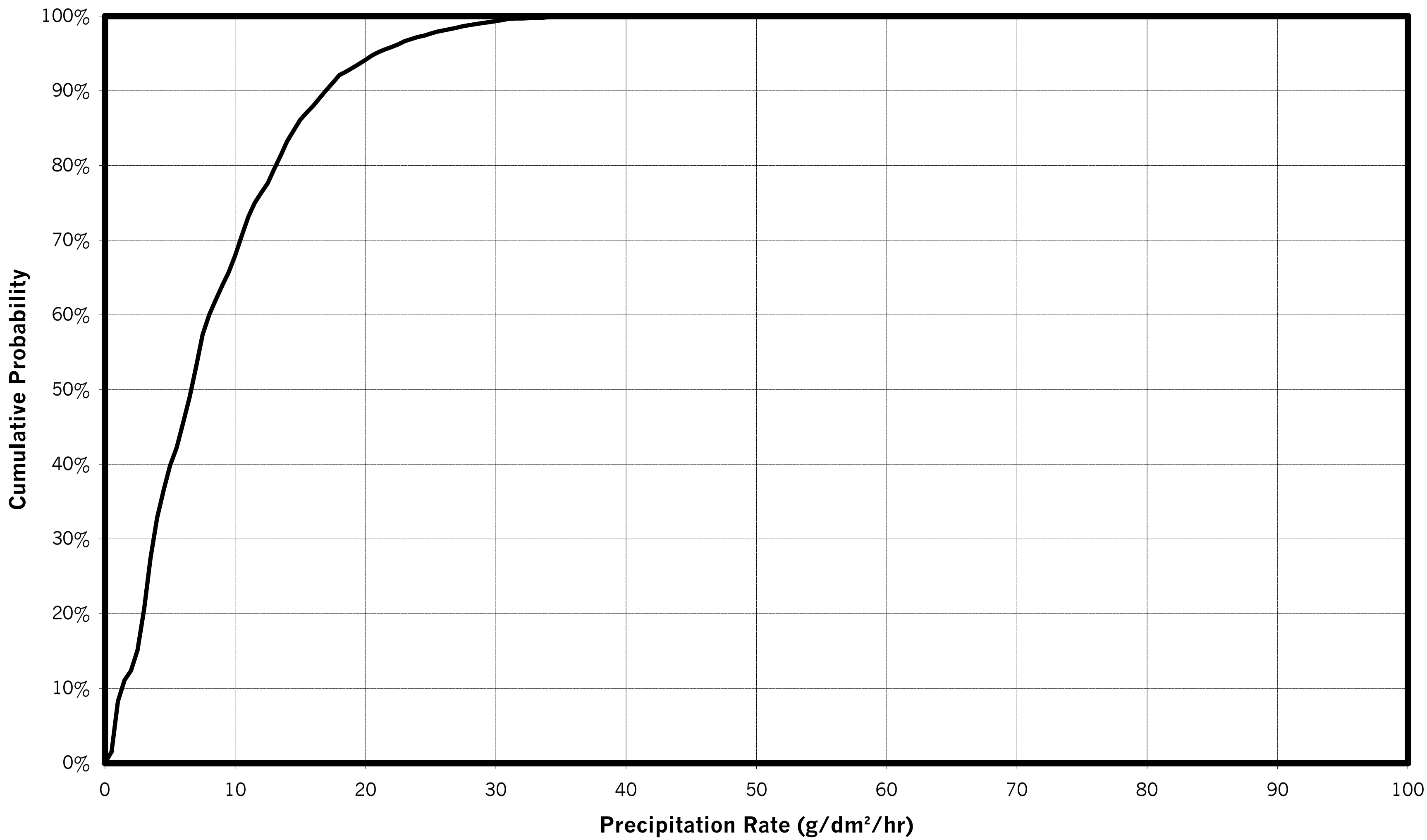
cm1514/analysis/readac/snow/Anal_-7
At: 35 min Hist
02/01/01, 5:55 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-3 to -7°C

35-MINUTE RATE EVERY MINUTE

1995-1999



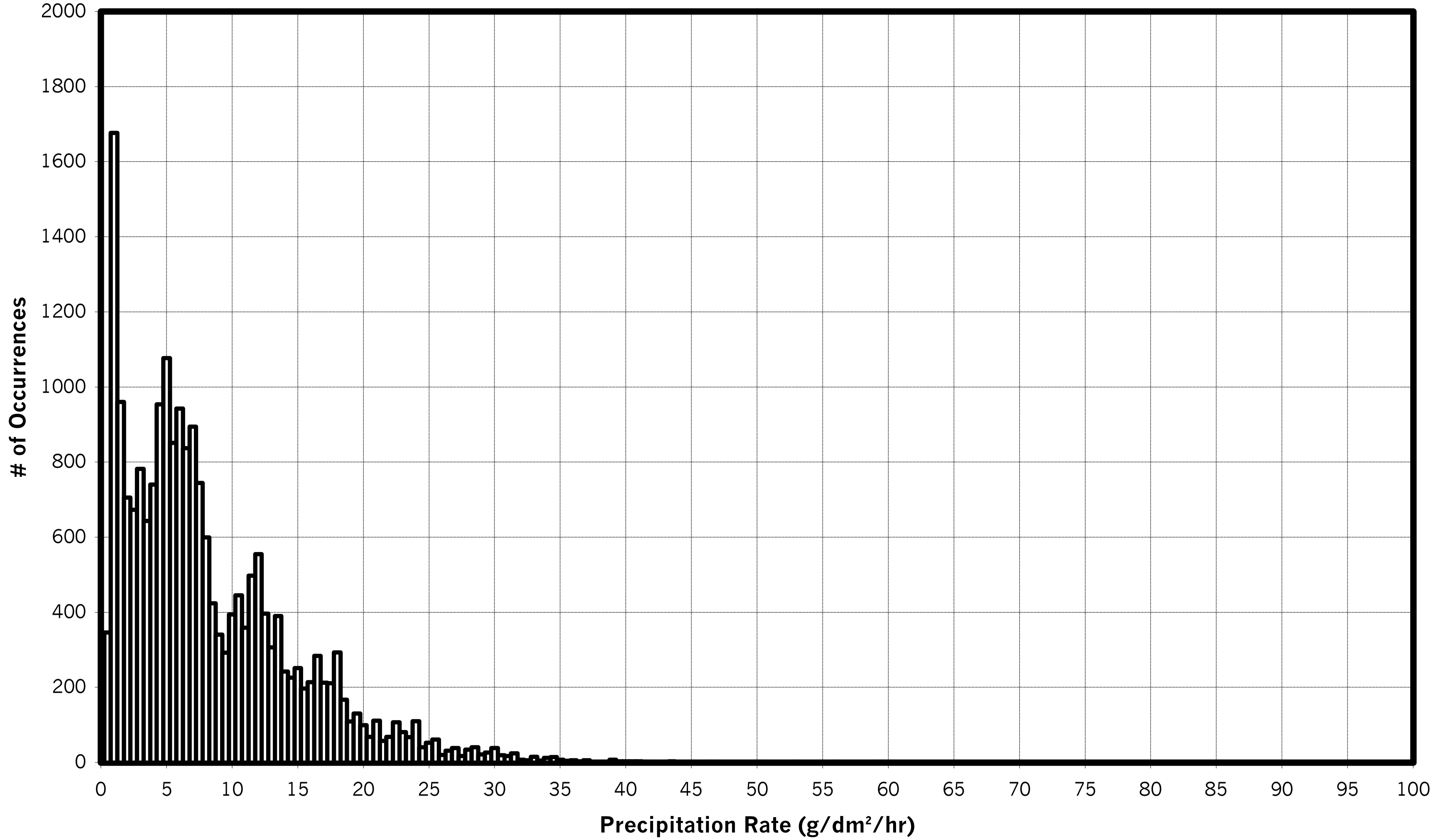
cm1514/analysis/readac/snow/Anal_-7
At: 35 min Cuml.
02/01/01, 5:55 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-3 TO -7°C

20-MINUTE RATE EVERY MINUTE

1995-1999



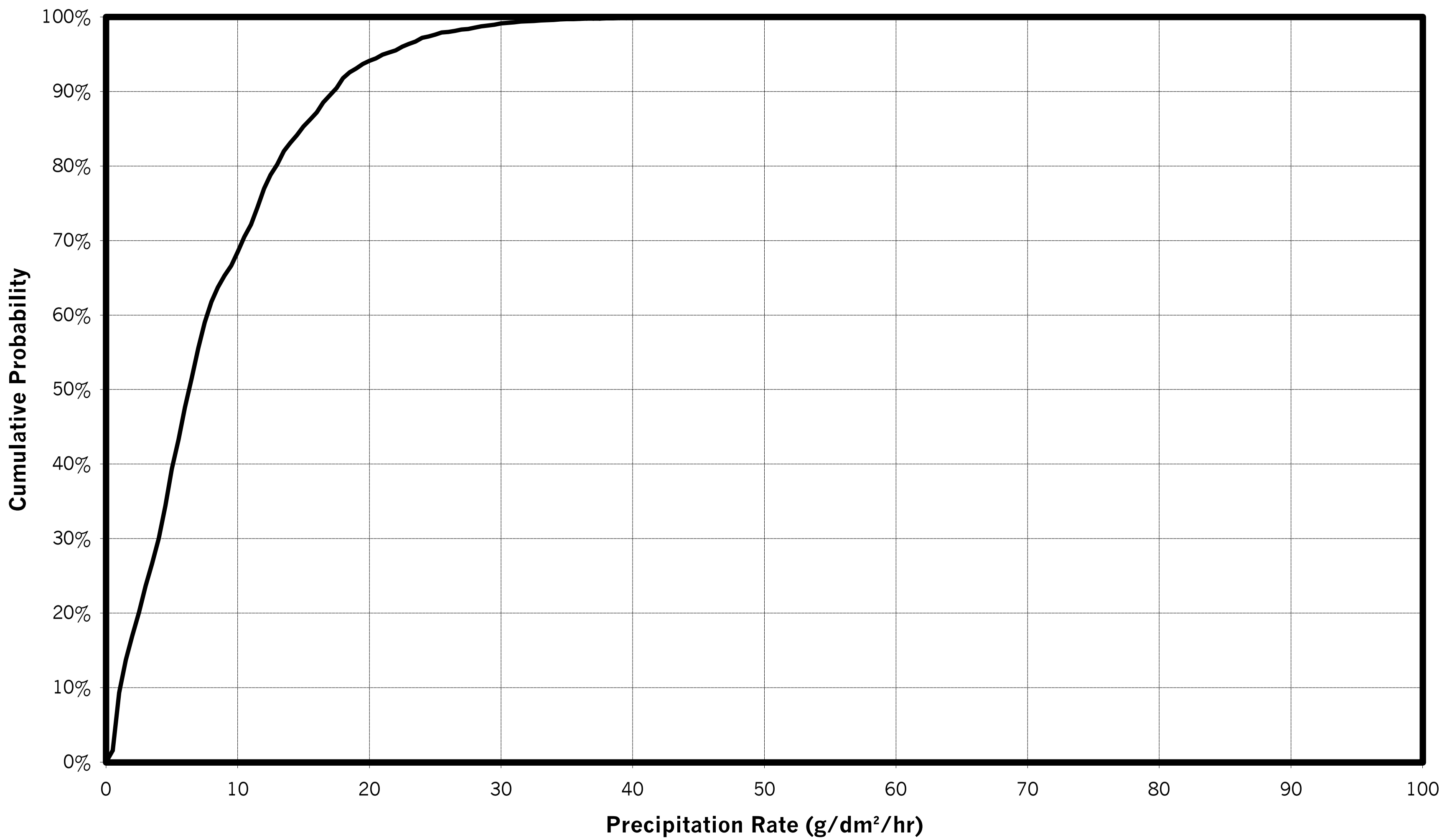
cm1514/analysis/readac/snow/Anal_-7
At: 20 min Hist
02/01/01, 5:55 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-3 TO -7°C

20-MINUTE RATE EVERY MINUTE

1995-1999



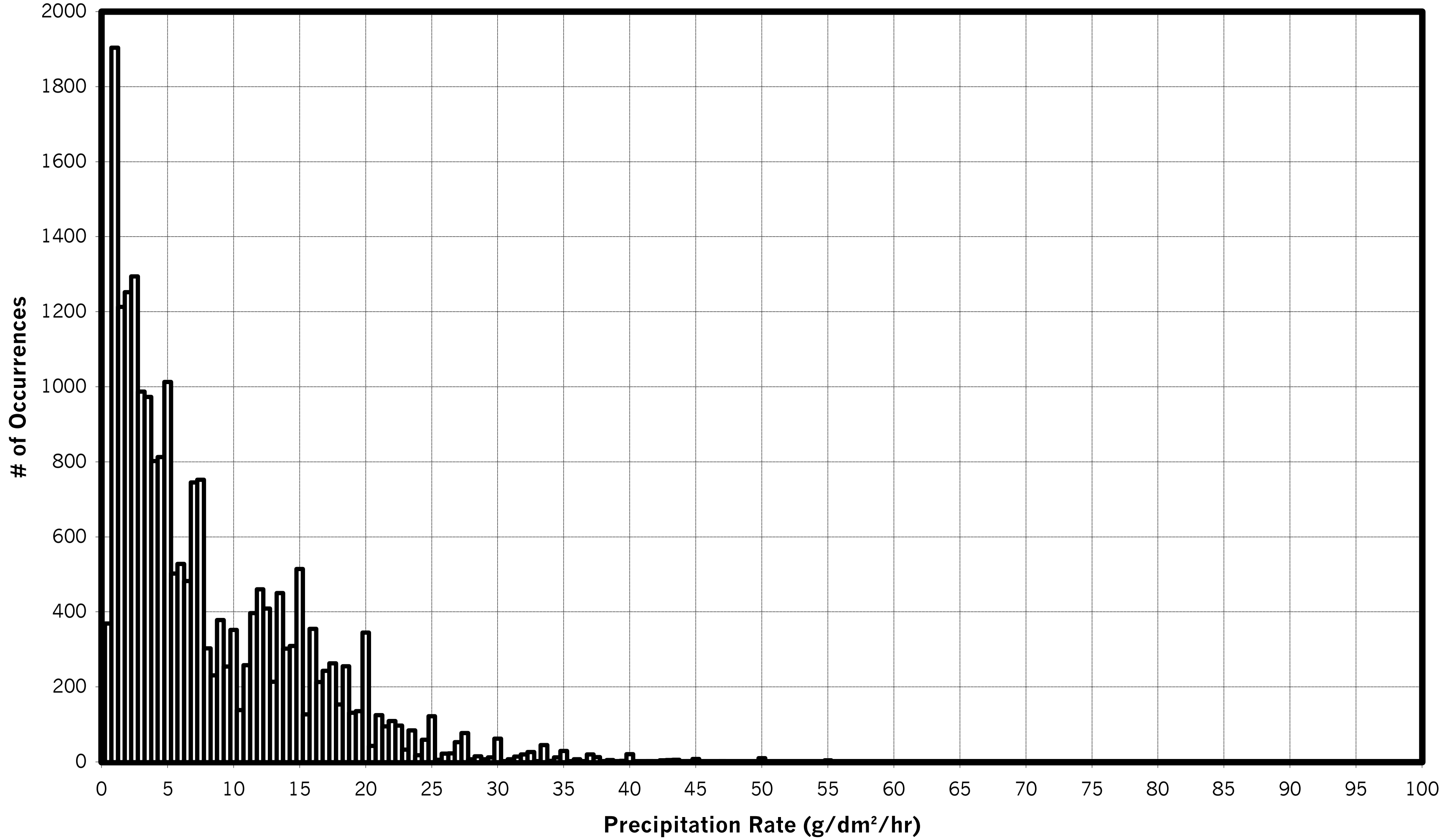
cm1514/analysis/readac/snow/Anal_-7
At: 20 min Cuml.
02/01/01, 5:56 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-3 TO -7°C

6-MINUTE RATE EVERY MINUTE

1995-1999



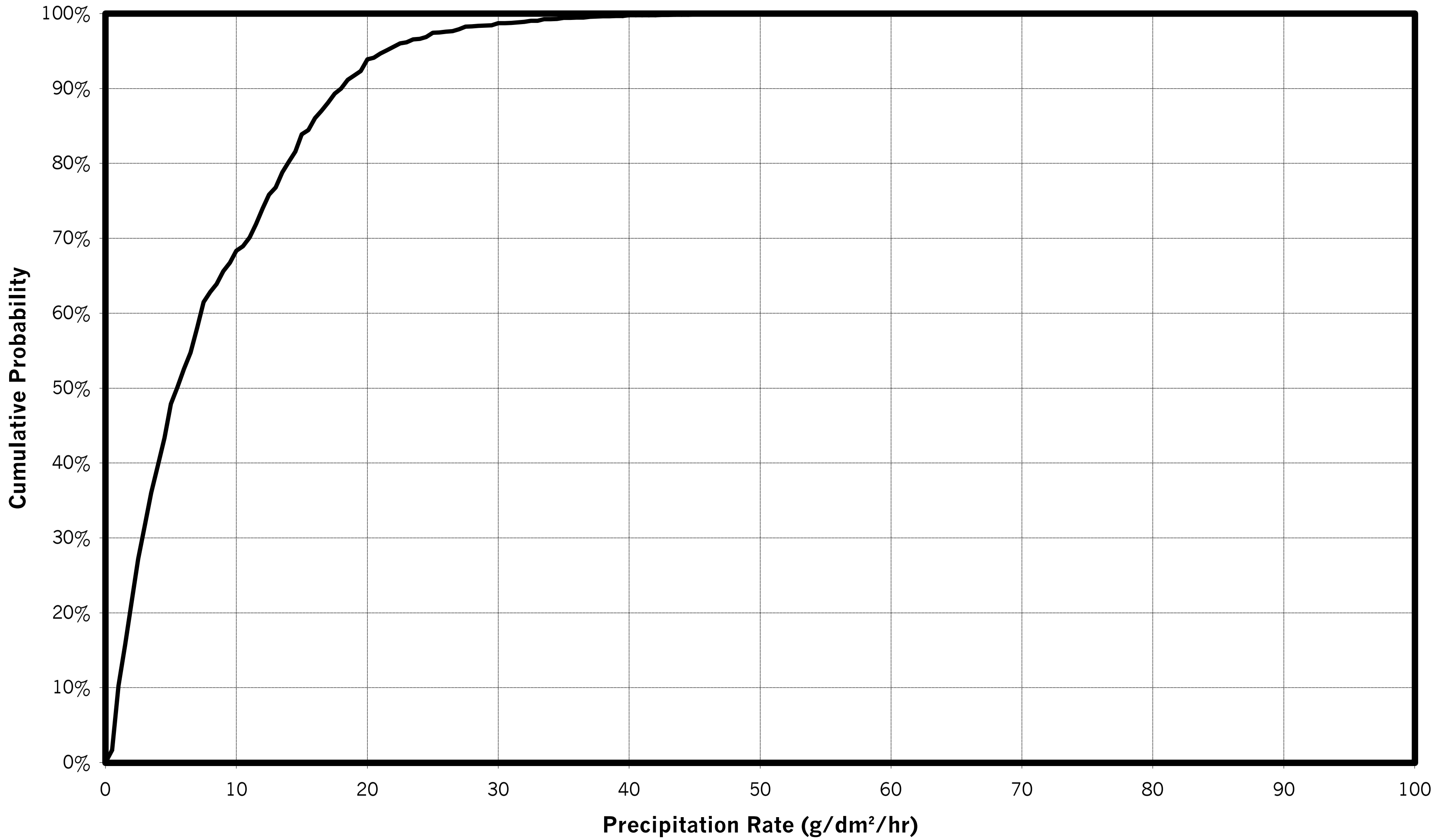
cm1514/analysis/readac/snow/Anal_-7
At: 6 min Hist
02/01/01, 5:56 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-3 TO -7°C

6-MINUTE RATE EVERY MINUTE

1995-1999



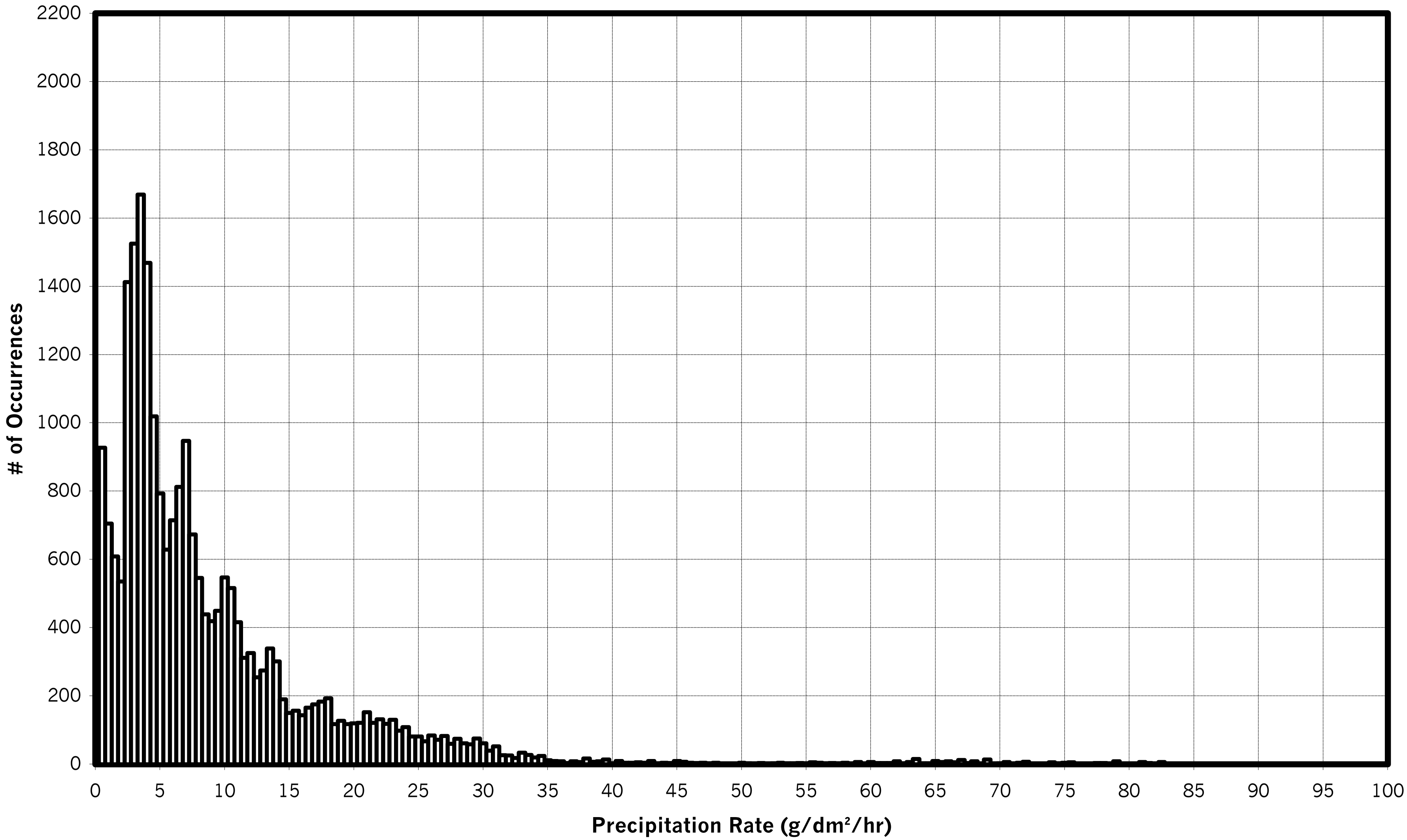
cm1514/analysis/readac/snow/Anal_-7
At: 6 min Cuml.
02/01/01, 5:56 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-7 TO -14°C

35-MINUTE RATE EVERY MINUTE

1995-1999



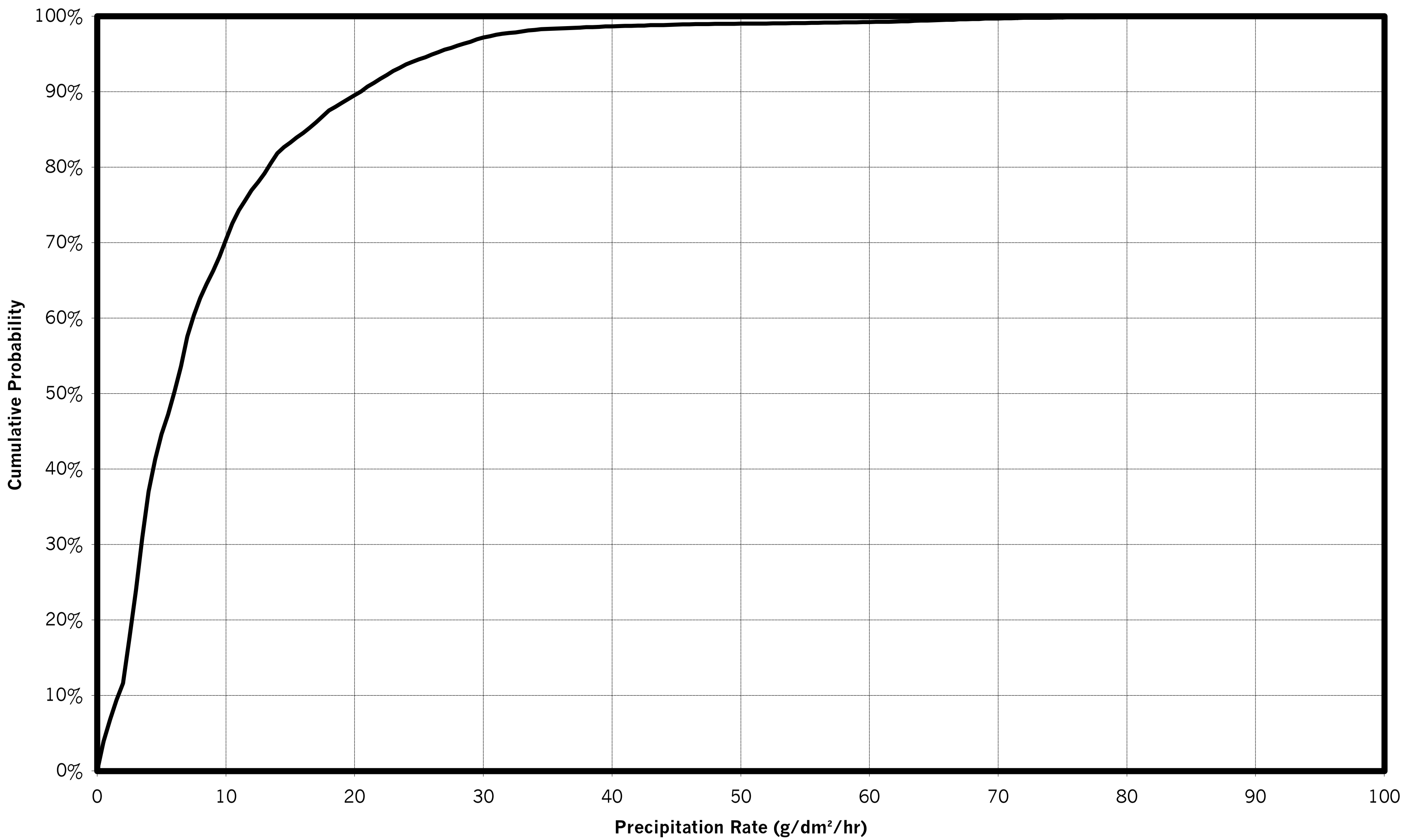
cm1514/analysis/readac/snow/Anal_-14
At: 35 min Hist
02/01/01, 5:58 PM

READADAC AND CR21X ANALYSIS - NATURAL SNOW

-7 TO -14°C

35-MINUTE RATE EVERY MINUTE

1995-1999



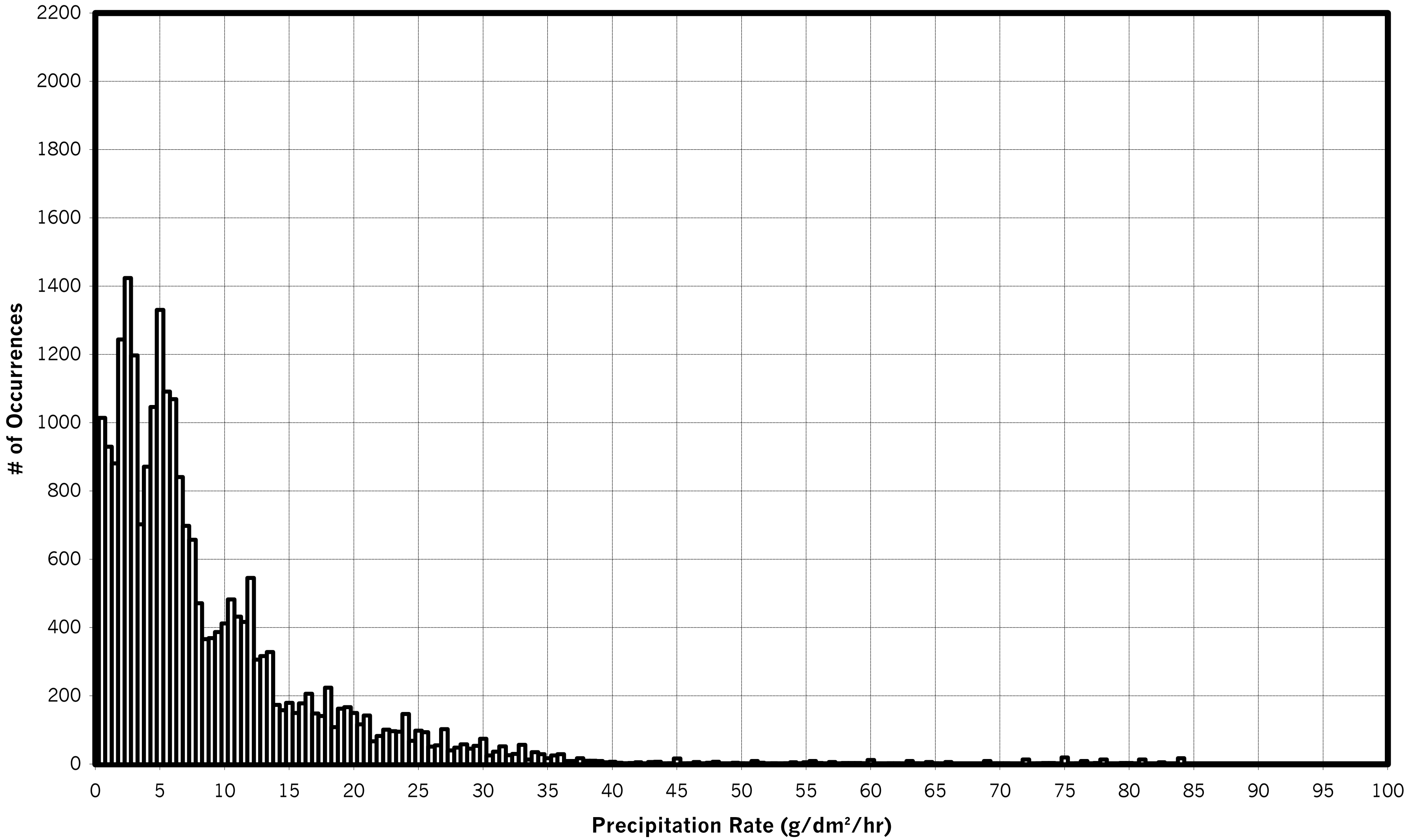
cm1514/analysis/readac/snow/Anal_-14
At: 35 min Cuml.
02/01/01, 5:58 PM

READADAC AND CR21X ANALYSIS - NATURAL SNOW

-7 TO -14°C

20-MINUTE RATE EVERY MINUTE

1995-1999



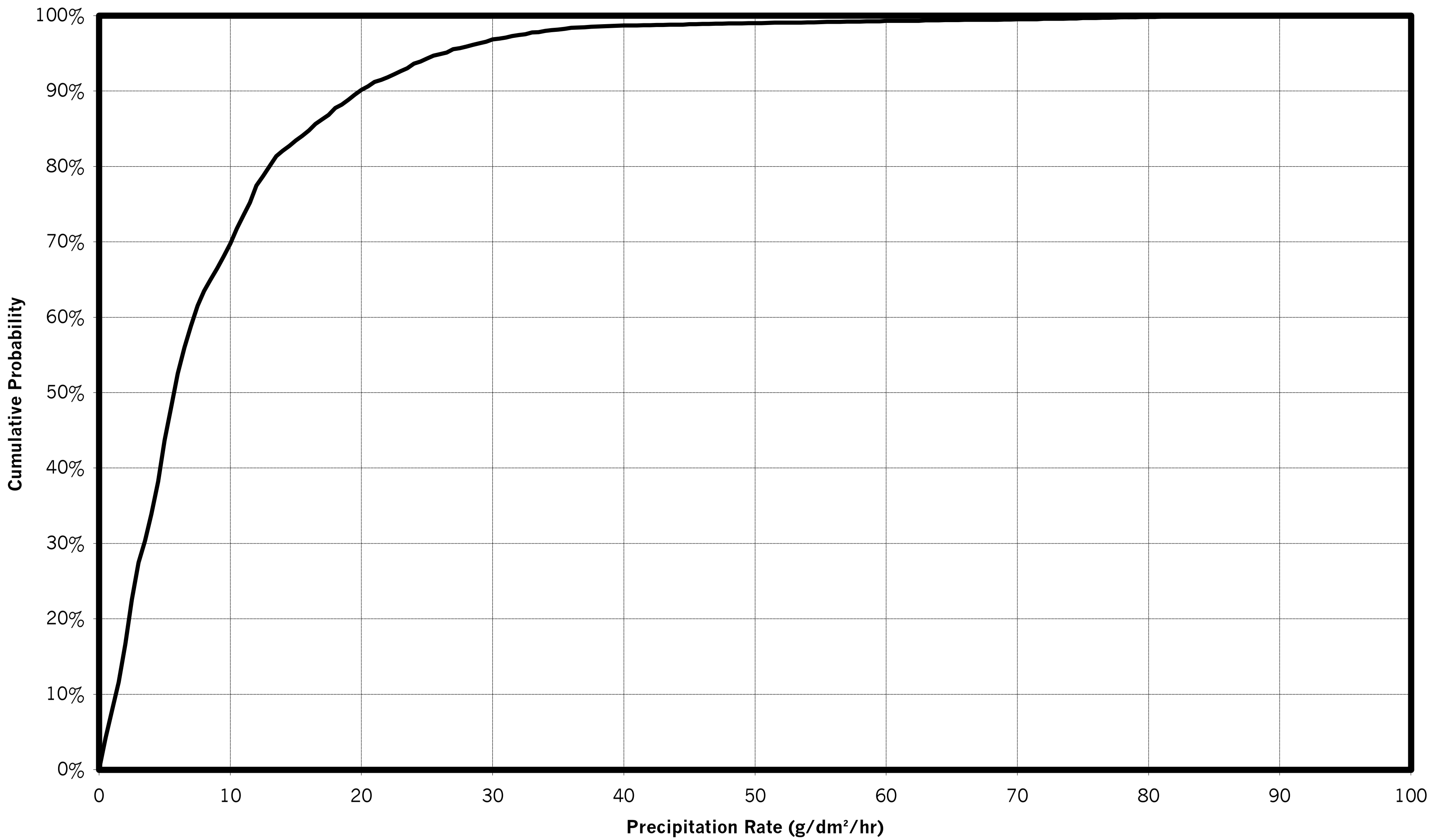
cm1514/analysis/readac/snow/Anal_-14
At: 20 min Hist
02/01/01, 5:59 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-7 TO -14°C

20-MINUTE RATE EVERY MINUTE

1995-1999



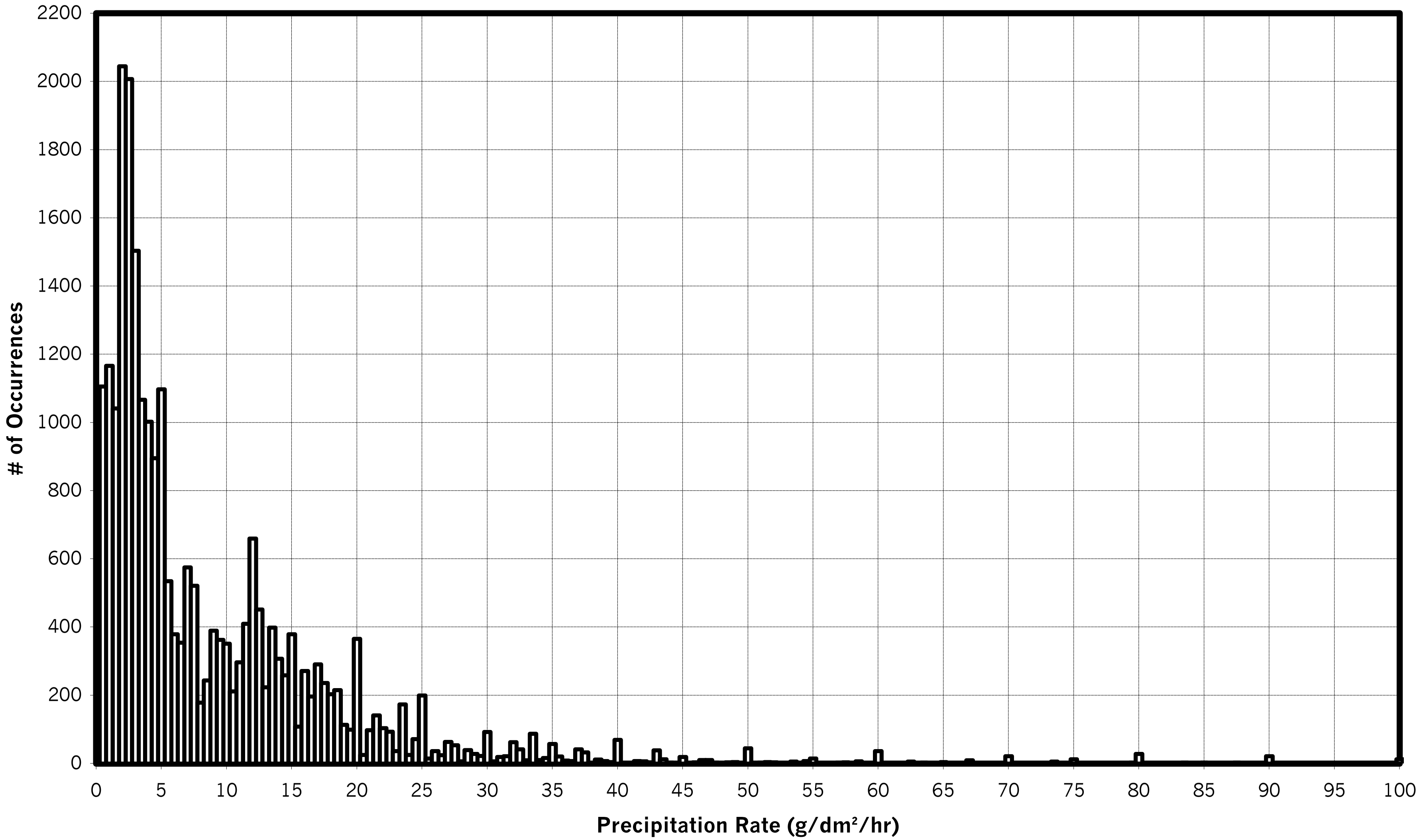
cm1514/analysis/readac/snow/Anal_-14
At: 20 min Cuml.
02/01/01, 5:59 PM

READADAC AND CR21X ANALYSIS - NATURAL SNOW

-7 TO -14°C

6-MINUTE RATE EVERY MINUTE

1995-1999



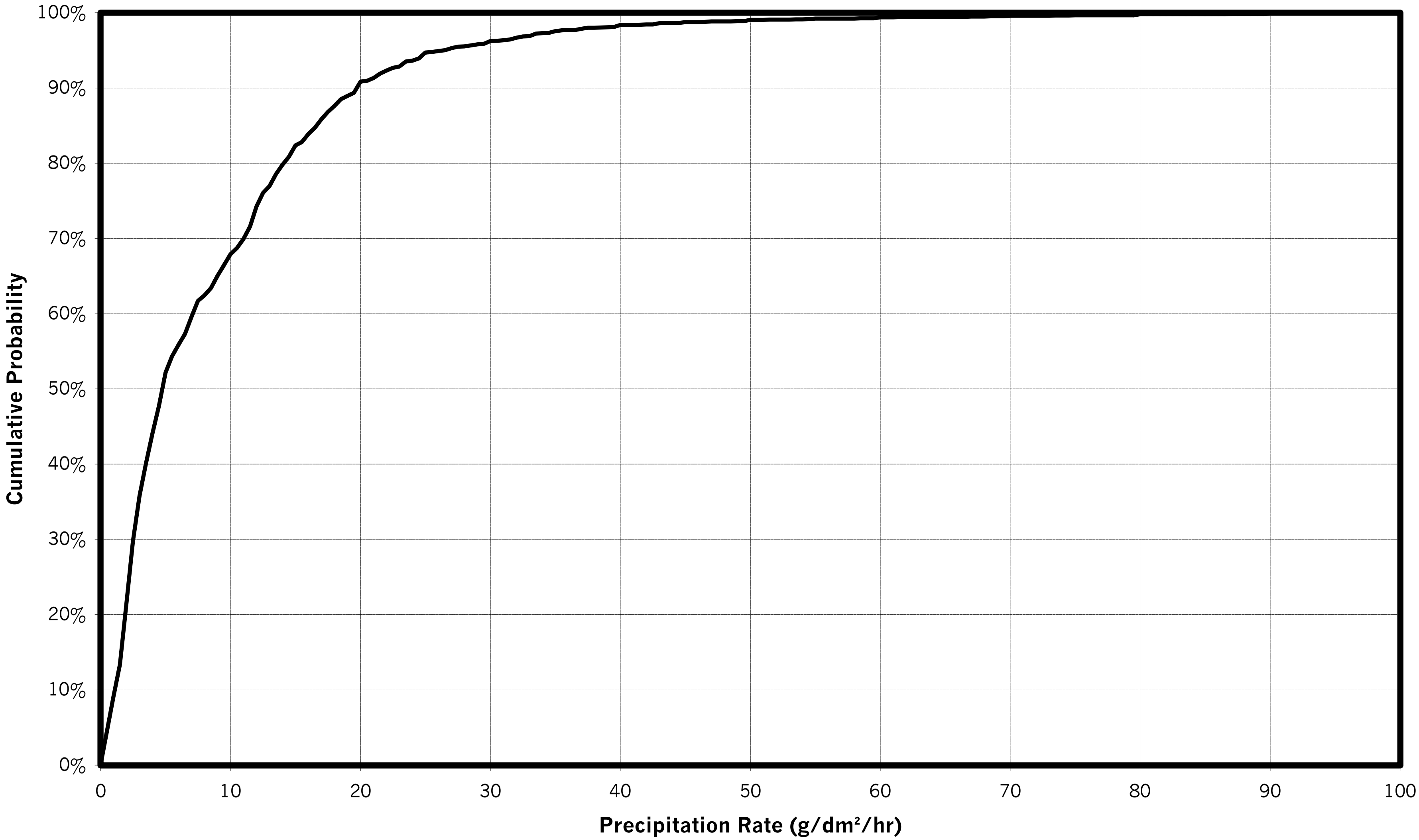
cm1514/analysis/readac/snow/Anal_-14
At: 6 min Hist
02/01/01, 5:59 PM

READADAC AND CR21X ANALYSIS - NATURAL SNOW

-7 TO -14°C

6-MINUTE RATE EVERY MINUTE

1995-1999



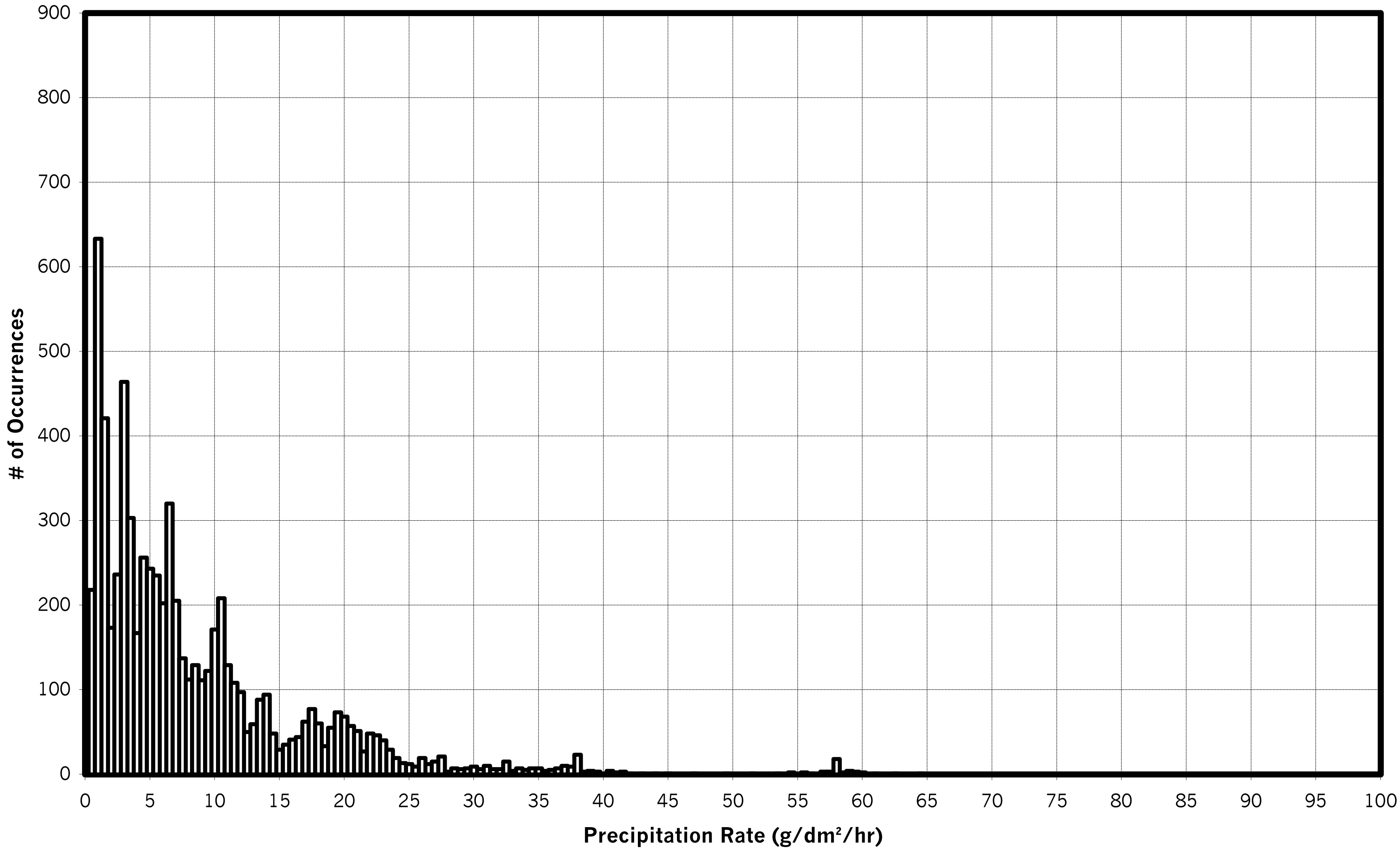
cm1514/analysis/readac/snow/Anal_-14
At: 6 min Cuml.
02/01/01, 6:00 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -25°C

35-MINUTE RATE EVERY MINUTE

1995-1999



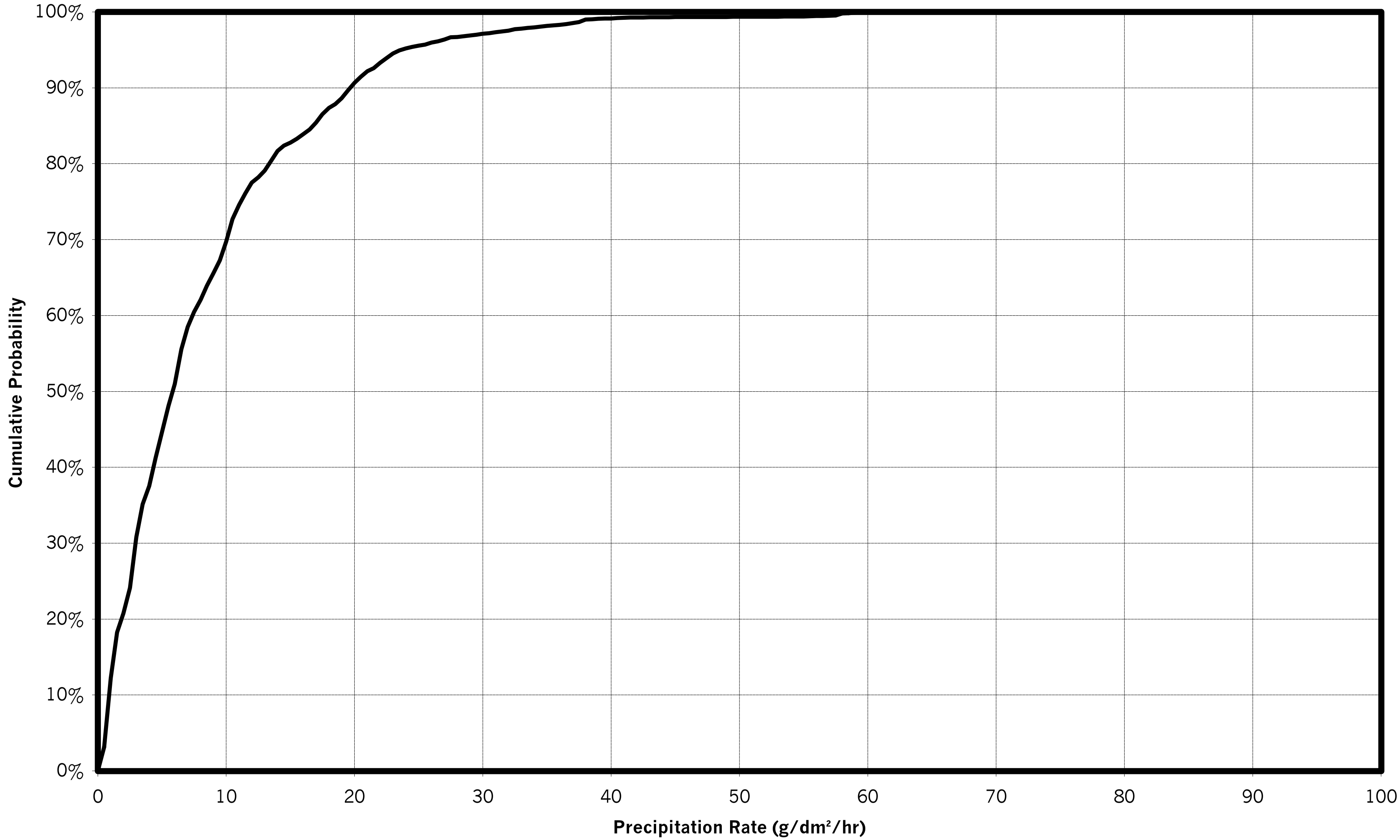
cm1514/analysis/readac/snow/Anal_-25
At: 35 min Hist
02/01/01, 6:01 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -25°C

35-MINUTE RATE EVERY MINUTE

1995-1999



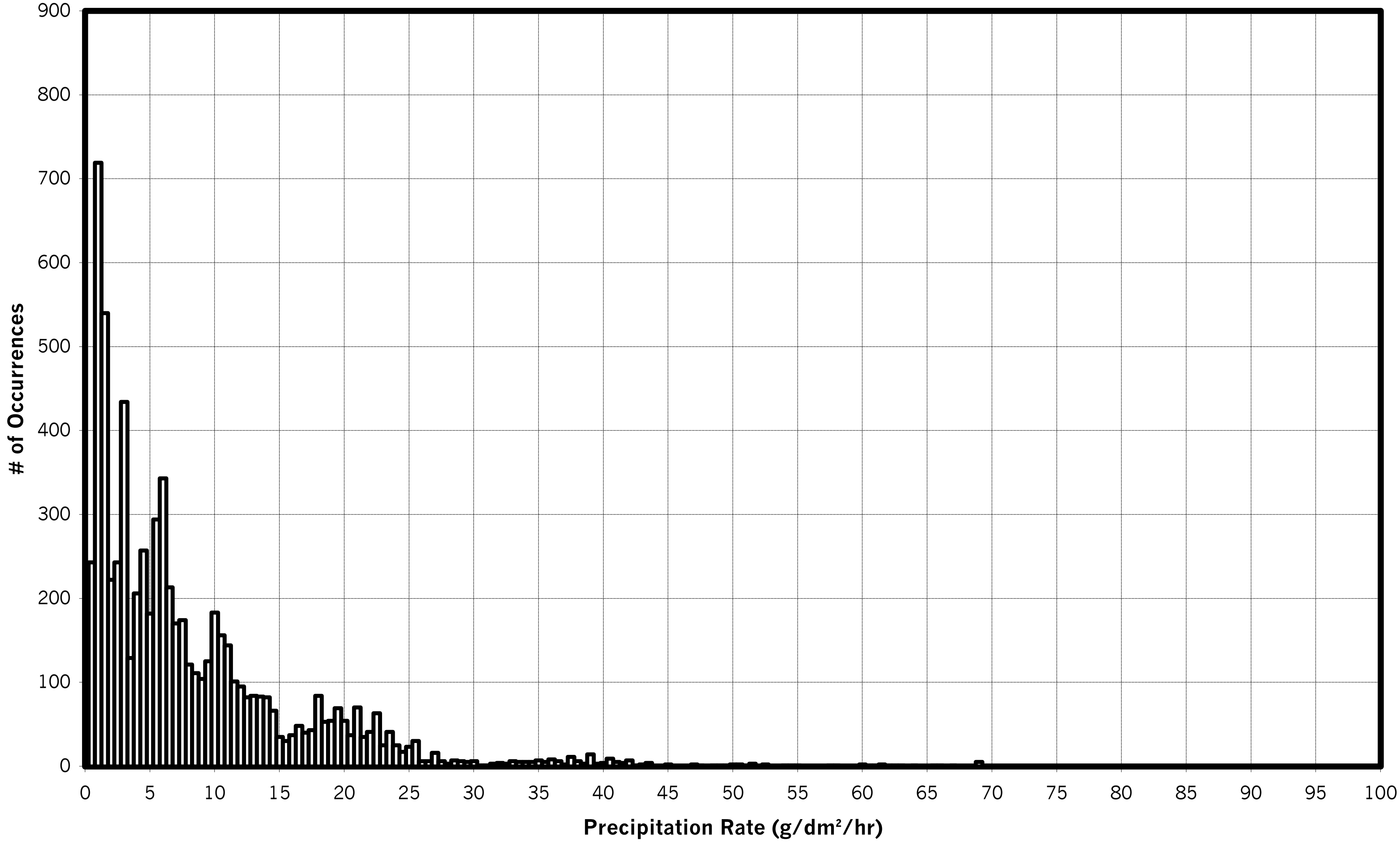
cm1514/analysis/readac/snow/Anal_-25
At: 35 min Cuml.
02/01/01, 6:01 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -25°C

20-MINUTE RATE EVERY MINUTE

1995-1999



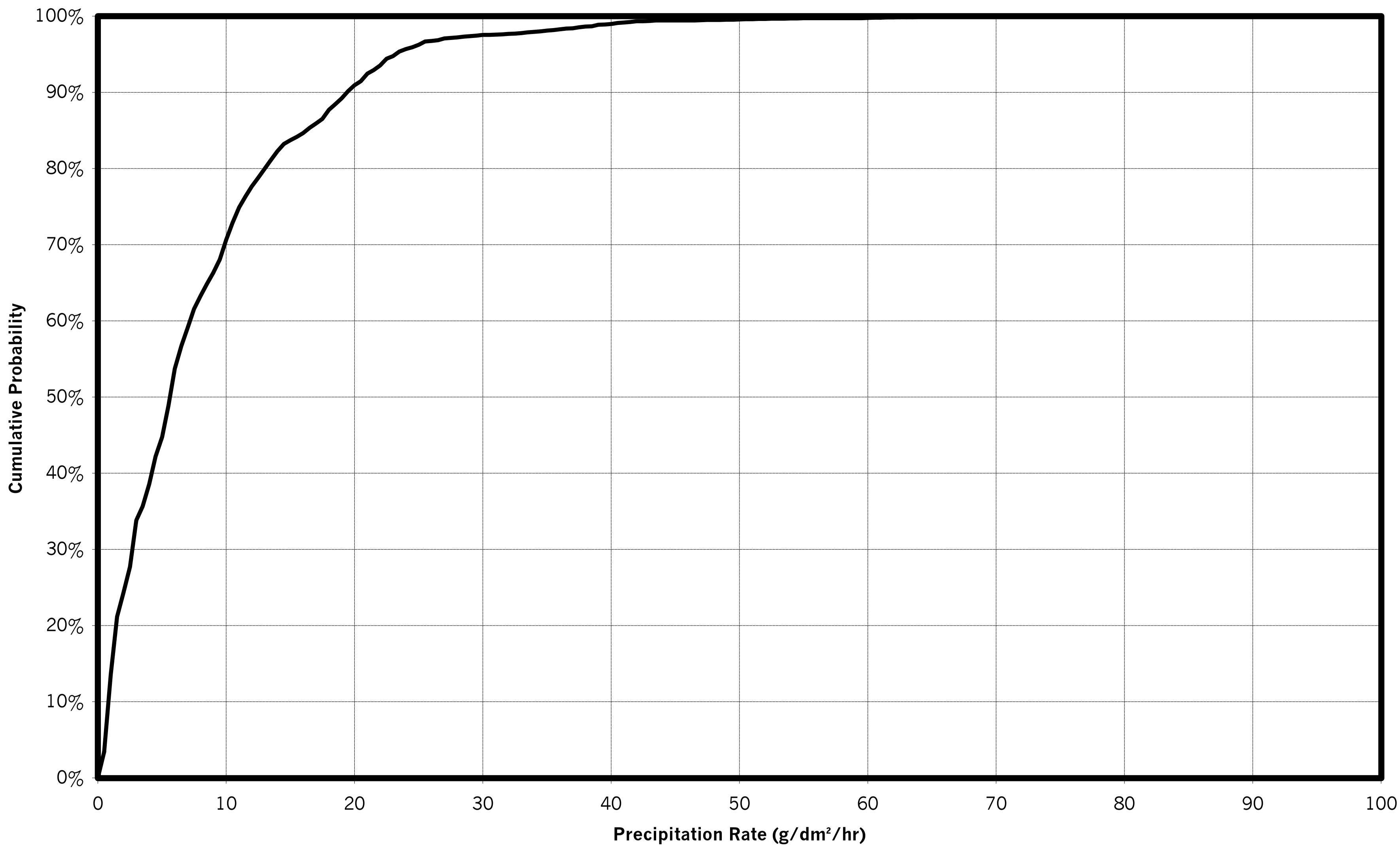
cm1514/analysis/readac/snow/Anal_-25
At: 20 min Hist
02/01/01, 6:02 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -25°C

20-MINUTE RATE EVERY MINUTE

1995-1999



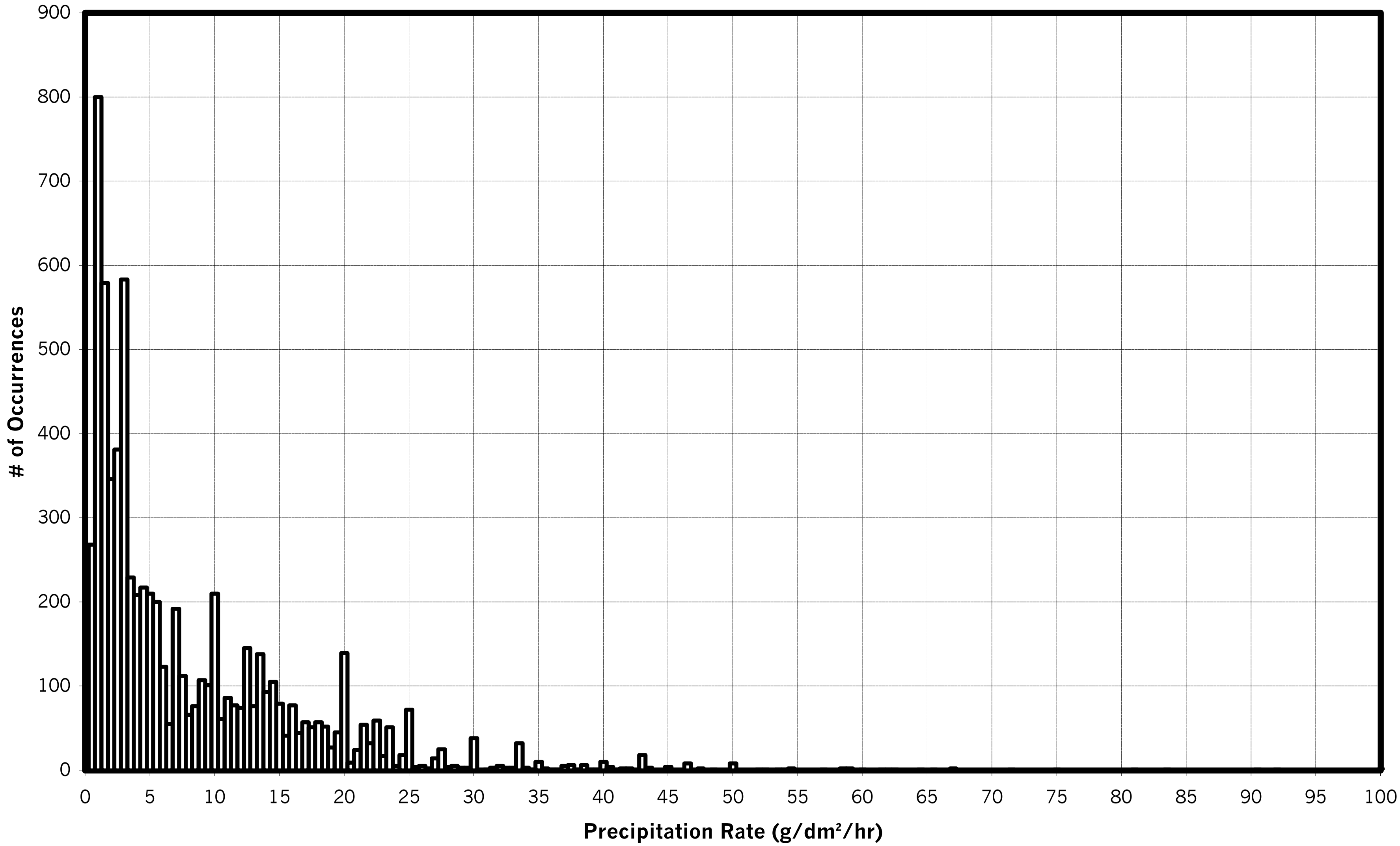
cm1514/analysis/readac/snow/Anal_-25
At: 20 min Cuml.
02/01/01, 6:02 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -25°C

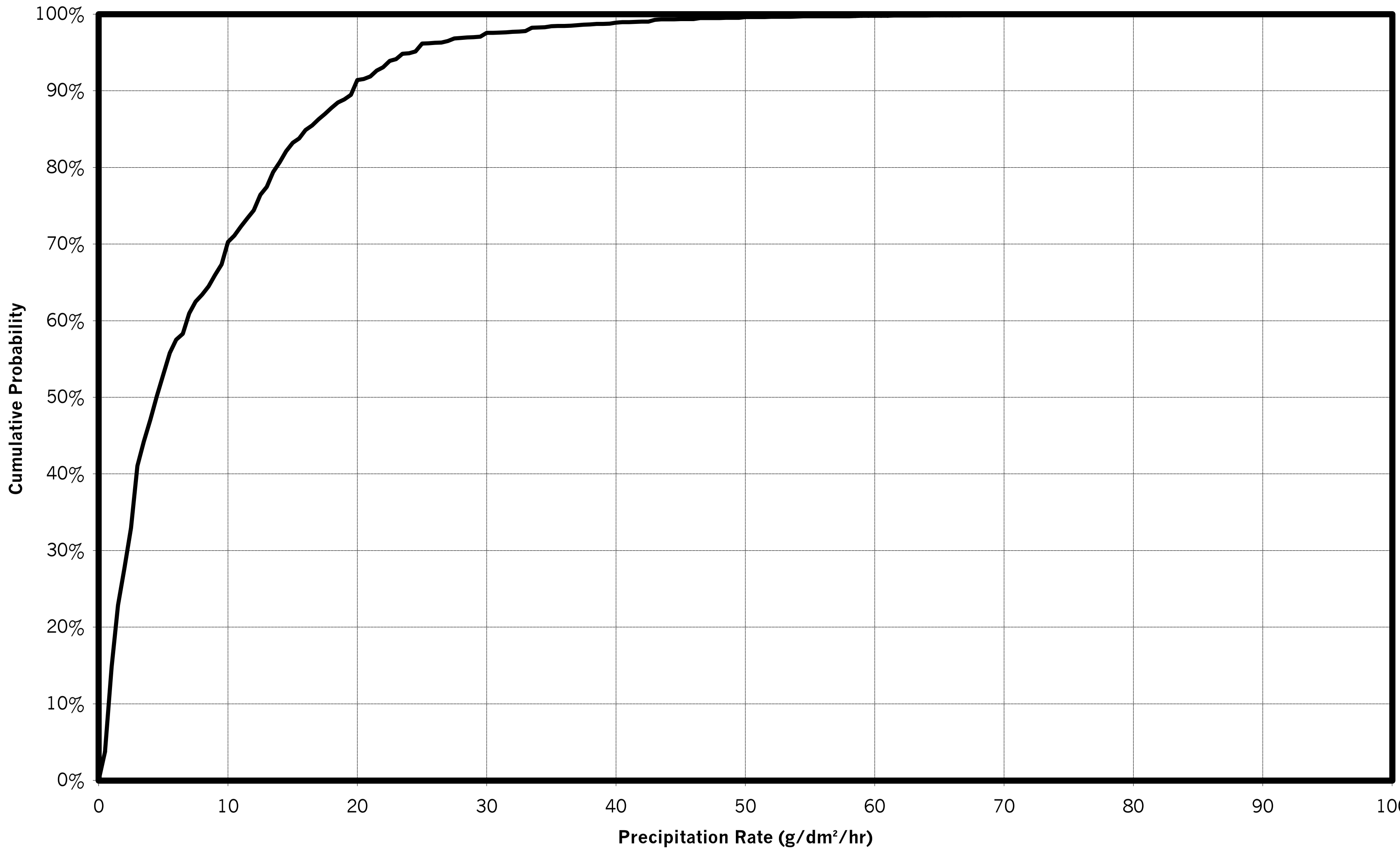
6-MINUTE RATE EVERY MINUTE

1995-1999



cm1514/analysis/readac/snow/Anal_-25
At: 6 min Hist
02/01/01, 6:02 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW
-14 TO -25°C
6-MINUTE RATE EVERY MINUTE
1995-1999



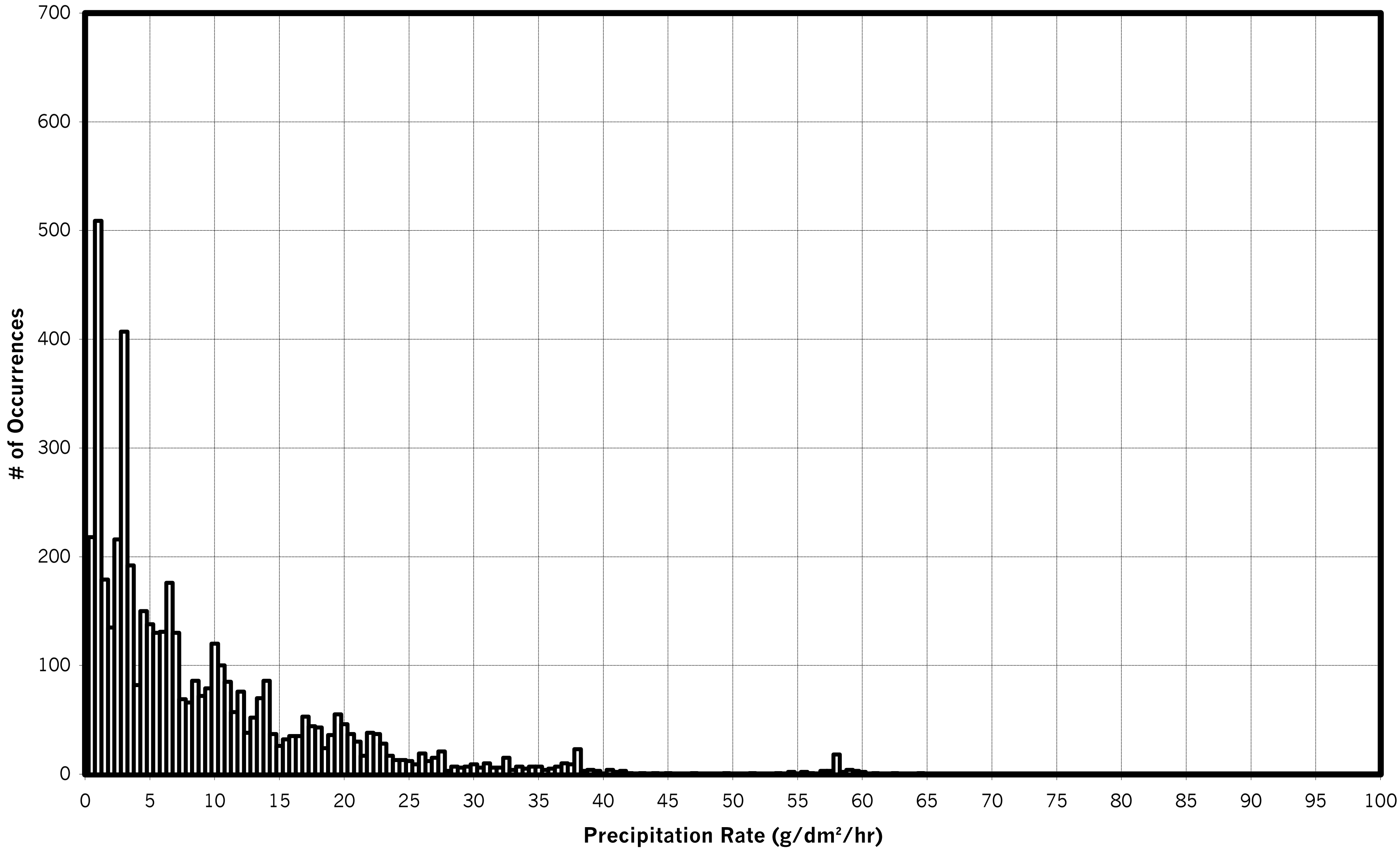
cm1514/analysis/readac/snow/Anal_-25
At: 6 min Cuml.
02/01/01, 6:03 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -18°C

35-MINUTE RATE EVERY MINUTE

1995-1999



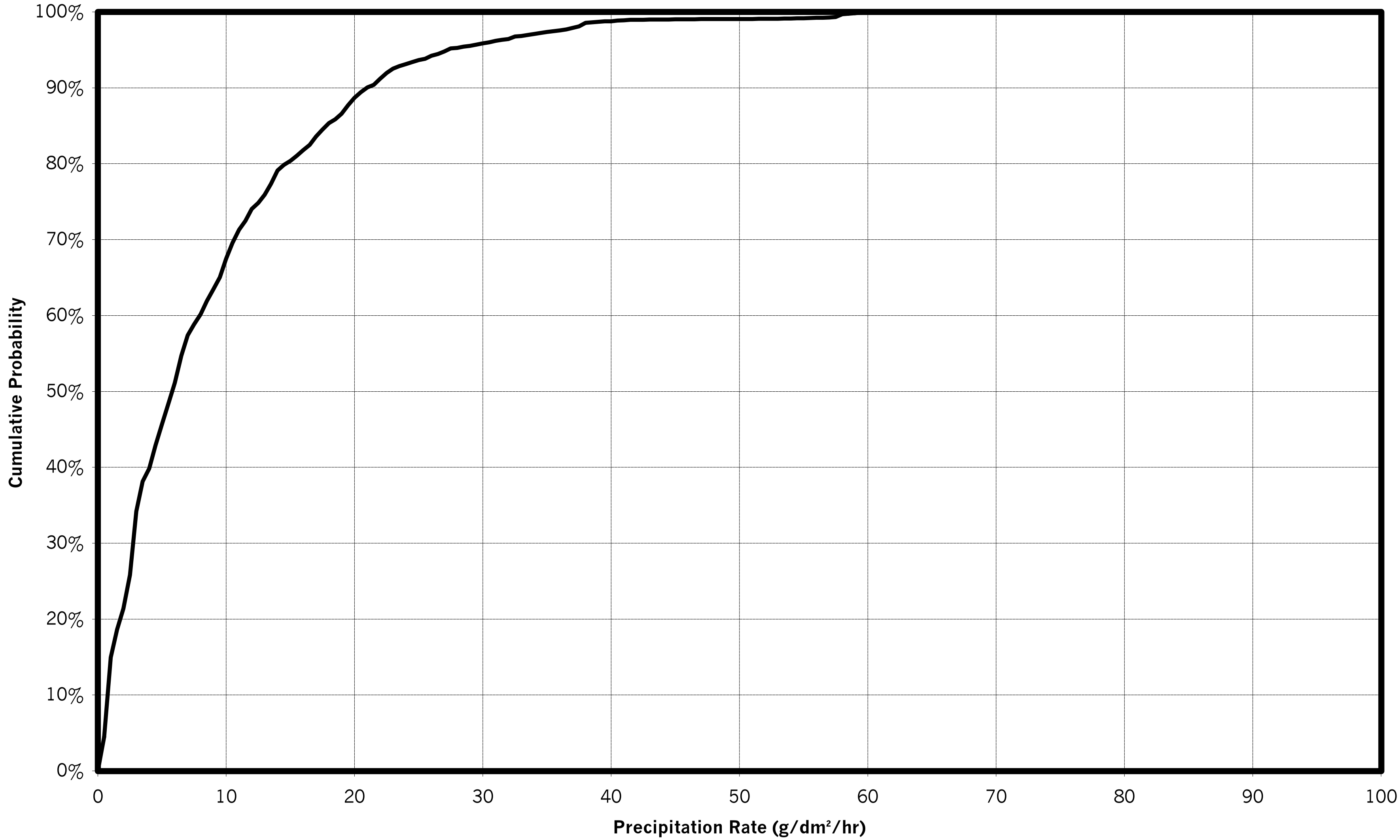
cm1514/analysis/readac/snow/anal -14 to -18C
At: 35 min Hist
02/01/01, 6:06 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -18°C

35-MINUTE RATE EVERY MINUTE

1995-1999



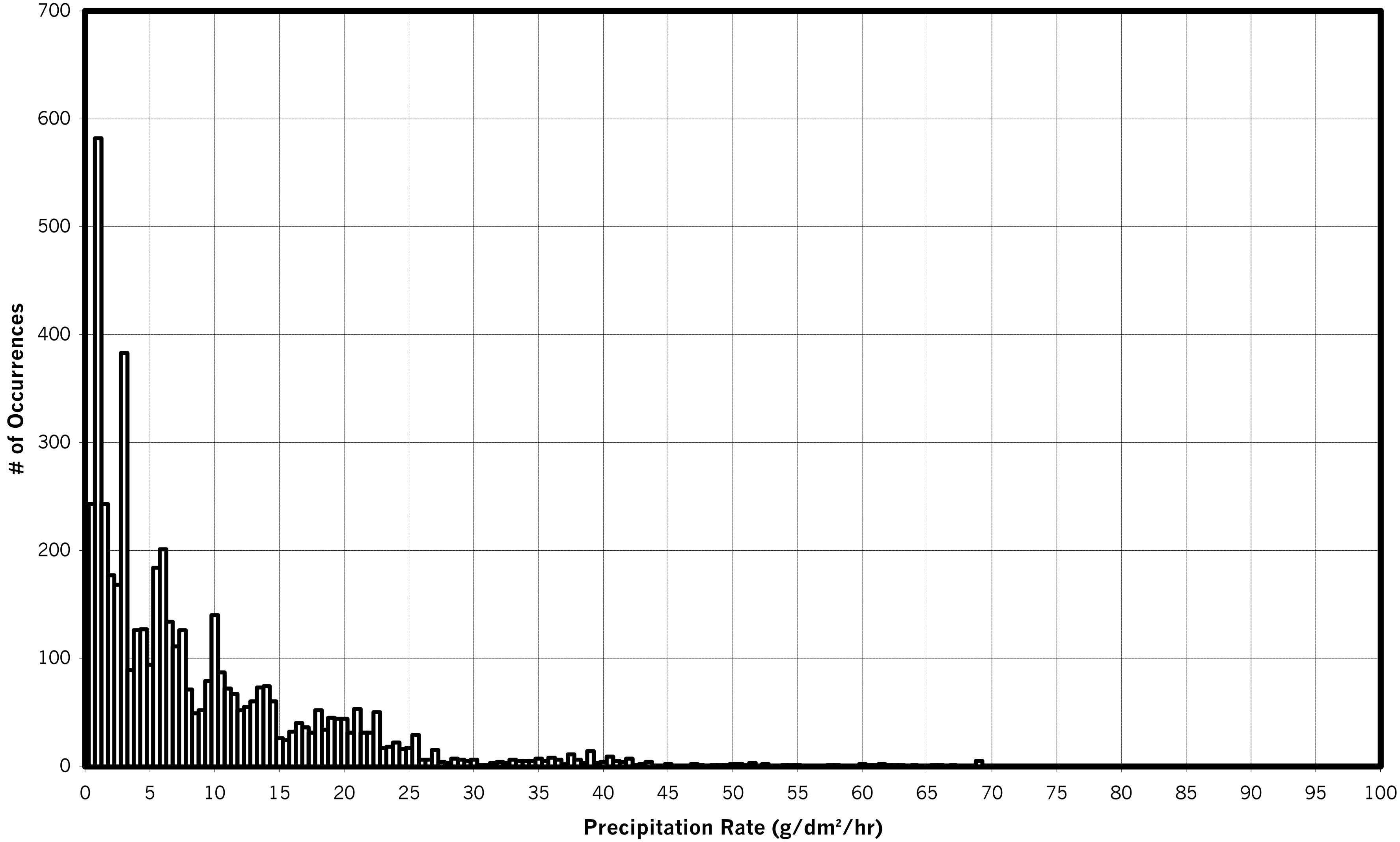
cm1514/analysis/readac/snow/anal -14 to -18C
At: 35 min Cuml.
02/01/01, 6:06 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -18°C

20-MINUTE RATE EVERY MINUTE

1995-1999



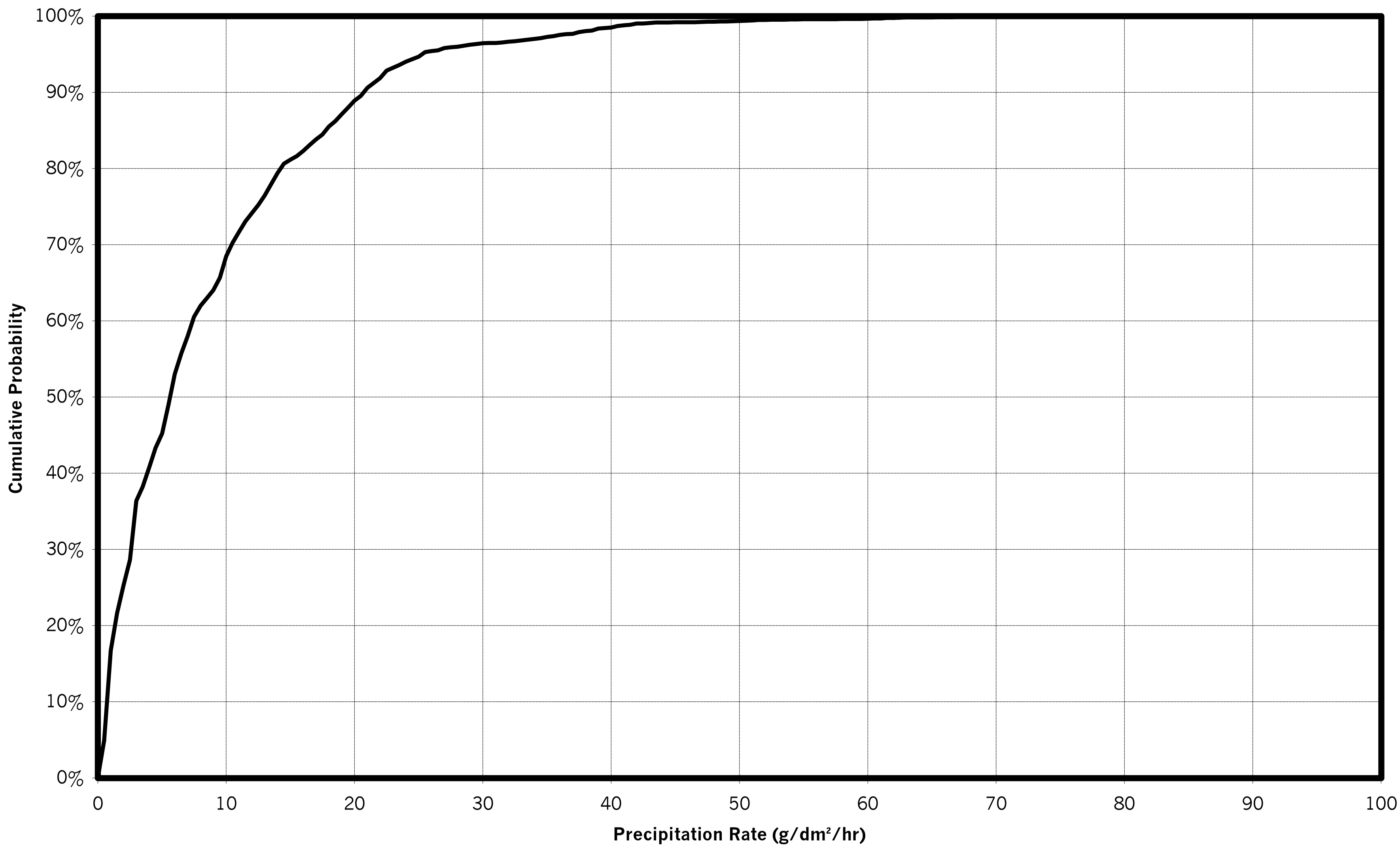
cm1514/analysis/readac/snow/anal -14 to -18C
At: 20 min Hist
02/01/01, 6:07 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -18°C

20-MINUTE RATE EVERY MINUTE

1995-1999



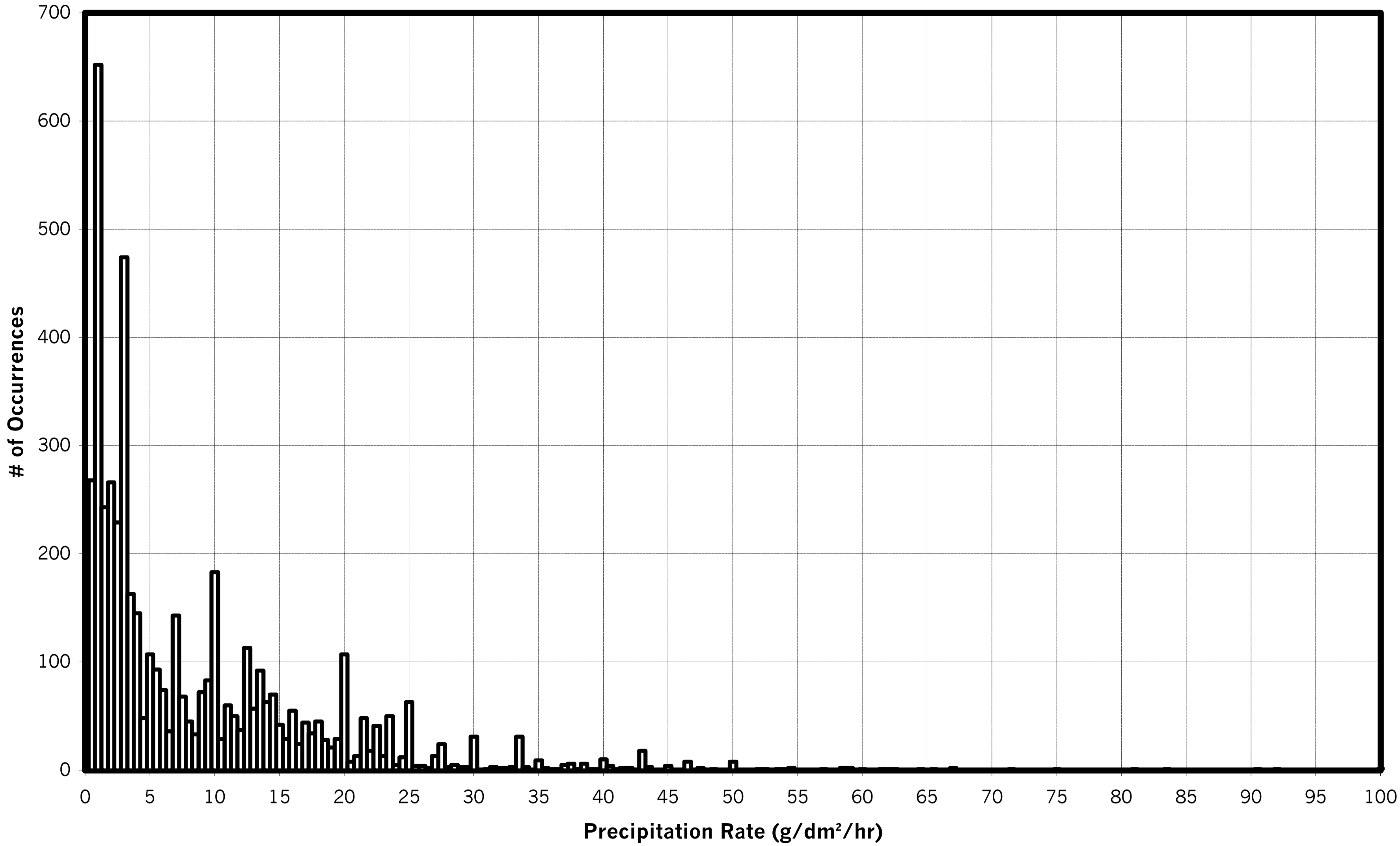
cm1514/analysis/readac/snow/anal -14 to -18C
At: 20 min Cuml.
02/01/01, 6:07 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -18°C

6-MINUTE RATE EVERY MINUTE

1995-1999



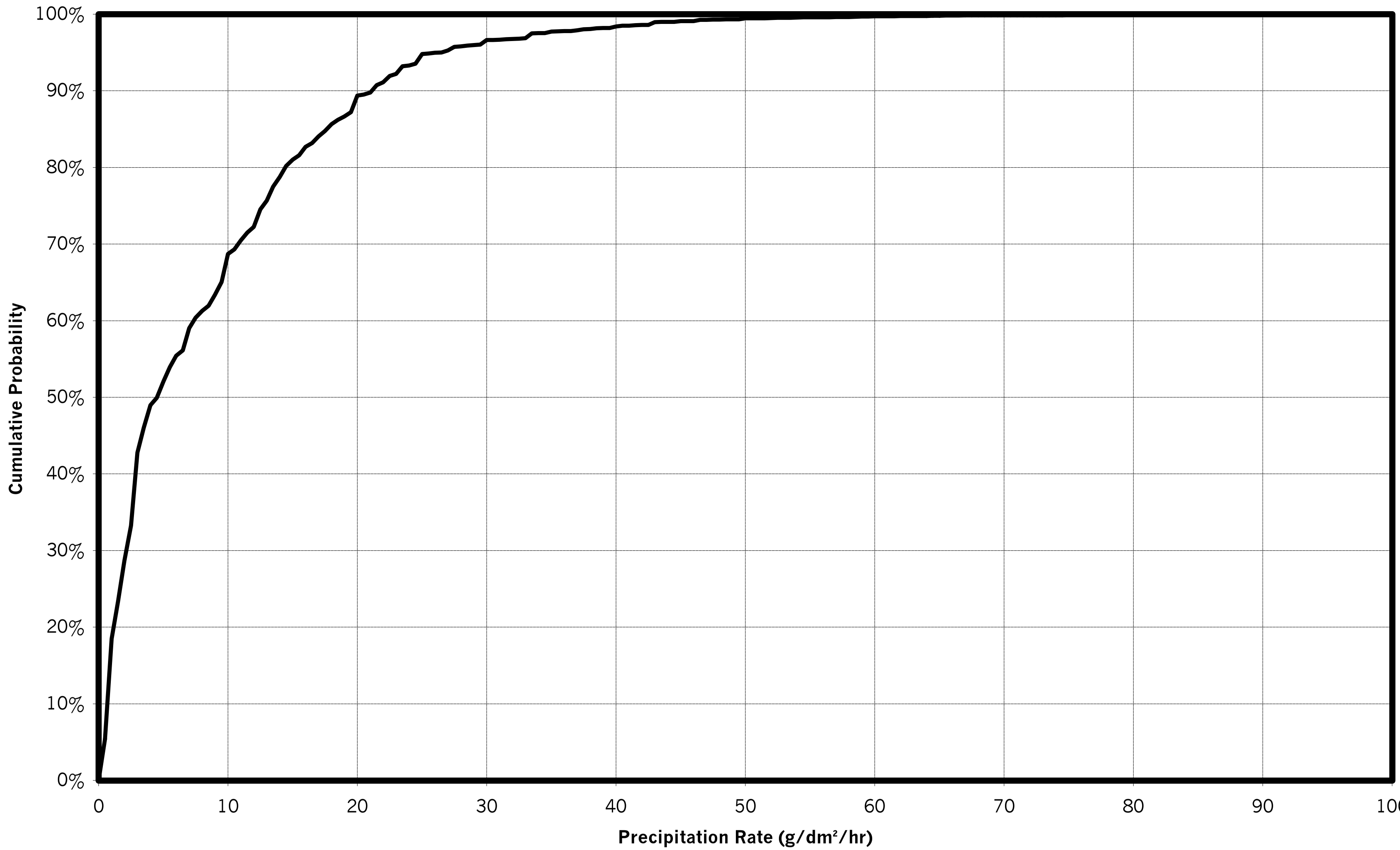
cm1514/analysis/readac/snow/anal -14 to -18C
At: 6 min Hist
02/01/01, 6:07 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-14 TO -18°C

6-MINUTE RATE EVERY MINUTE

1995-1999



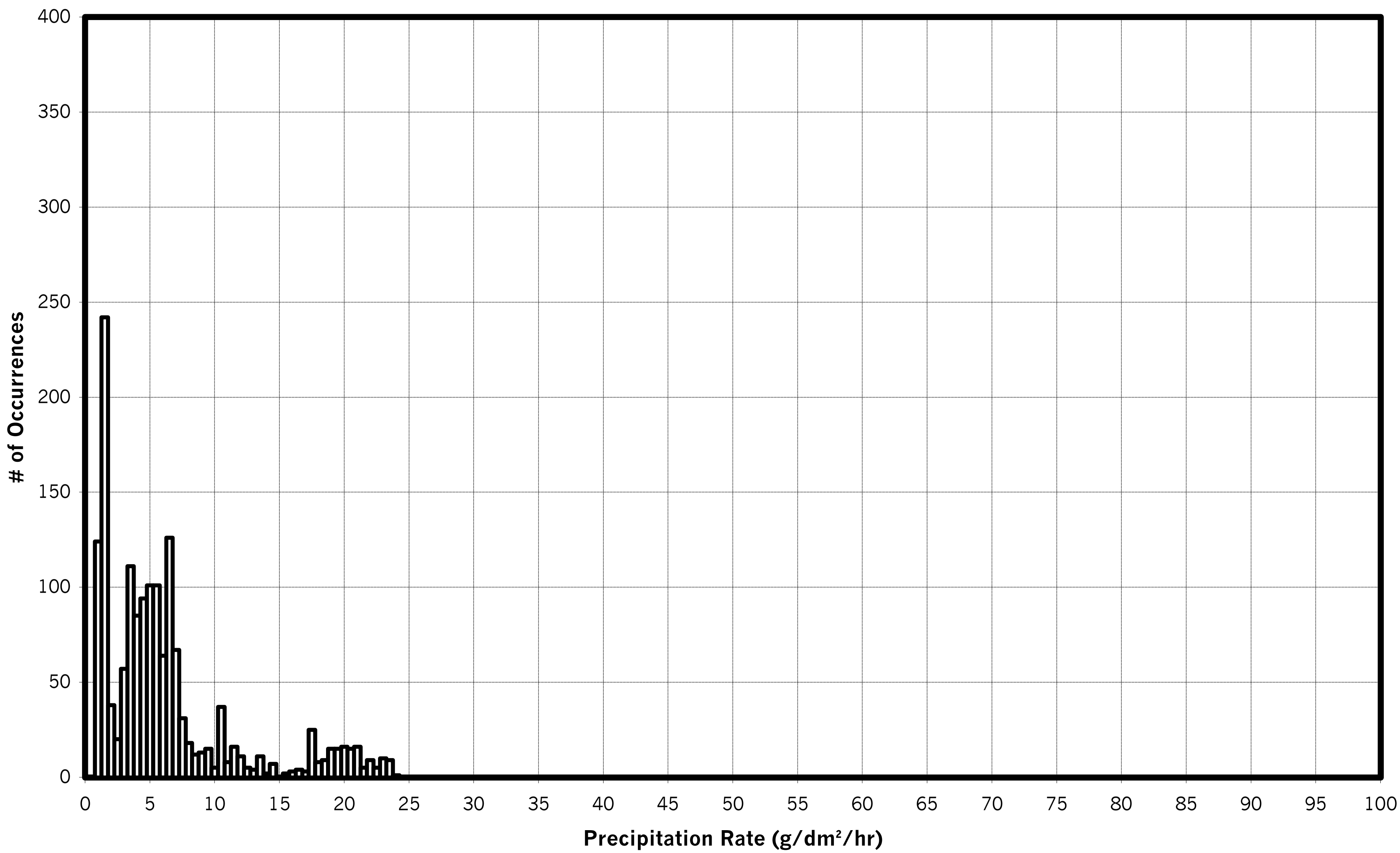
cm1514/analysis/readac/snow/anal -14 to -18C
At: 6 min Cuml.
02/01/01, 6:07 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-18 TO -22°C

35-MINUTE RATE EVERY MINUTE

1995-1999



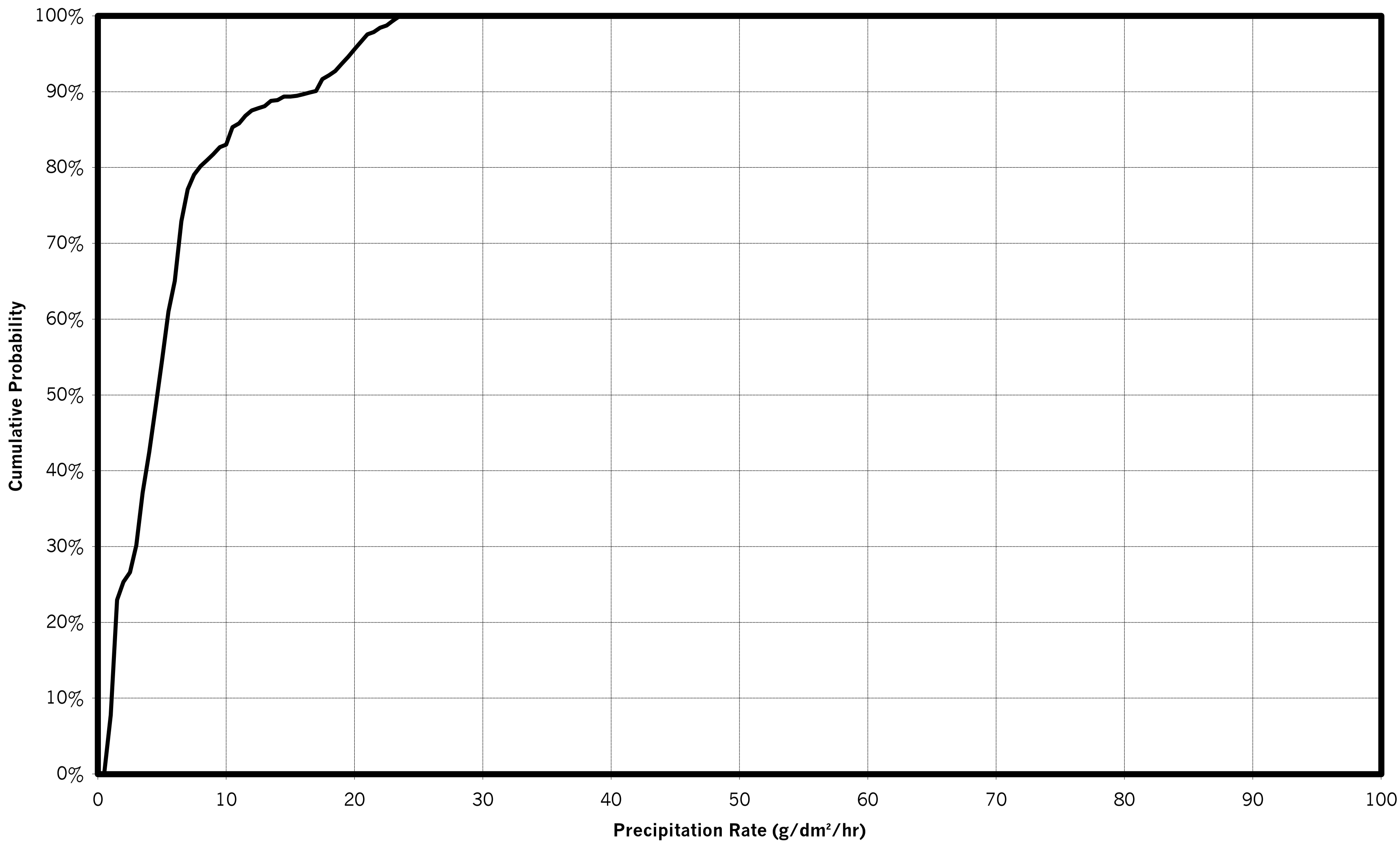
cm1514/analysis/readac/snow/anal -18 to -22C
At: 35 min Hist
02/01/01, 6:09 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-18 TO -22°C

35-MINUTE RATE EVERY MINUTE

1995-1999



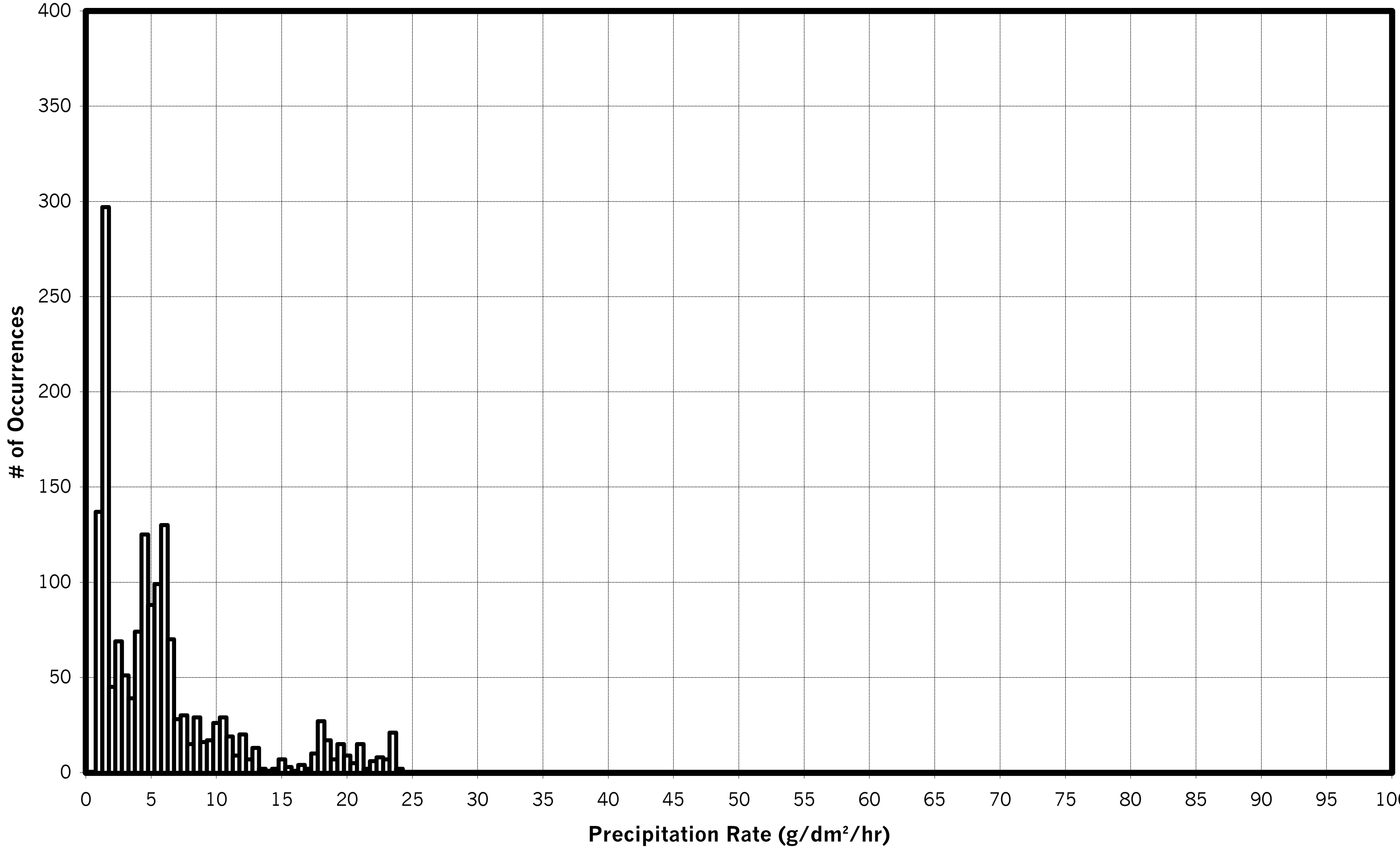
cm1514/analysis/readac/snow/anal -18 to -22C
At: 35 min Cuml.
02/01/01, 6:09 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-18 TO -22°C

20-MINUTE RATE EVERY MINUTE

1995-1999



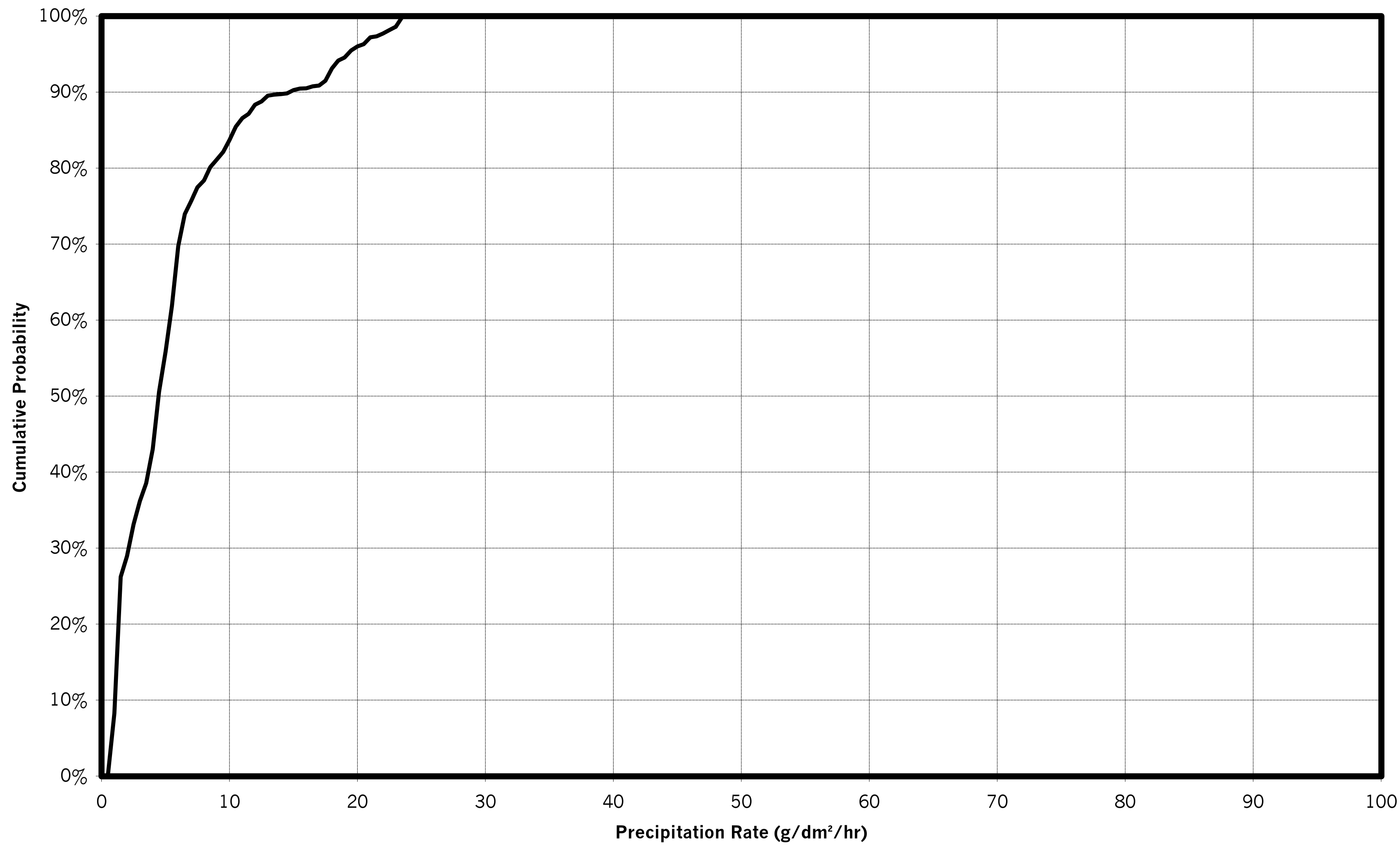
cm1514/analysis/readac/snow/anal -18 to -22C
At: 20 min Hist
02/01/01, 6:10 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-18 TO -22°C

20-MINUTE RATE EVERY MINUTE

1995-1999



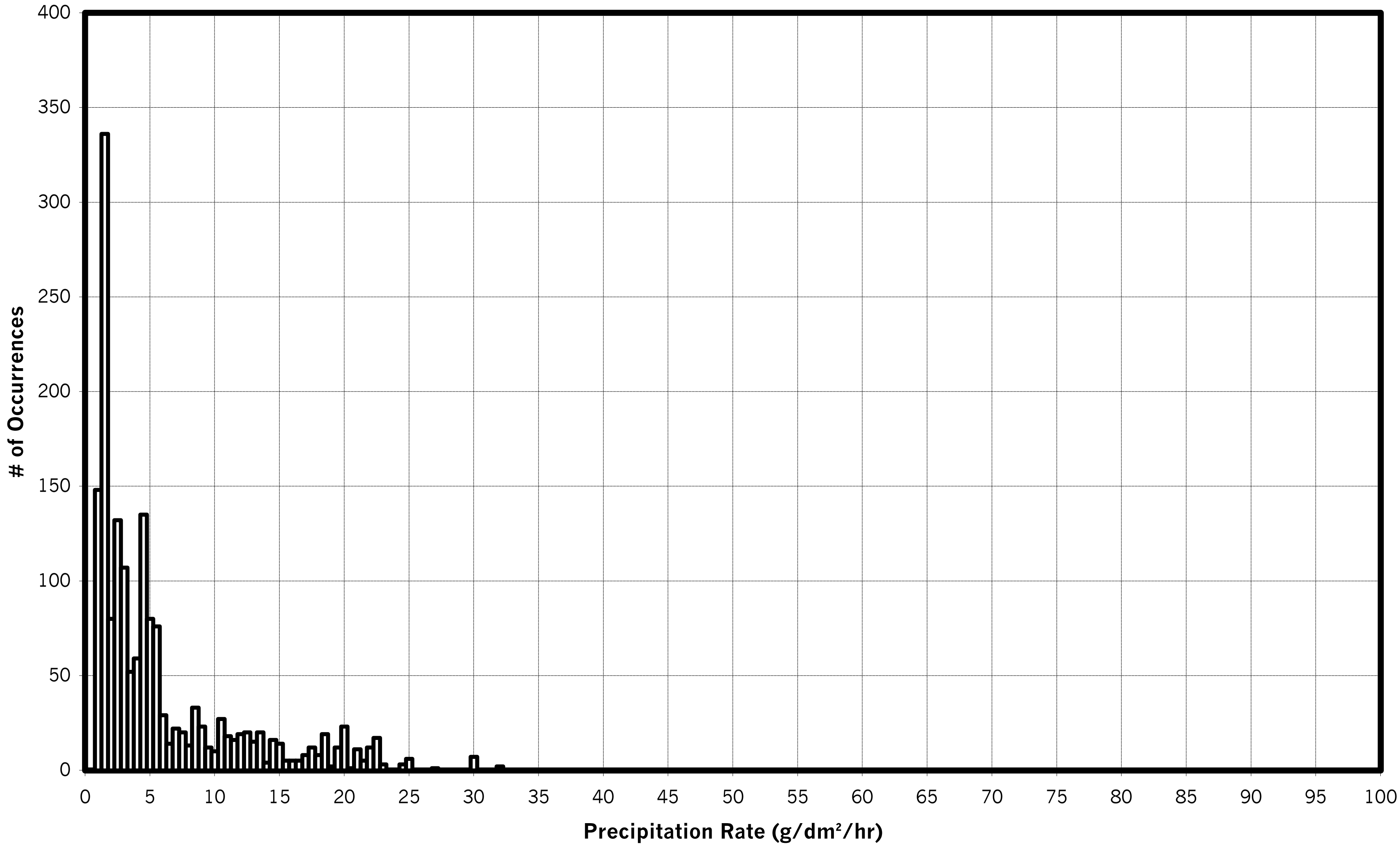
cm1514/analysis/readac/snow/anal -18 to -22C
At: 20 min Cuml.
02/01/01, 6:10 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-18 TO -22°C

6-MINUTE RATE EVERY MINUTE

1995-1999



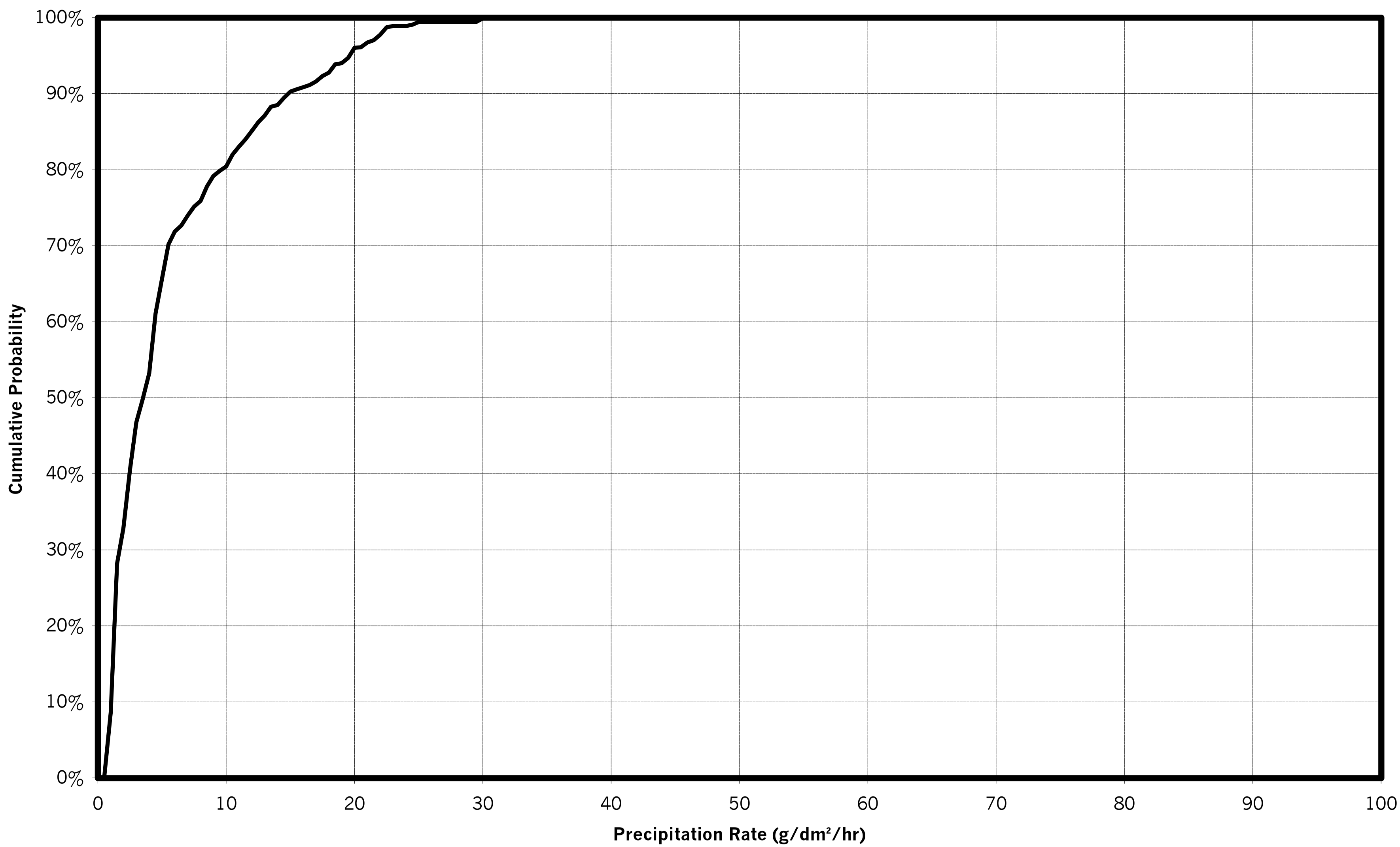
cm1514/analysis/readac/snow/anal -18 to -22C
At: 6 min Hist
02/01/01, 6:11 PM

READADAC AND CR21X ANALYSIS - NATURAL SNOW

-18 TO -22°C

6-MINUTE RATE EVERY MINUTE

1995-1999



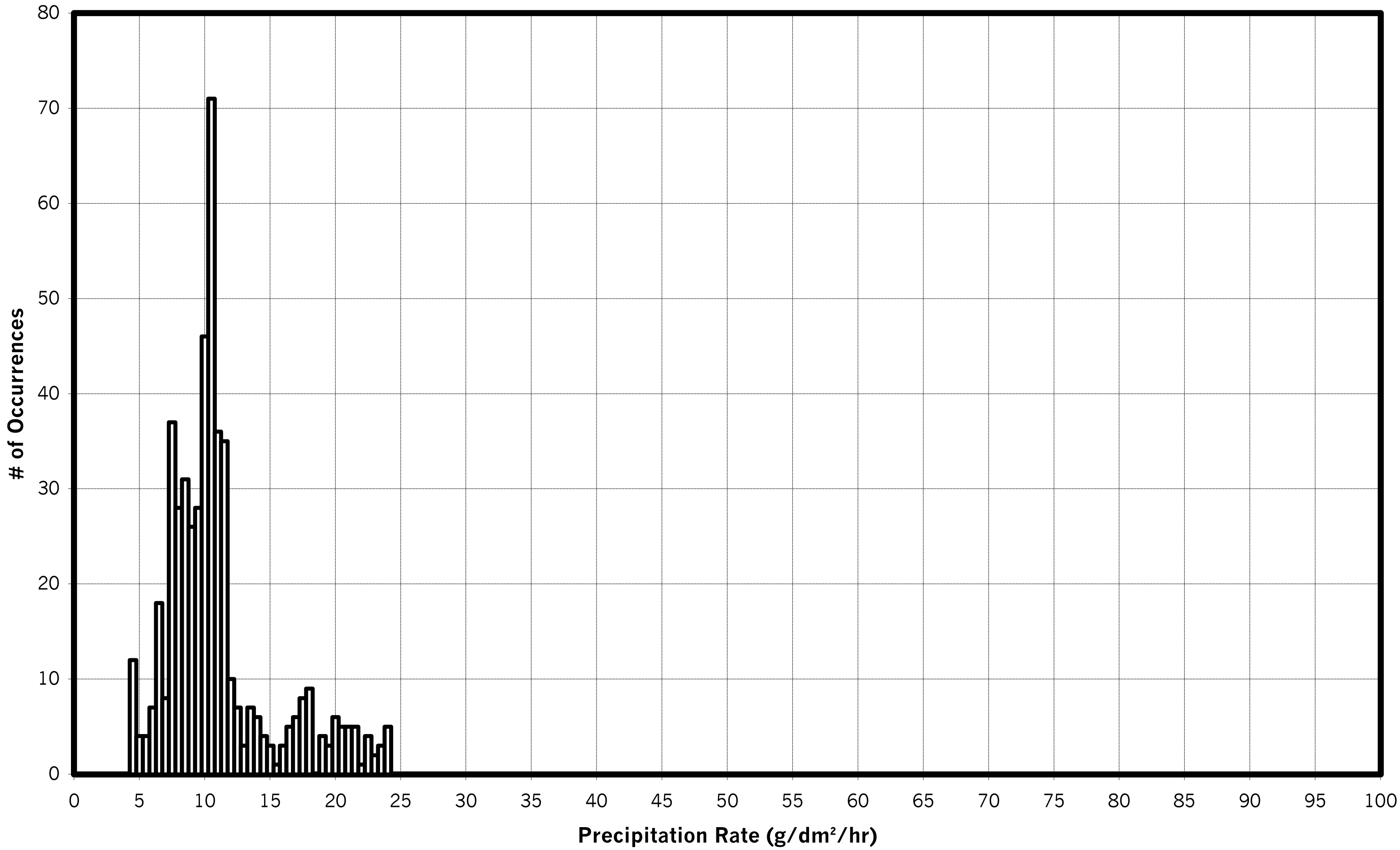
cm1514/analysis/readac/snow/anal -18 to -22C
At: 6 min Cuml.
02/01/01, 6:11 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-22 TO -25°C

35-MINUTE RATE EVERY MINUTE

1995-1999



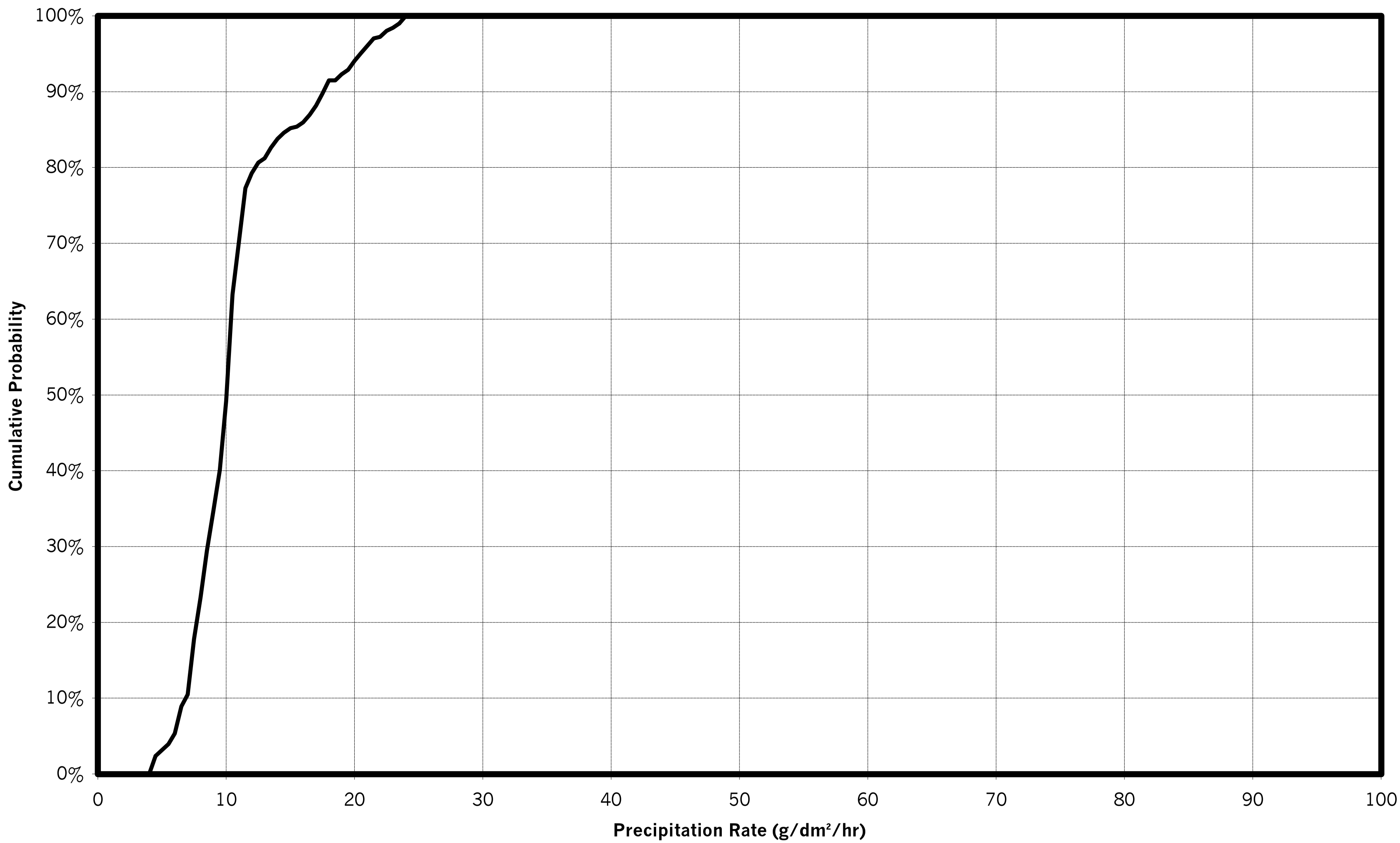
cm1514/analysis/readac/snow/anal -22 to -25C
At: 35 min Hist
02/01/01, 6:12 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

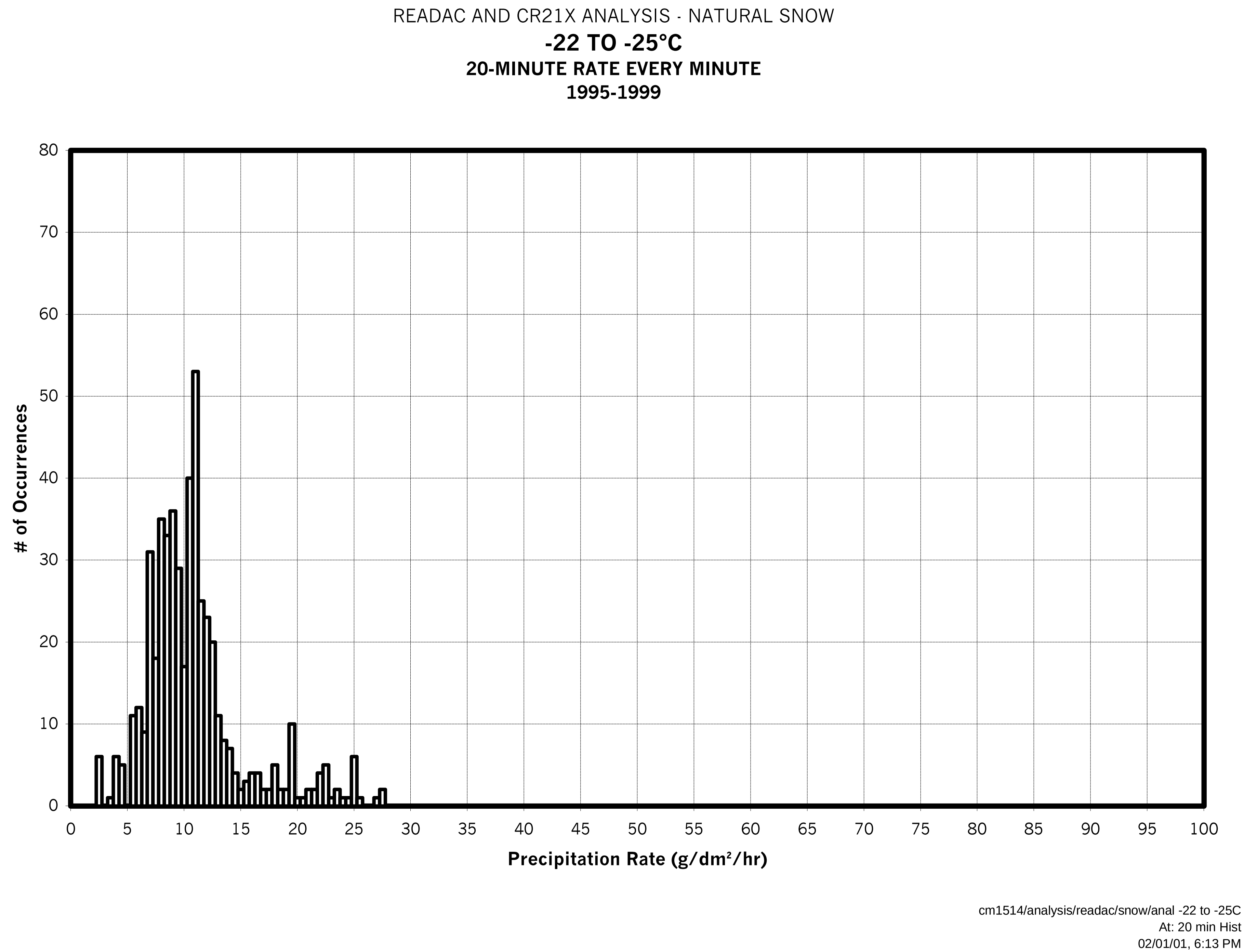
-22 TO -25°C

35-MINUTE RATE EVERY MINUTE

1995-1999



cm1514/analysis/readac/snow/anal -22 to -25C
At: 35 min Cuml.
02/01/01, 6:13 PM

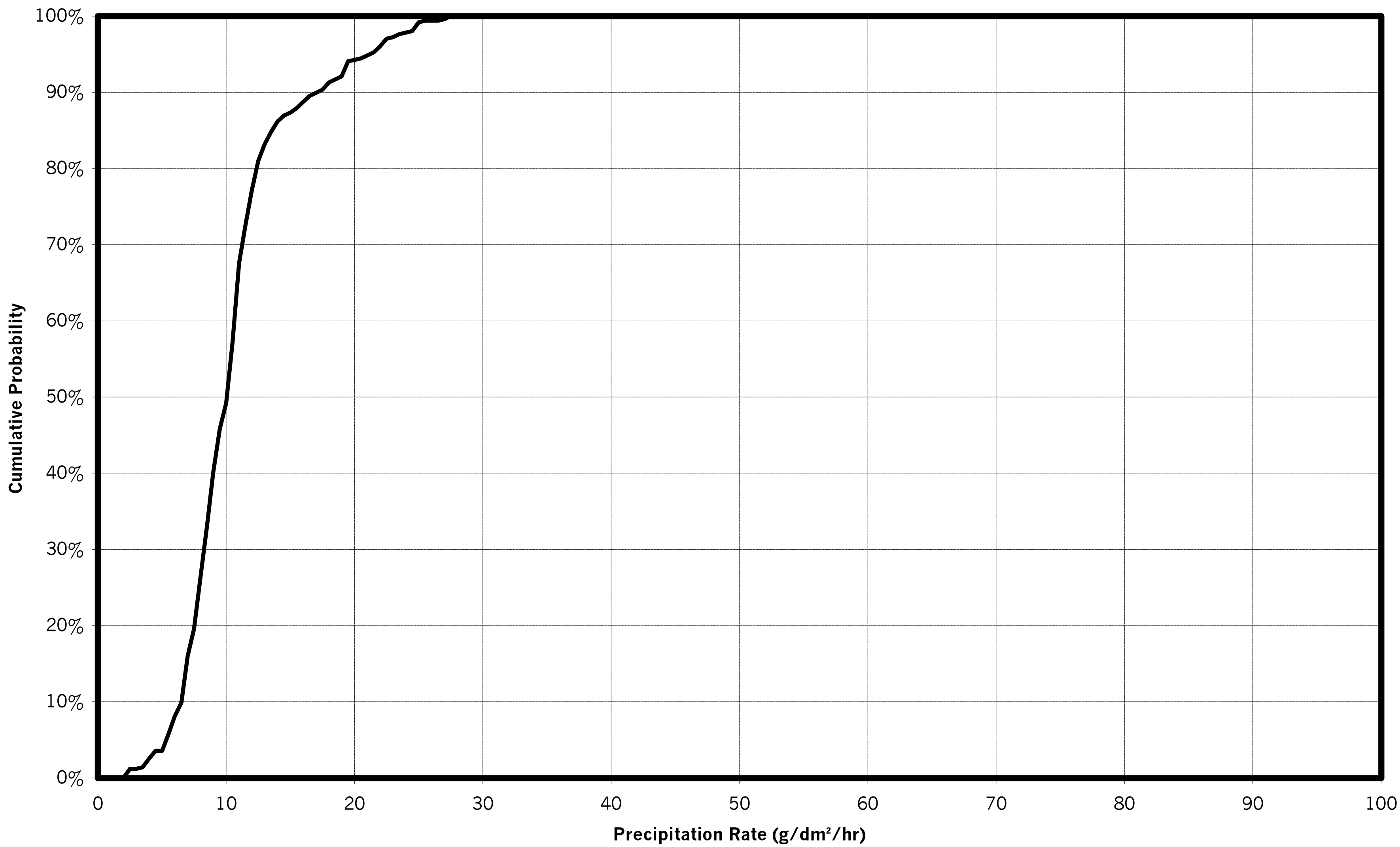

READADC AND CR21X ANALYSIS - NATURAL SNOW
-22 TO -25°C
20-MINUTE RATE EVERY MINUTE
1995-1999
# of Occurrences
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Precipitation Rate (g/dm²/hr)
cm1514/analysis/readac/snow/anal -22 to -25C
At: 20 min Hist
02/01/01, 6:13 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW

-22 TO -25°C

20-MINUTE RATE EVERY MINUTE

1995-1999



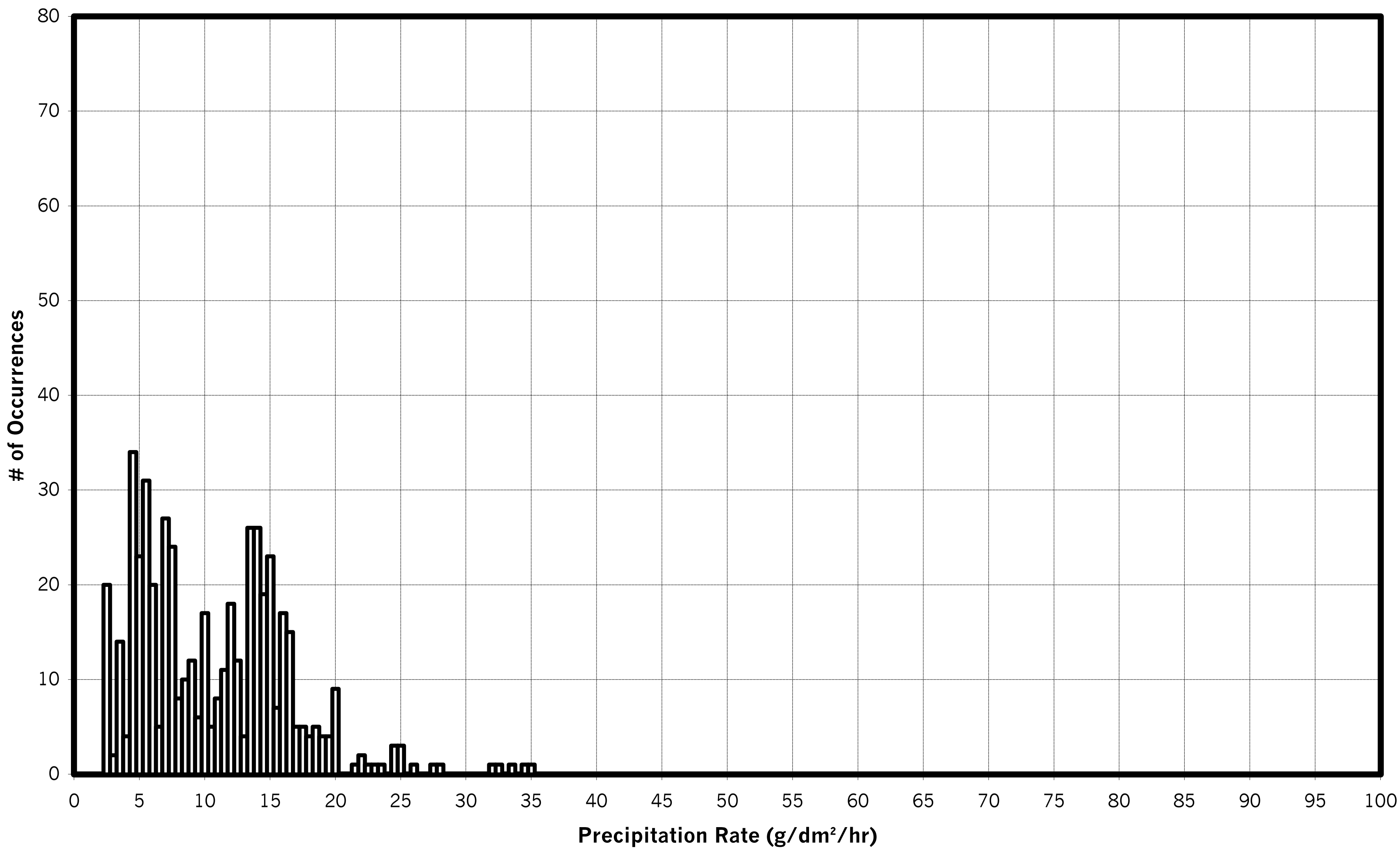
cm1514/analysis/readac/snow/anal -22 to -25C
At: 20 min Cuml.
02/01/01, 6:13 PM

READADAC AND CR21X ANALYSIS - NATURAL SNOW

-22 TO -25°C

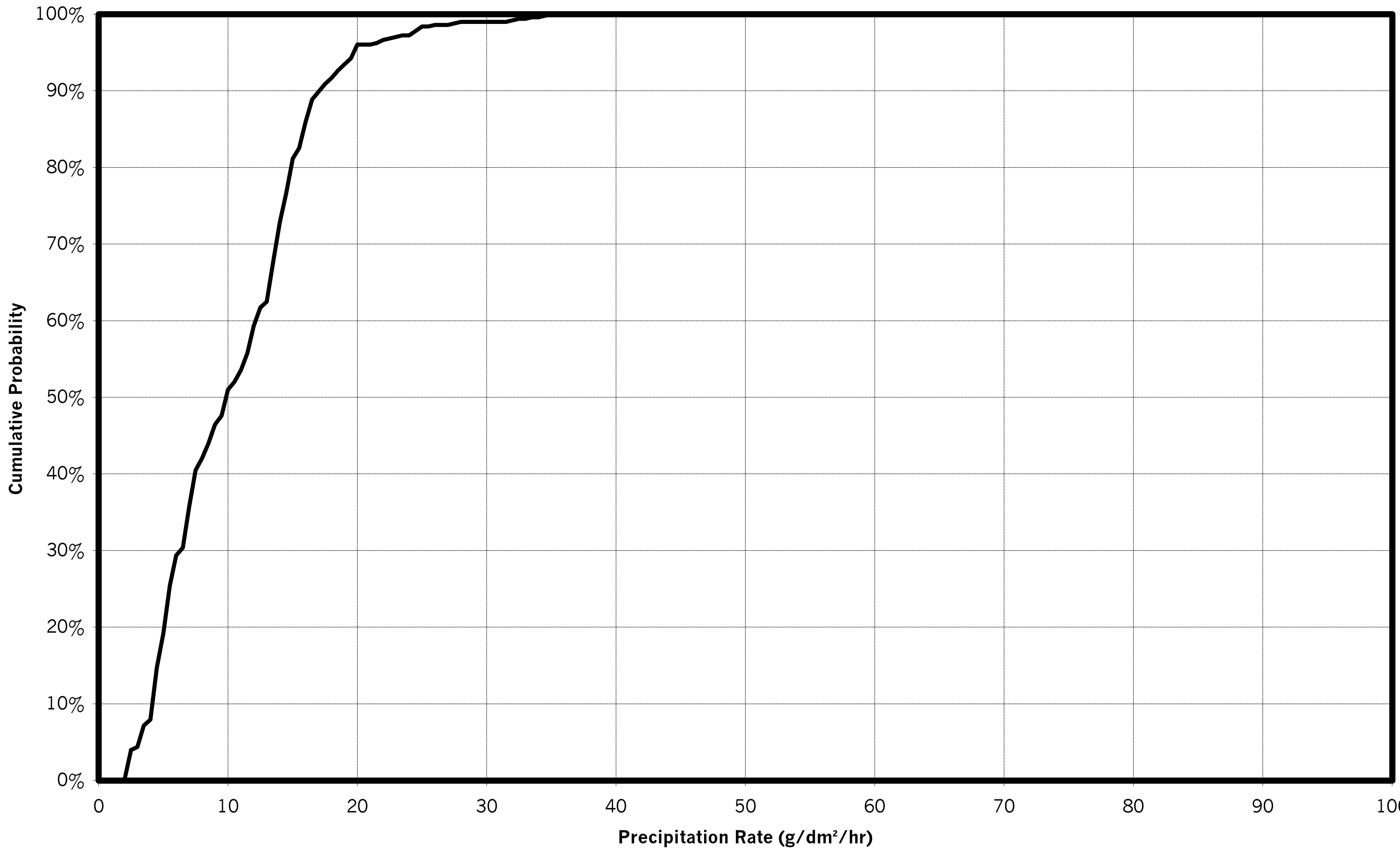
6-MINUTE RATE EVERY MINUTE

1995-1999



cm1514/analysis/readac/snow/anal -22 to -25C
At: 6 min Hist
02/01/01, 6:14 PM

READADC AND CR21X ANALYSIS - NATURAL SNOW
-22 TO -25°C
6-MINUTE RATE EVERY MINUTE
1995-1999

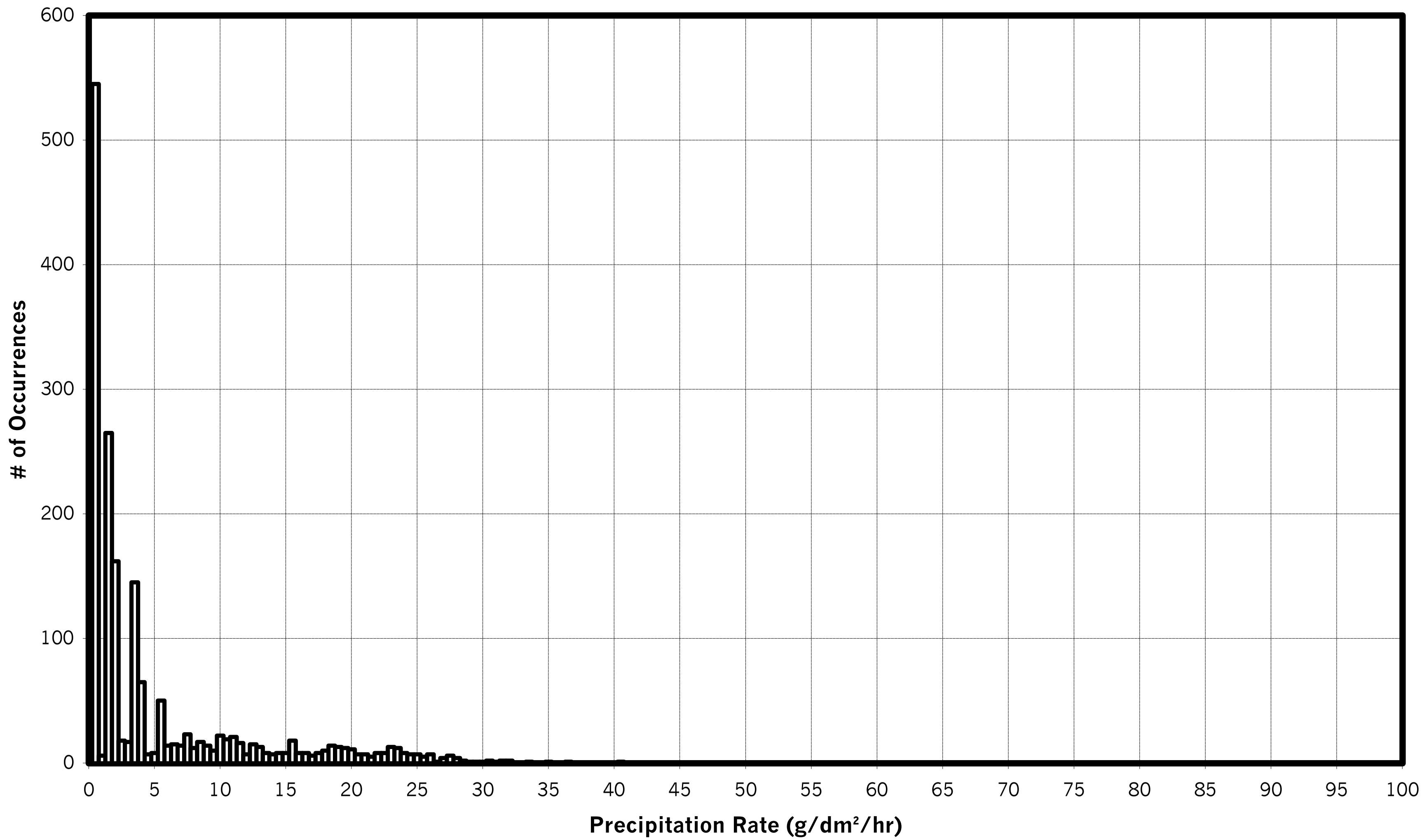


cm1514/analysis/readac/snow/anal -22 to -25C
At: 6 min Cuml.
02/01/01, 6:14 PM

READADC ANALYSIS - LIGHT FREEZING RAIN

0 TO -3°C

35-MINUTE RATE EVERY MINUTE

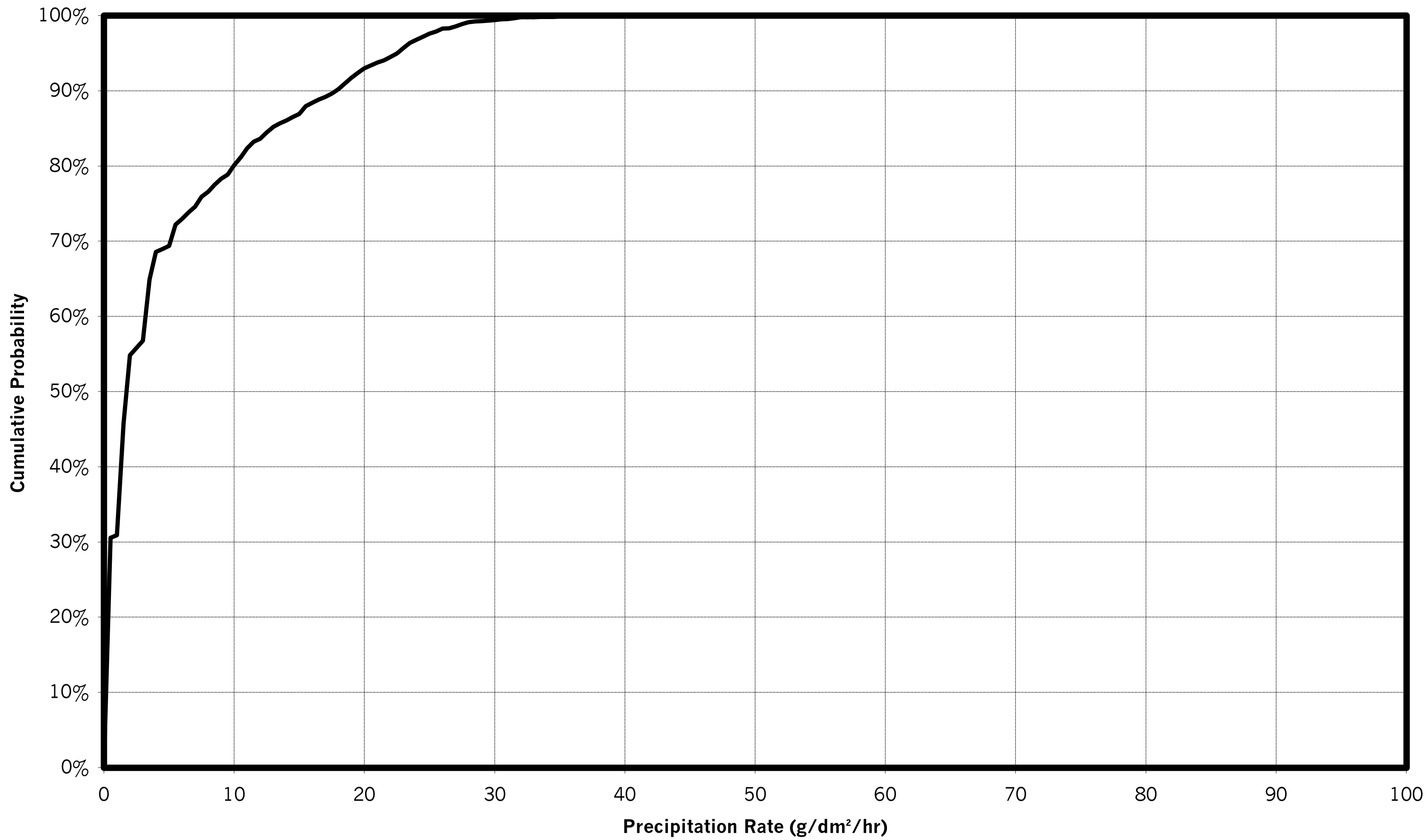


cm1514/anal;ysis/readac/Zr_-3
At: 35 min Hist
02/01/01, 6:15 PM

READADC ANALYSIS - LIGHT FREEZING RAIN

0 TO -3°C

35-MINUTE RATE EVERY MINUTE

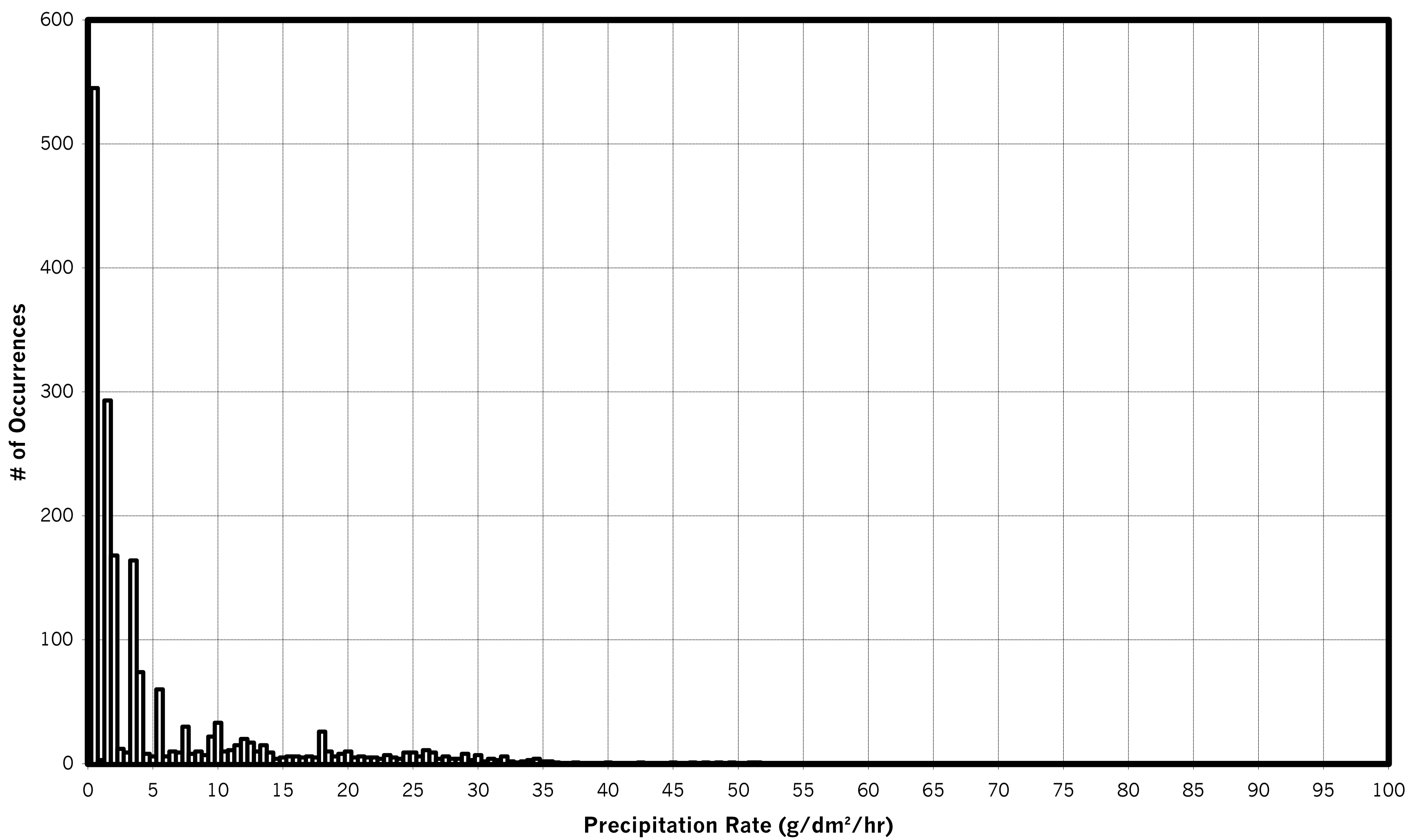


cm1514/anal;ysis/readac/Zr_-3
At: 35 min Cuml.
02/01/01, 6:15 PM

READADAC ANALYSIS - LIGHT FREEZING RAIN

0 TO -3°C

20-MINUTE RATE EVERY MINUTE

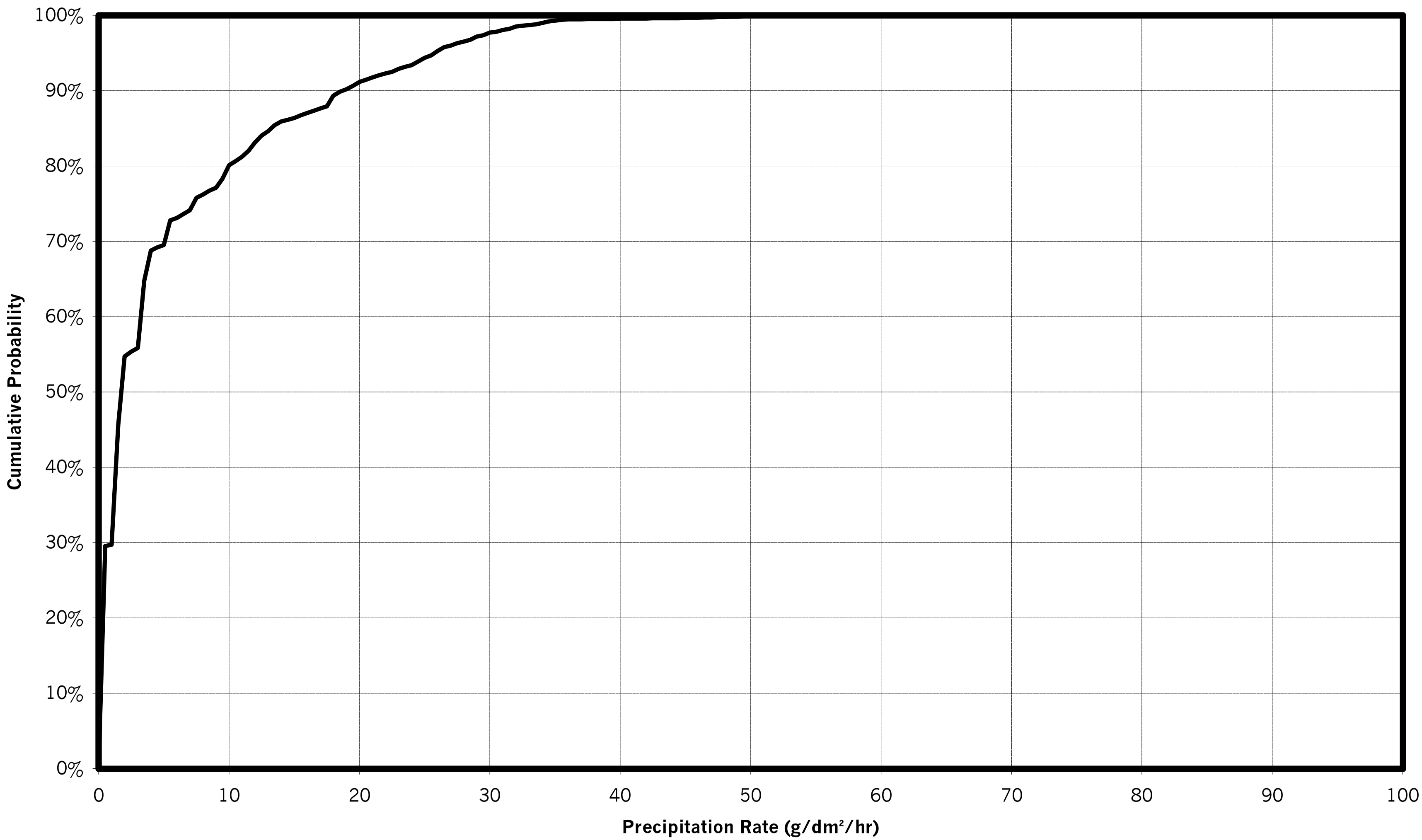


cm1514/anal;ysis/readac/Zr_-3
At: 20 min Hist
02/01/01, 6:16 PM

READADC ANALYSIS - LIGHT FREEZING RAIN

0 TO -3°C

20-MINUTE RATE EVERY MINUTE

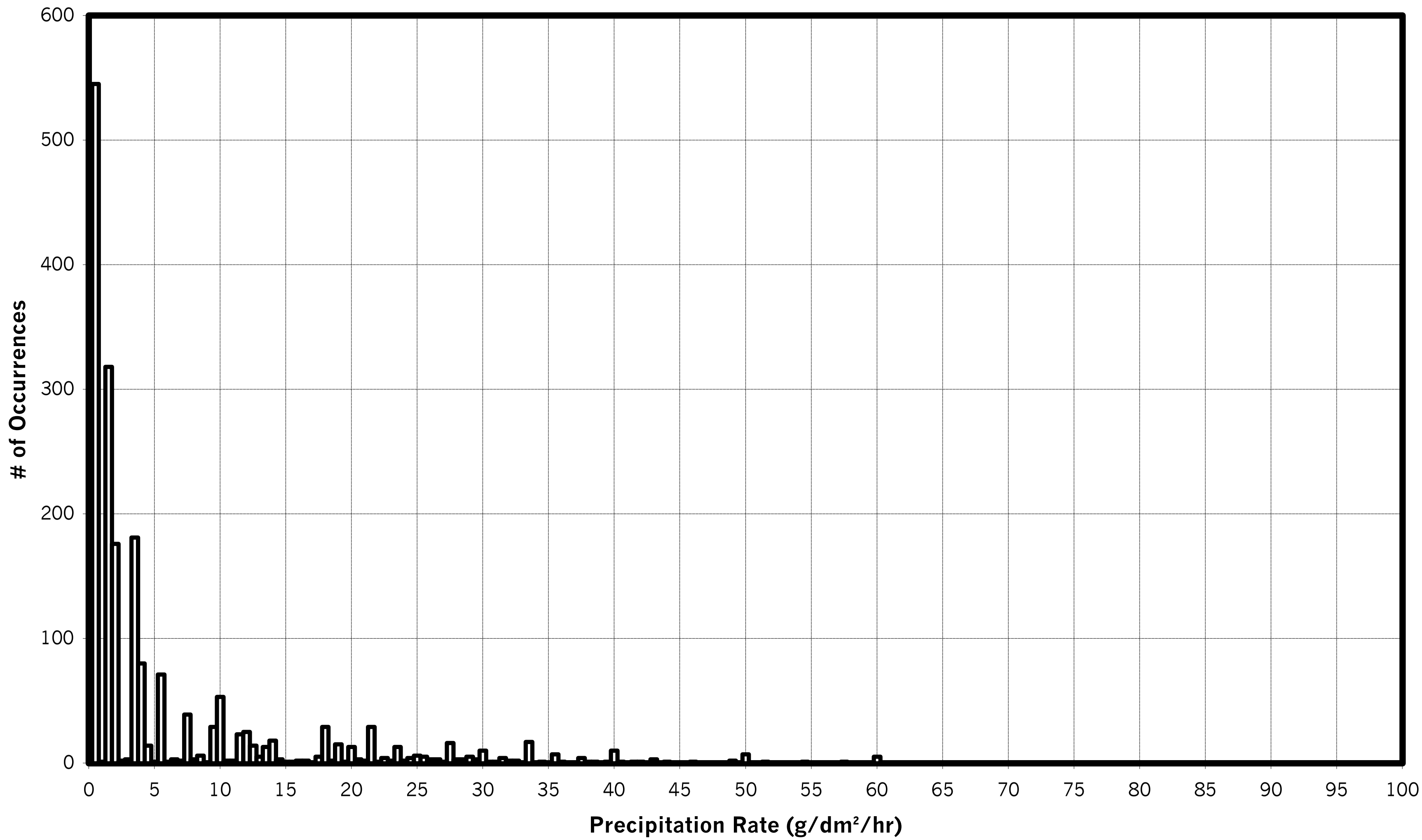


cm1514/anal;ysis/readac/Zr_-3
At: 20 min Cuml.
02/01/01, 6:16 PM

READADC ANALYSIS - LIGHT FREEZING RAIN

0 TO -3°C

6-MINUTE RATE EVERY MINUTE

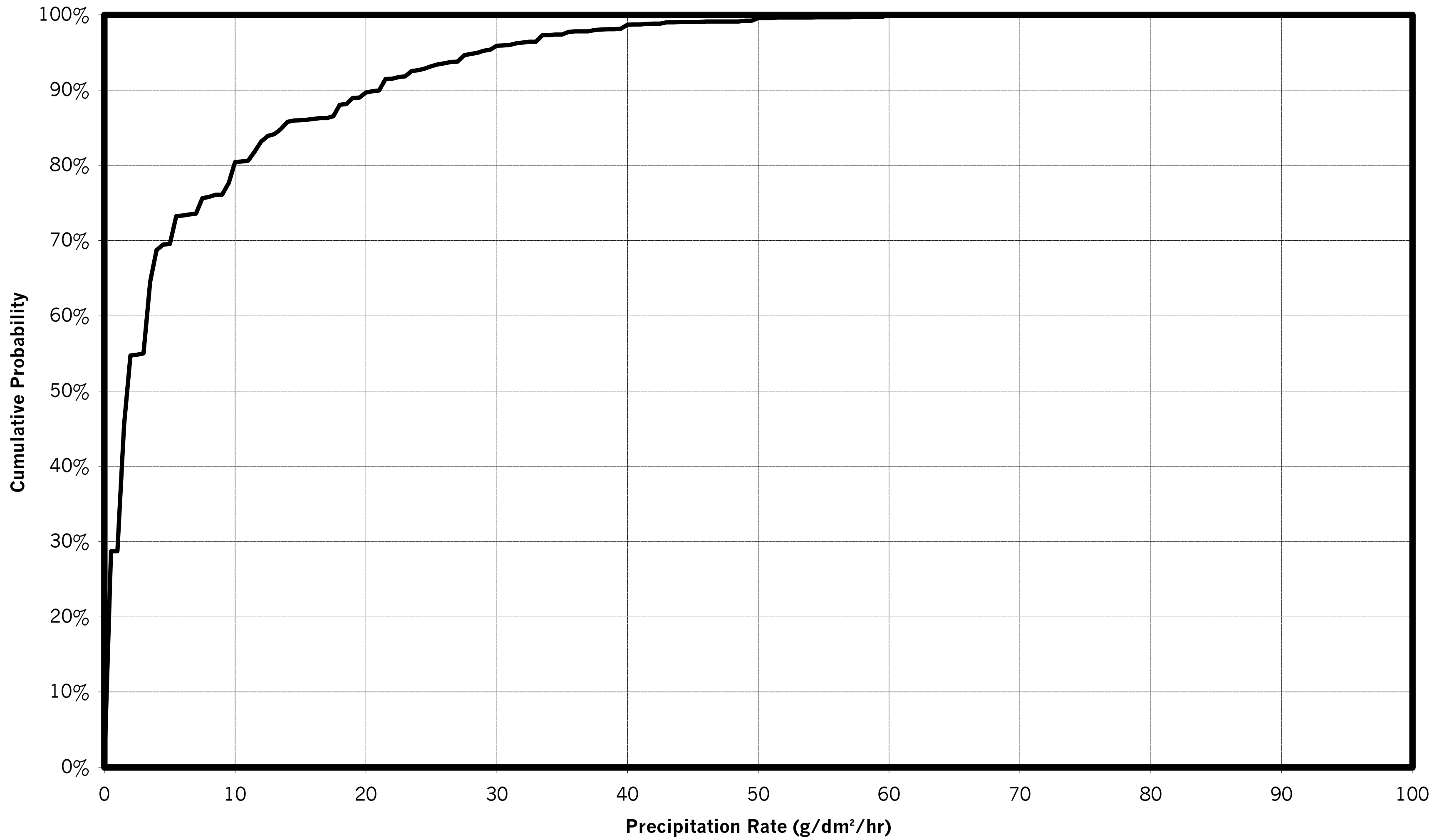


cm1514/anal;ysis/readac/Zr_-3
At: 6 min Hist
02/01/01, 6:16 PM

READADC ANALYSIS - LIGHT FREEZING RAIN

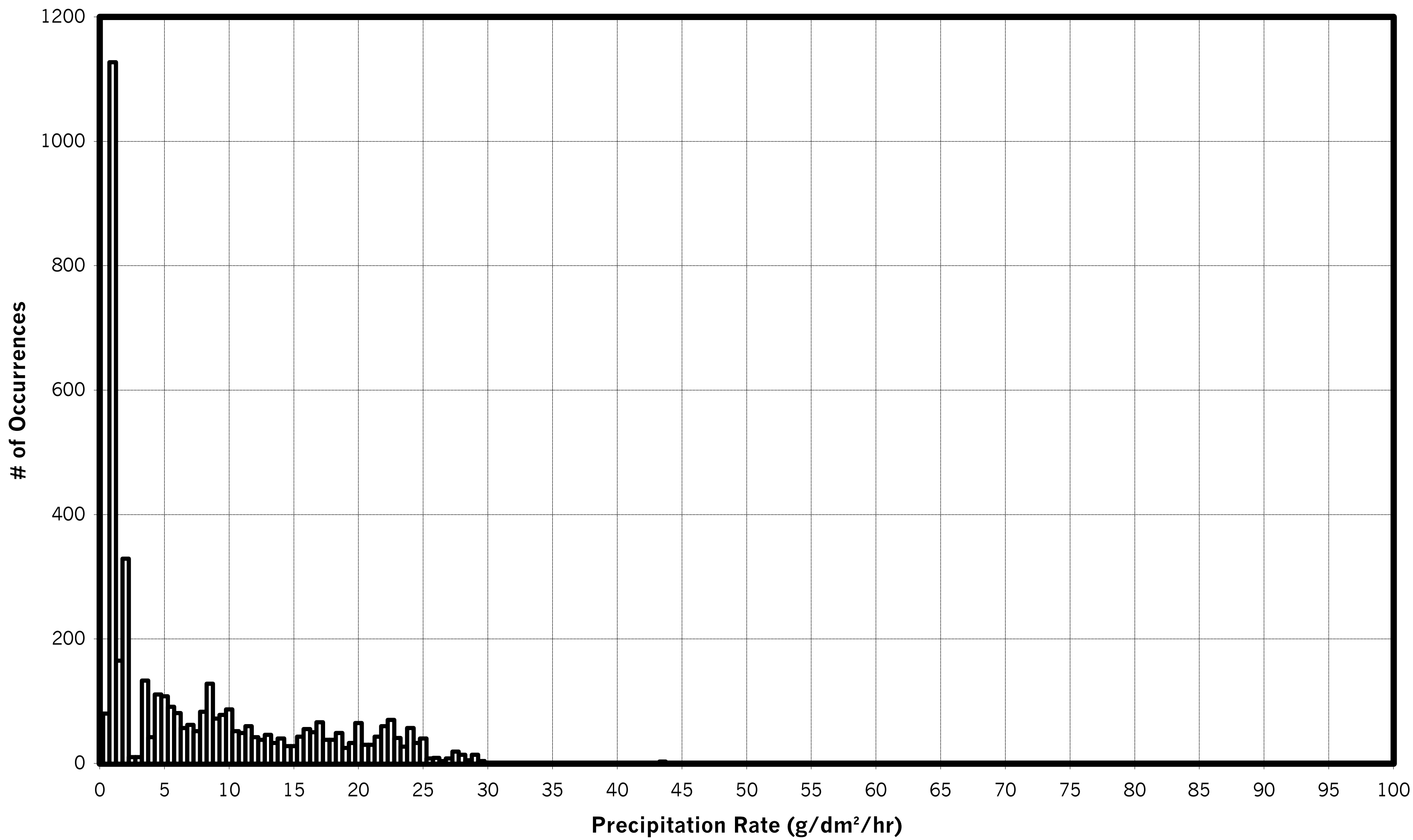
0 TO -3°C

6-MINUTE RATE EVERY MINUTE



cm1514/anal;ysis/readac/Zr_-3
At: 6 min Cuml.
02/01/01, 6:17 PM

READADC ANALYSIS - LIGHT FREEZING RAIN
-3 TO -10°C
35-MINUTE RATE EVERY MINUTE

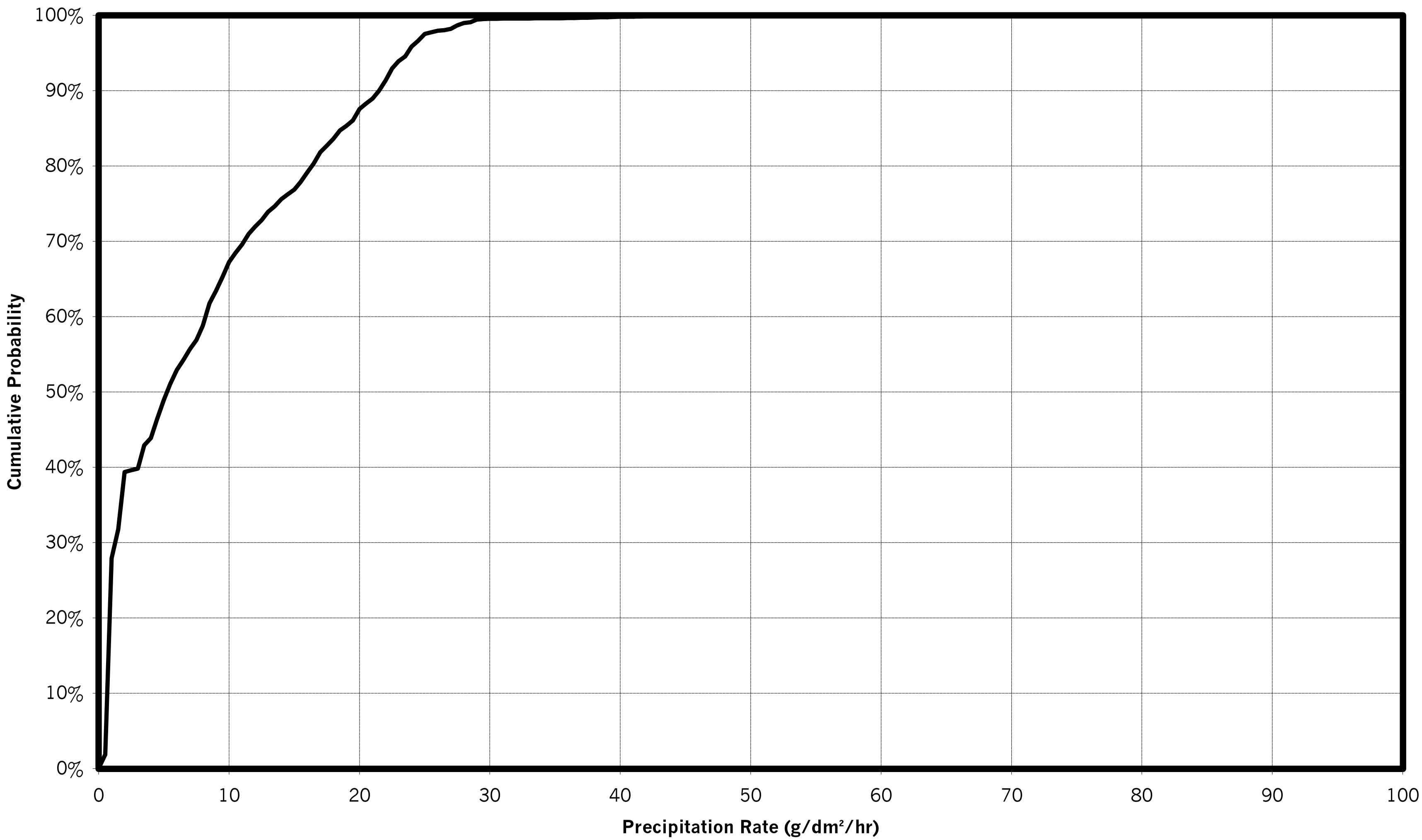


cm1514/analysis/readac/Zr_-10
At: 35 min Hist
02/01/01, 6:18 PM

READADC ANALYSIS - LIGHT FREEZING RAIN

-3 TO -10°C

35-MINUTE RATE EVERY MINUTE

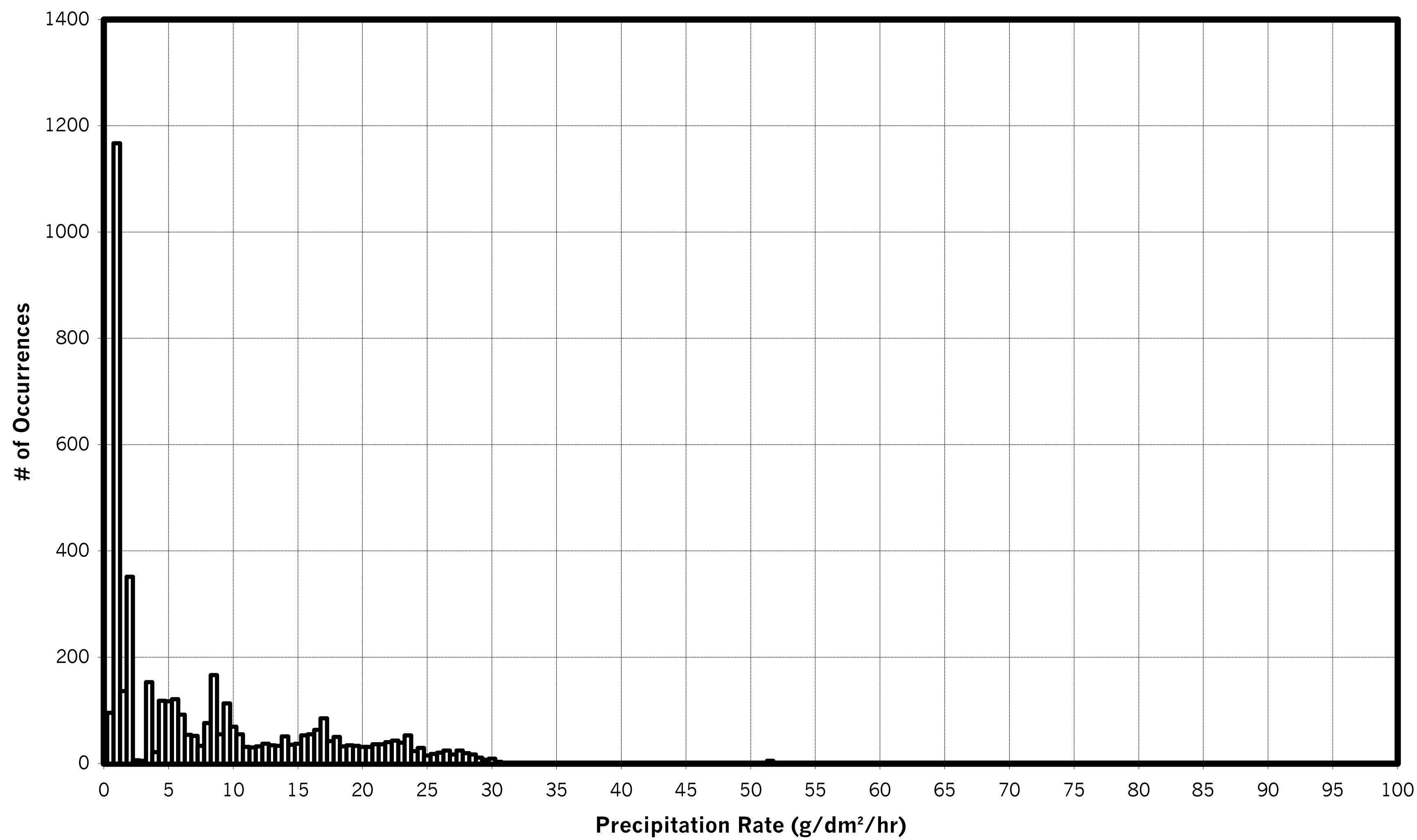


cm1514/analysis/readac/Zr_-10
At: 35 min Cuml.
02/01/01, 6:18 PM

READADC ANALYSIS - LIGHT FREEZING RAIN

-3 TO -10°C

20-MINUTE RATE EVERY MINUTE

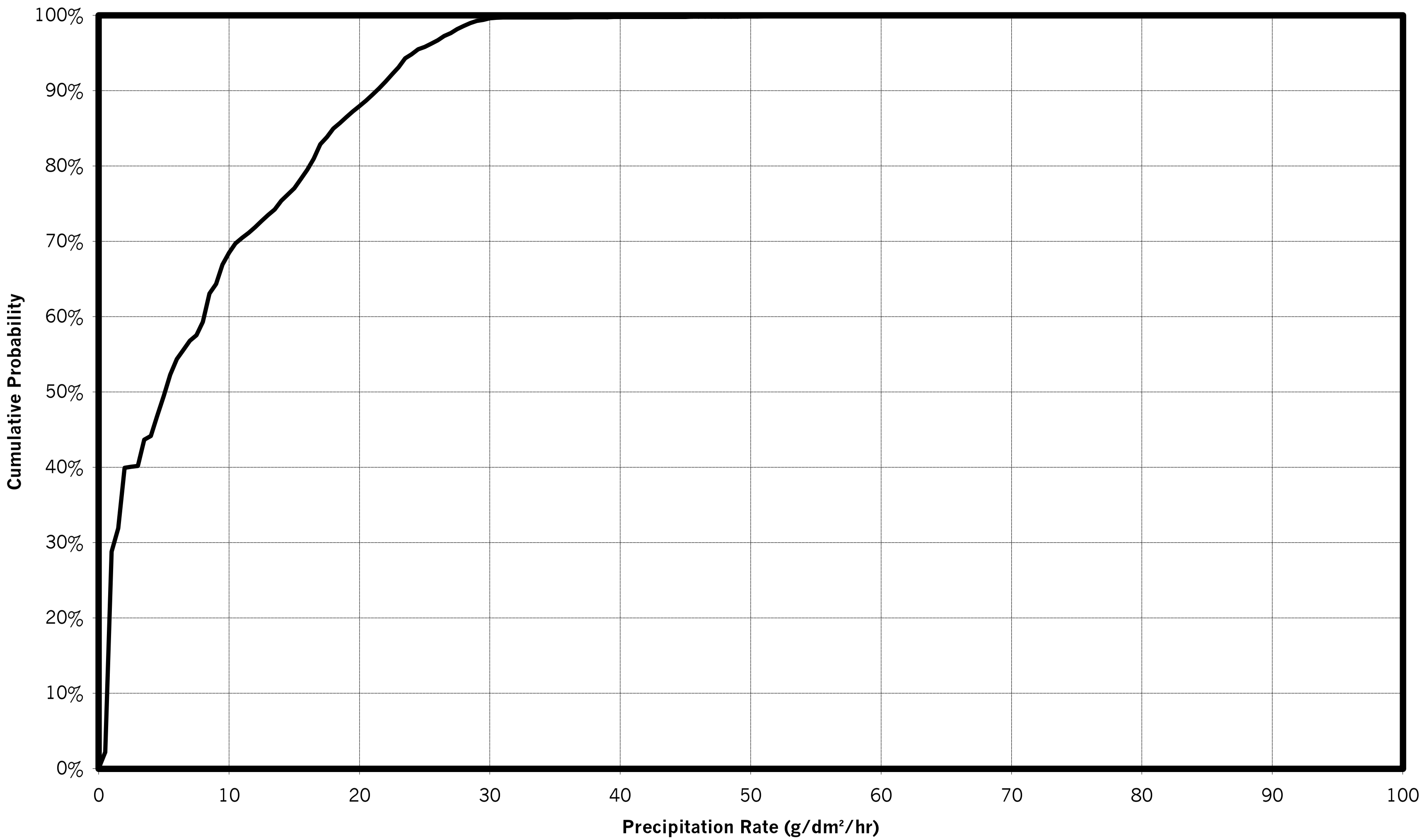


cm1514/analysis/readac/Zr_-10
At: 20 min Hist
02/01/01, 6:19 PM

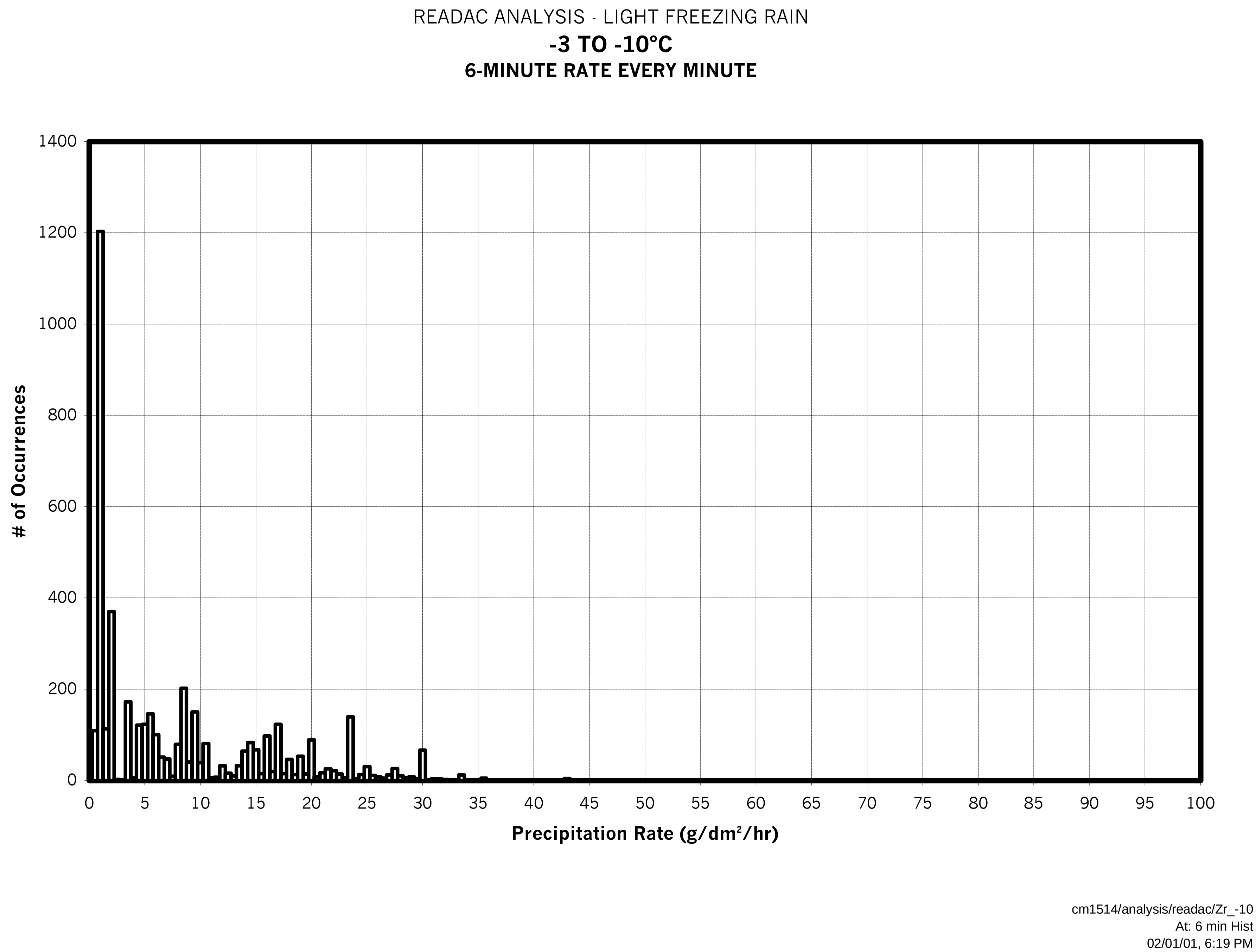
READADC ANALYSIS - LIGHT FREEZING RAIN

-3 TO -10°C

20-MINUTE RATE EVERY MINUTE



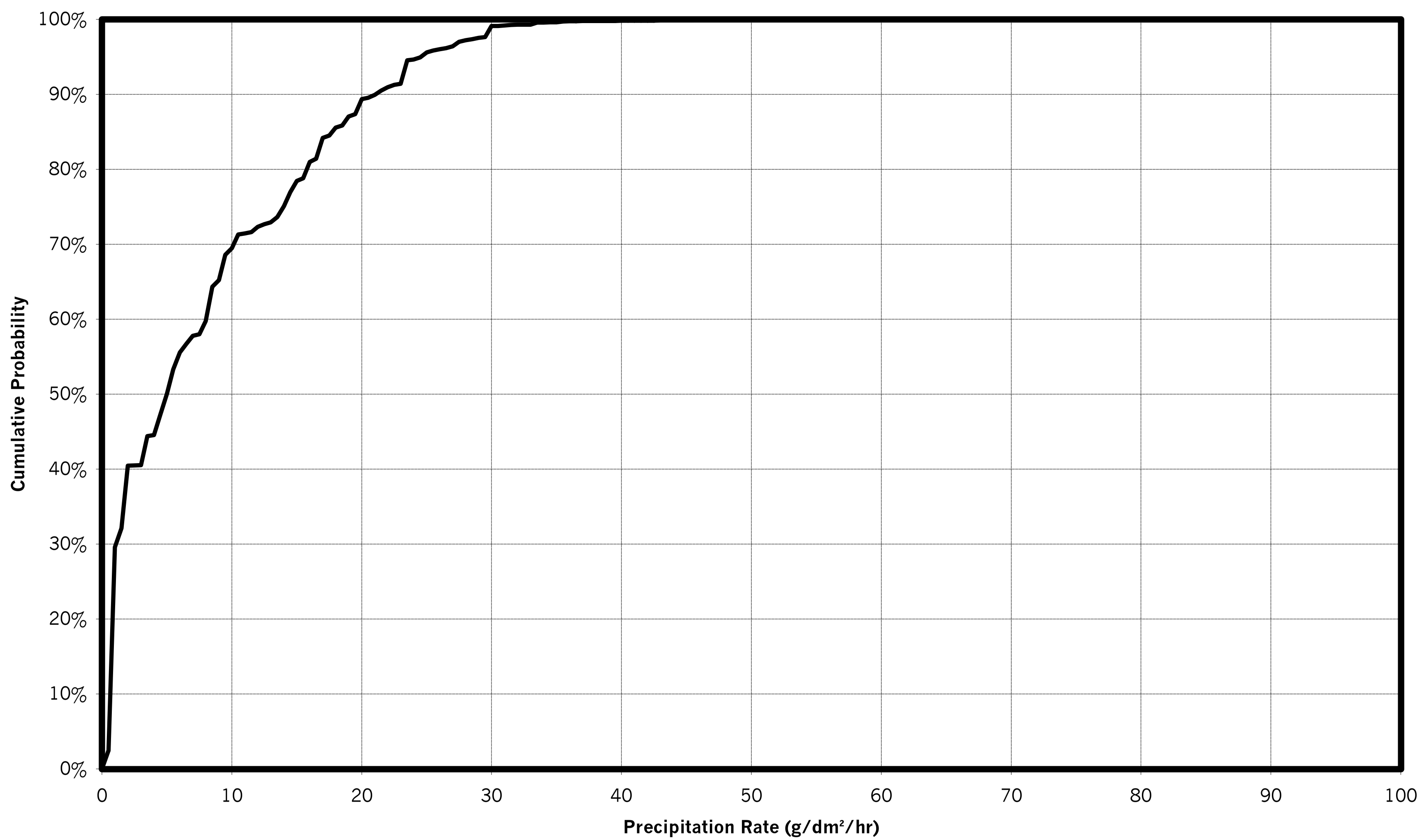
cm1514/analysis/readac/Zr_-10
At: 20 min Cuml.
02/01/01, 6:19 PM


READADC ANALYSIS - LIGHT FREEZING RAIN
-3 TO -10°C
6-MINUTE RATE EVERY MINUTE
# of Occurrences
0
200
400
600
800
1000
1200
1400
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Precipitation Rate (g/dm²/hr)
cm1514/analysis/readac/Zr_-10
At: 6 min Hist
02/01/01, 6:19 PM

READADC ANALYSIS - LIGHT FREEZING RAIN

-3 TO -10°C

6-MINUTE RATE EVERY MINUTE

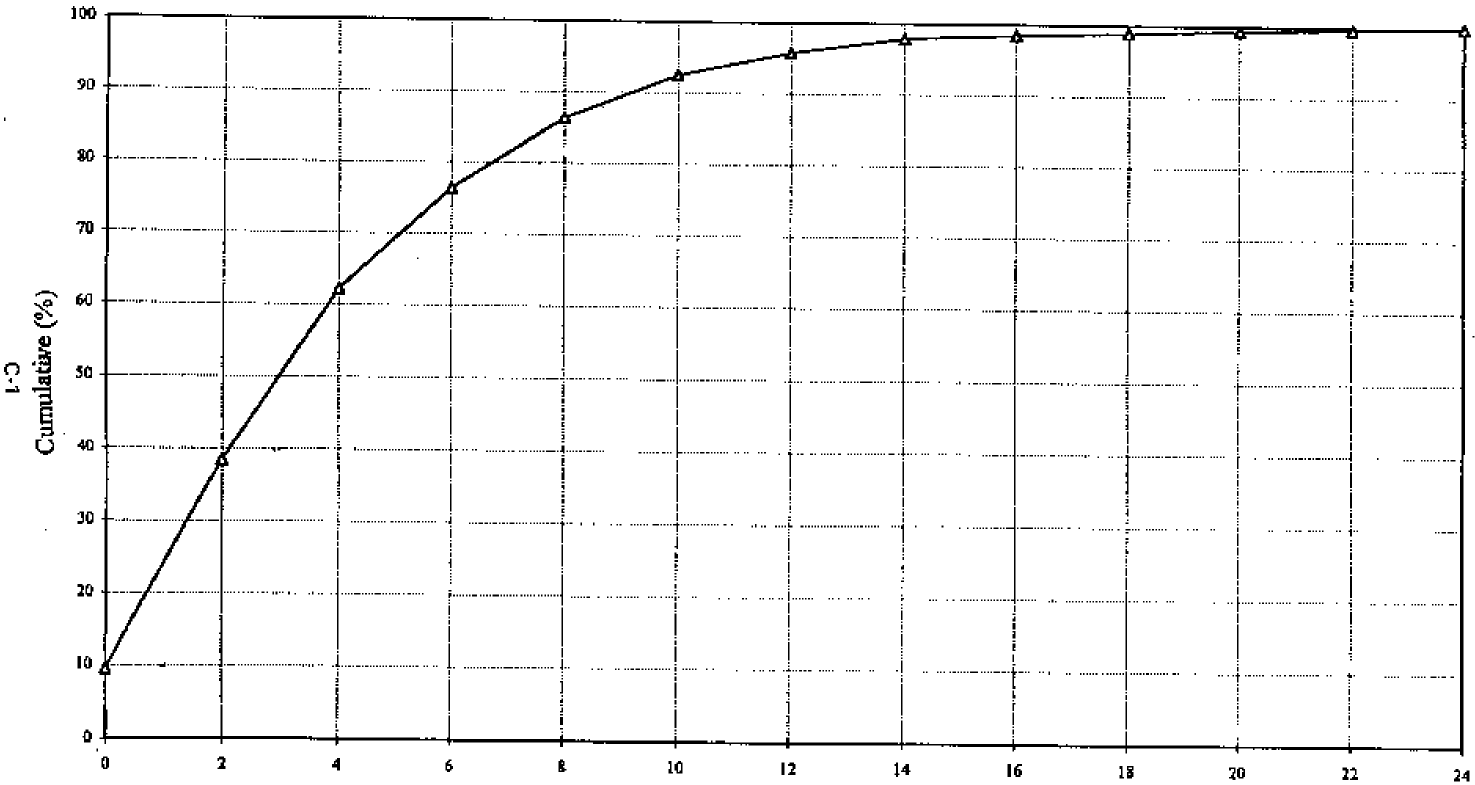


cm1514/analysis/readac/Zr_-10
At: 6 min Cuml.
02/01/01, 6:19 PM

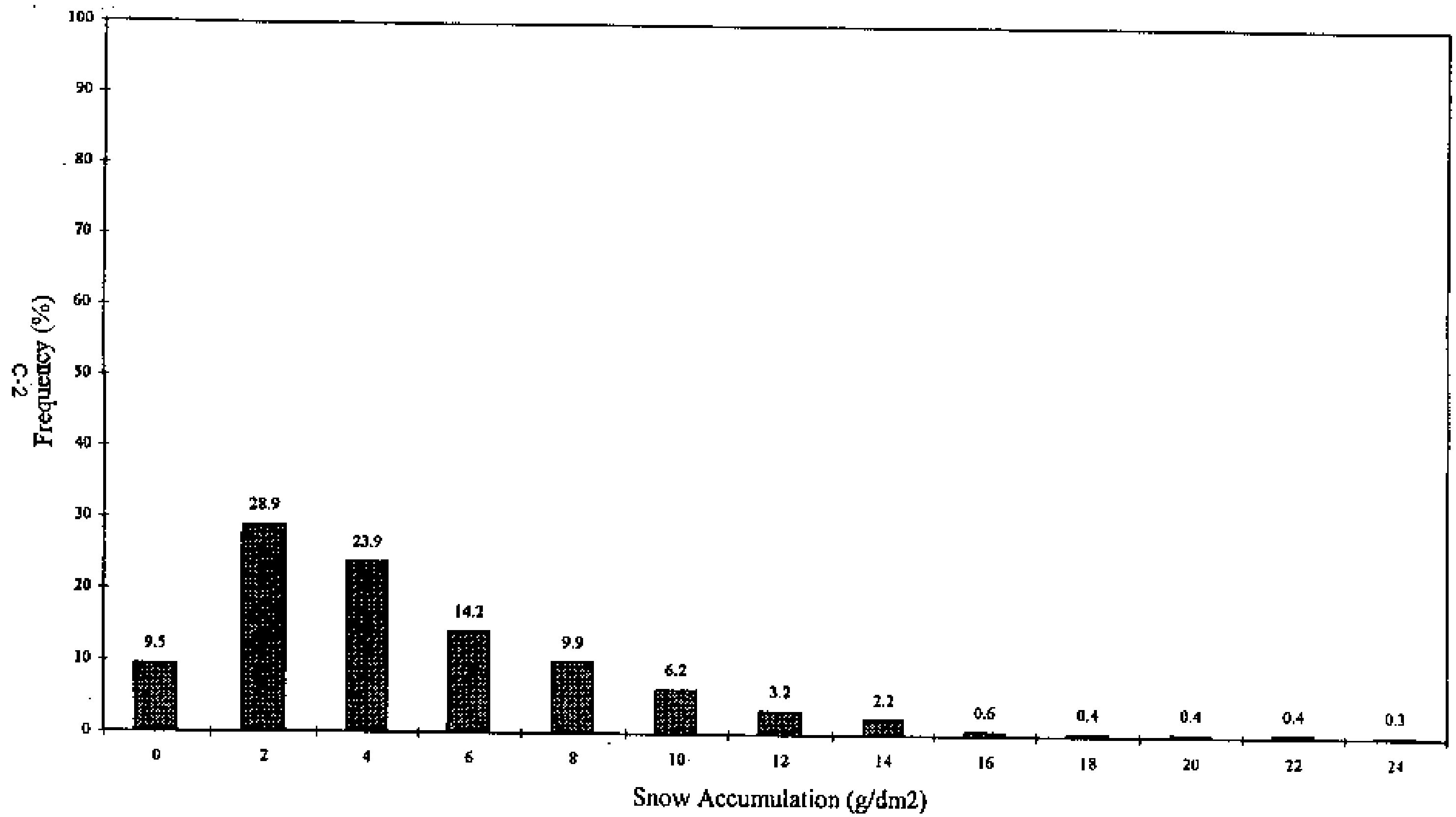
APPENDIX C

SNOW WEATHER DATA 1993/94 AND 1994/95

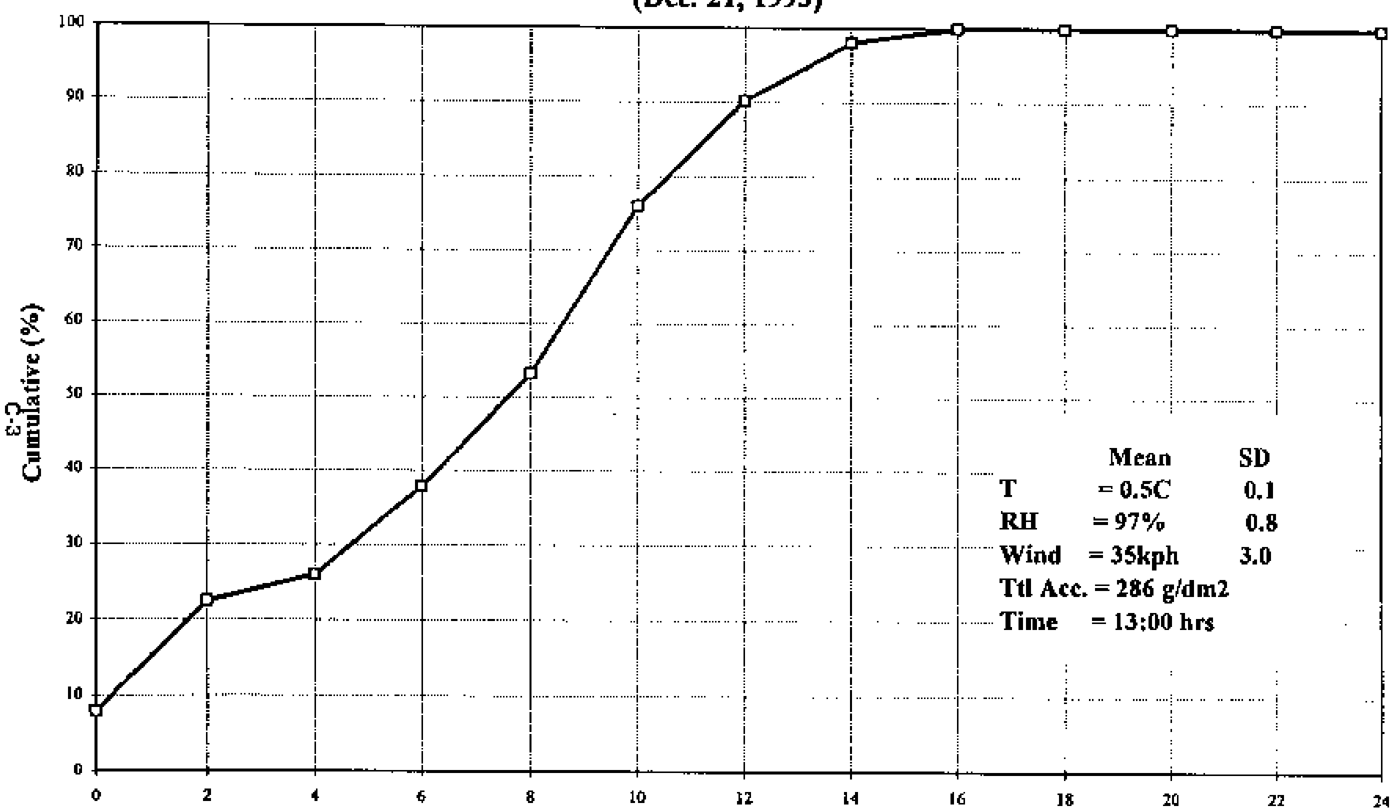
Distribution for Snow Accumulation
For 21 min. at Every 3 min.
For 1993/1994 Winter



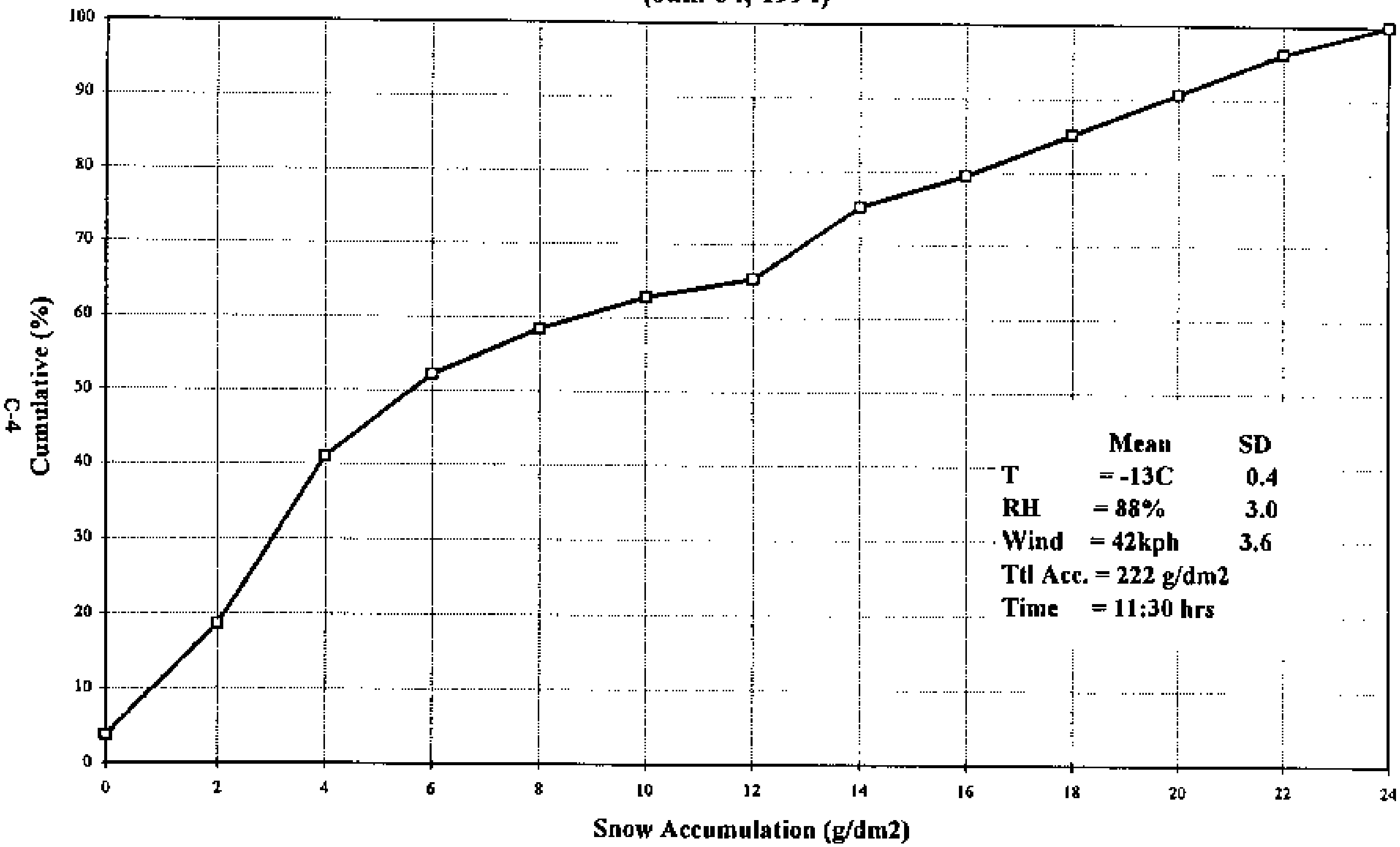
Histogram for Snow Accumulation For 21 min. at Every 3 min. For 1993/1994 Winter



Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Dec. 21, 1993)

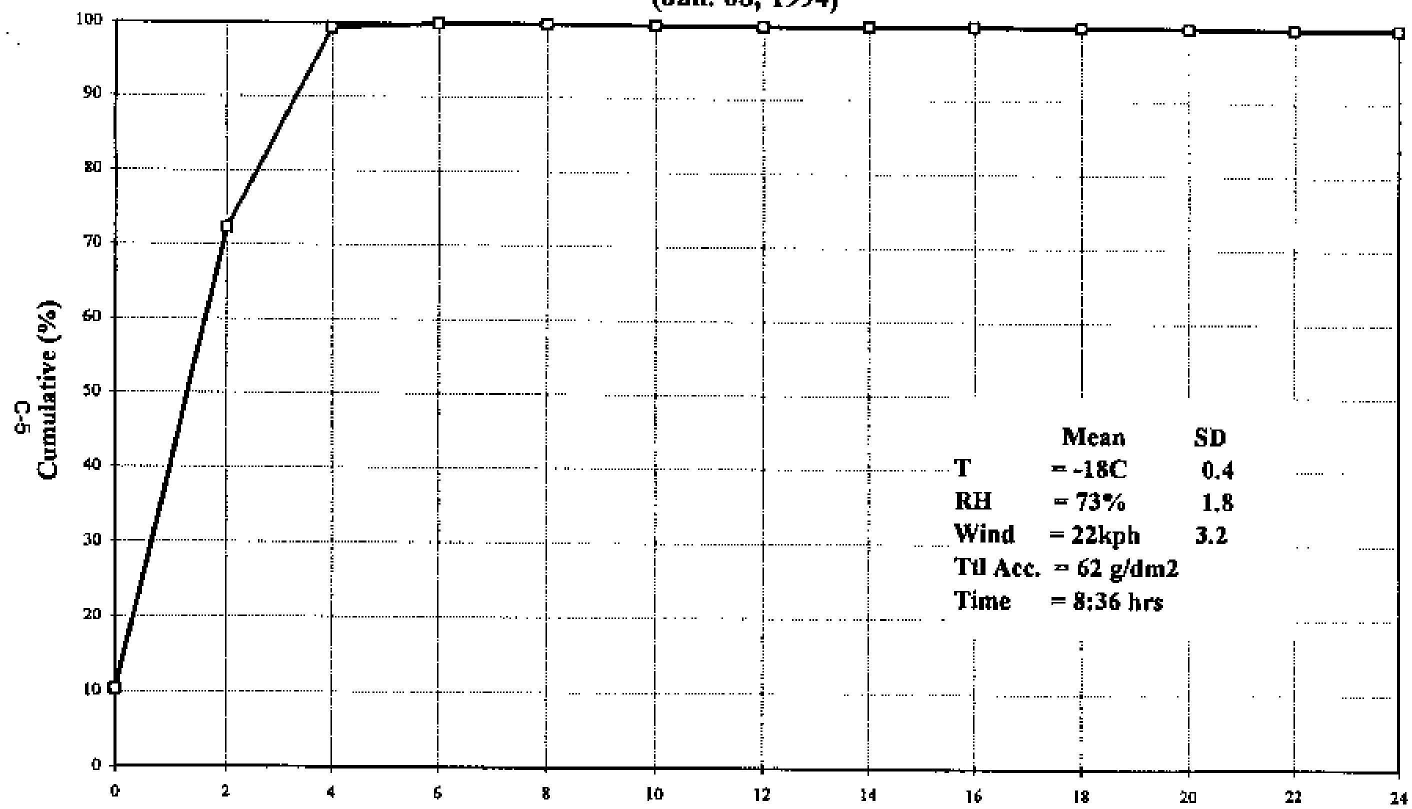


Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Jan. 04, 1994)

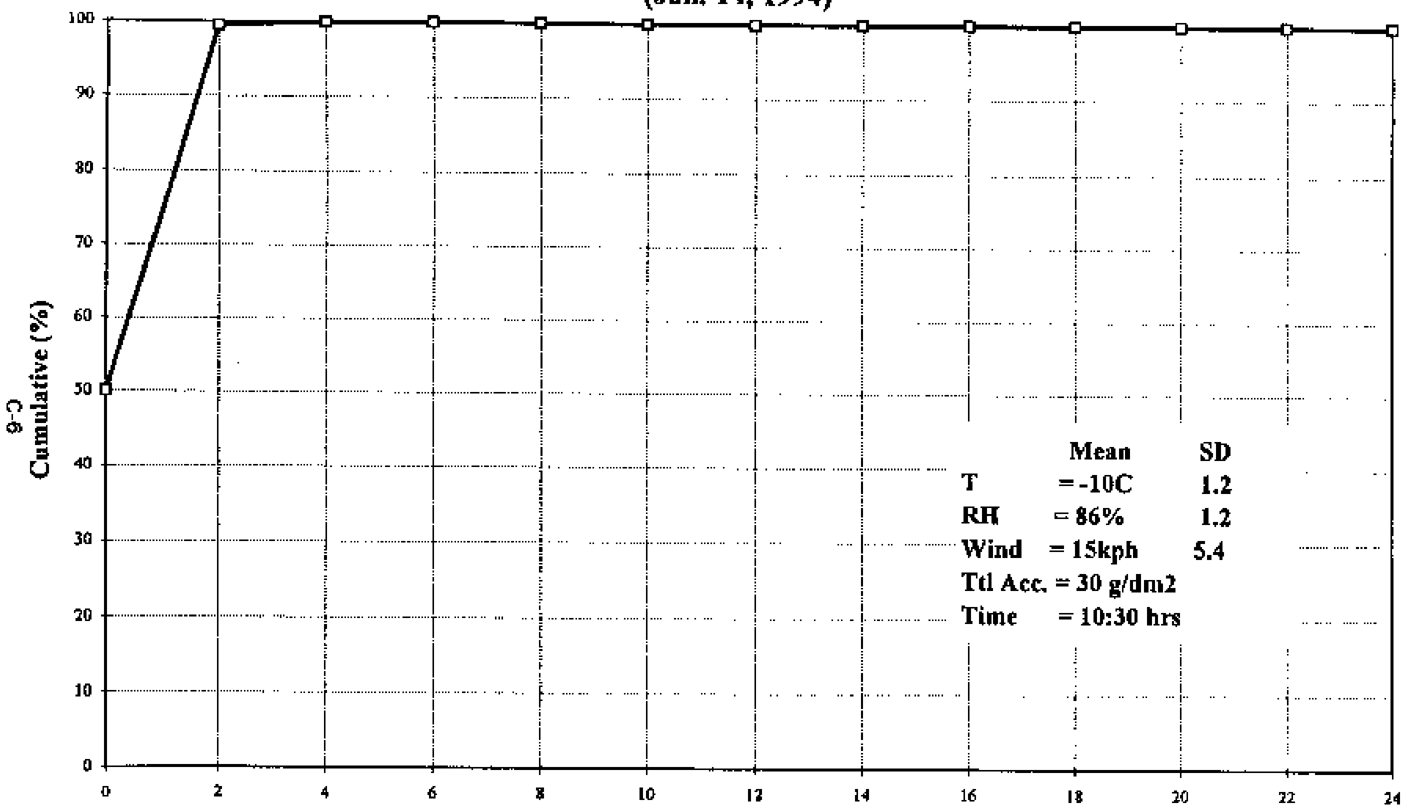


16/8/95 15:11 JAN0494.XLS

Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Jan. 08, 1994)



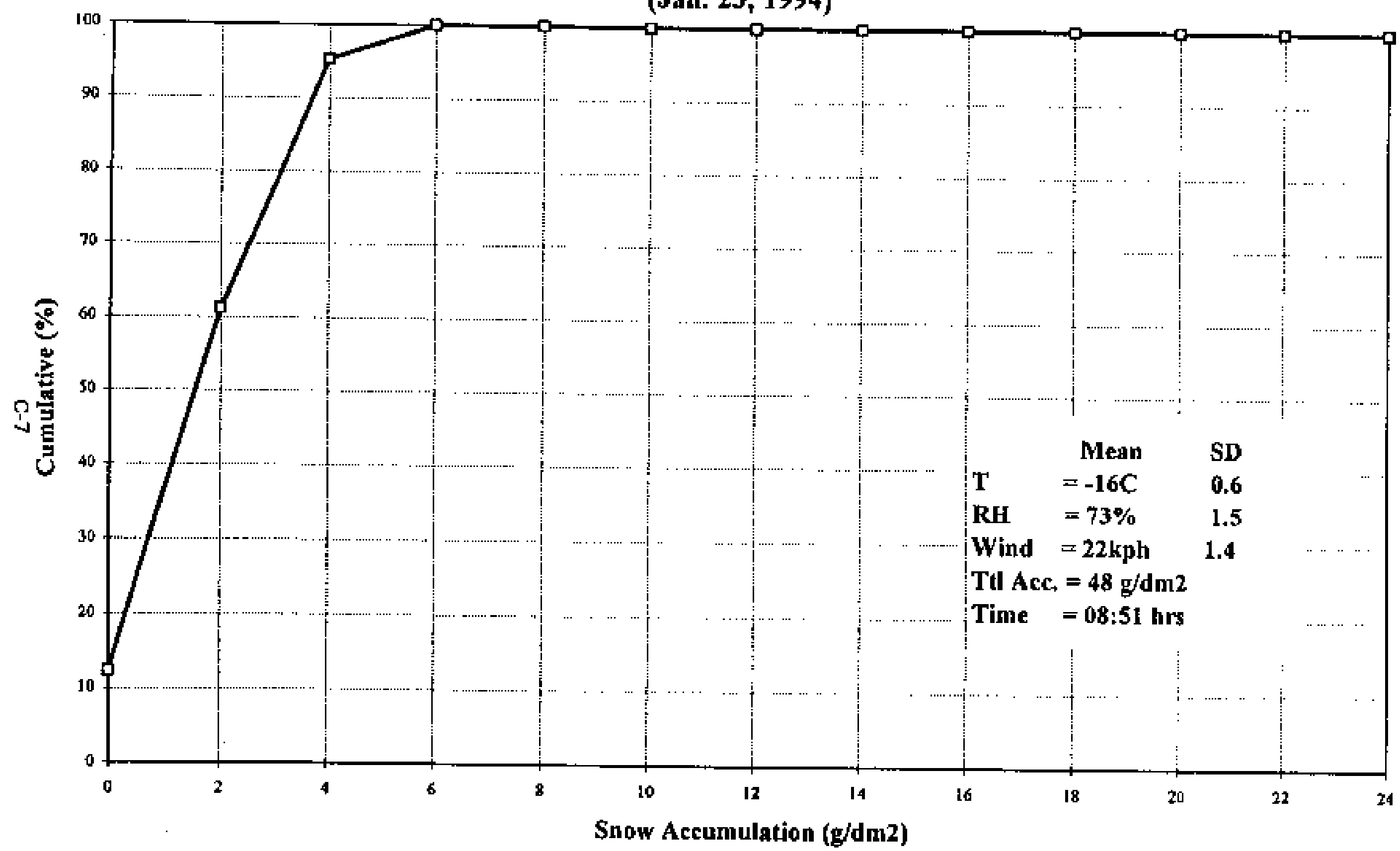
Distribution of Snow Accumulation For 21 min. at Every 3 min. (Jan. 14, 1994)



18/8/95 16:22

JAN1494.XLS

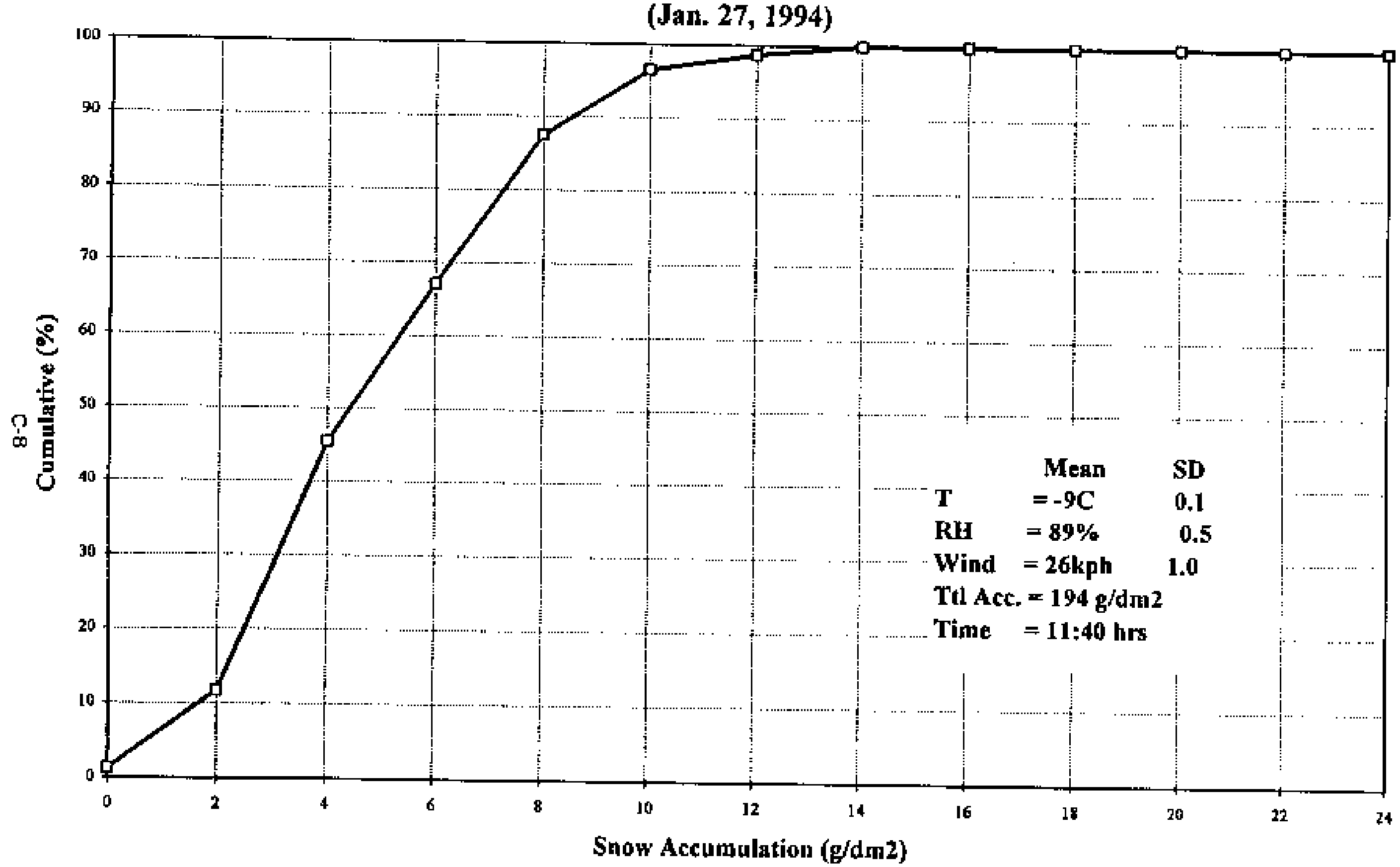
Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Jan. 23, 1994)



17/8/95 16:00

JAN2394.XLS

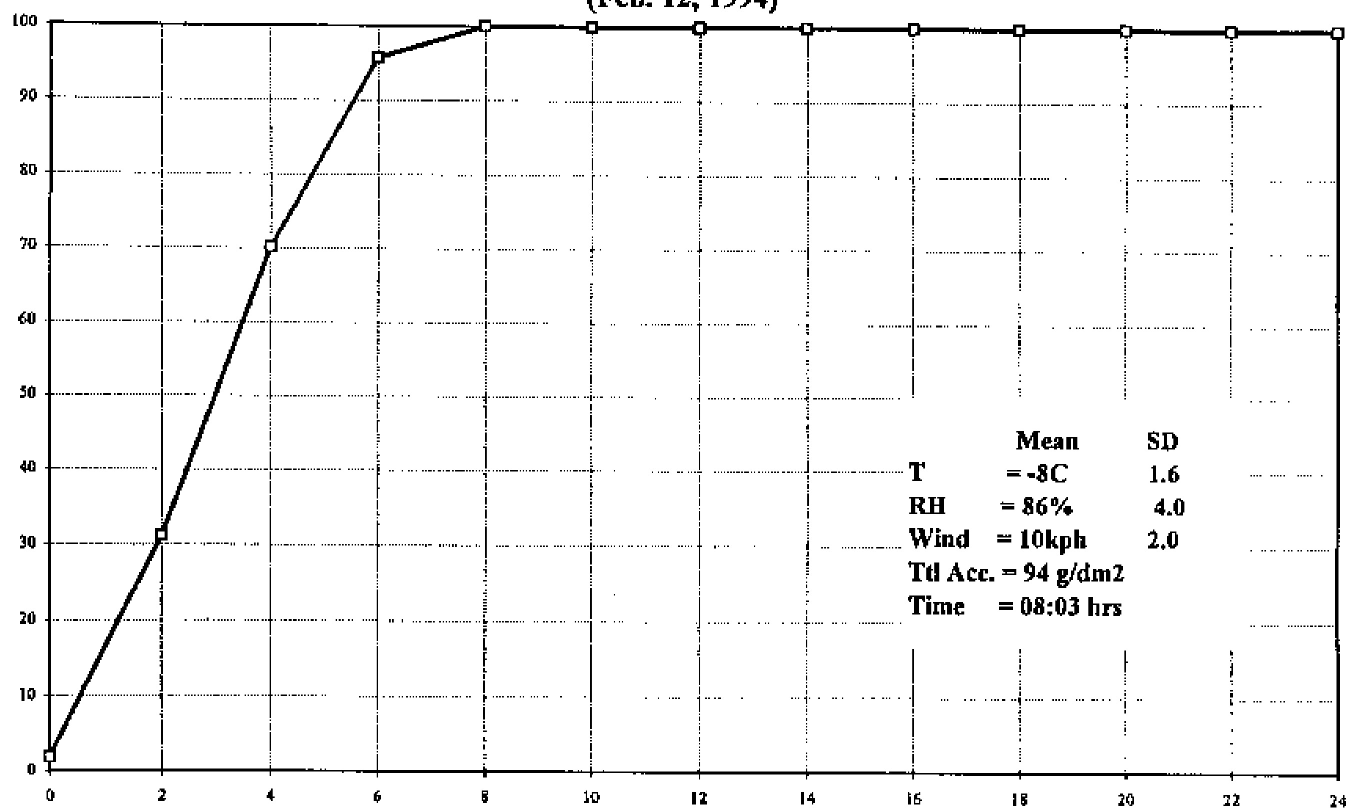
Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Jan. 27, 1994)



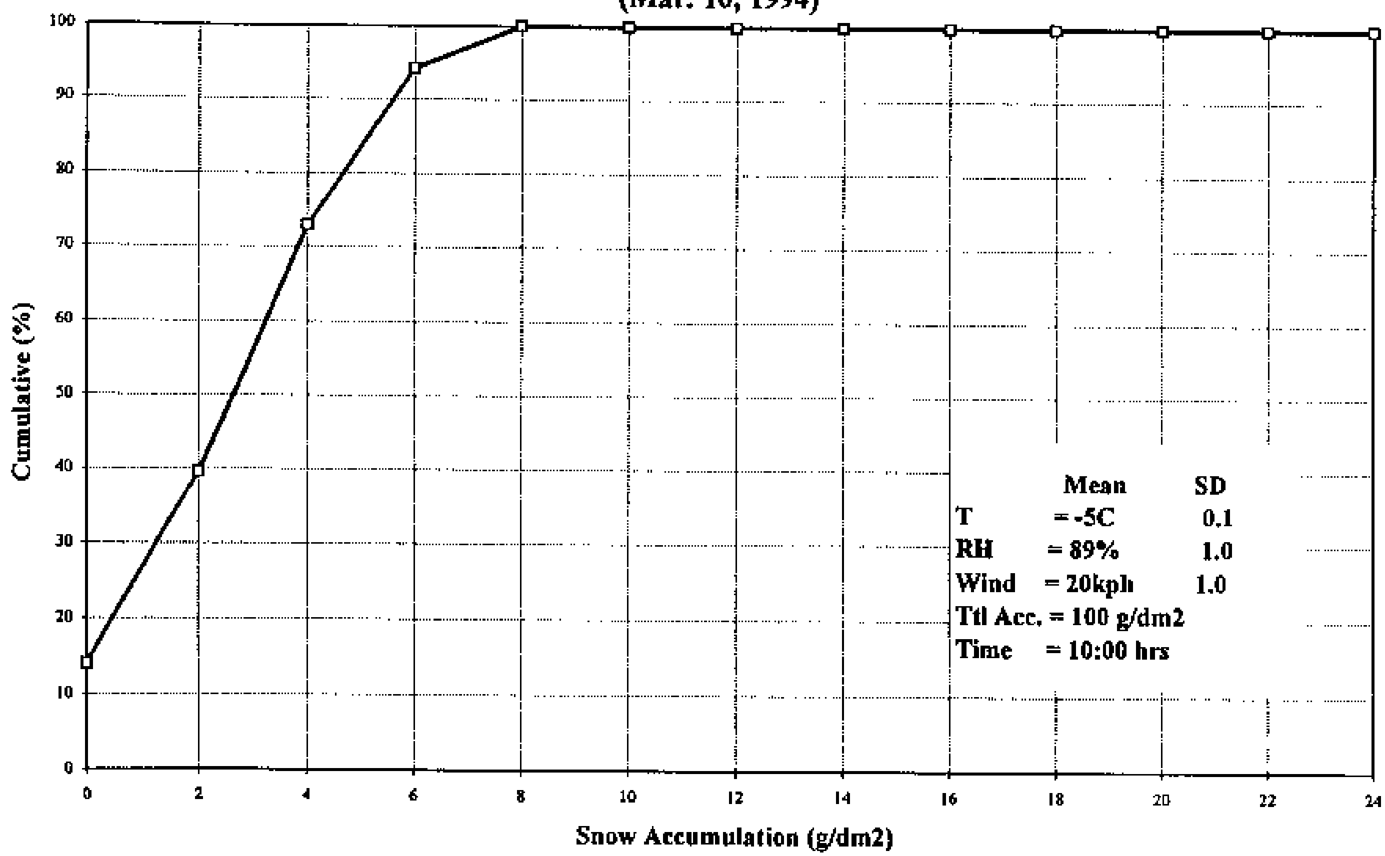
18/8/95 16:20

JAN2794.XLS

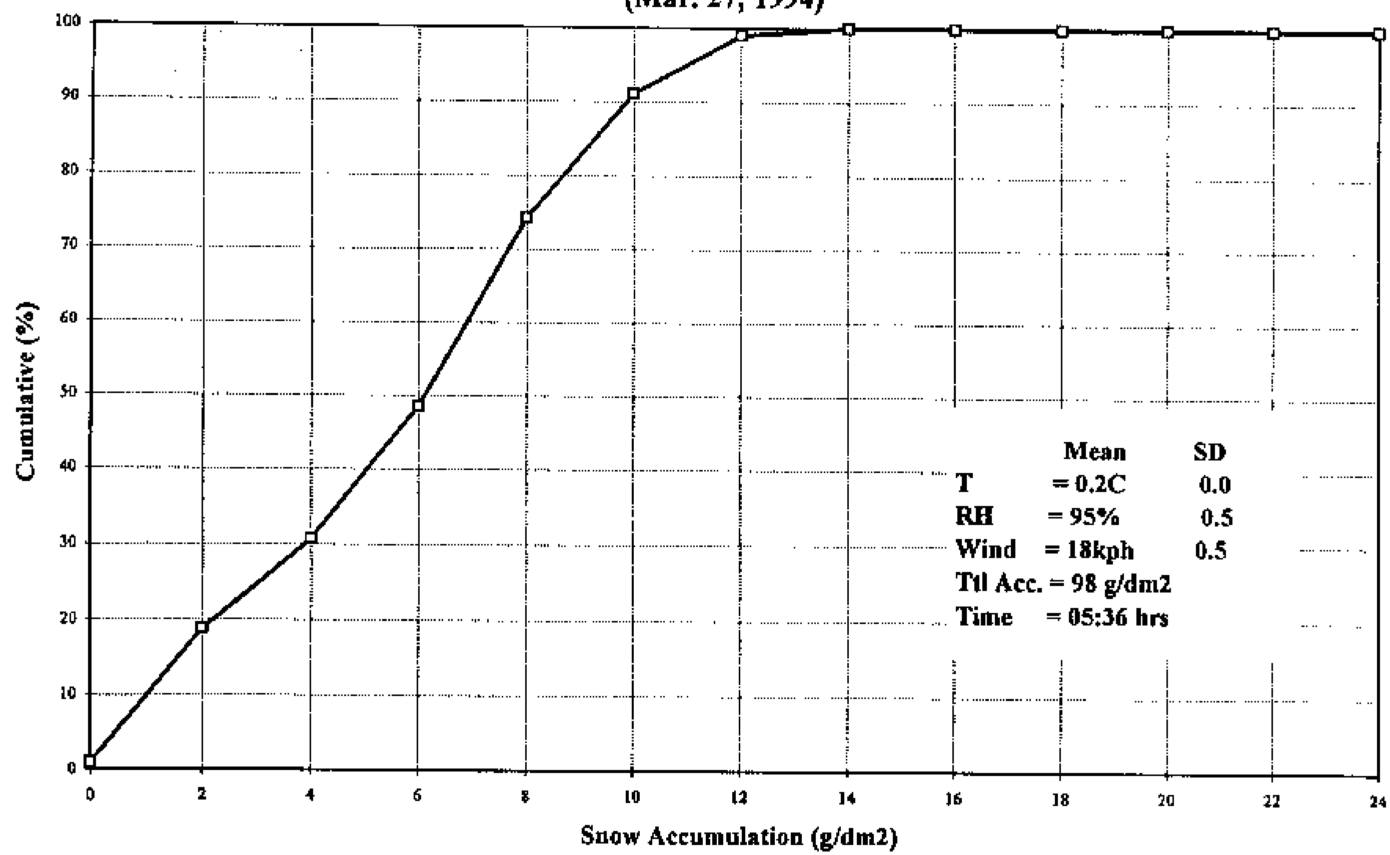
Distribution of Snow Accumulation For 21 min. at Every 3 min. (Feb. 12, 1994)



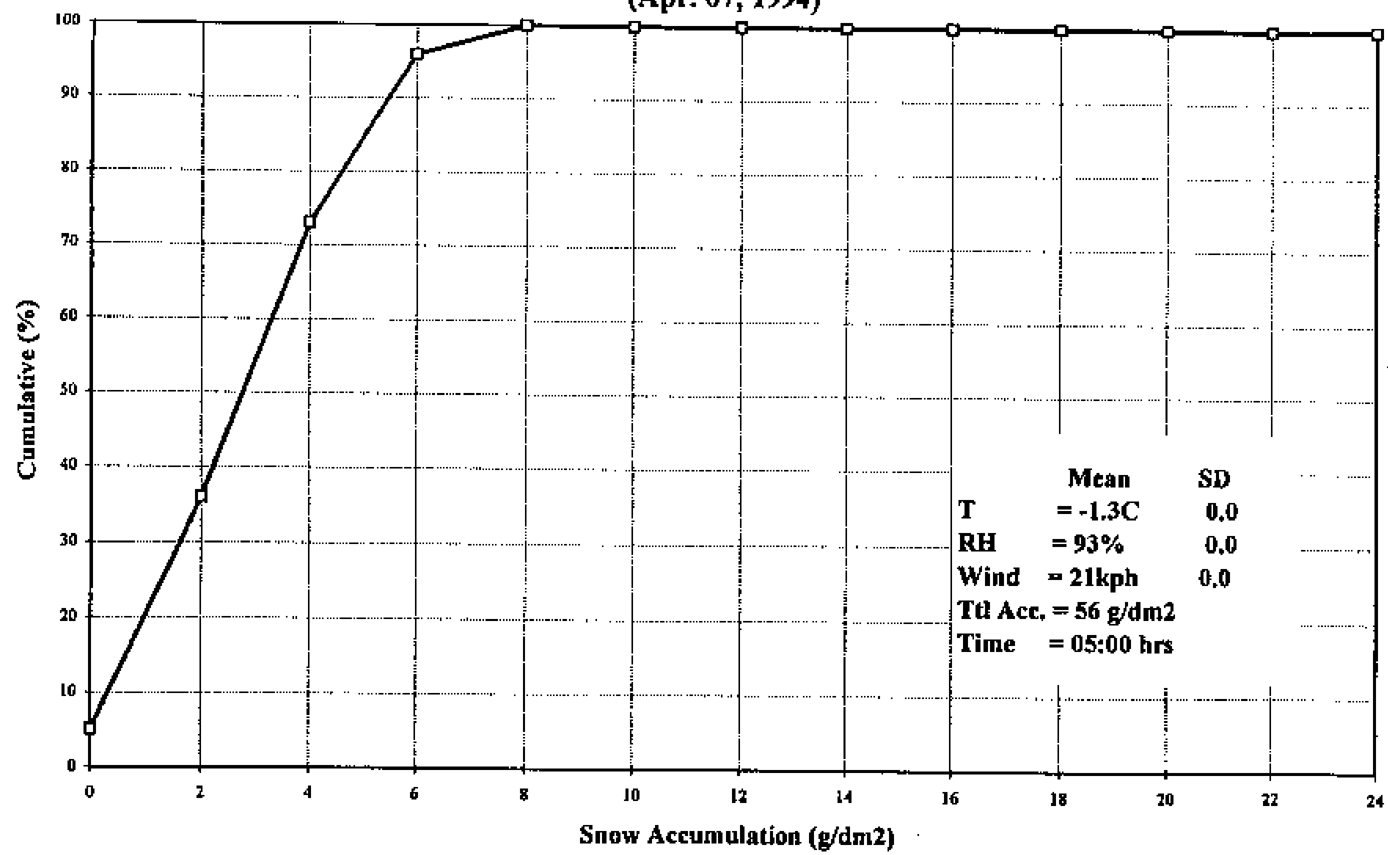
Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Mar. 10, 1994)



Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Mar. 27, 1994)

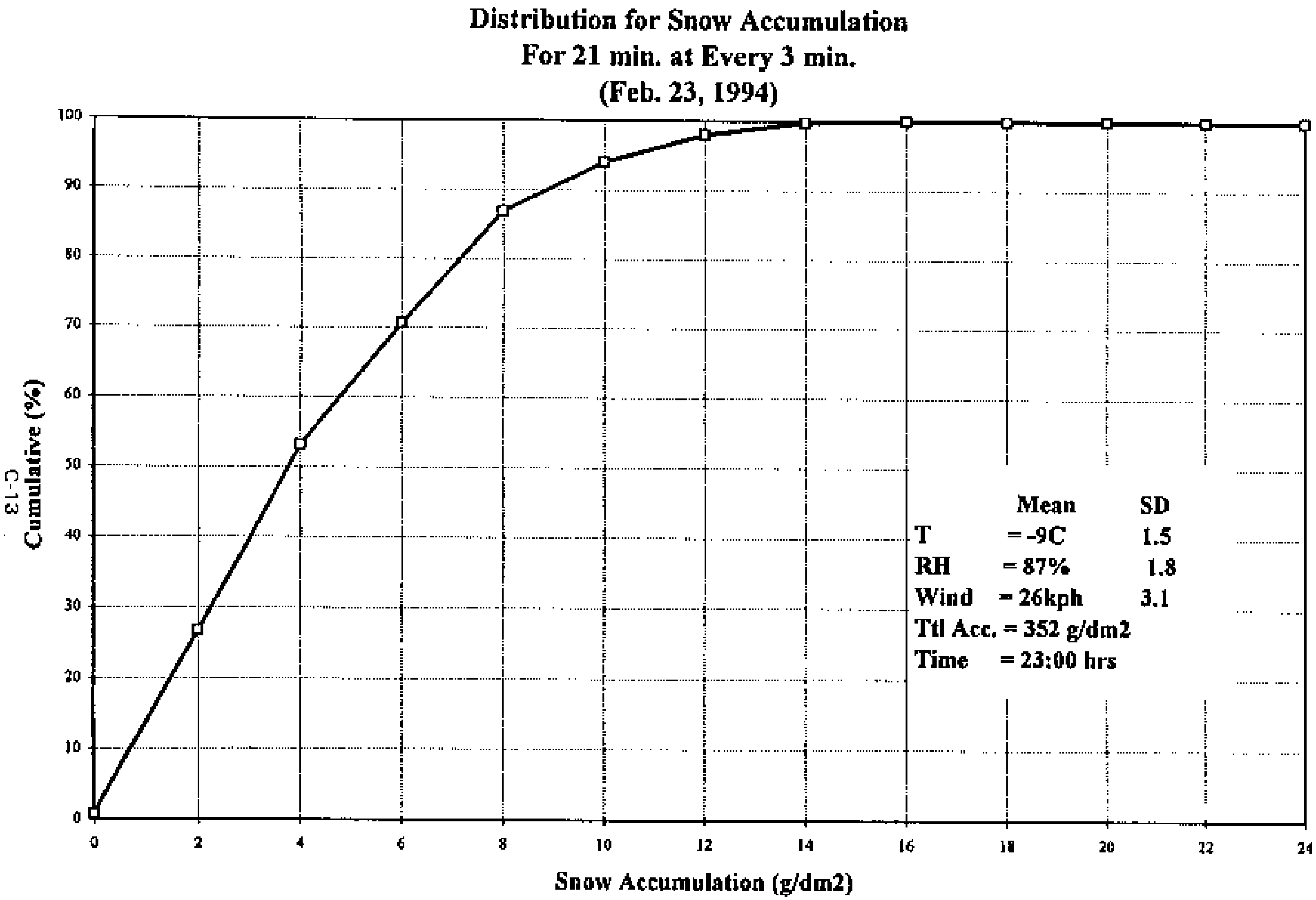


Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Apr. 07, 1994)



17/8/95 16:37

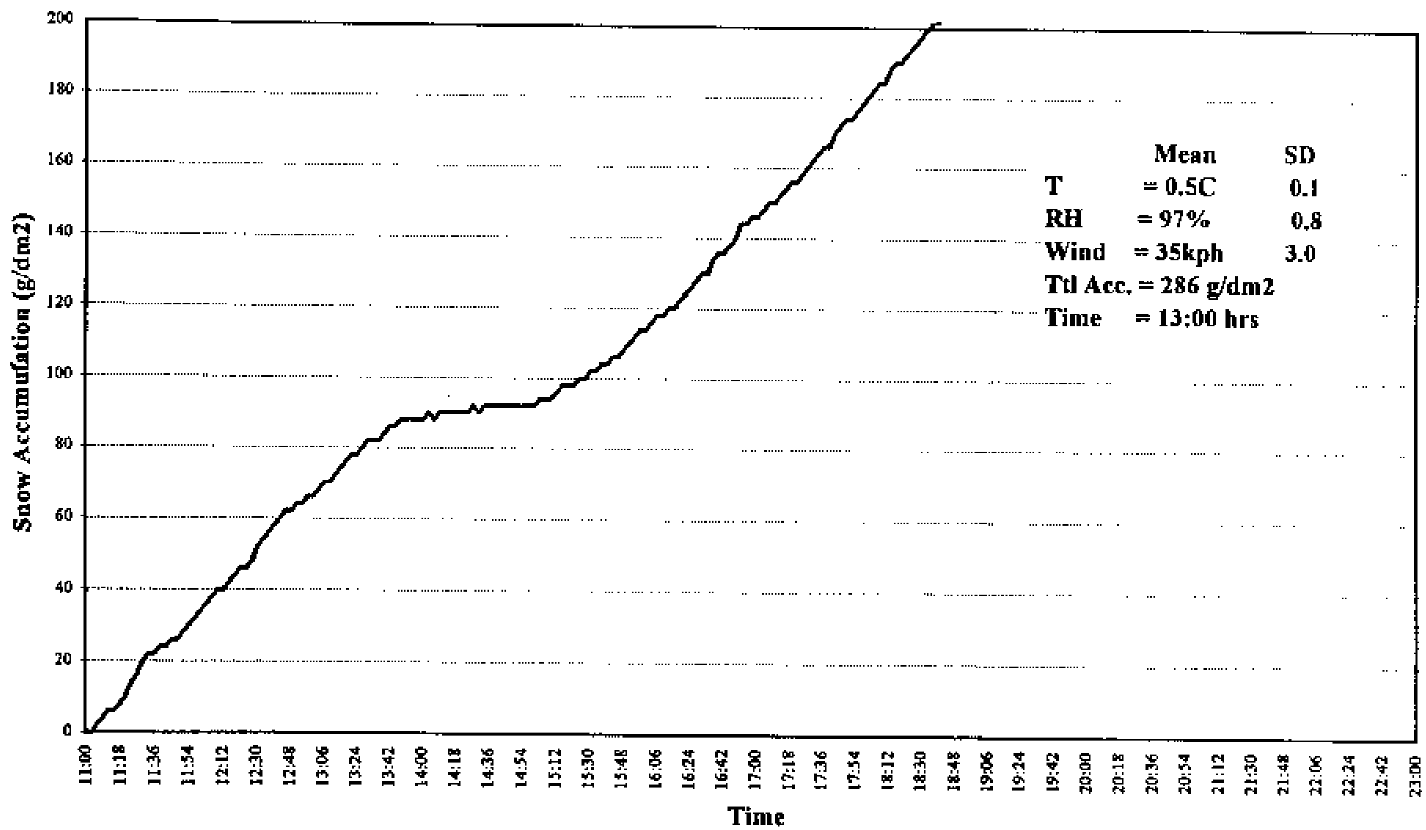
APR0794.XLS



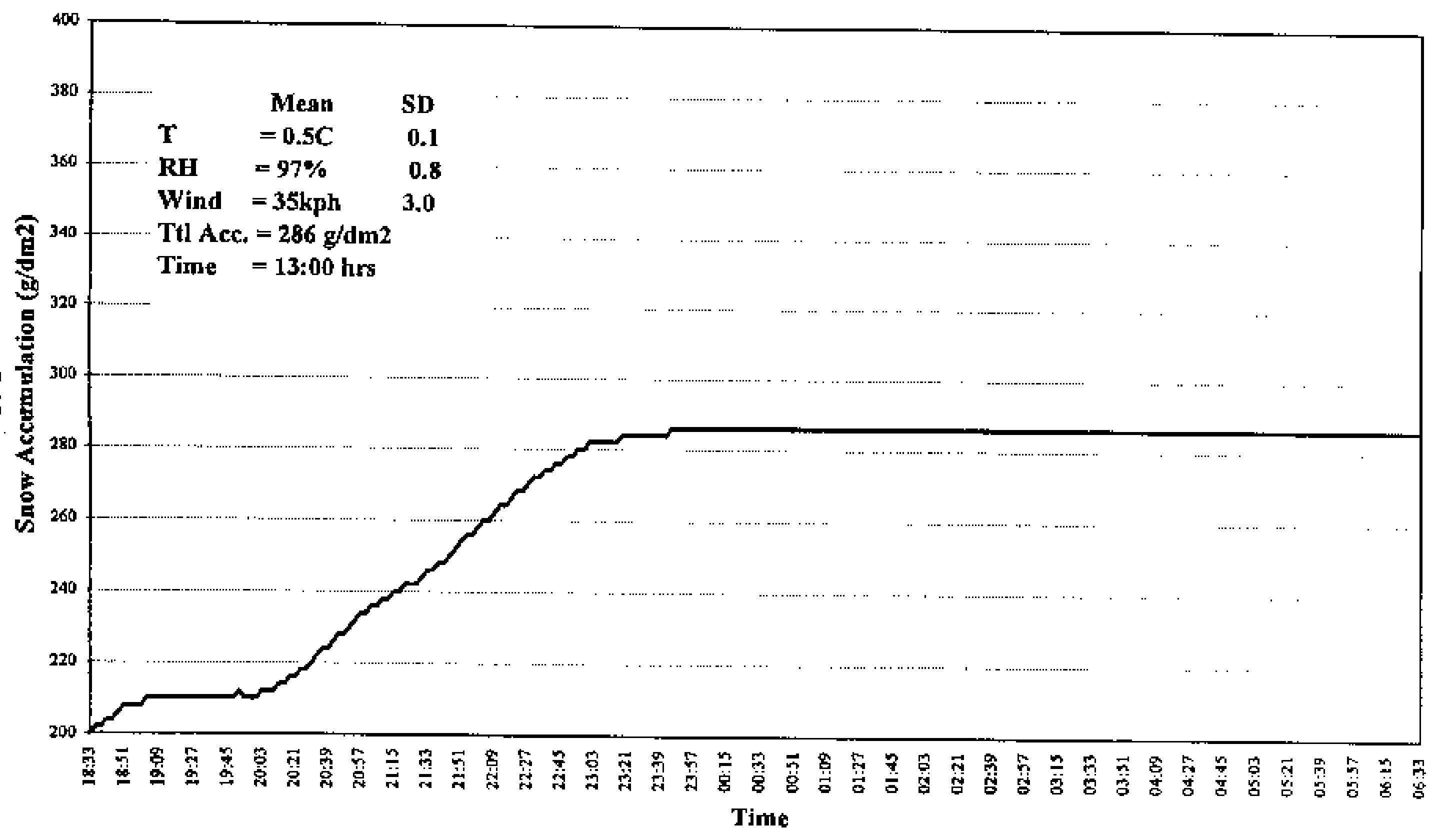
16/8/95 15:21

FEB2394.XLS

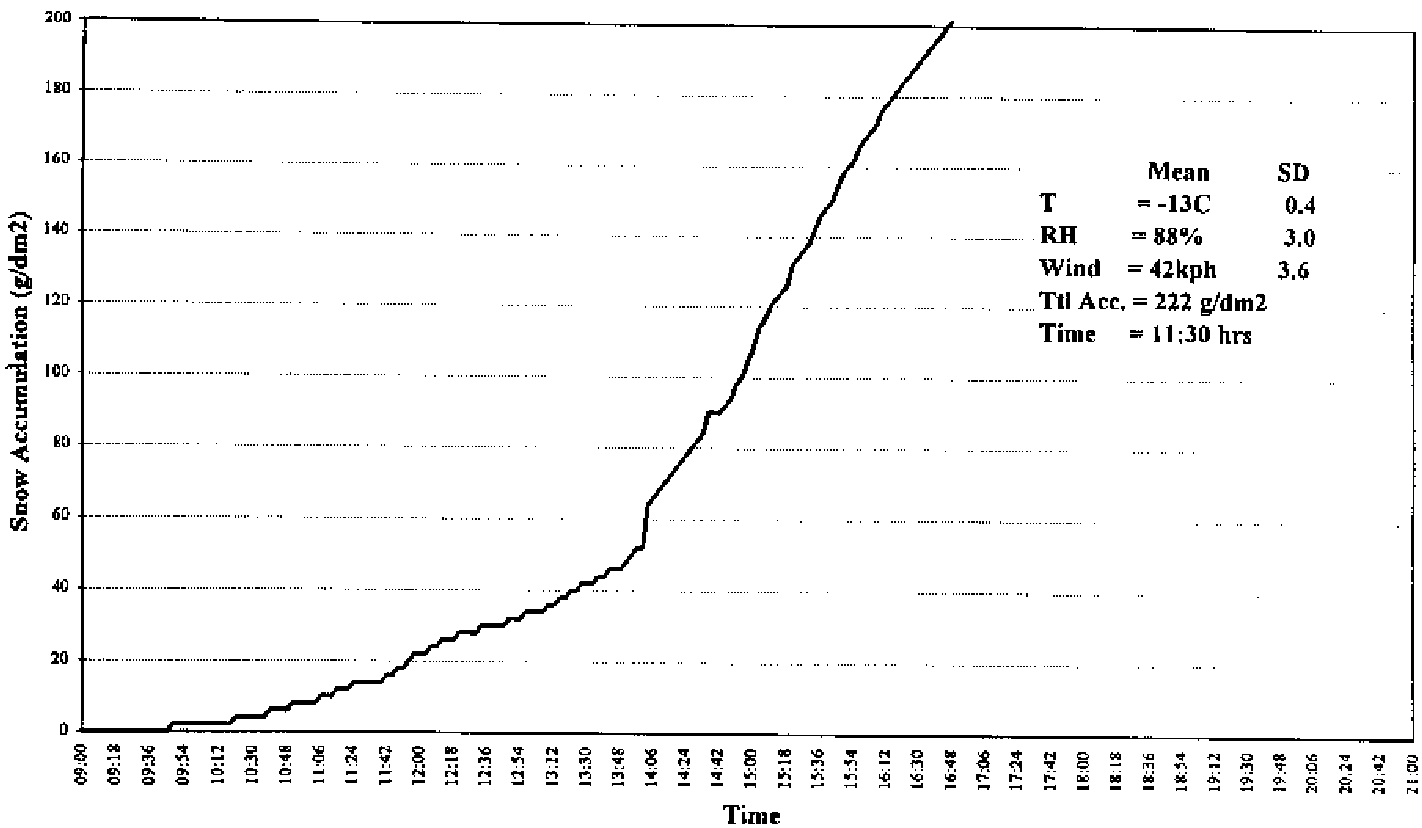
Total Snow Accumulation for Dec. 21, 1993



Total Snow Accumulation for Dec. 21, 1993



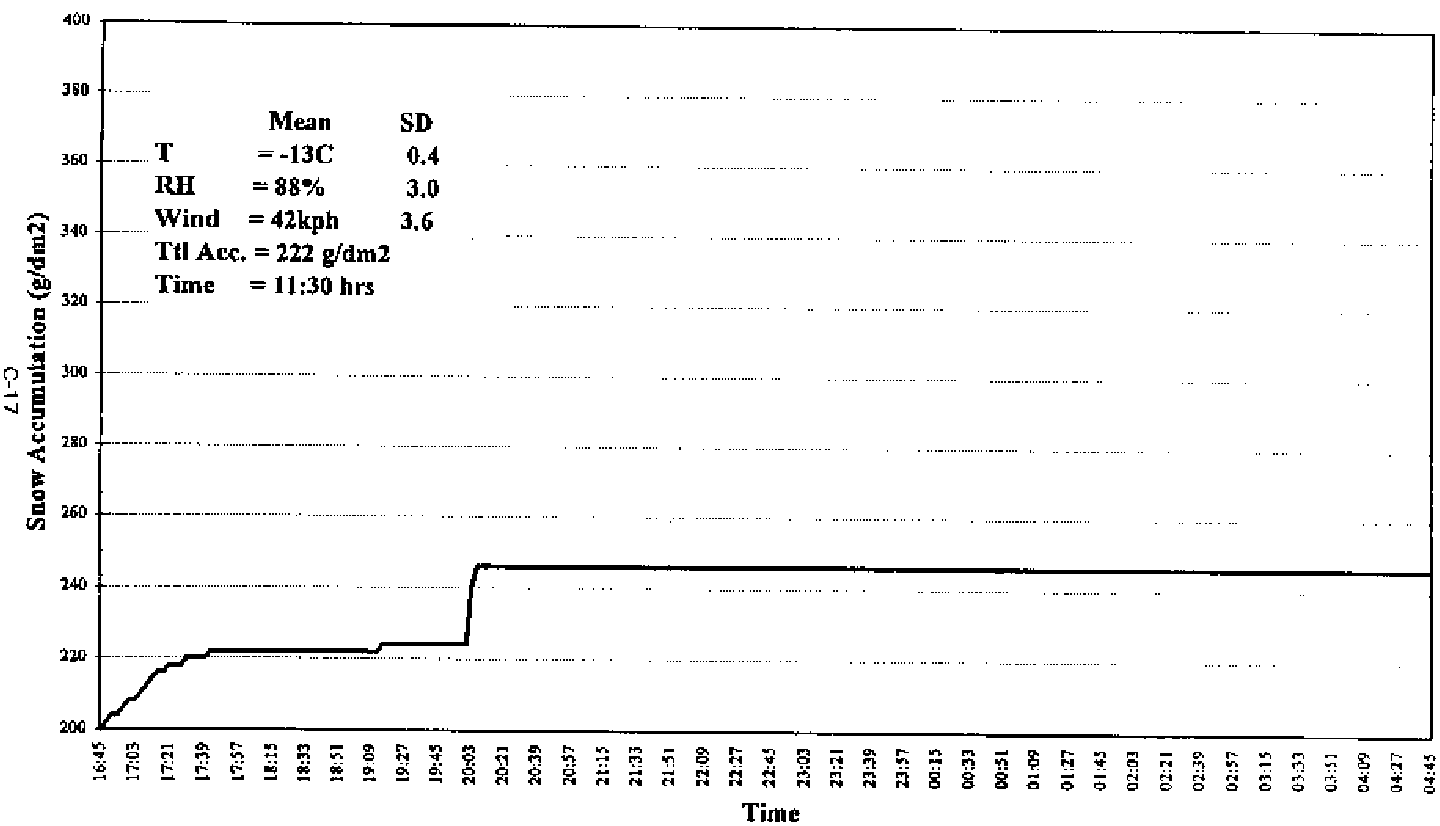
Total Snow Accumulation
for Jan 04, 1994



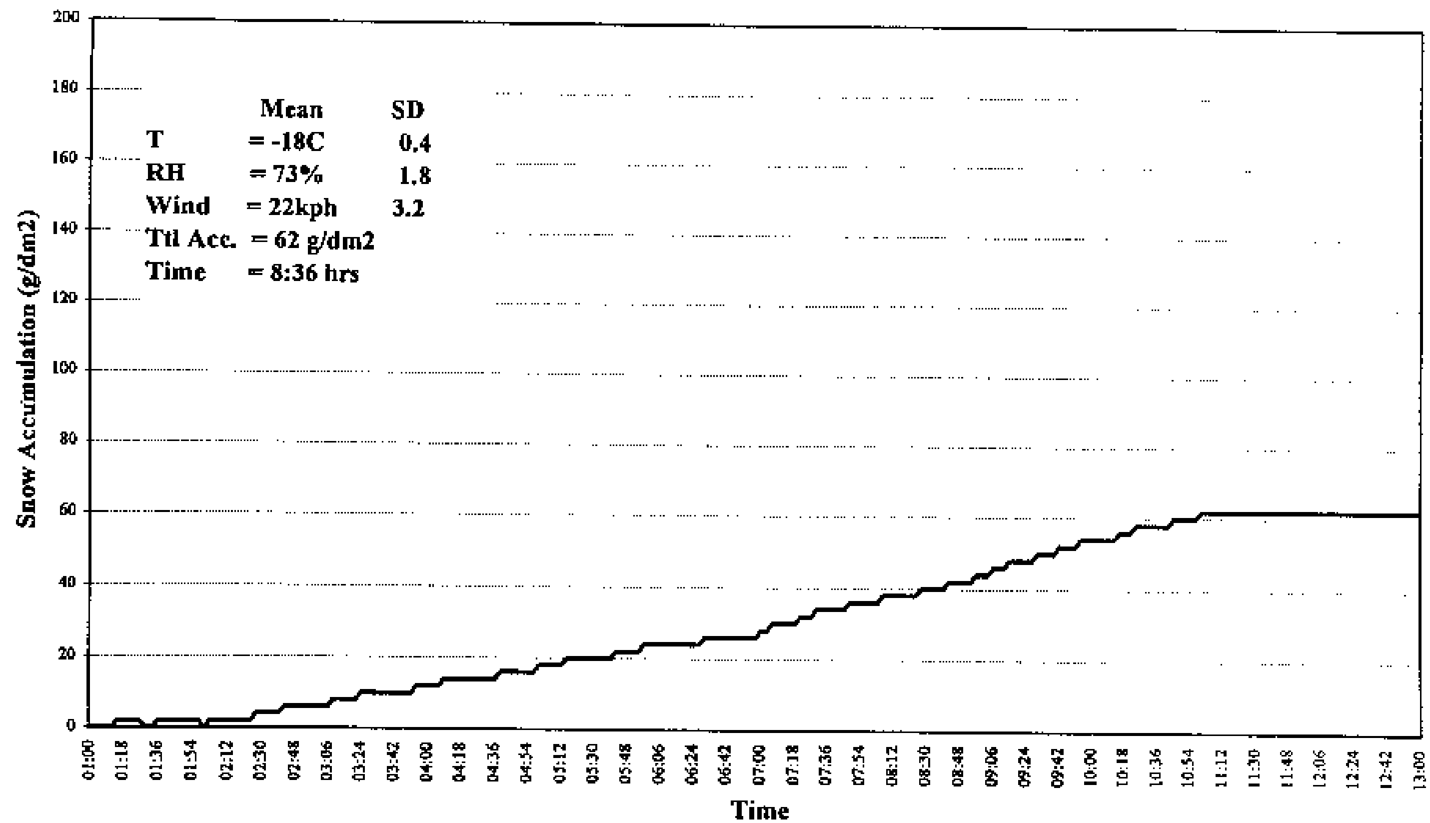
14/8/95 15:29

JAN0494.XLS

Total Snow Accumulation for Jan 04, 1994



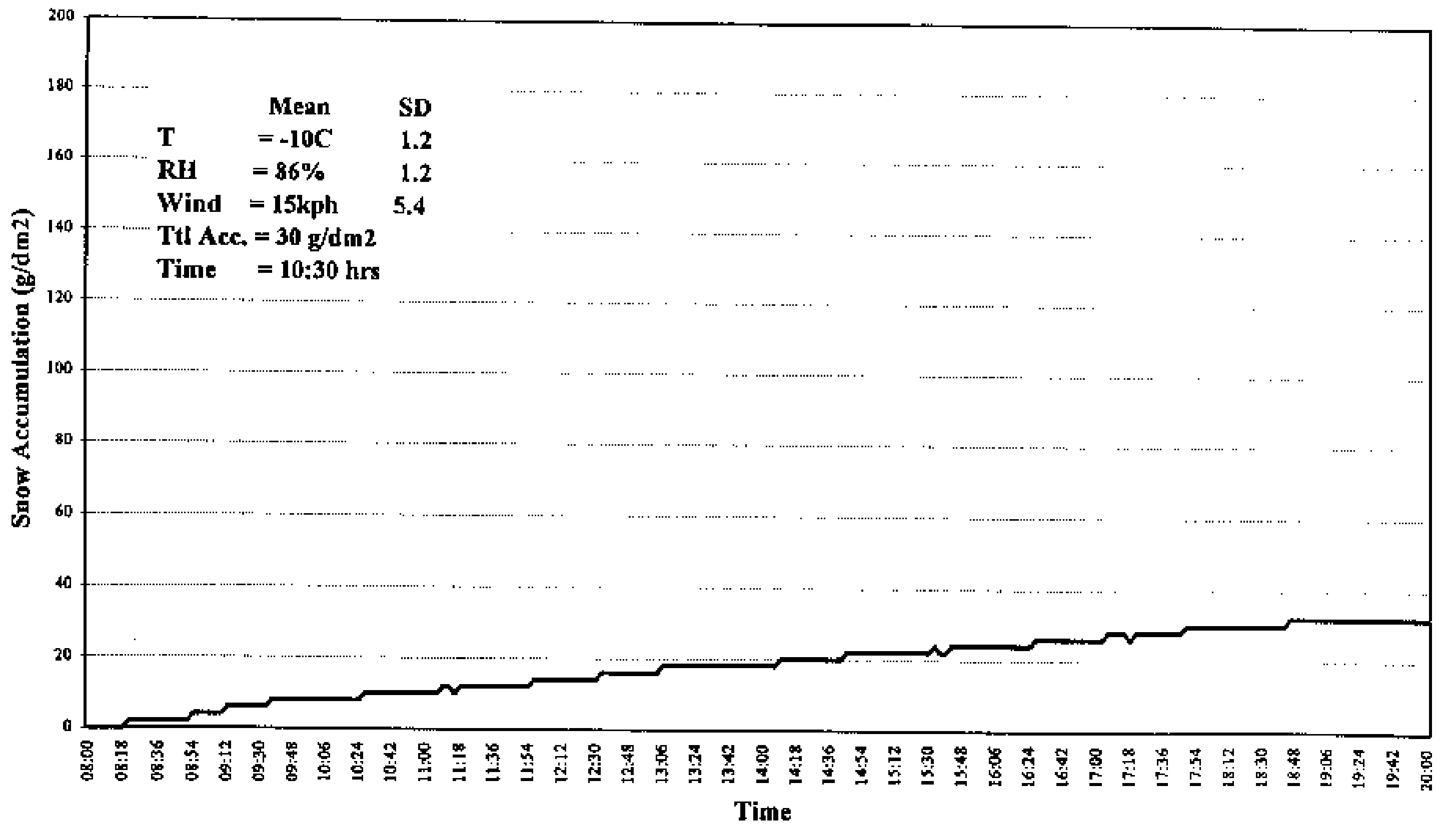
Total Snow Accumulation for Jan. 08, 1994



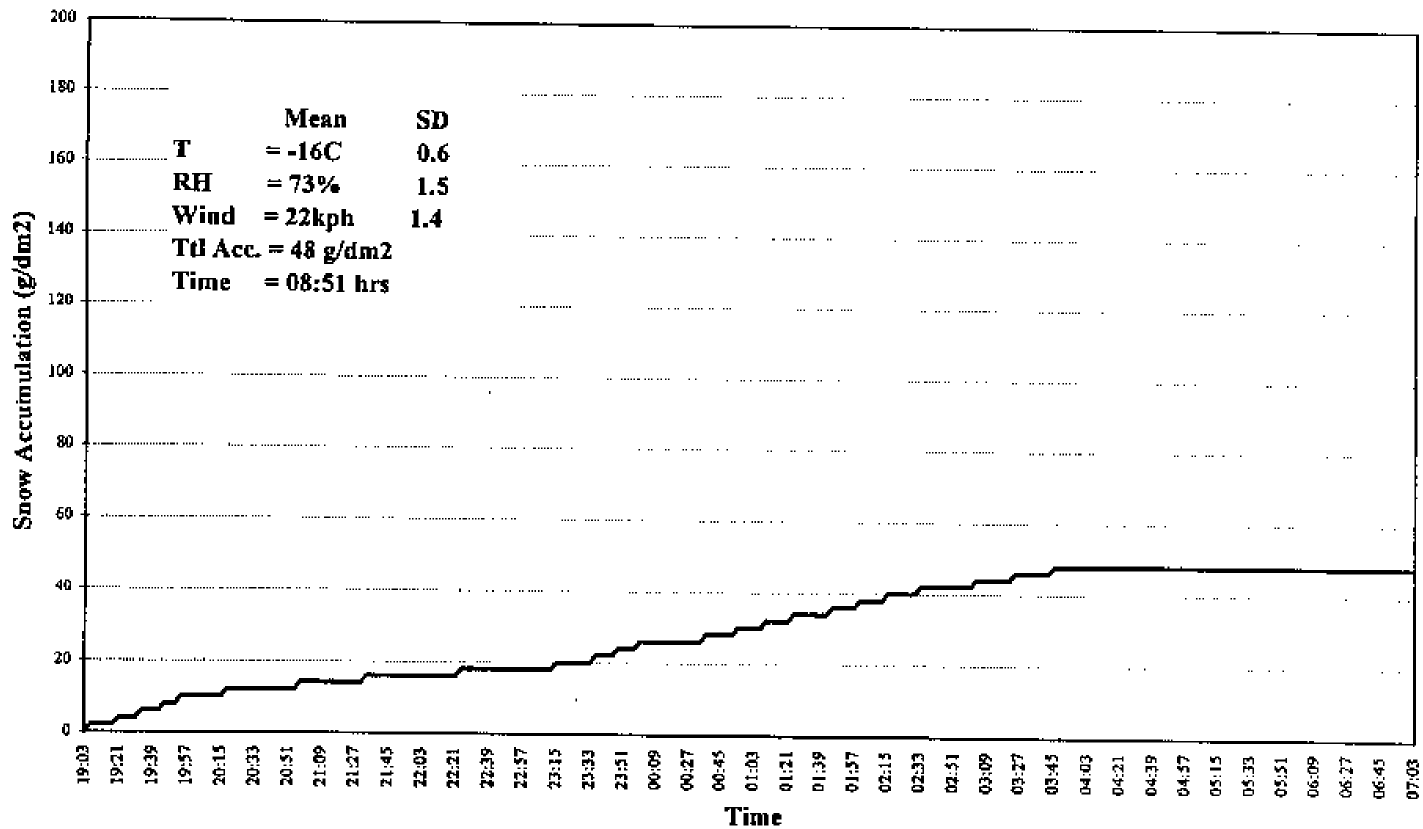
14/8/95 15:23

JAN0894.XLS

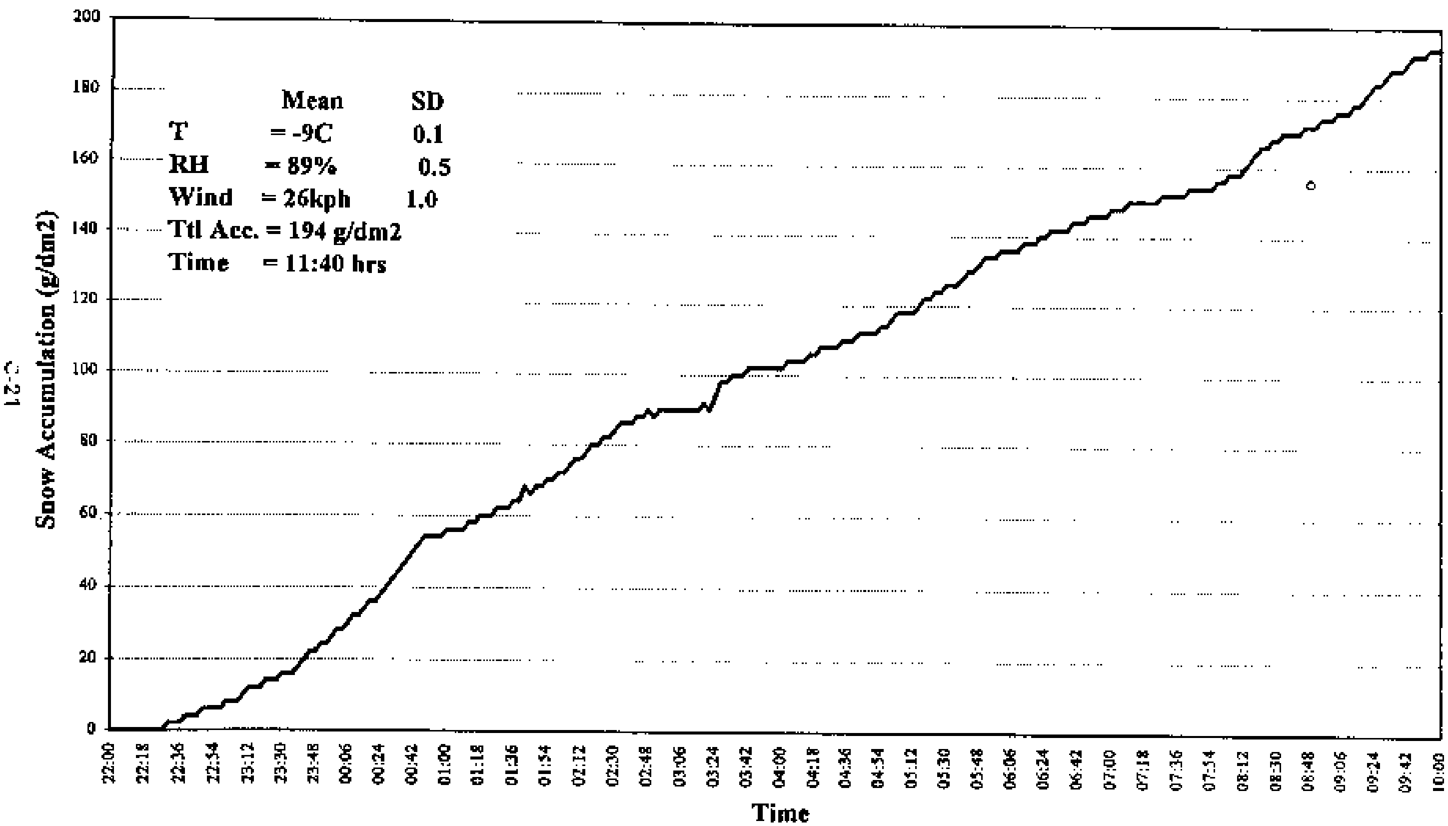
Total Snow Accumulation
for Jan 14, 1994



Total Snow Accumulation for Jan. 23, 1994



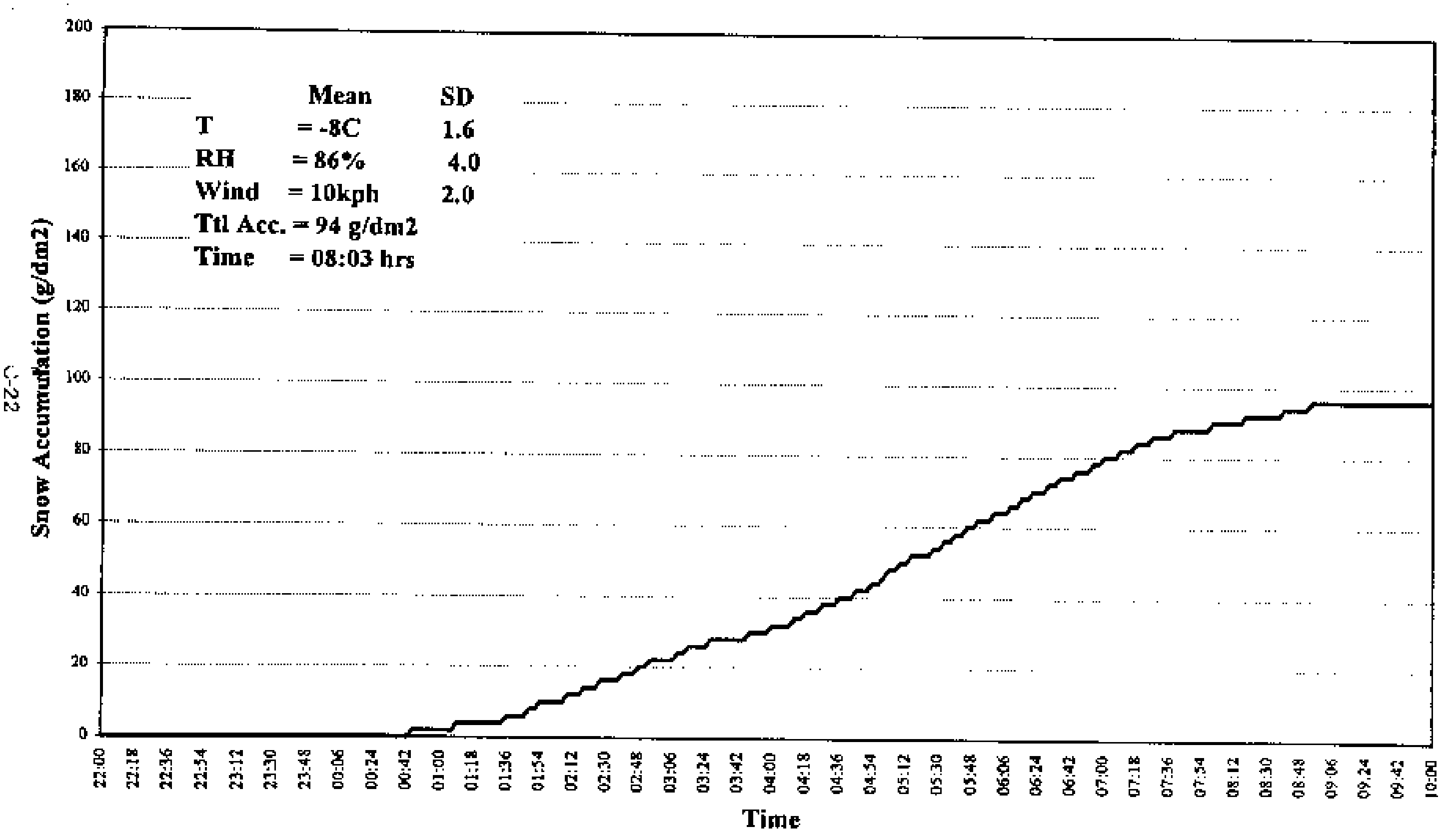
Total Snow Accumulation
for Jan. 27, 1993



14/8/95 15:26

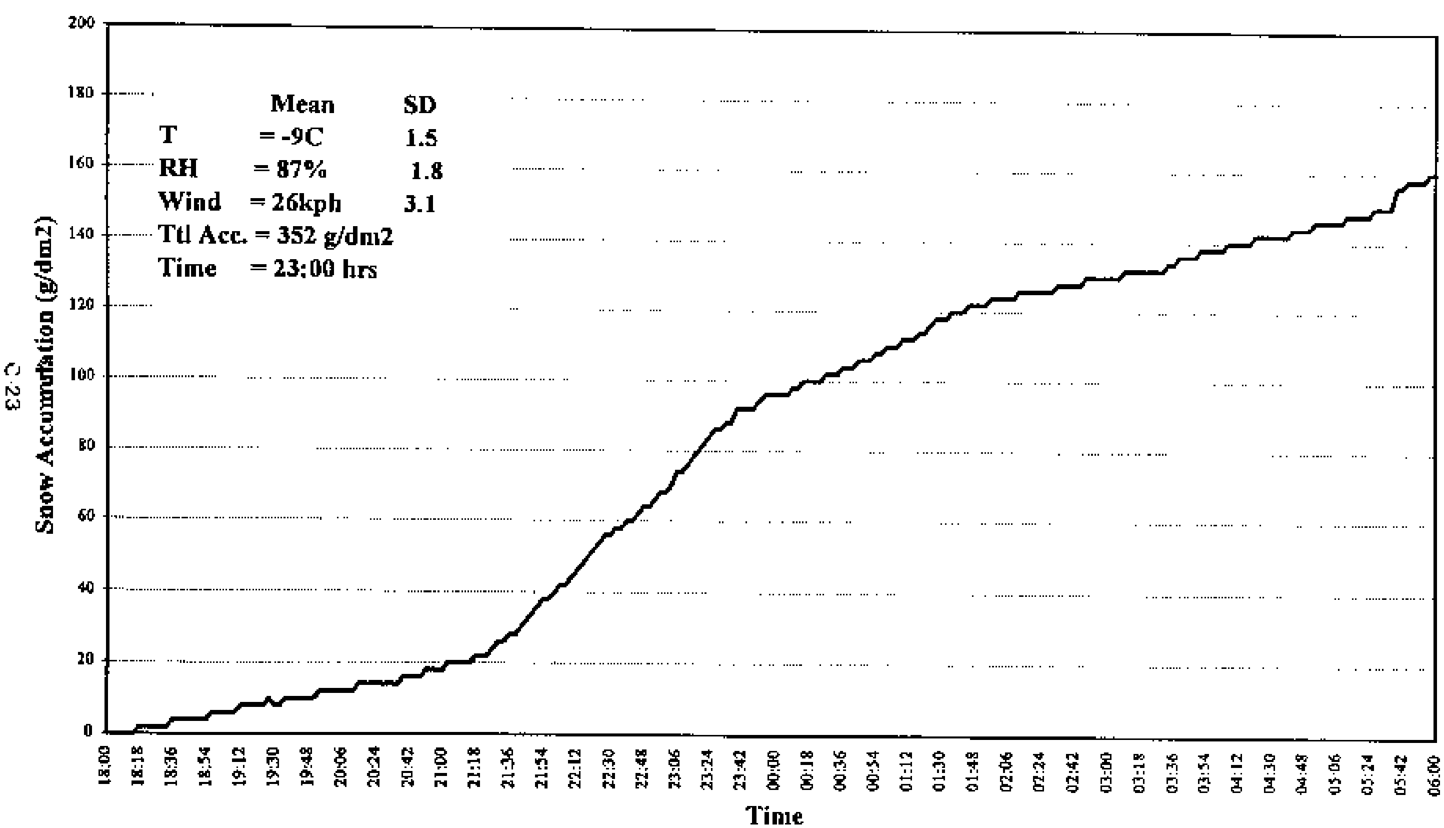
JAN2794.XLS

Total Snow Accumulation
for Feb. 12-13, 1993



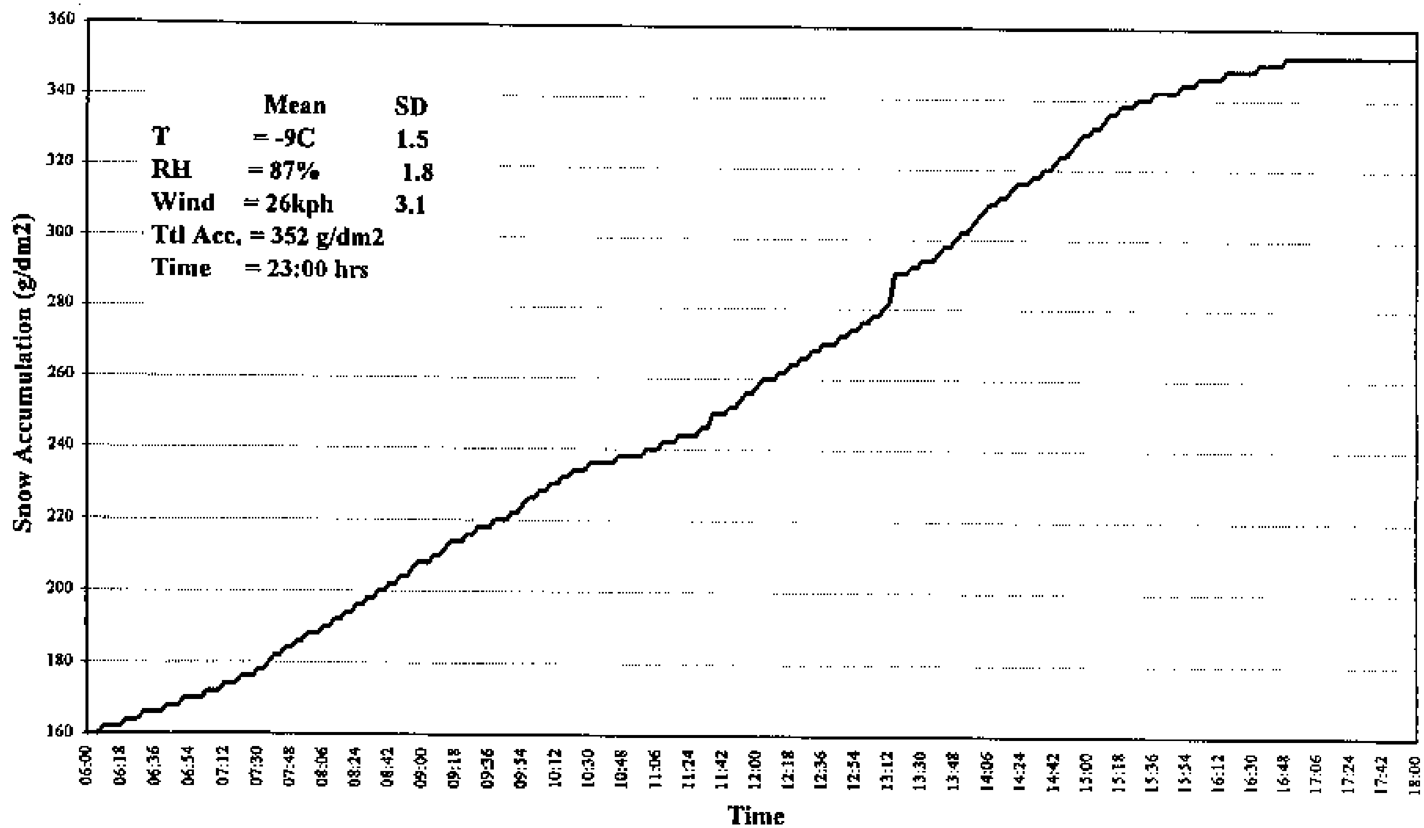
14/8/95 15:34 FEB1294.XLS

Total Snow Accumulation for Feb 23-24, 1994

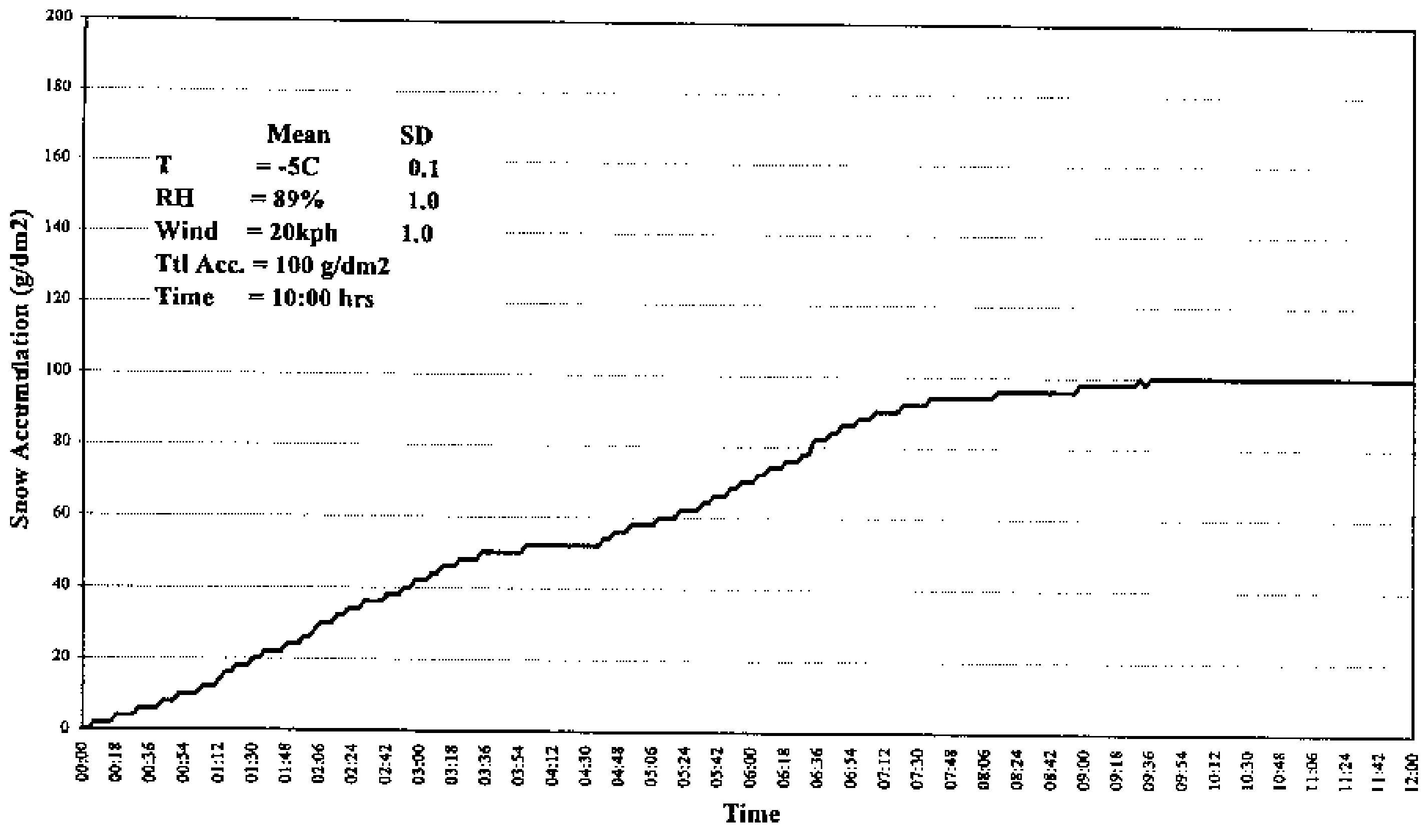


14/8/95 15:35 FEB2394.XLS

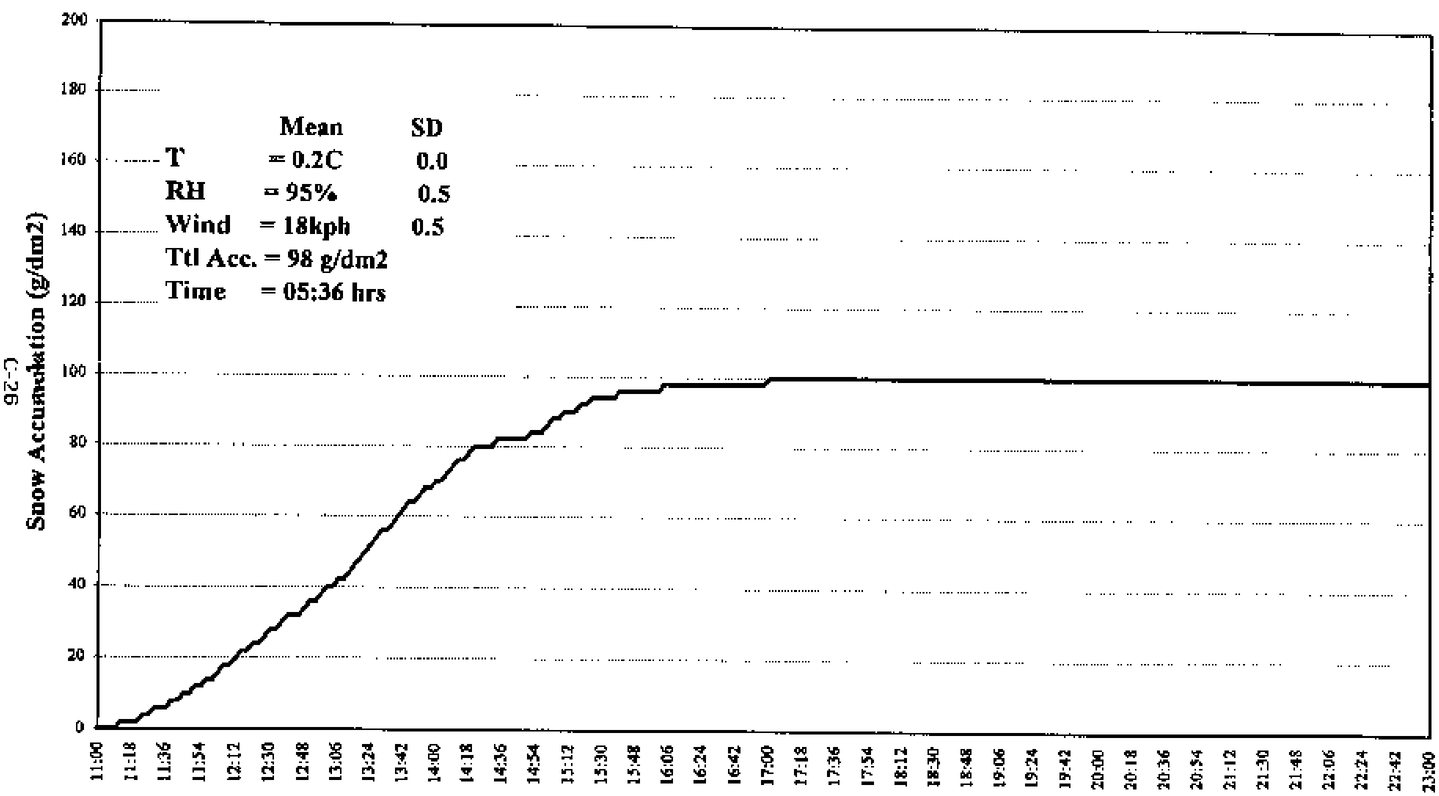
Total Snow Accumulation
for Feb 23-24, 1994



Total Snow Accumulation for Mar. 10, 1994



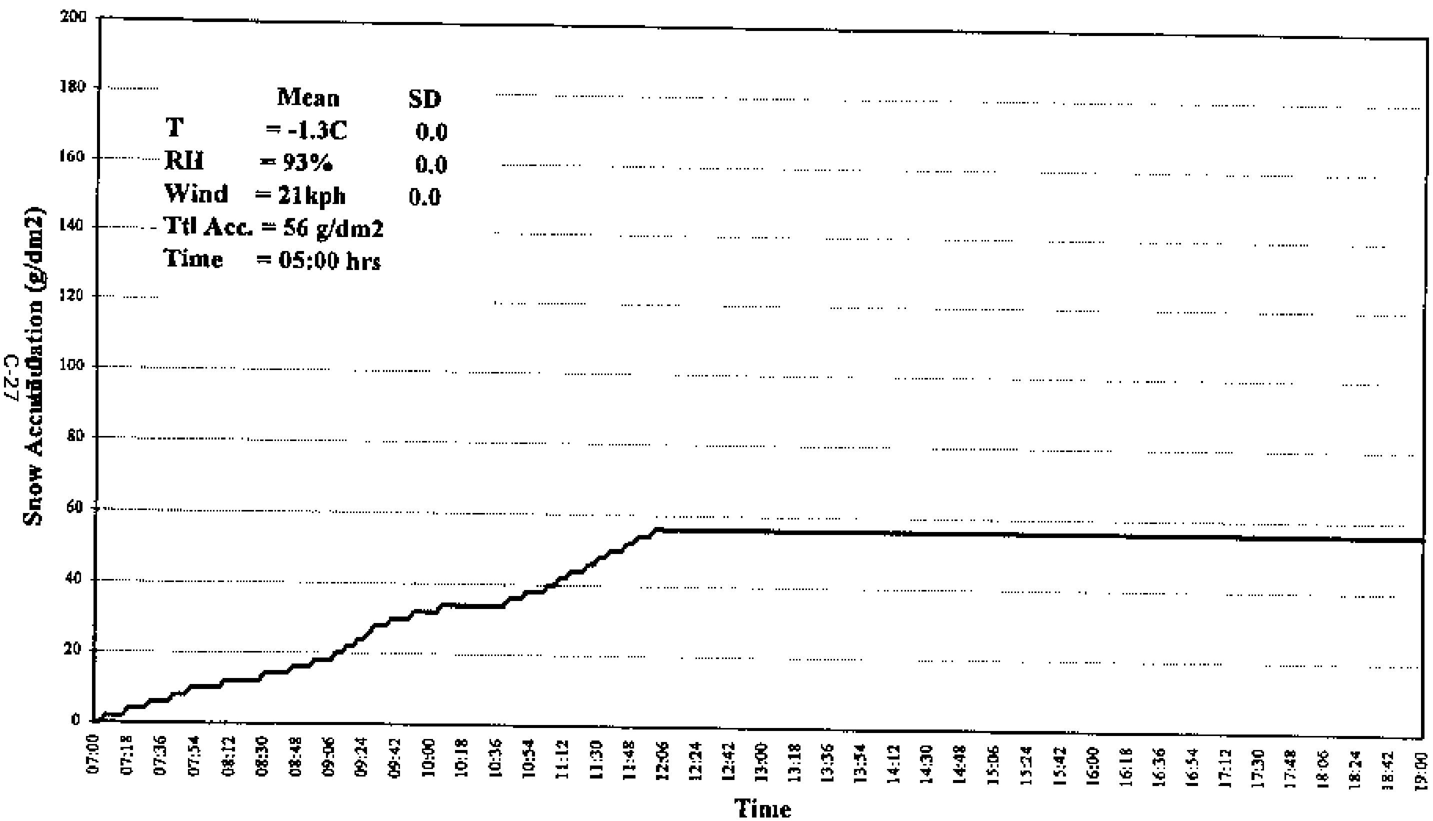
Total Snow Accumulation
for Mar. 27, 1994



14/8/95 15:36

MAR2794.XLS

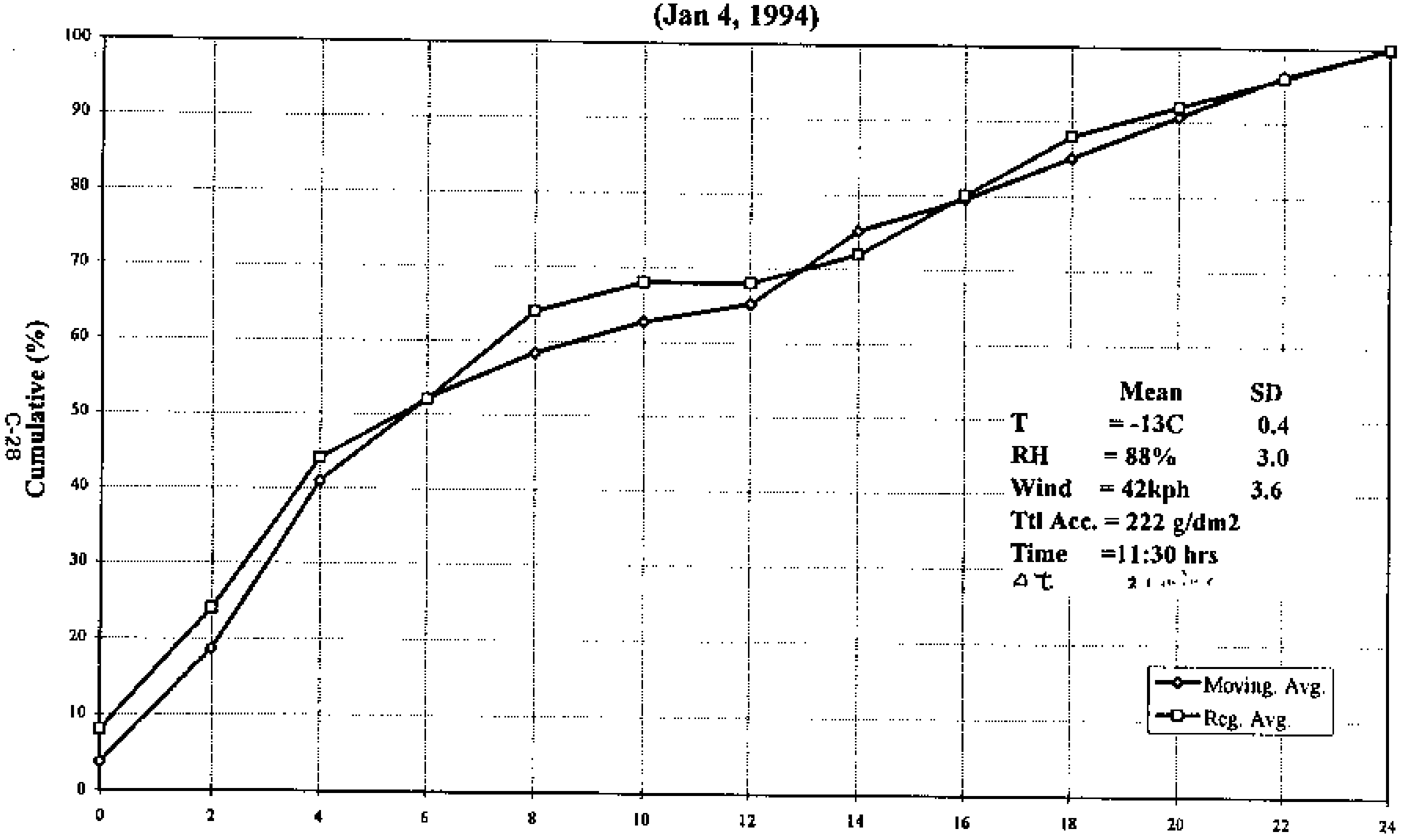
Total Snow Accumulation for Apr. 07, 1994



14/8/95 15:38

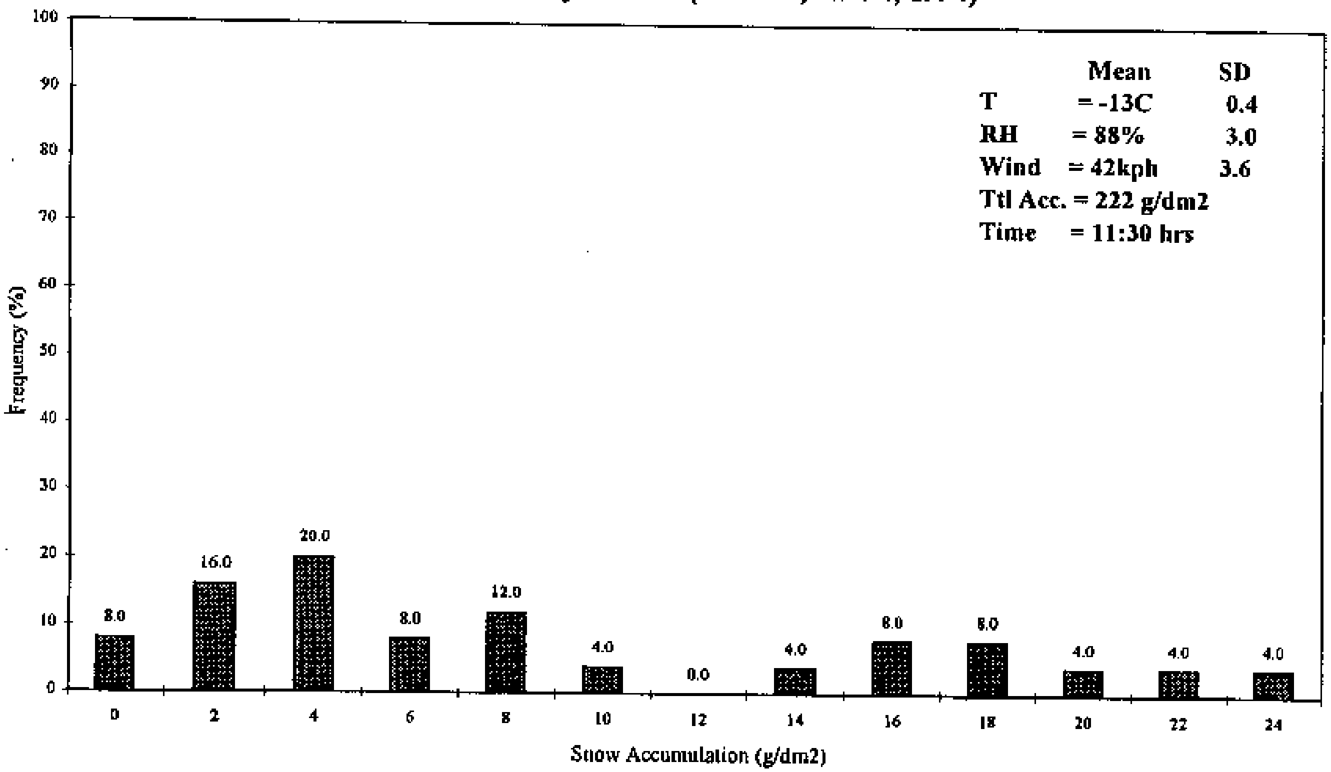
APR0794.XLS

Comparison Between Moving & Reg. Averages for Distribution for Snow Accumulation (Jan 4, 1994)



16/8/95 14:05 JAN0494.XLS

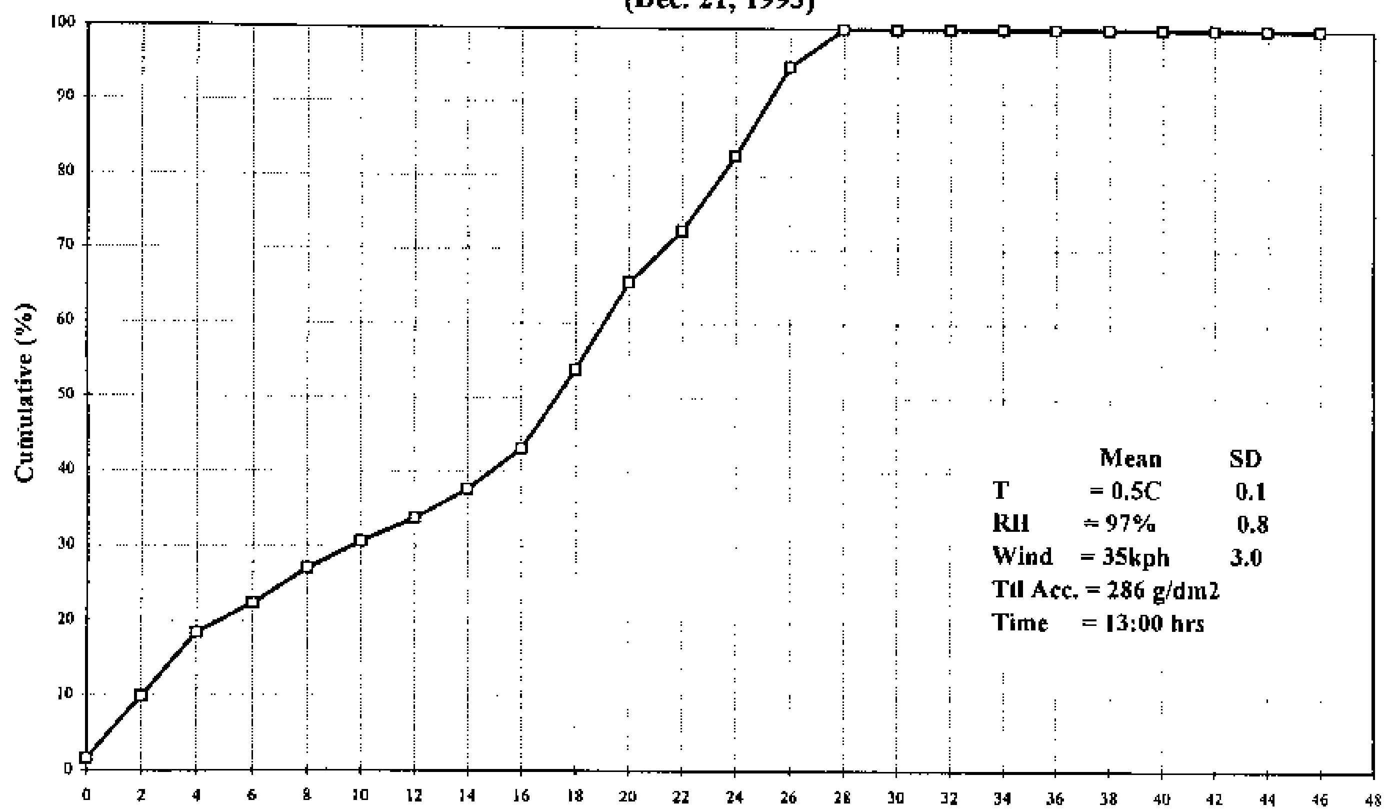
Histogram for Snow Accumulation
Every 21 min. (Series 1, Jan. 4, 1994)



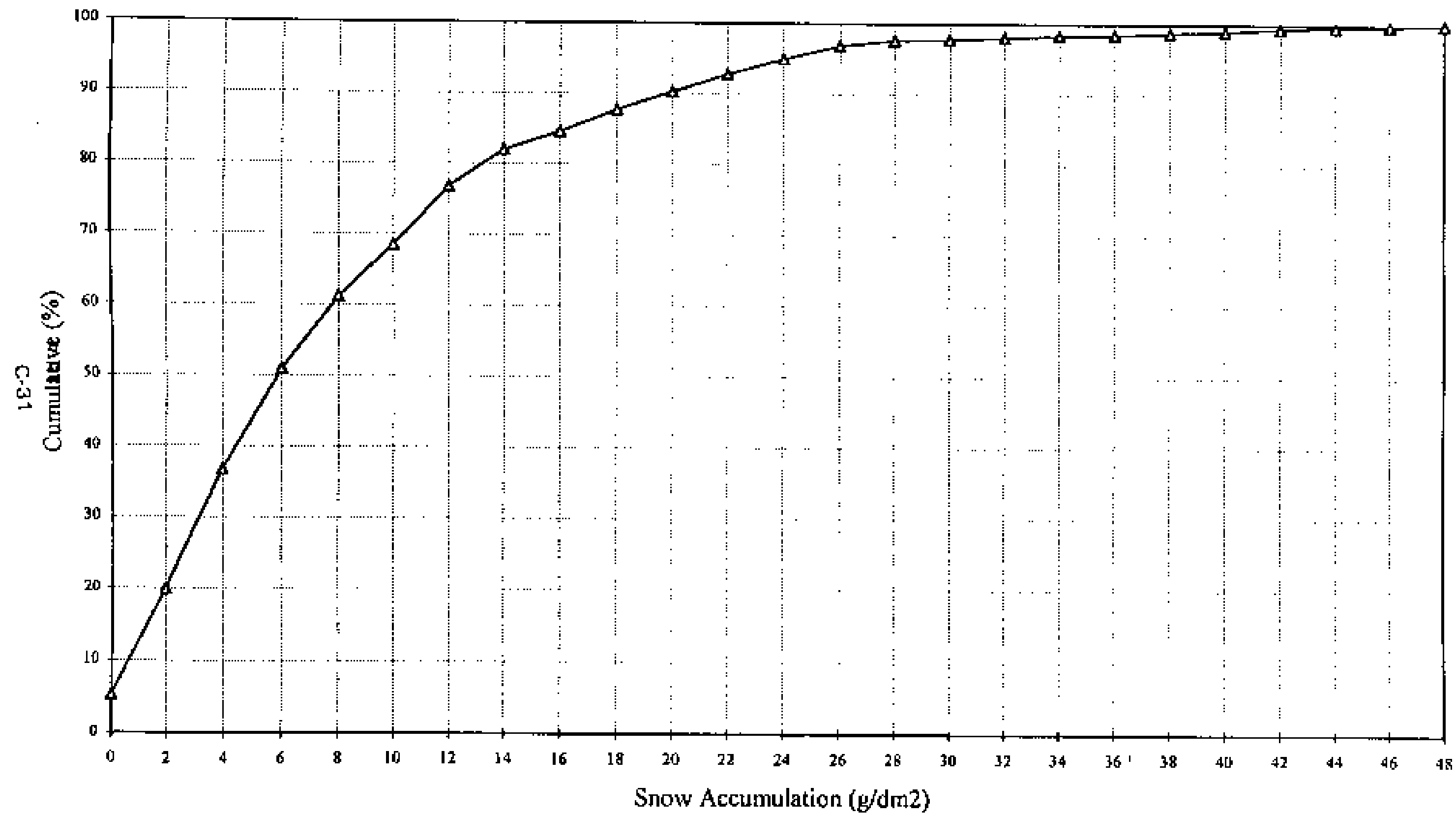
18/8/95 16:47

JAN0494.XLS

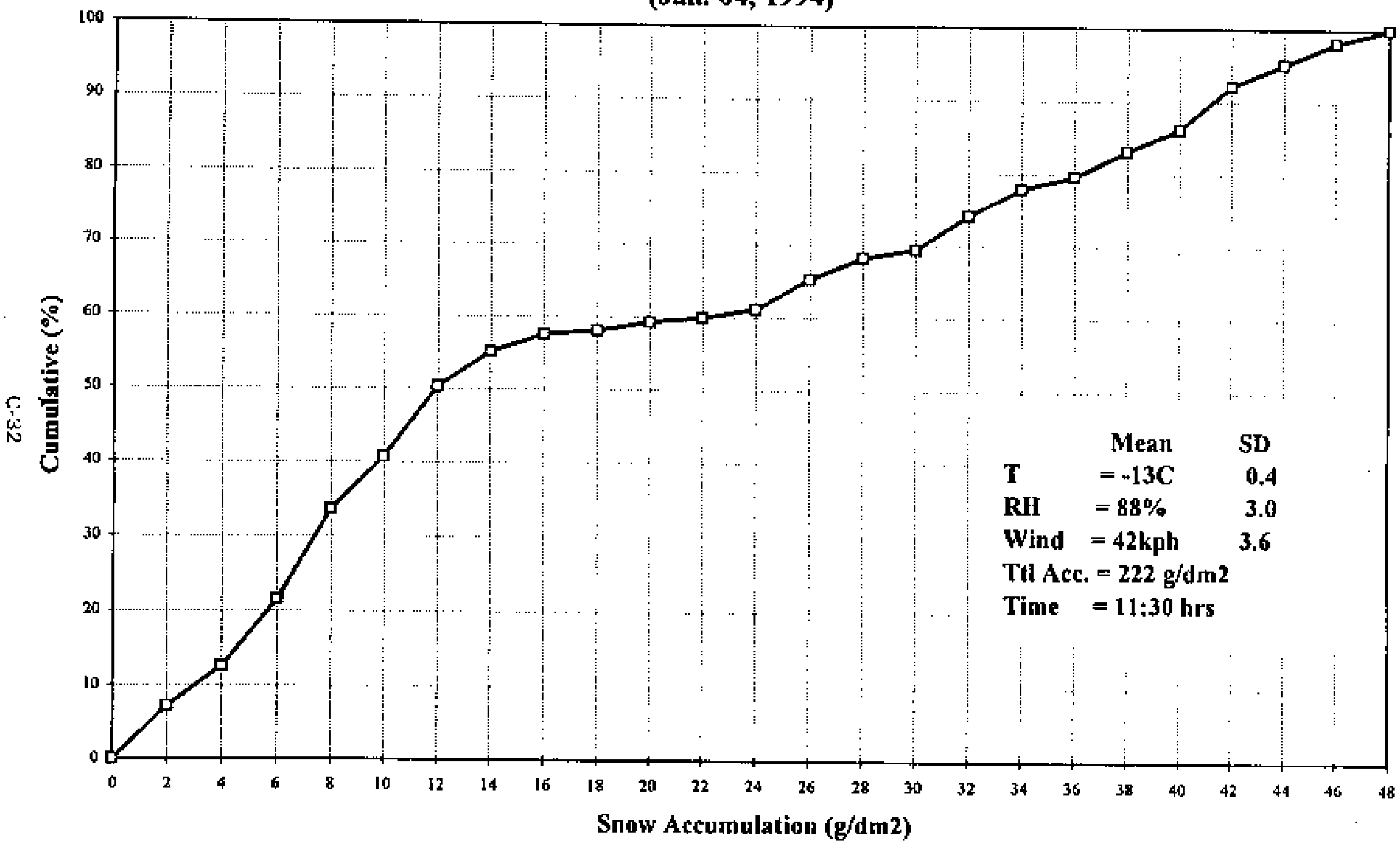
Distribution of Snow Accumulation For 45 min. at Every 3 min. (Dec. 21, 1993)



Distribution for Snow Accumulation For 45 min. at Every 3 min. For 1993/1994 Winter



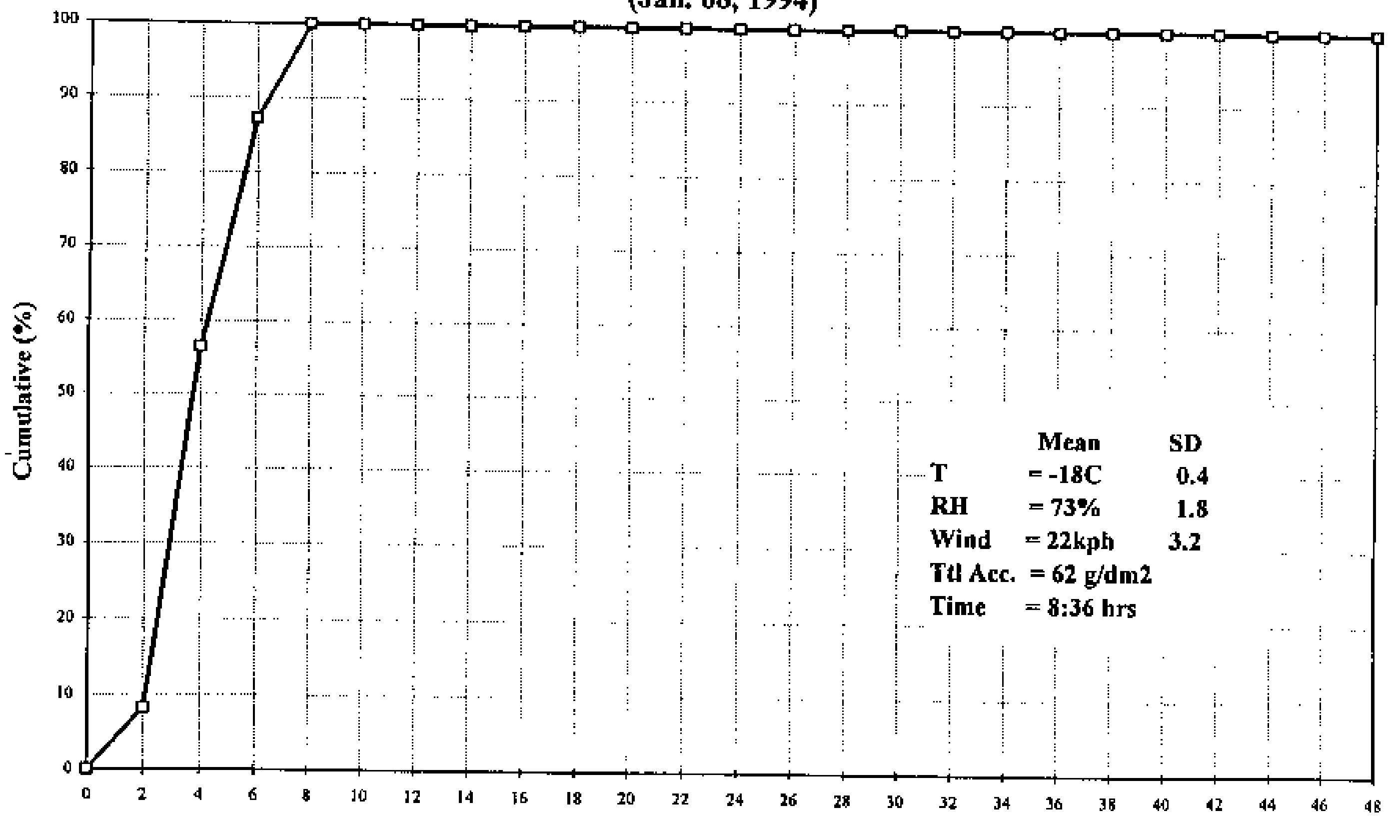
Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Jan. 04, 1994)



18/8/95 16:24

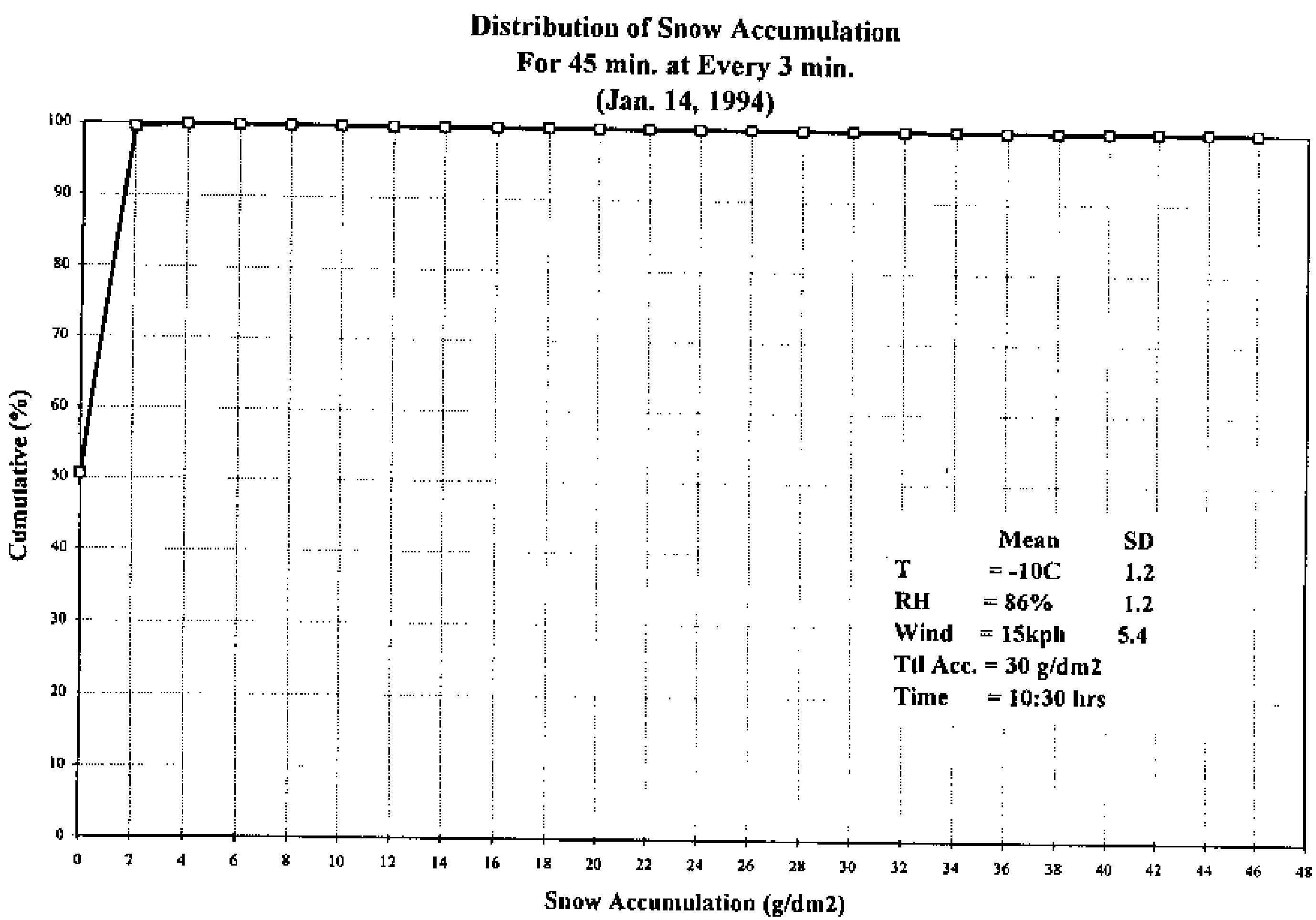
JAN0494.XLS

Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Jan. 08, 1994)



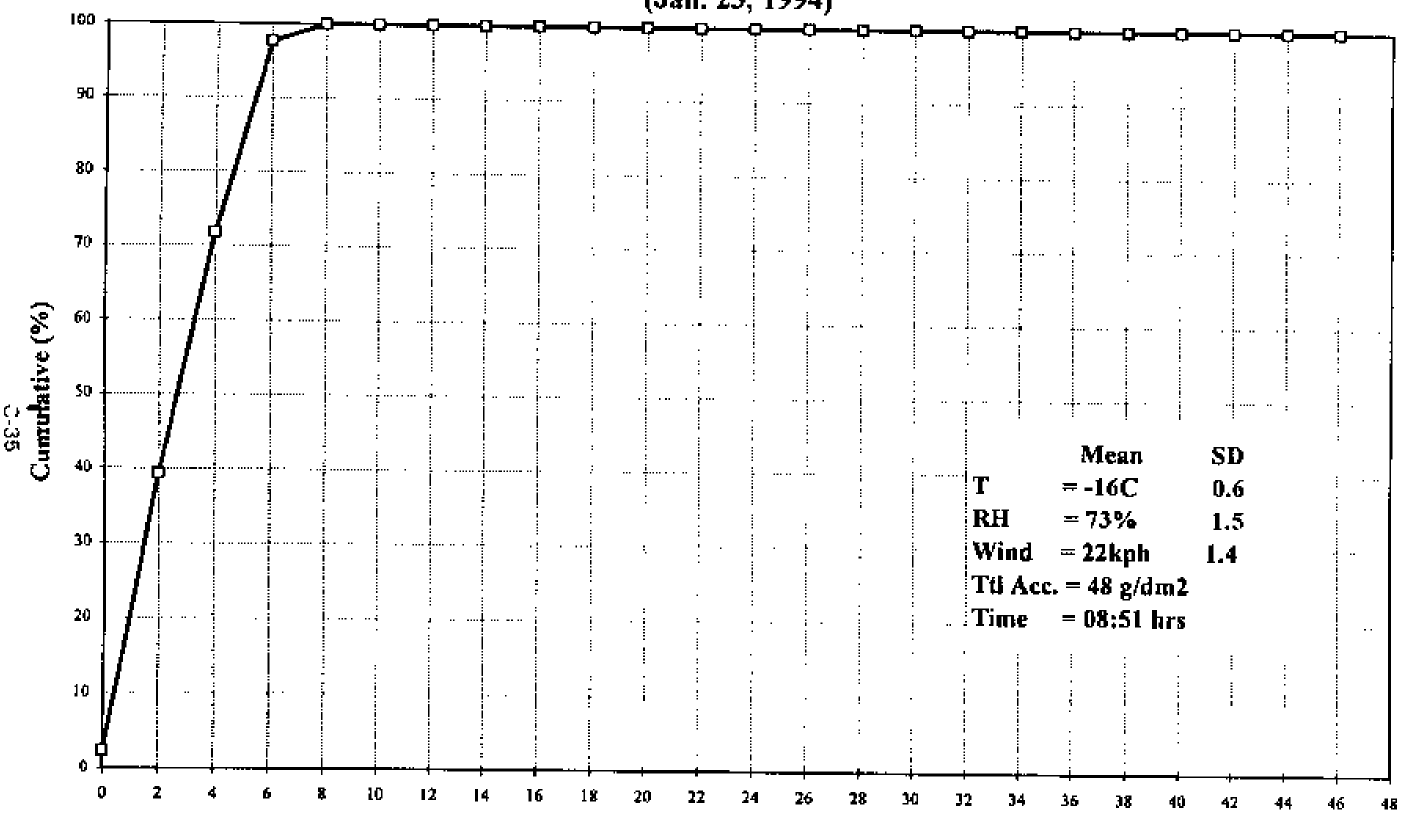
18/8/95 16:23

JAN0894.XLS

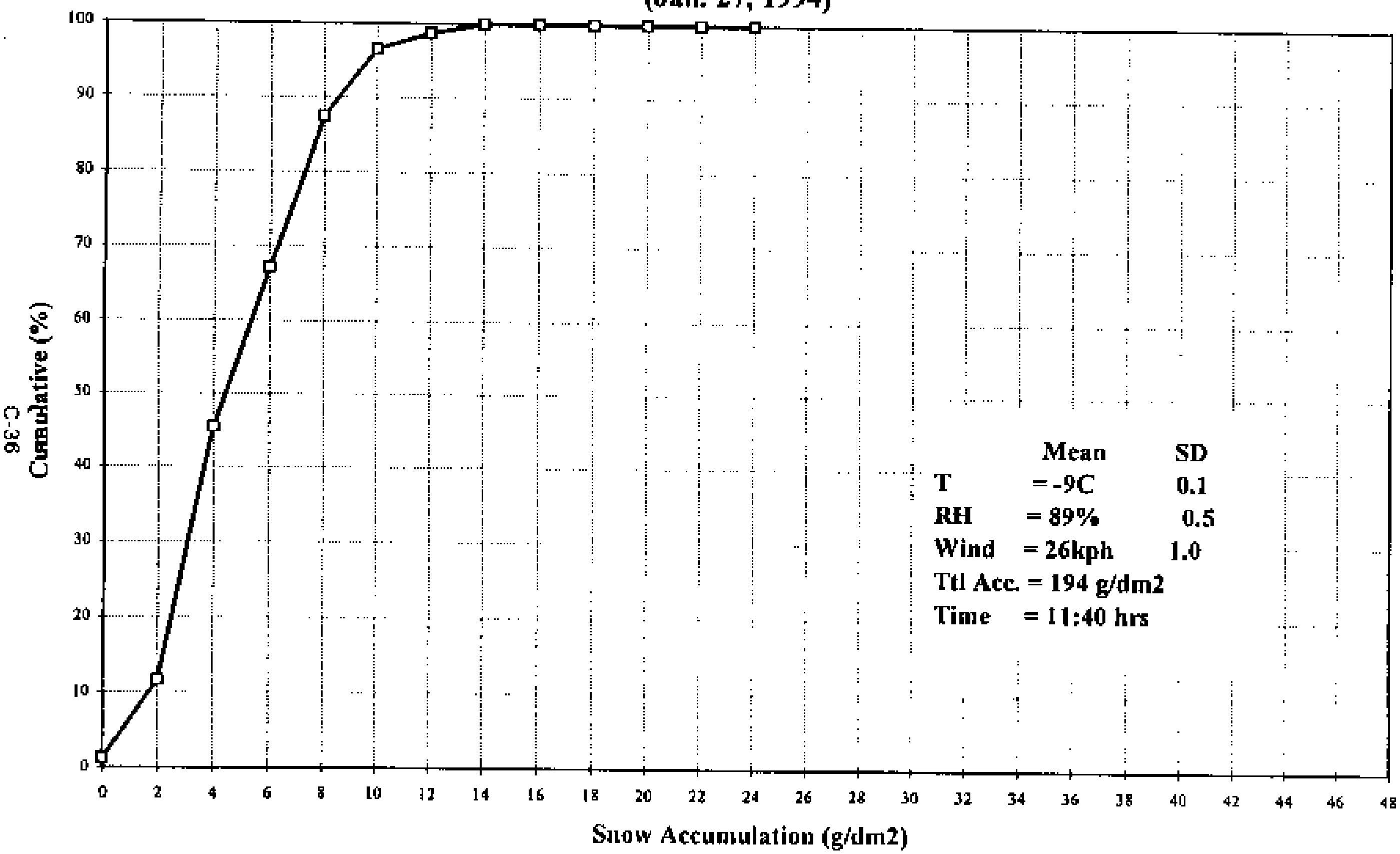


Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Jan. 14, 1994)
Cumulative (%)
Snow Accumulation (g/dm2)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
Mean
SD
T = -10C 1.2
RH = 86% 1.2
Wind = 15kph 5.4
Ttl Acc. = 30 g/dm2
Time = 10:30 hrs

Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Jan. 23, 1994)

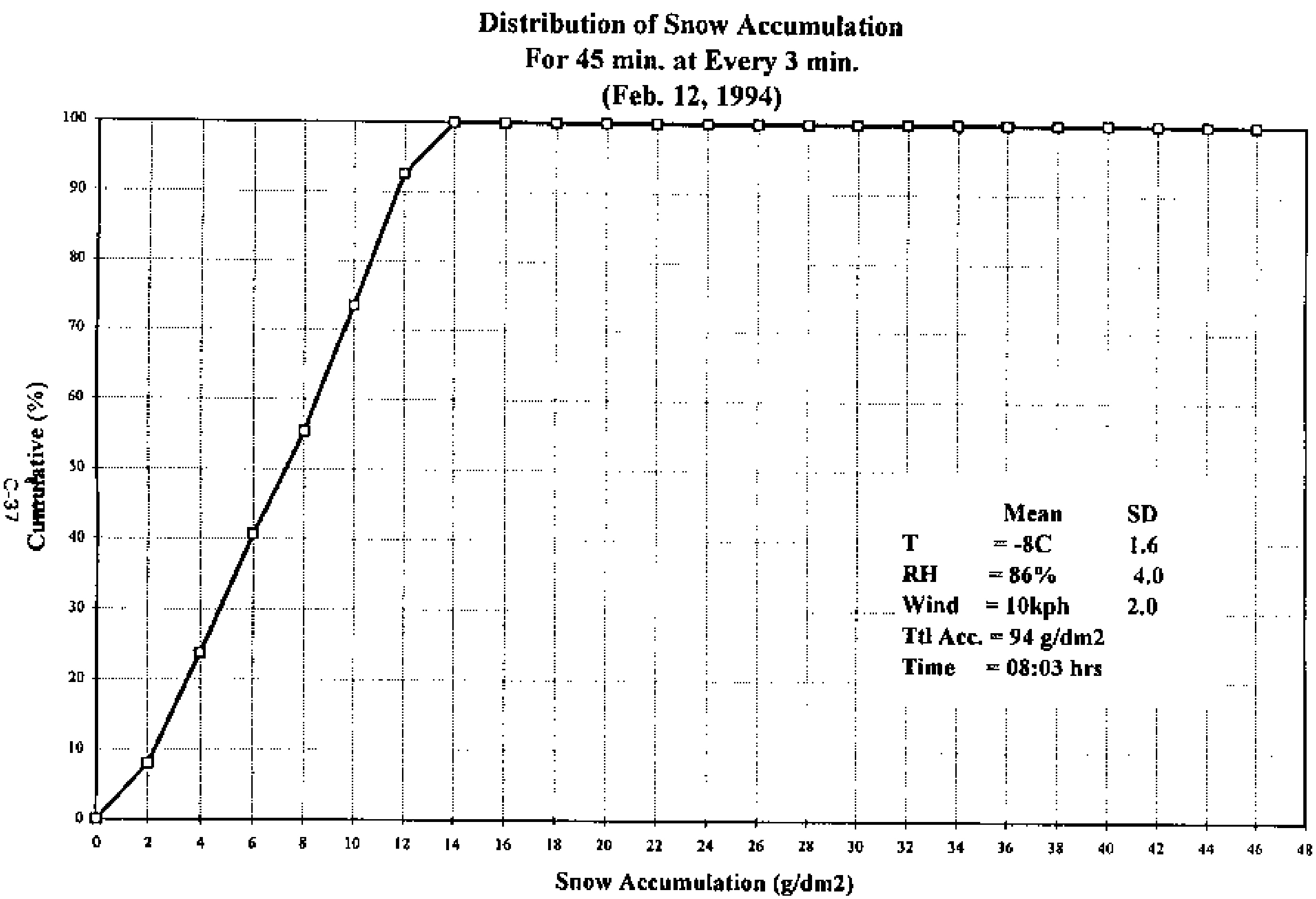


Distribution of Snow Accumulation For 45 min. at Every 3 min. (Jan. 27, 1994)

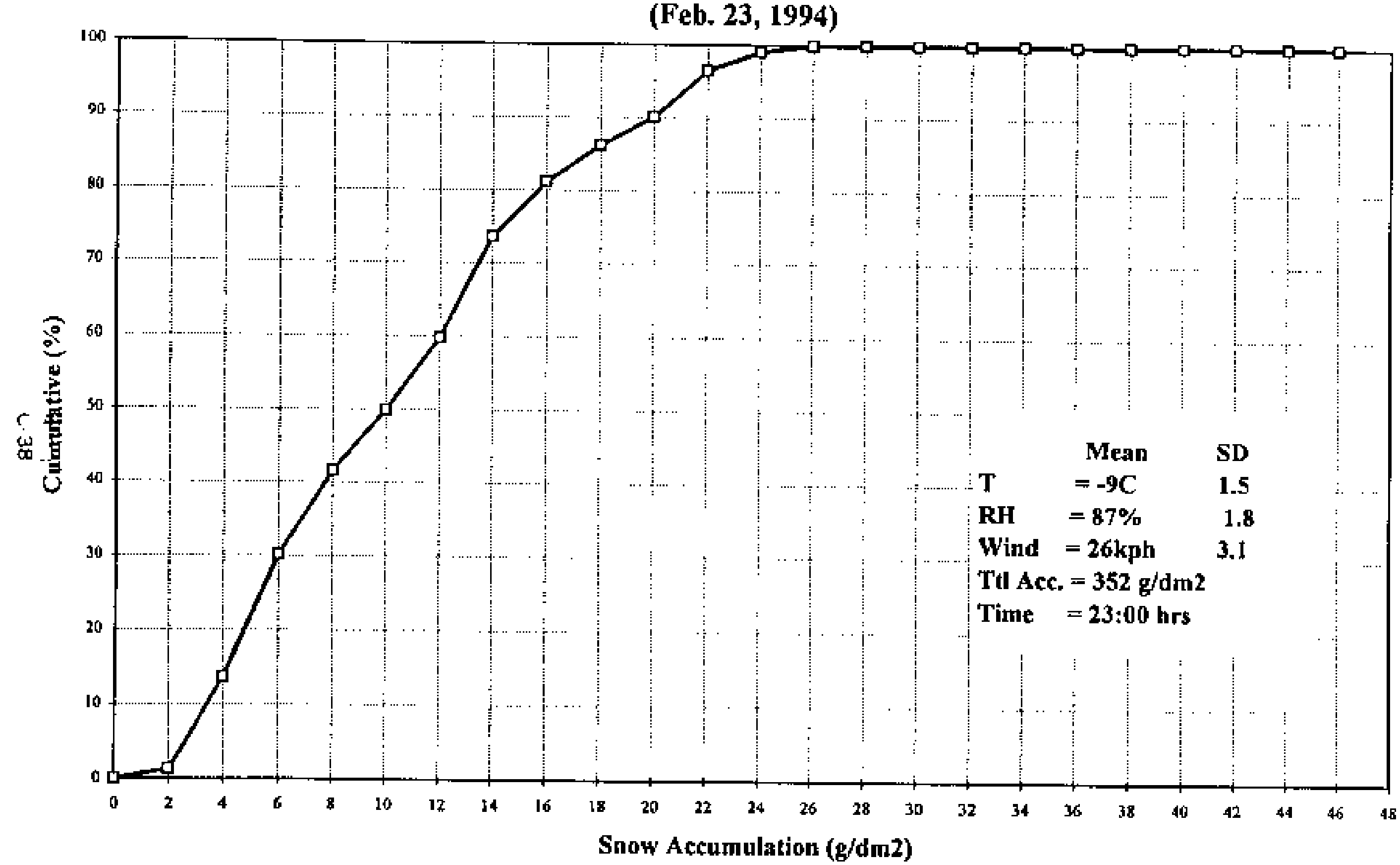


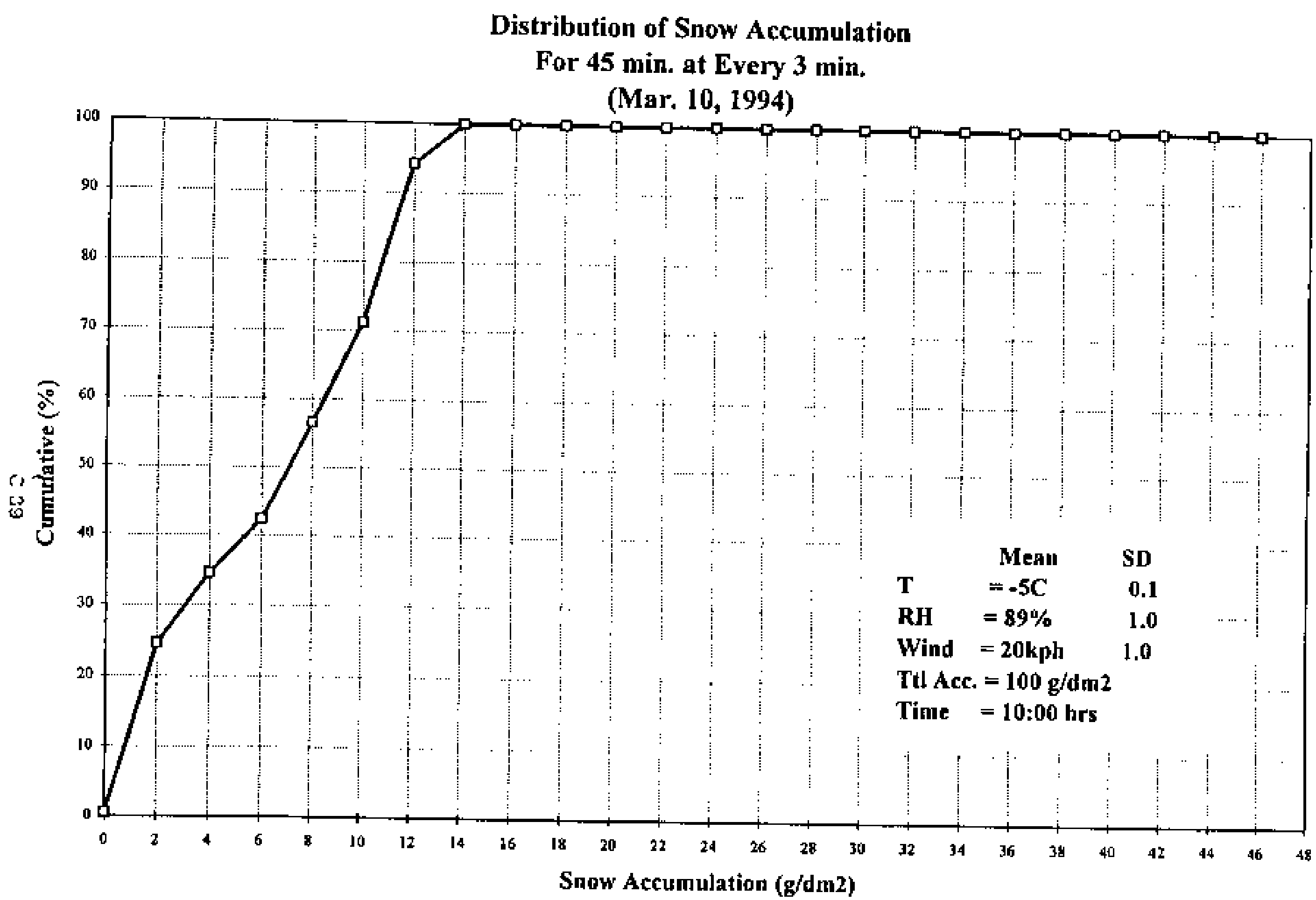
18/8/95 16:20

JAN2794.XLS


Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Feb. 12, 1994)
Cumulative (%)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
Snow Accumulation (g/dm2)
Mean SD
T = -8C 1.6
RH = 86% 4.0
Wind = 10kph 2.0
Ttl Acc. = 94 g/dm2
Time = 08:03 hrs

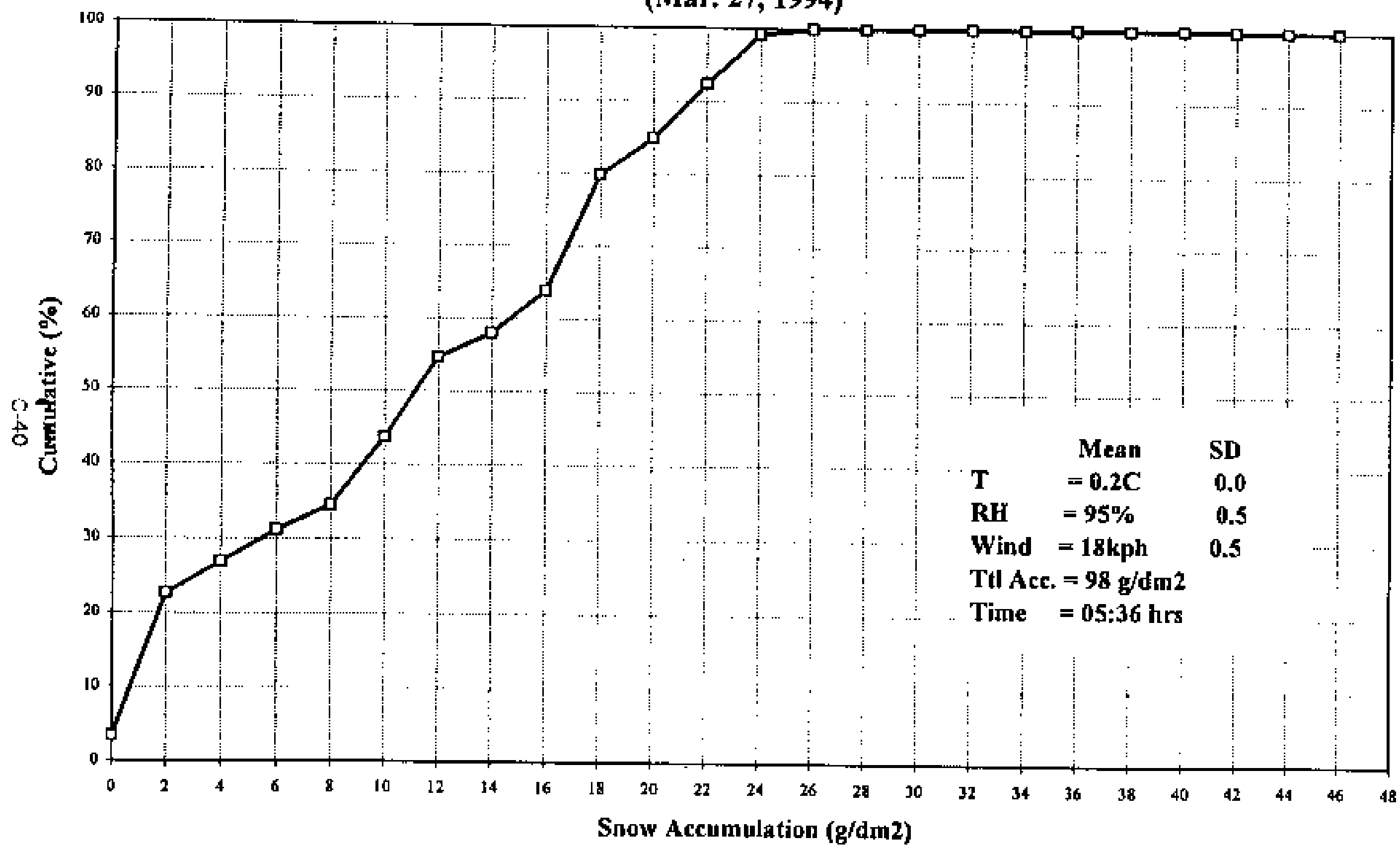
Distribution for Snow Accumulation For 45 min. at Every 3 min. (Feb. 23, 1994)



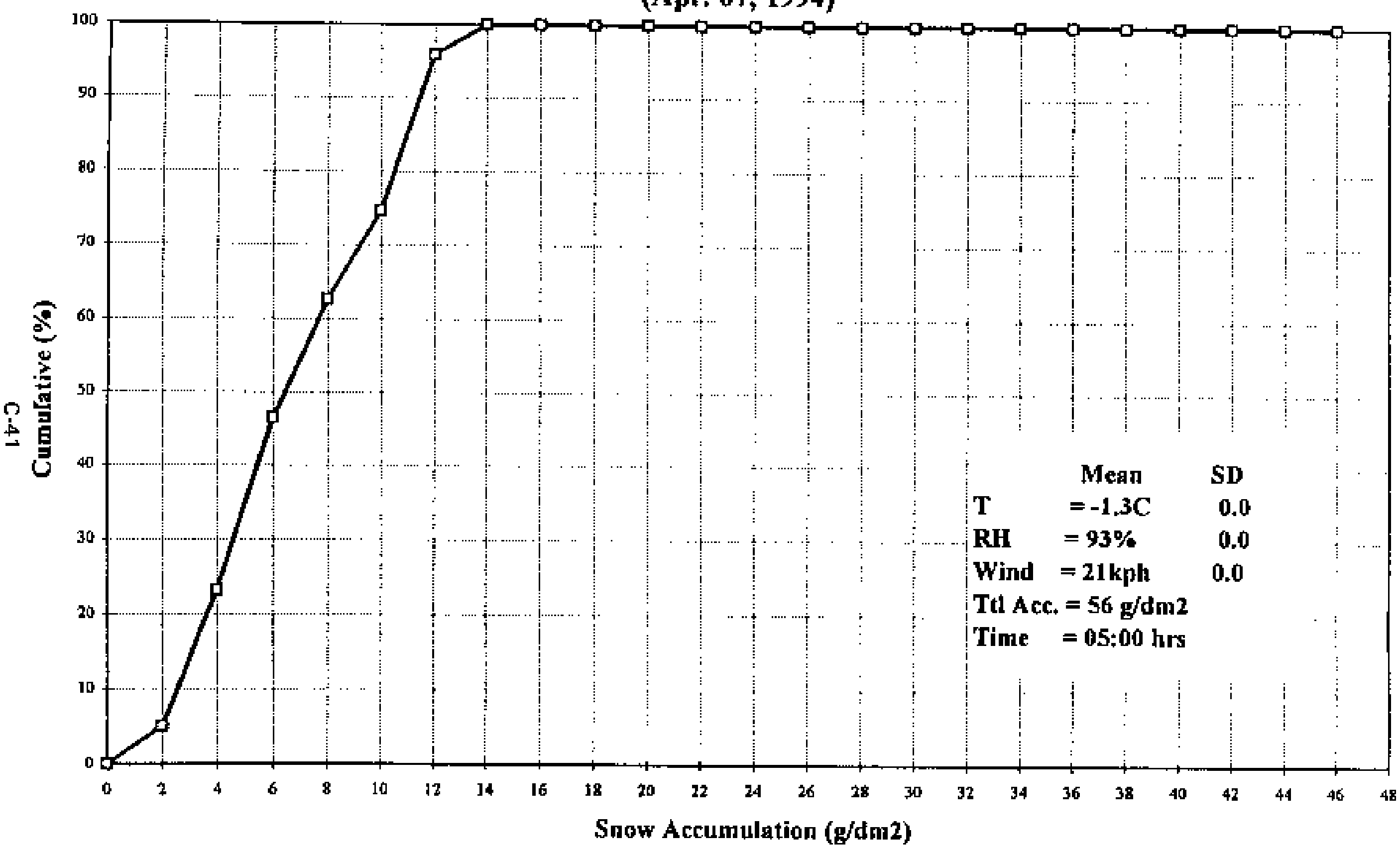


Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Mar. 10, 1994)
Cumulative (%)
Snow Accumulation (g/dm2)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
Mean
SD
T = -5C 0.1
RH = 89% 1.0
Wind = 20kph 1.0
Ttl Acc. = 100 g/dm2
Time = 10:00 hrs

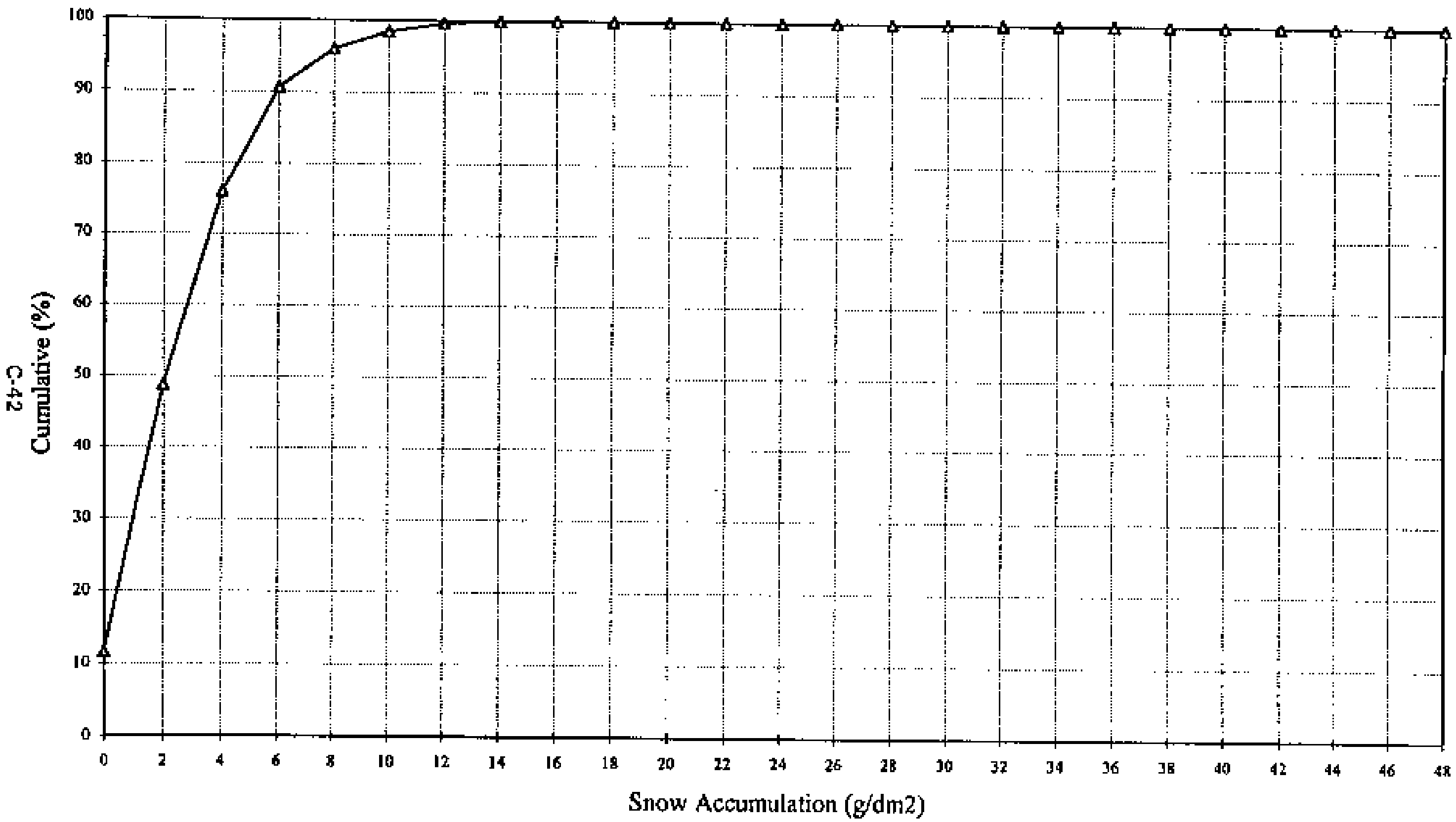
Distribution of Snow Accumulation For 45 min. at Every 3 min. (Mar. 27, 1994)



Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Apr. 07, 1994)



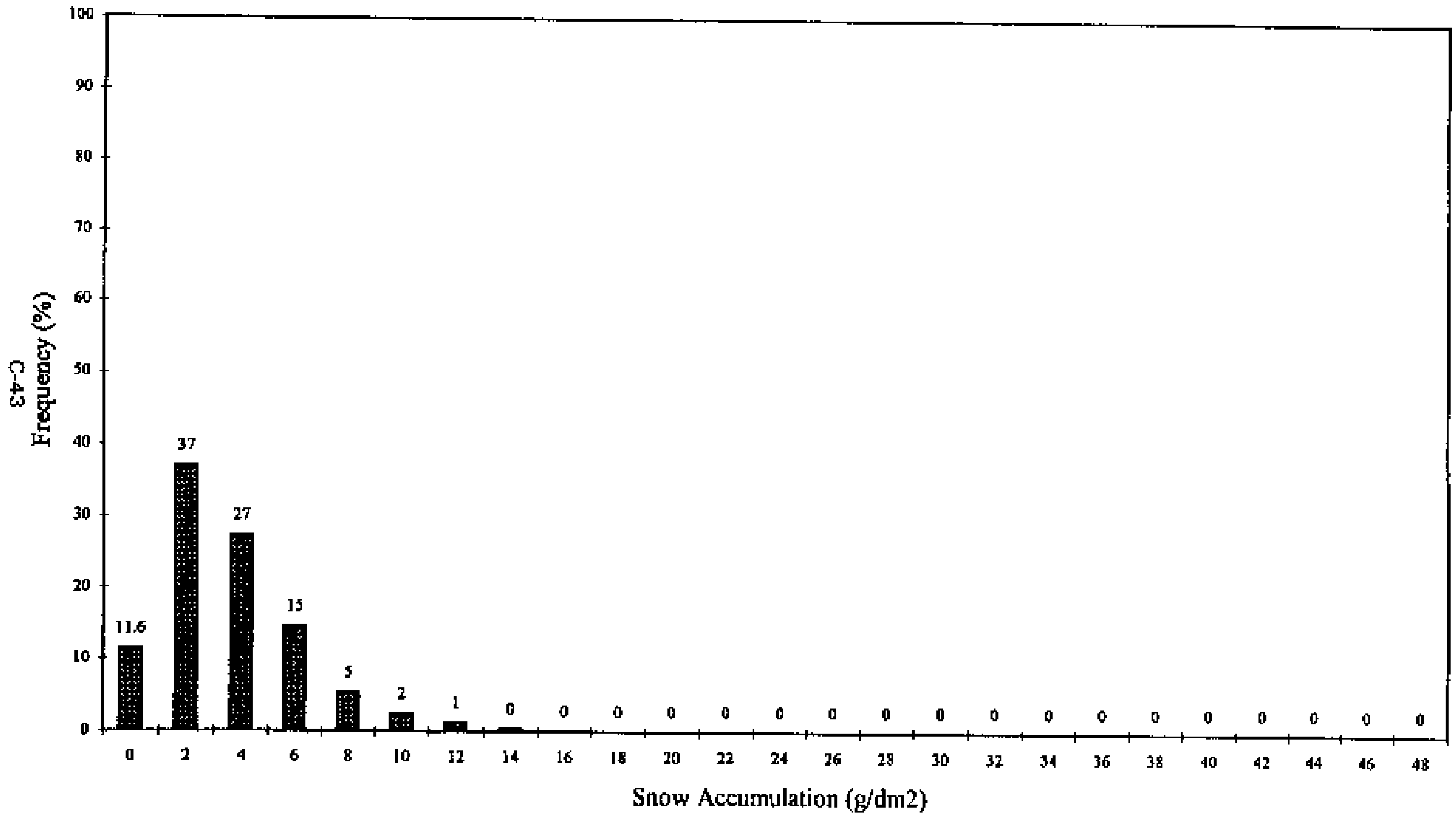
Distribution for Snow Accumulation
For 21 min. at Every 3 min.
For 1994/1995 Winter



18/8/95 15:25

MHIST95.XLS

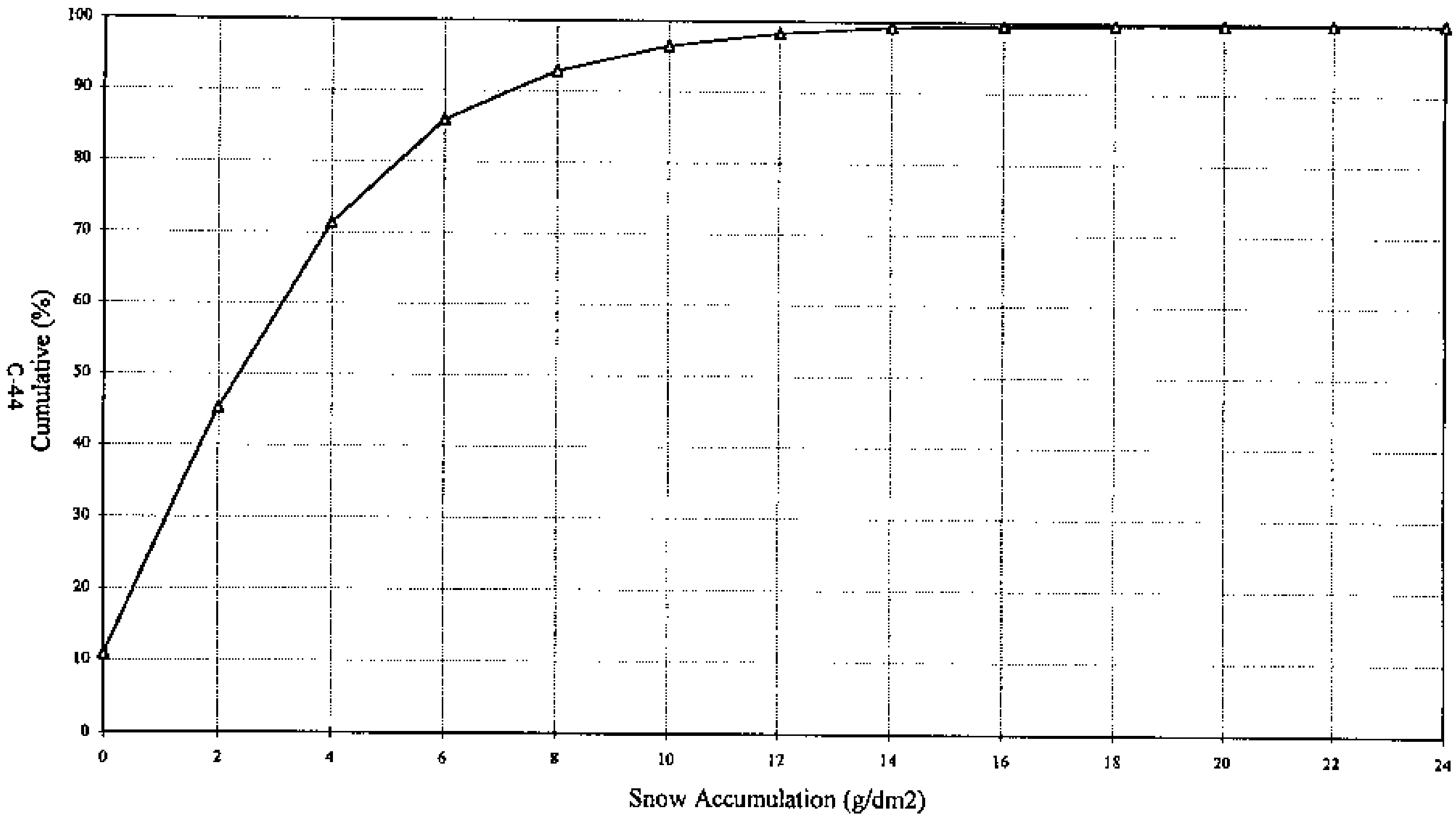
Histogram for Snow Accumulation
For 21 min. at Every 3 min.
For 1994/1995 Winter



18/8/95 11:36

MHIST95.XLS

Distribution for Snow Accumulation
For 21 min. at Every 3 min.
For 1993/94-1994/95 Winters



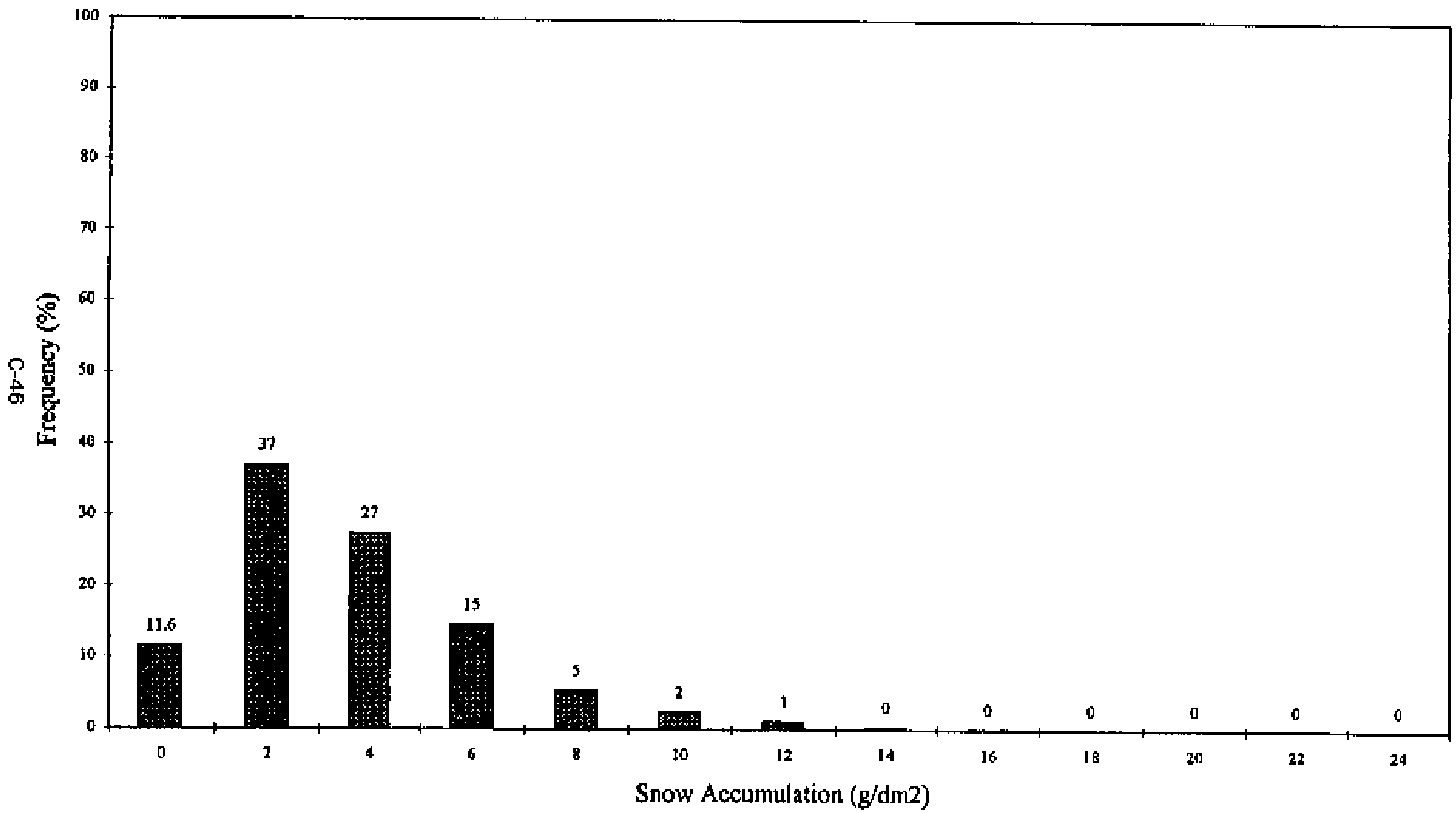
18/8/95 15:25

MHIST95.XLS

MOVING AVERAGE
1994/1995

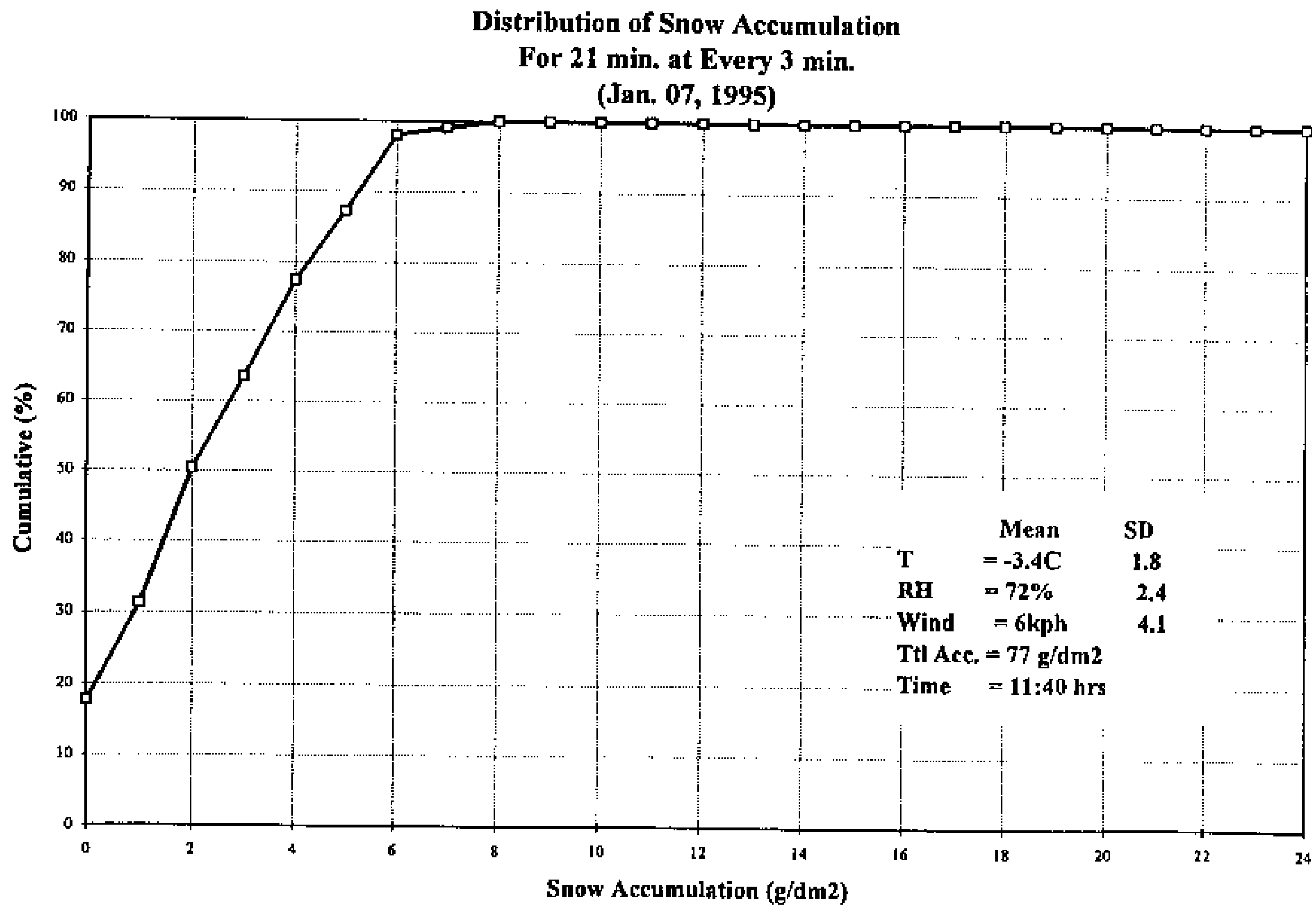
RANGE	950107	950112	950204	950211	950216	950224	950227	950306	950308A	950308B	950308C	SUM	%	CUMUL.
0	100	16	116	123	0	85	44	23	0	0	3	510	11.6	11.6
1	76	86	117	118	7	41	101	93	3	40	58	740	16.8	28.4
2	108	115	34	129	14	151	121	14	12	26	164	888	20.2	48.6
3	74	91	26	53	53	36	152	13	22	31	83	634	14.4	63.1
4	78	77	13	47	67	29	121	17	6	6	109	570	13.0	76.0
5	56	45	0	17	43	6	48	32	1	17	129	394	9.0	85.0
6	61	11	0	16	46	9	4	26	8	18	51	250	5.7	90.7
7	6	25	0	9	34	0	1	36	3	17	28	159	3.6	94.3
8	5	13	0	2	24	0	0	13	6	11	1	75	1.7	96.0
9	0	6	0	0	11	0	0	20	13	15	0	65	1.5	97.5
10	0	0	0	0	18	0	0	10	5	10	0	43	1.0	98.5
11	0	0	0	0	7	0	0	7	15	4	0	33	0.8	99.2
12	0	1	0	0	6	0	0	2	8	1	0	18	0.4	99.6
13	0	0	0	0	1	0	0	0	4	4	0	9	0.2	99.8
14	0	0	0	0	0	0	0	0	5	1	0	6	0.1	100.0
15	0	0	0	0	0	0	0	0	2	0	0	2	0.0	100.0
16	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0
17	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0
18	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0
19	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0
20	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0
21	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0
22	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0
23	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0
24	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0
												4396		

Histogram for Snow Accumulation For 21 min. at Every 3 min. For 1994/1995 Winter

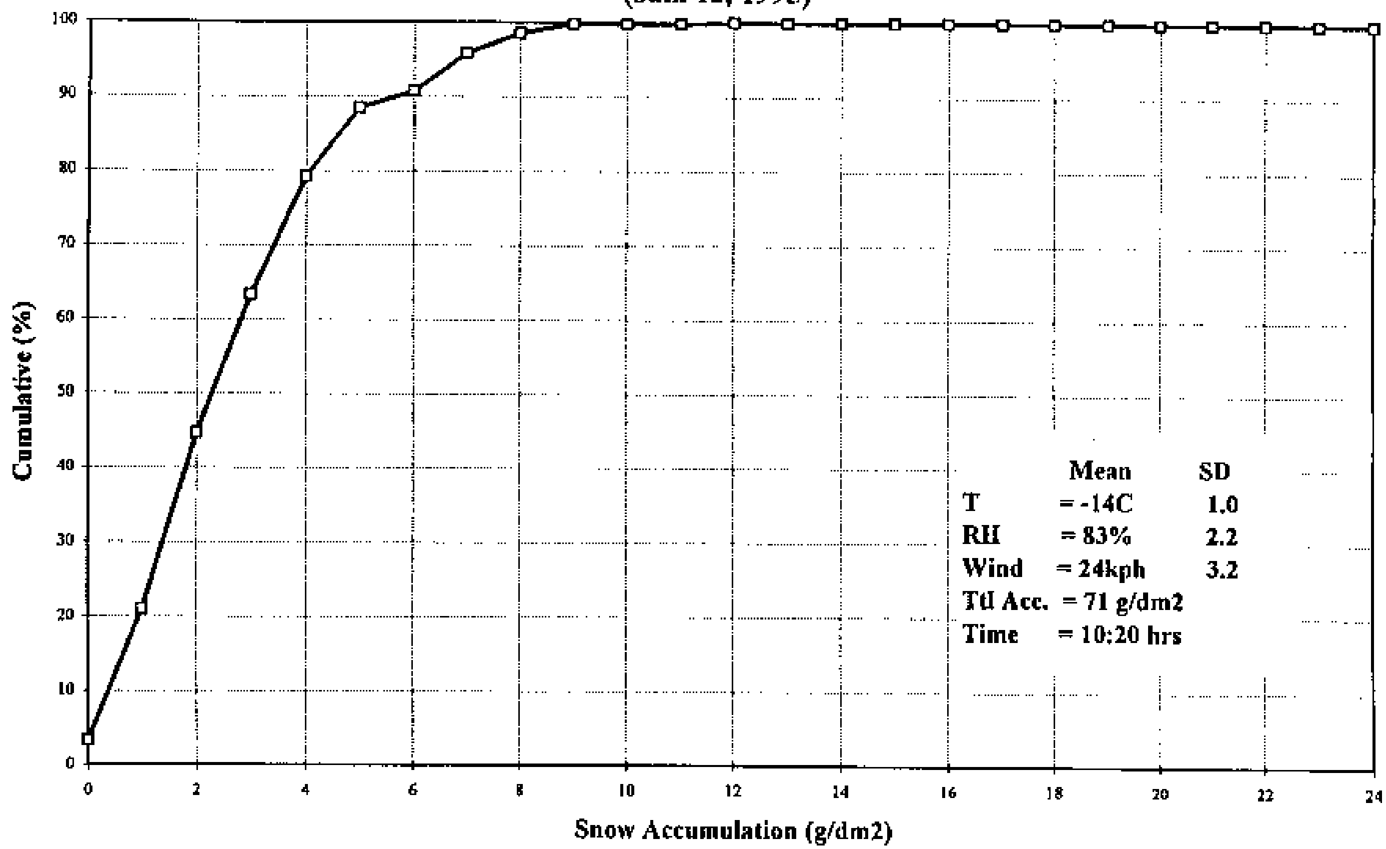


17/8/95 11:48

MHIST95.XLS


Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Jan. 07, 1995)
Cumulative (%)
Snow Accumulation (g/dm2)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12
14
16
18
20
22
24
Mean
SD
T = -3.4C 1.8
RH = 72% 2.4
Wind = 6kph 4.1
Ttl Acc. = 77 g/dm2
Time = 11:40 hrs

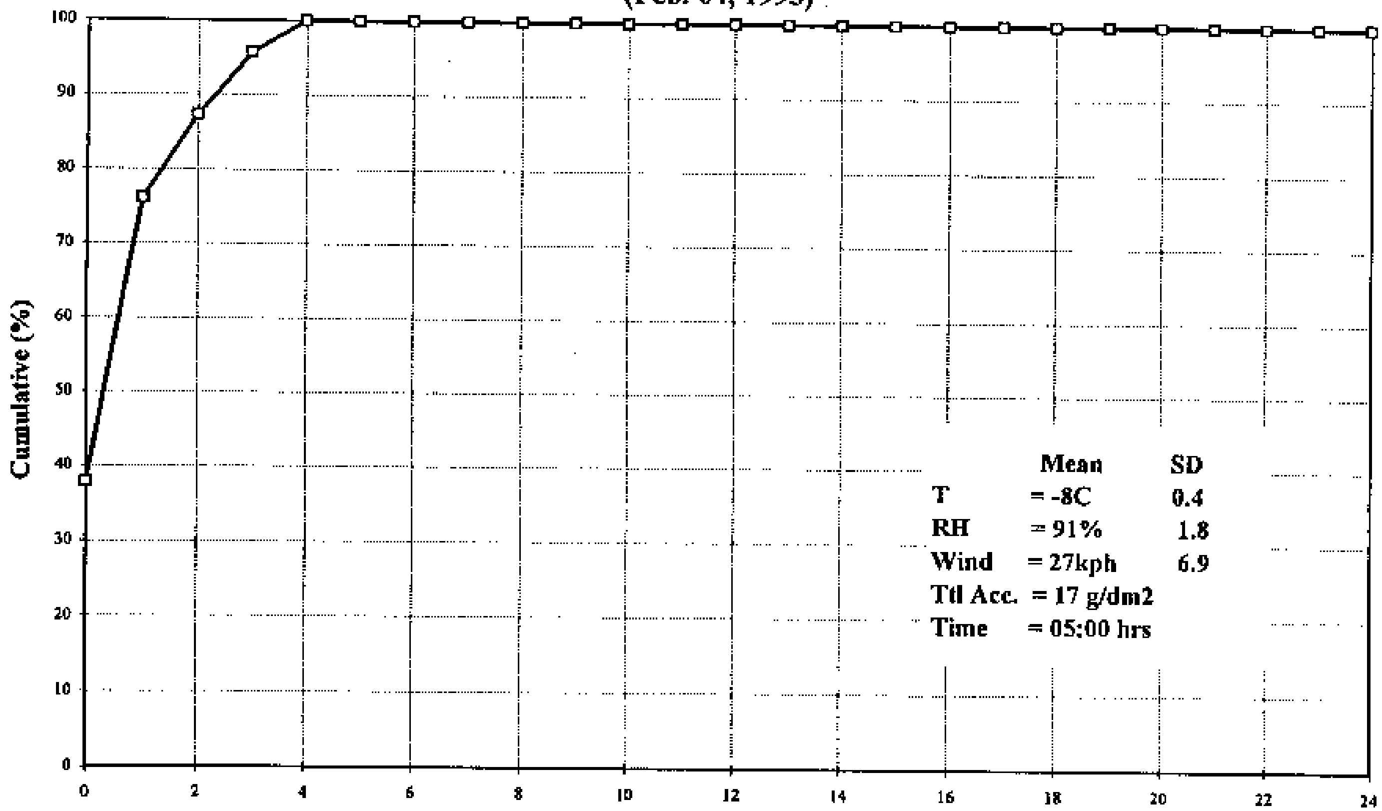
Distribution of Snow Accumulation For 21 min. at Every 3 min. (Jan. 12, 1995)



18/8/95 15:34

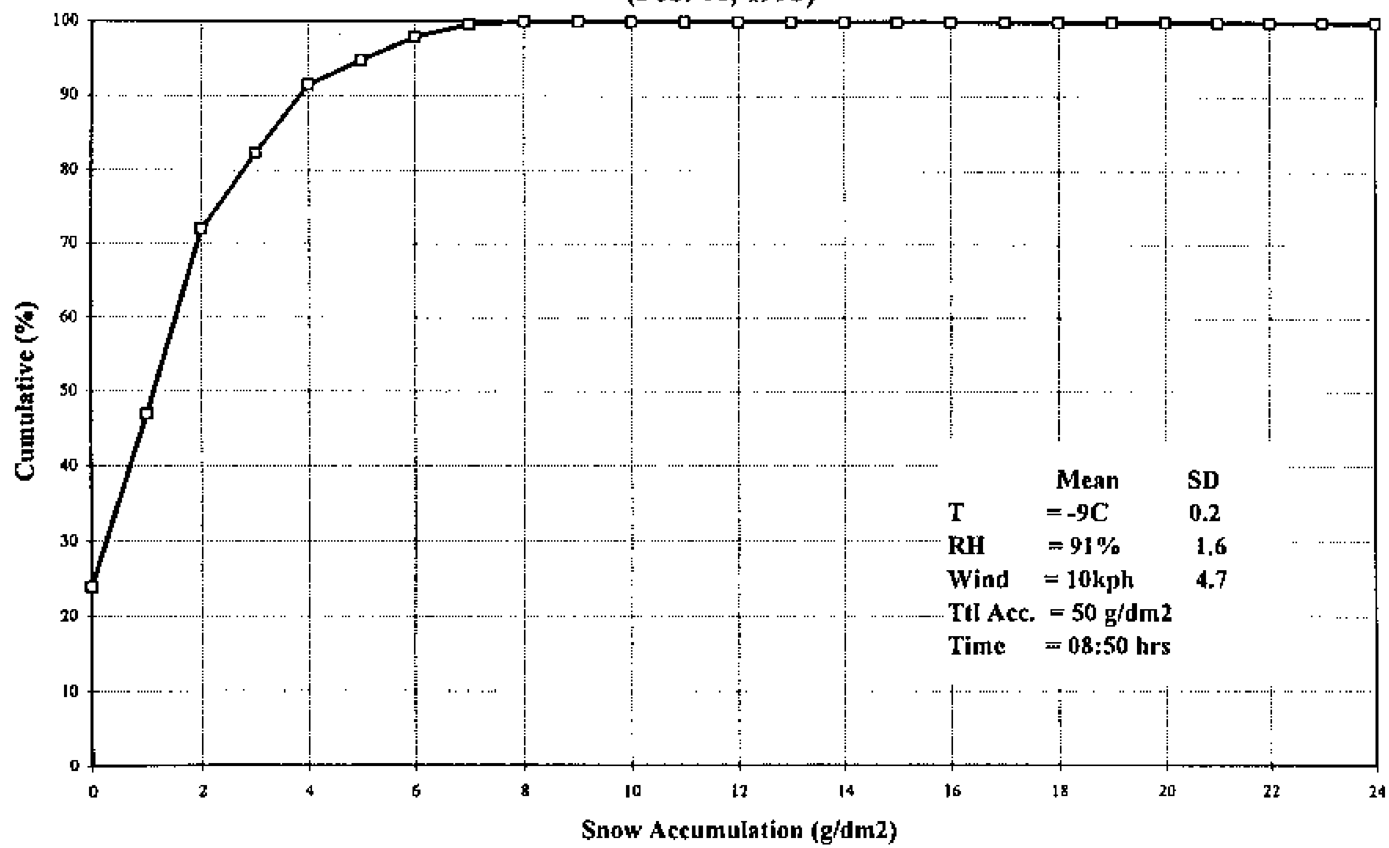
950112.XLS

Distribution of Snow Accumulation For 21 min. at Every 3 min. (Feb. 04, 1995)

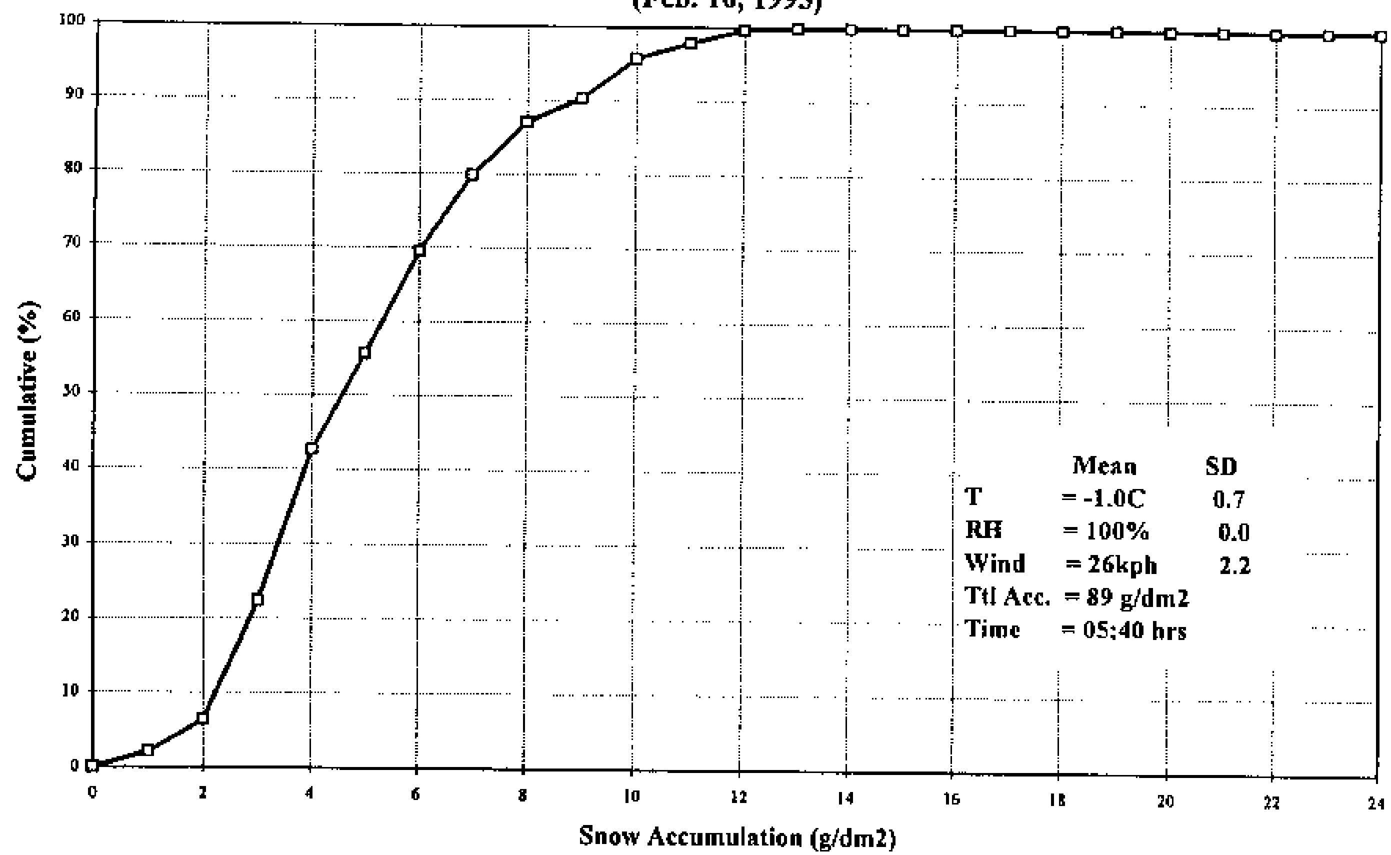


17/8/95 13:29 950204.XLS

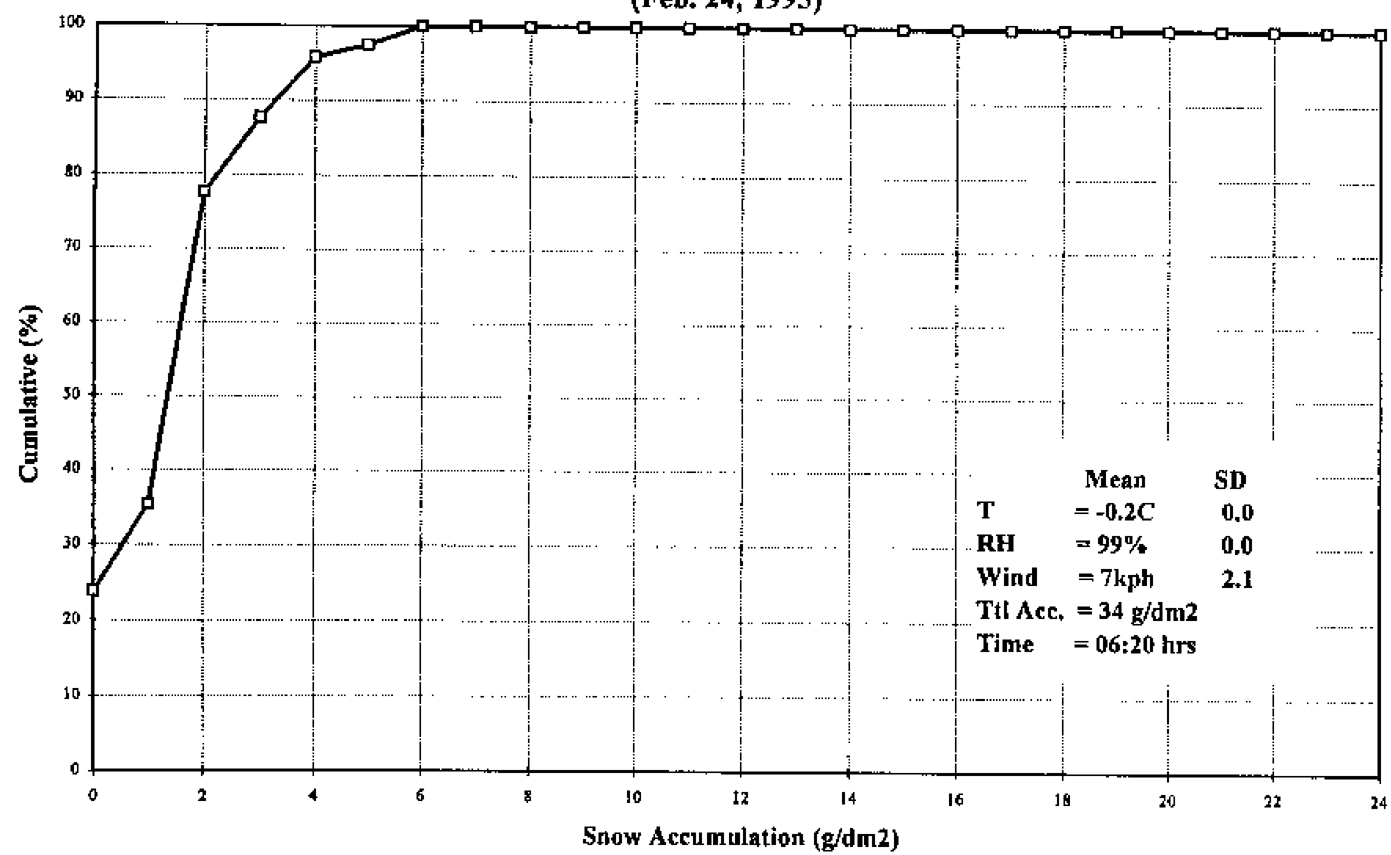
Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Feb. 11, 1995)



Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Feb. 16, 1995)



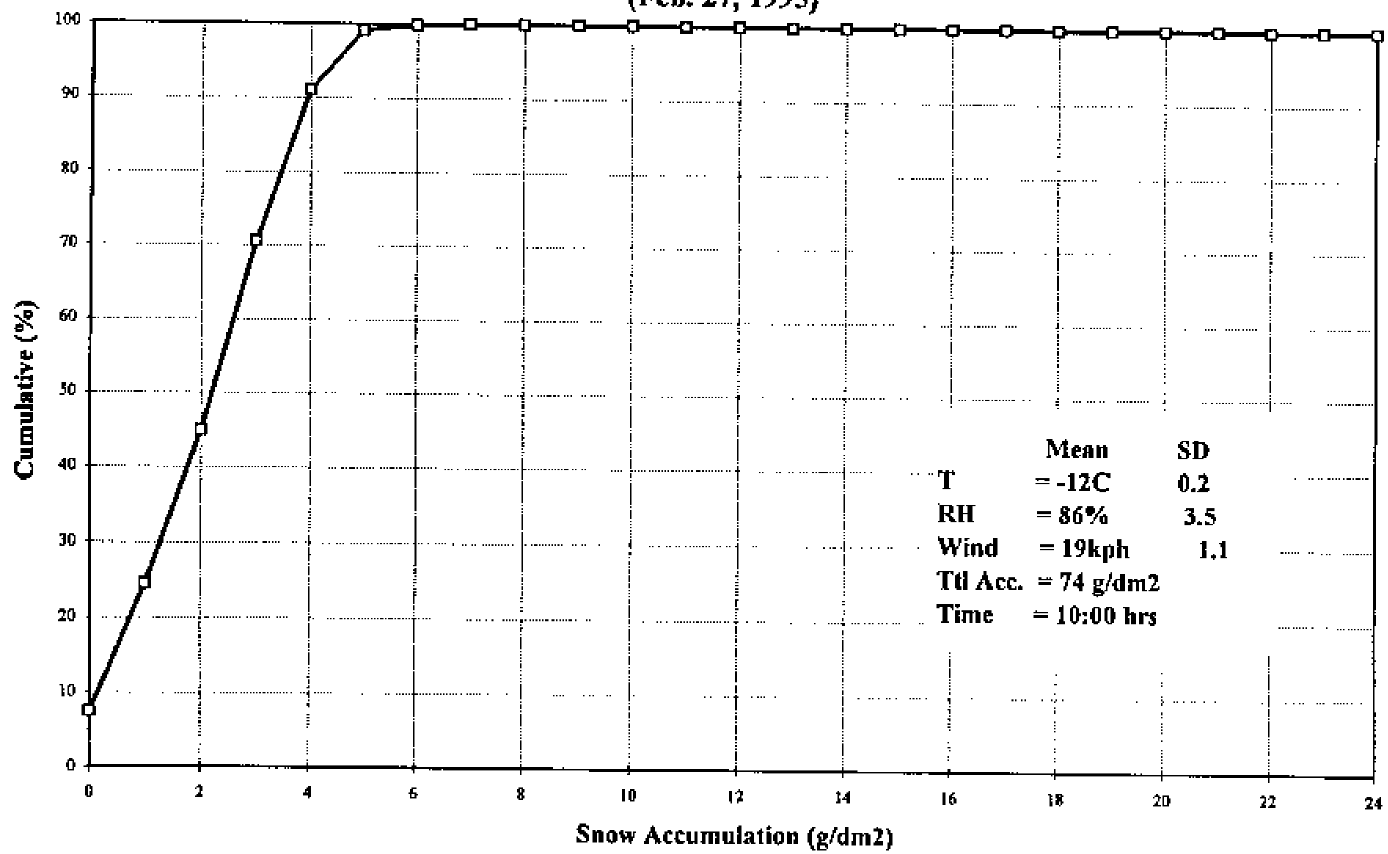
Distribution of Snow Accumulation For 21 min. at Every 3 min. (Feb. 24, 1995)



17/8/95 13:37

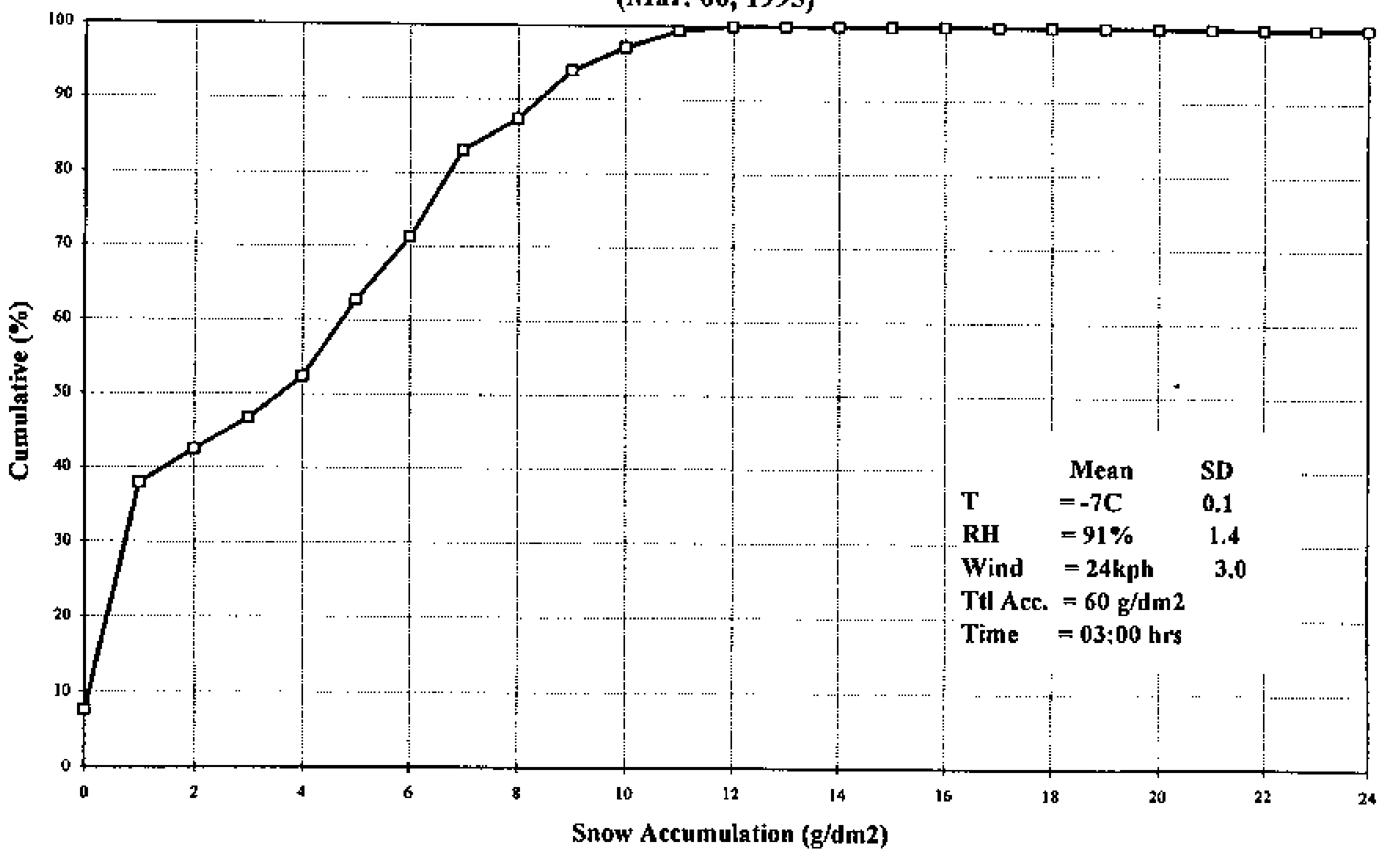
950224.XLS

Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Feb. 27, 1995)

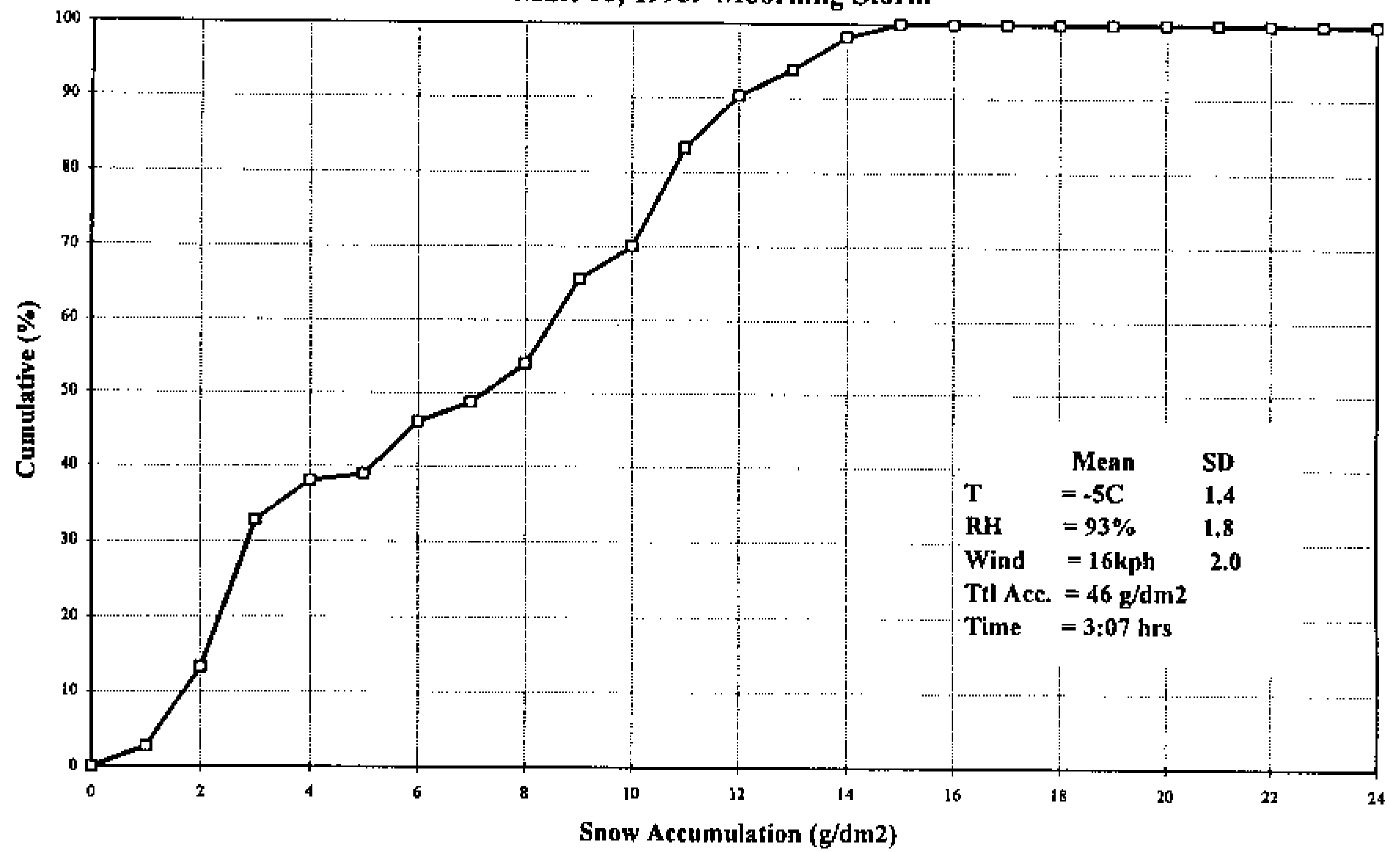


18/8/95 16:14 950227.XLS

Distribution of Snow Accumulation
For 21 min. at Every 3 min.
(Mar. 06, 1995)



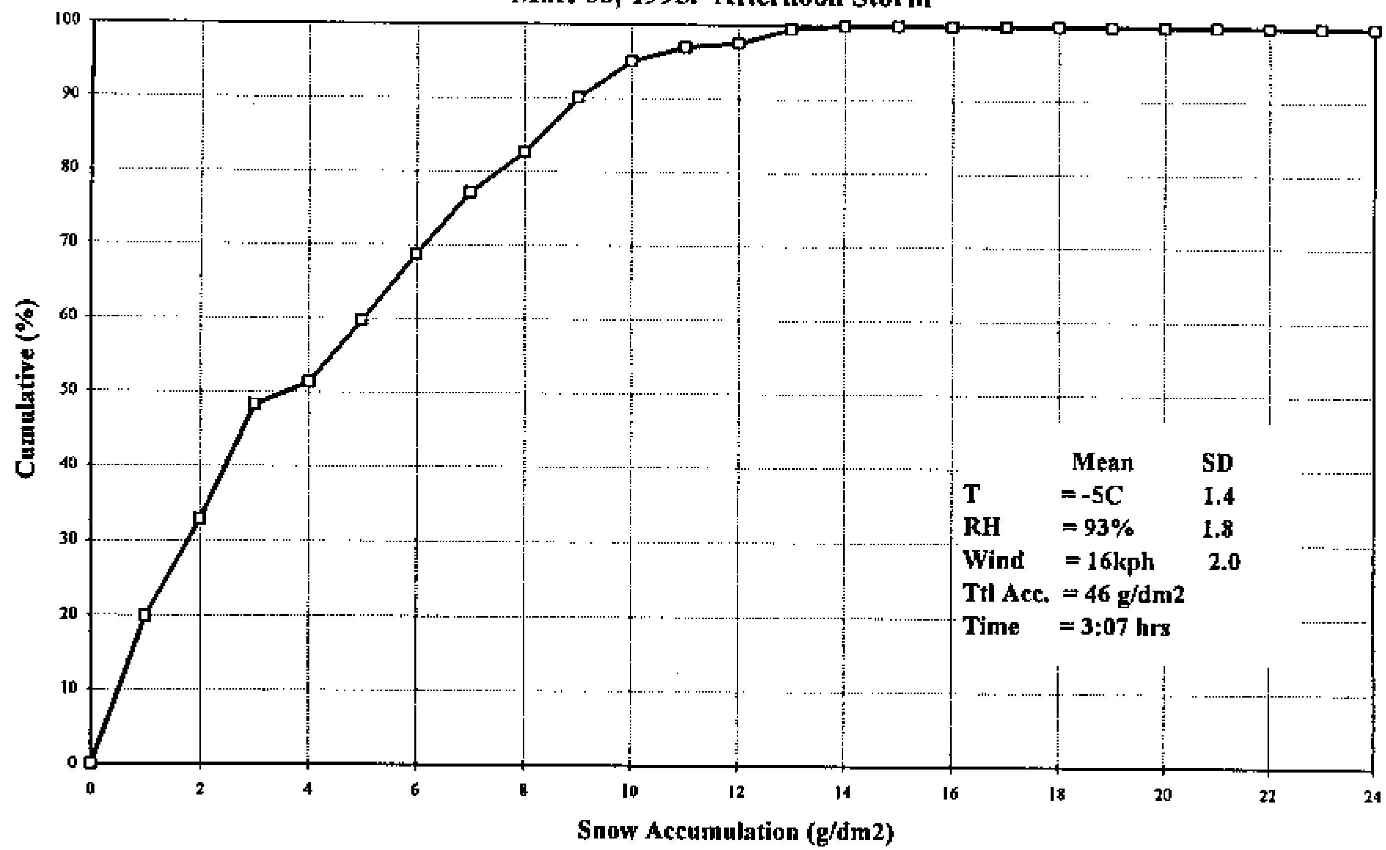
Distribution of Snow Accumulation
For 21 min. at Every 3 min.
Mar. 08, 1995. Moorning Storm



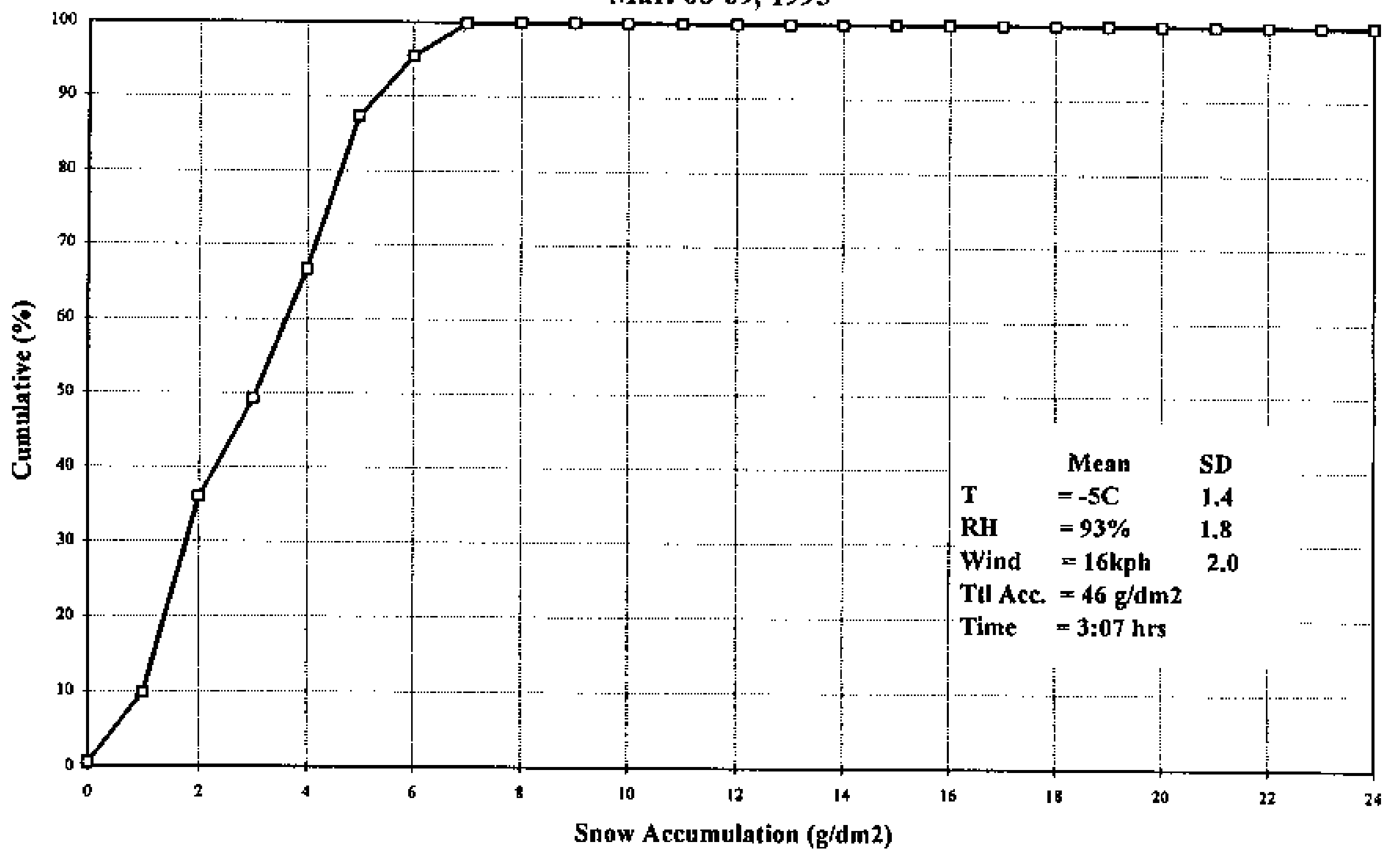
17/8/95 13:43

950308.XLS

Distribution of Snow Accumulation
For 21 min. at Every 3 min.
Mar. 08, 1995. Afternoon Storm



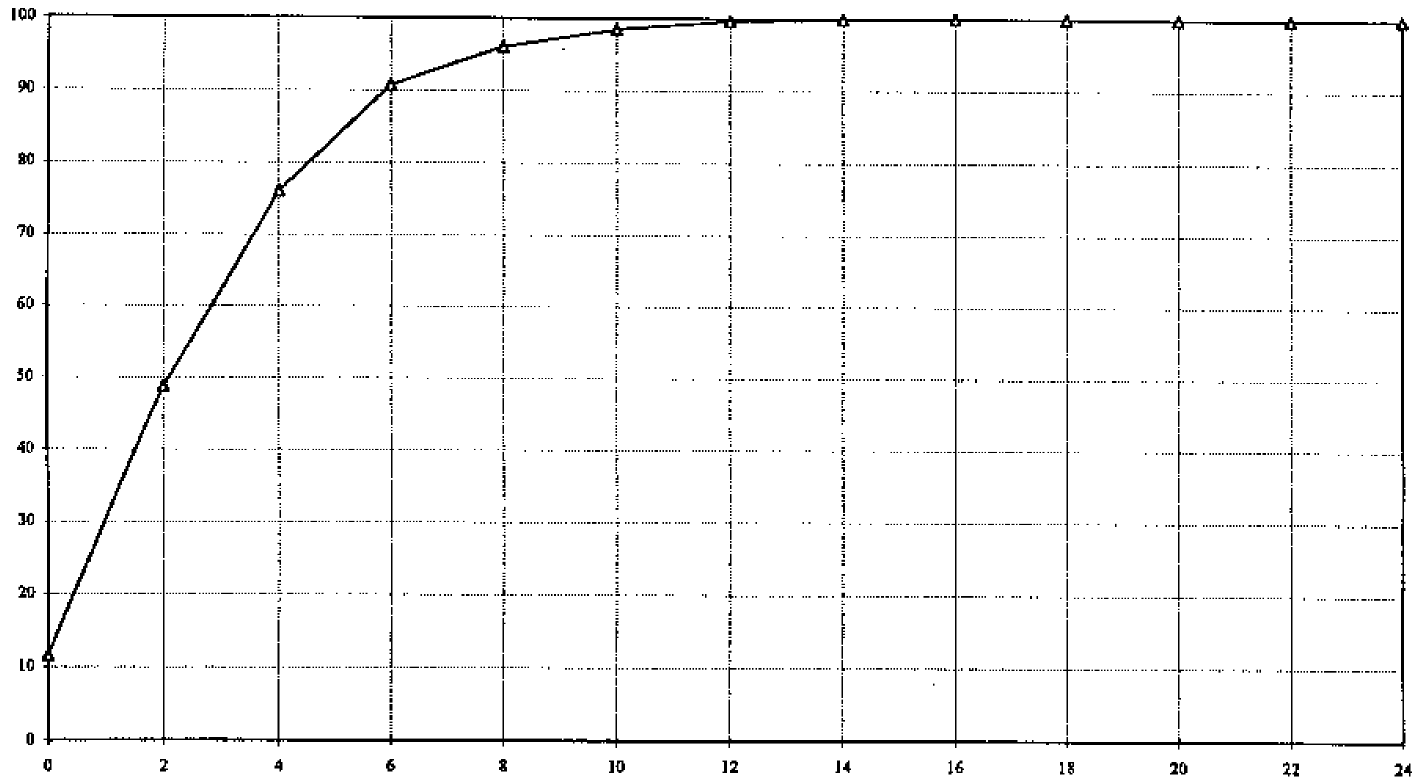
Distribution of Snow Accumulation
For 21 min. at Every 3 min.
Mar. 08-09, 1995



17/8/95 13:43

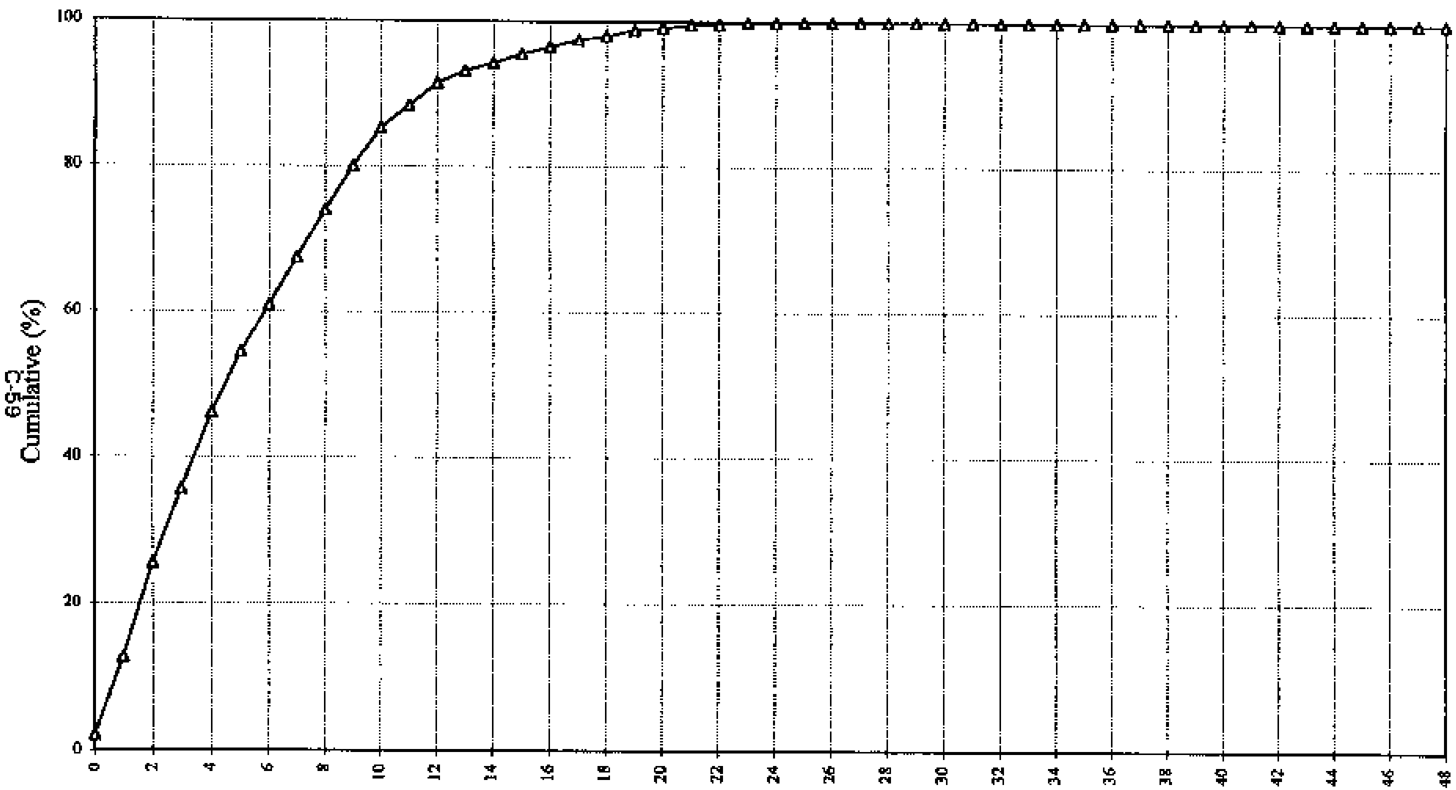
950308.XLS

Distribution for Snow Accumulation
For 21 min. at Every 3 min.
For 1994/1995 Winter



18/8/95 15:25 MHIST95.XLS

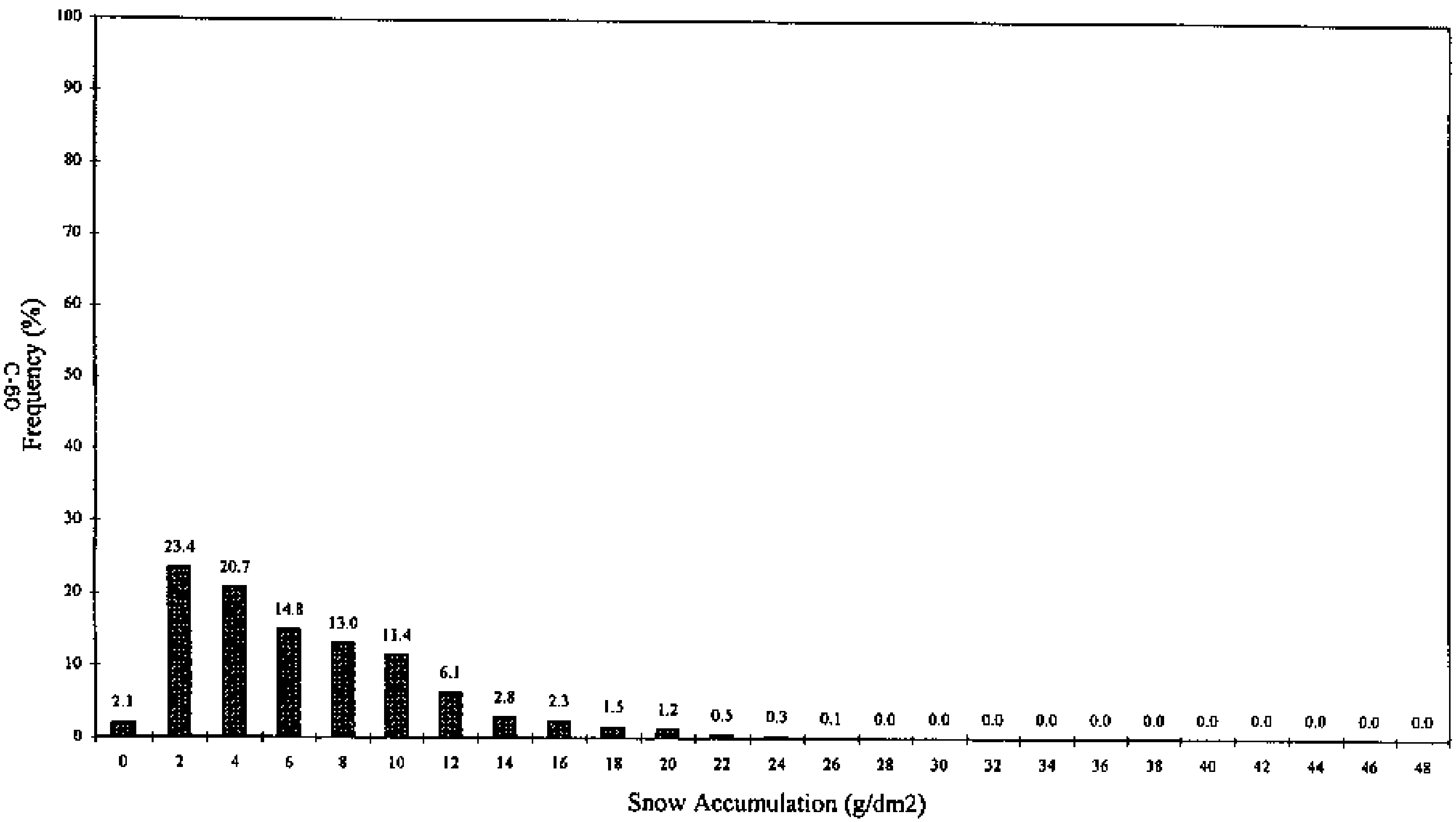
Distribution for Snow Accumulation
For 45 min. at Every 3 min.
For 1994/1995 Winter



18/8/95 14:32

MHIST95.XLS

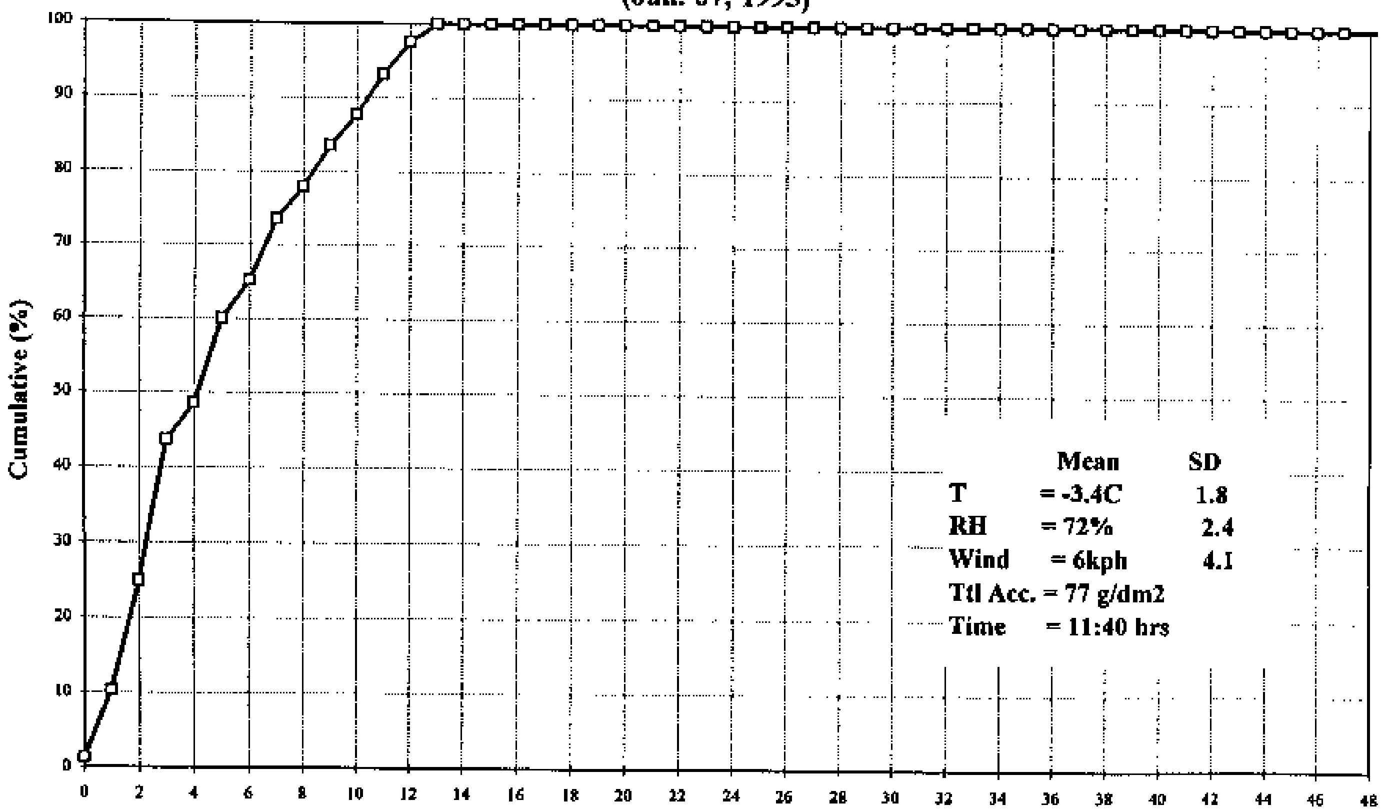
Histogram for Snow Accumulation
For 45 min. at Every 3 min.
For 1994/1995 Winter



18/8/95 14:28

MHIST95.XLS

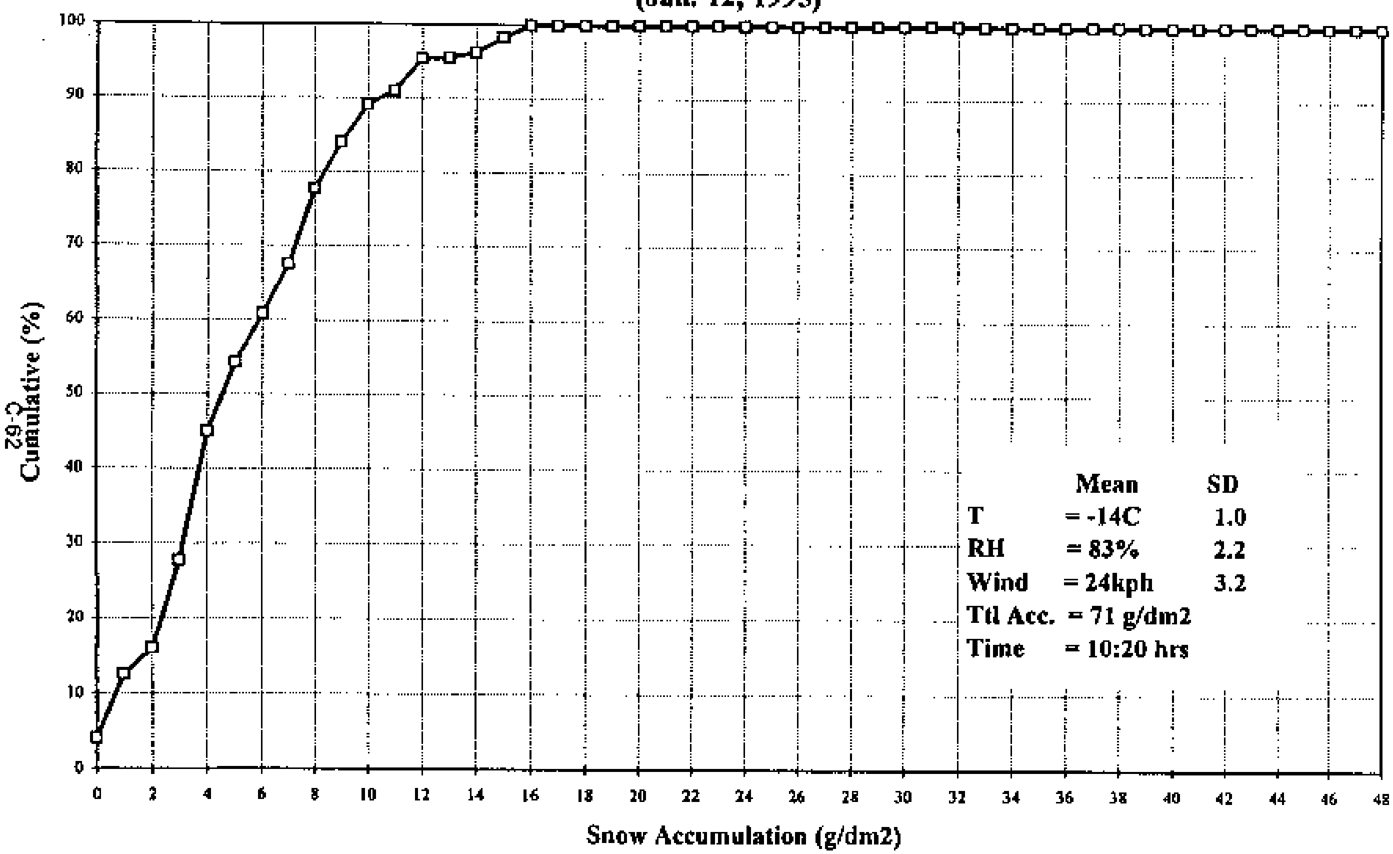
Distribution of Snow Accumulation For 45 min. at Every 3 min. (Jan. 07, 1995)



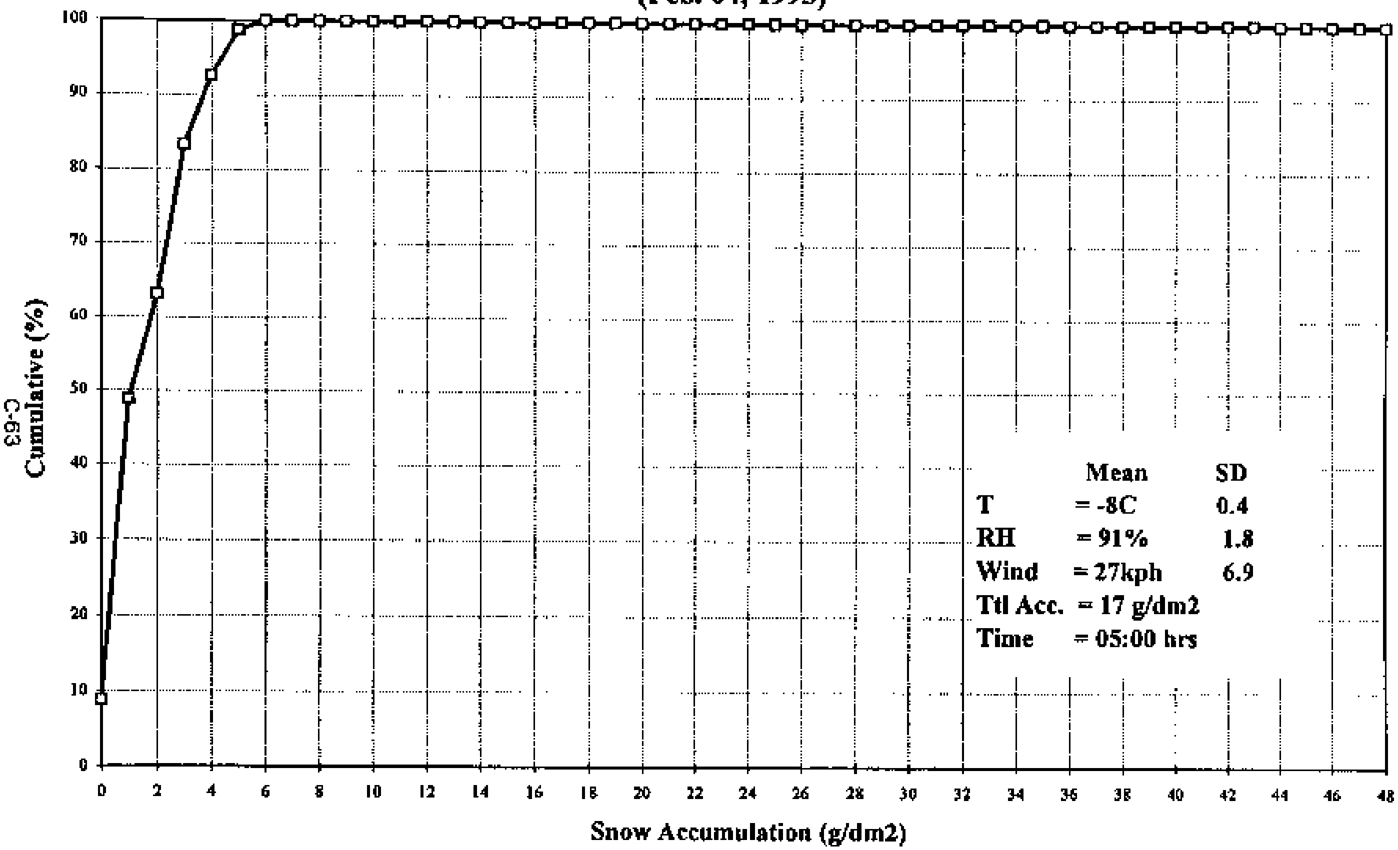
18/8/95 15:36

950107.XLS

Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Jan. 12, 1995)



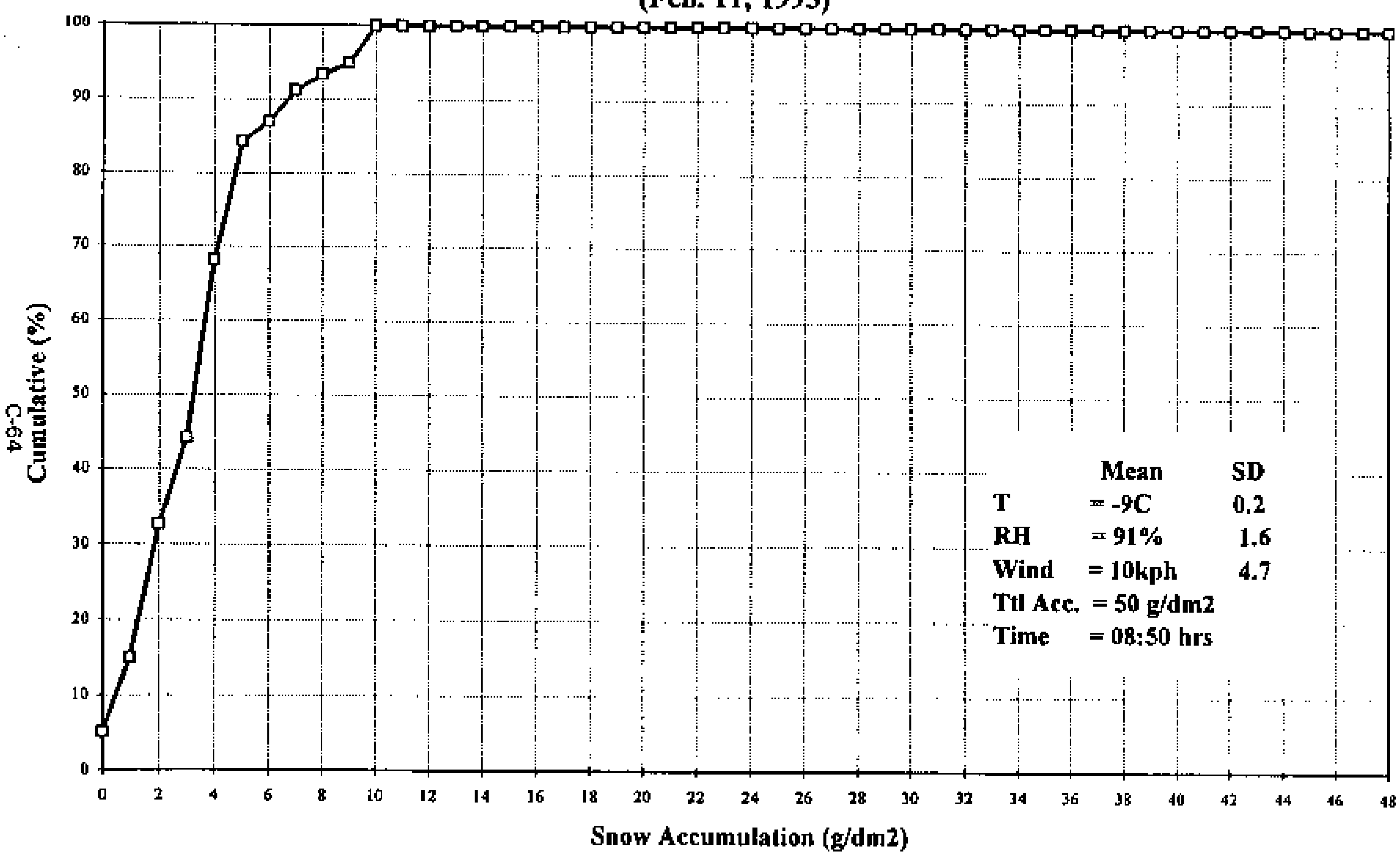
Distribution of Snow Accumulation For 45 min. at Every 3 min. (Feb. 04, 1995)



18/8/95 15:51

950204.XLS

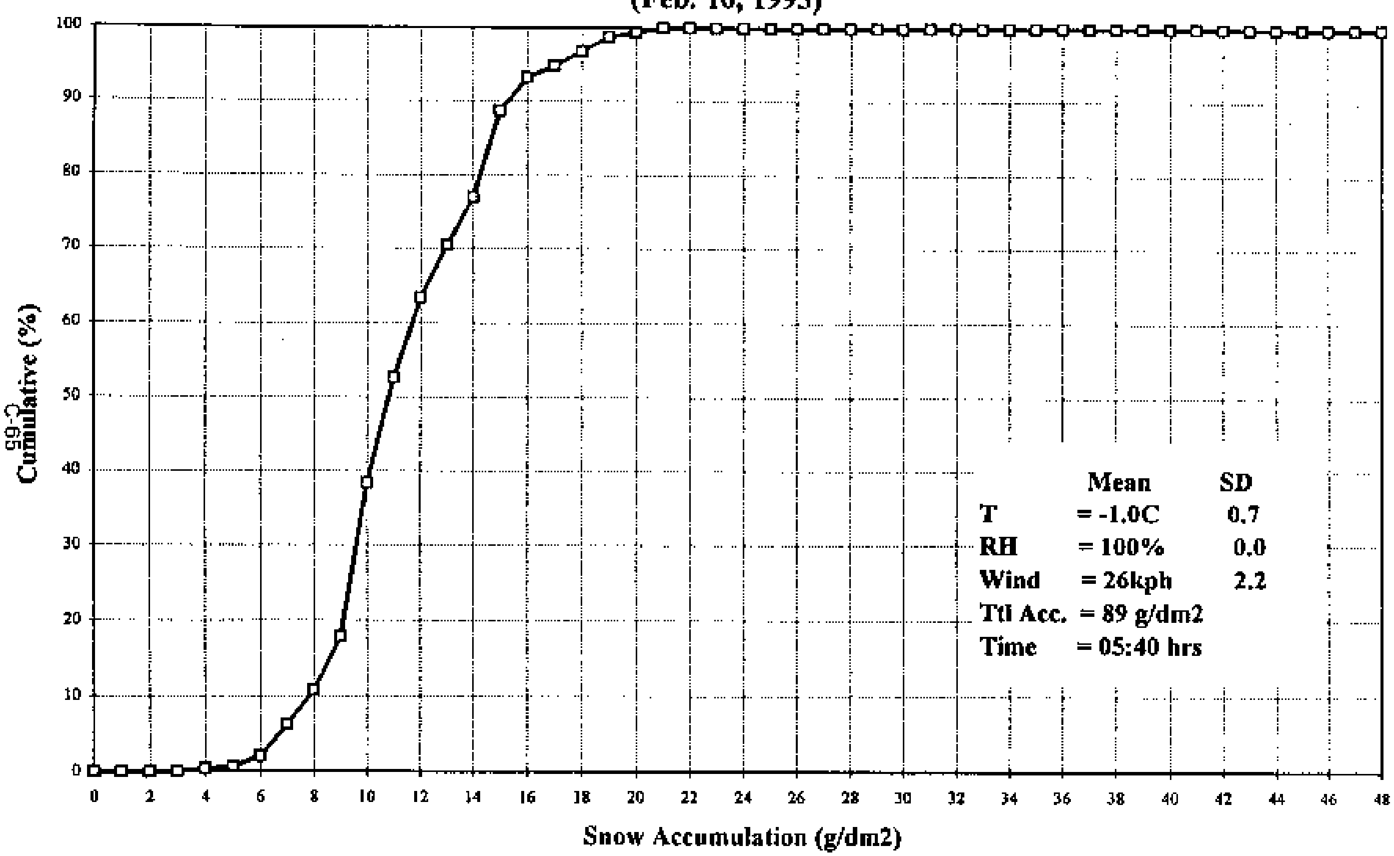
Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Feb. 11, 1995)

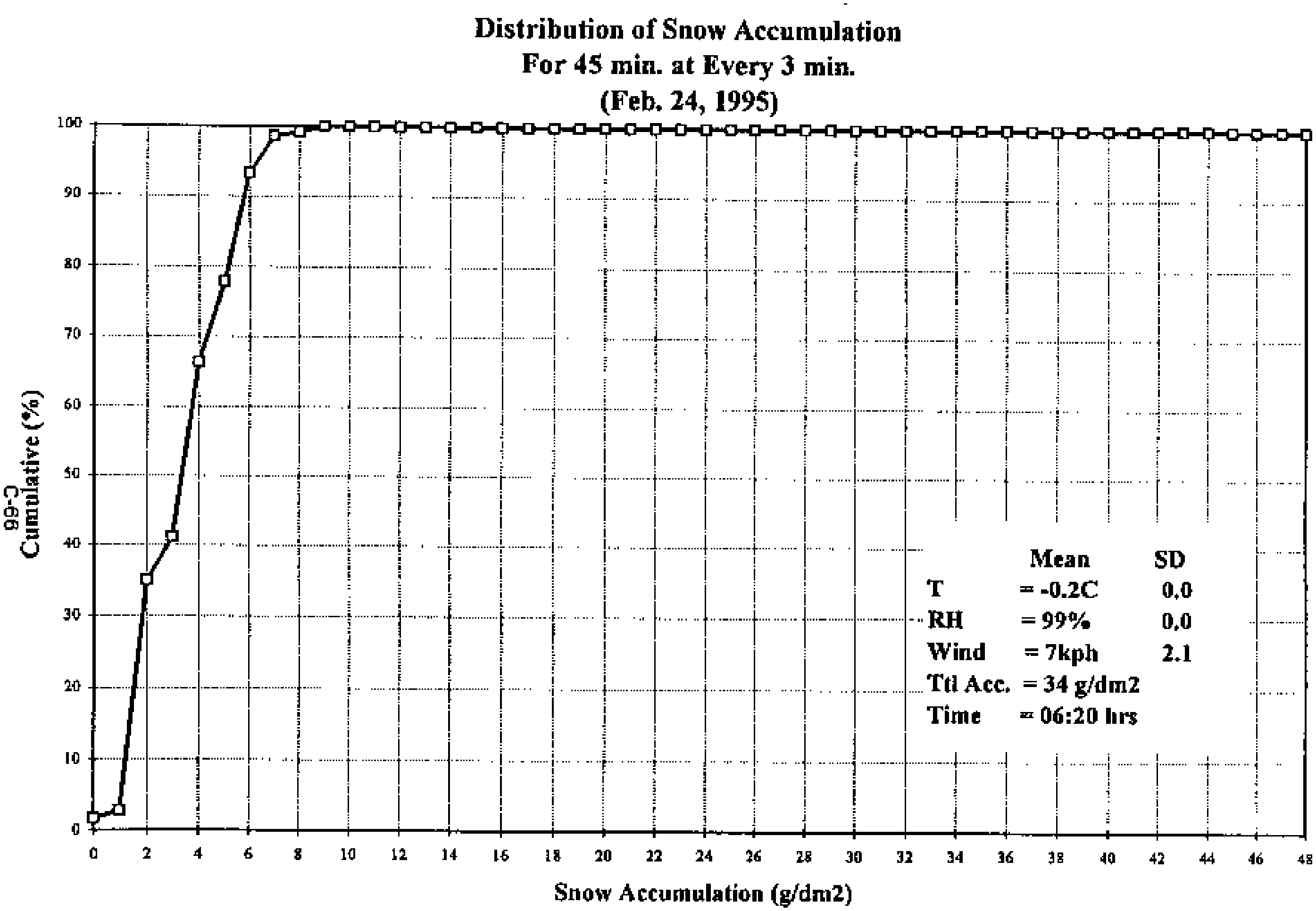


18/8/95 15:49

950211.XLS

Distribution of Snow Accumulation For 45 min. at Every 3 min. (Feb. 16, 1995)

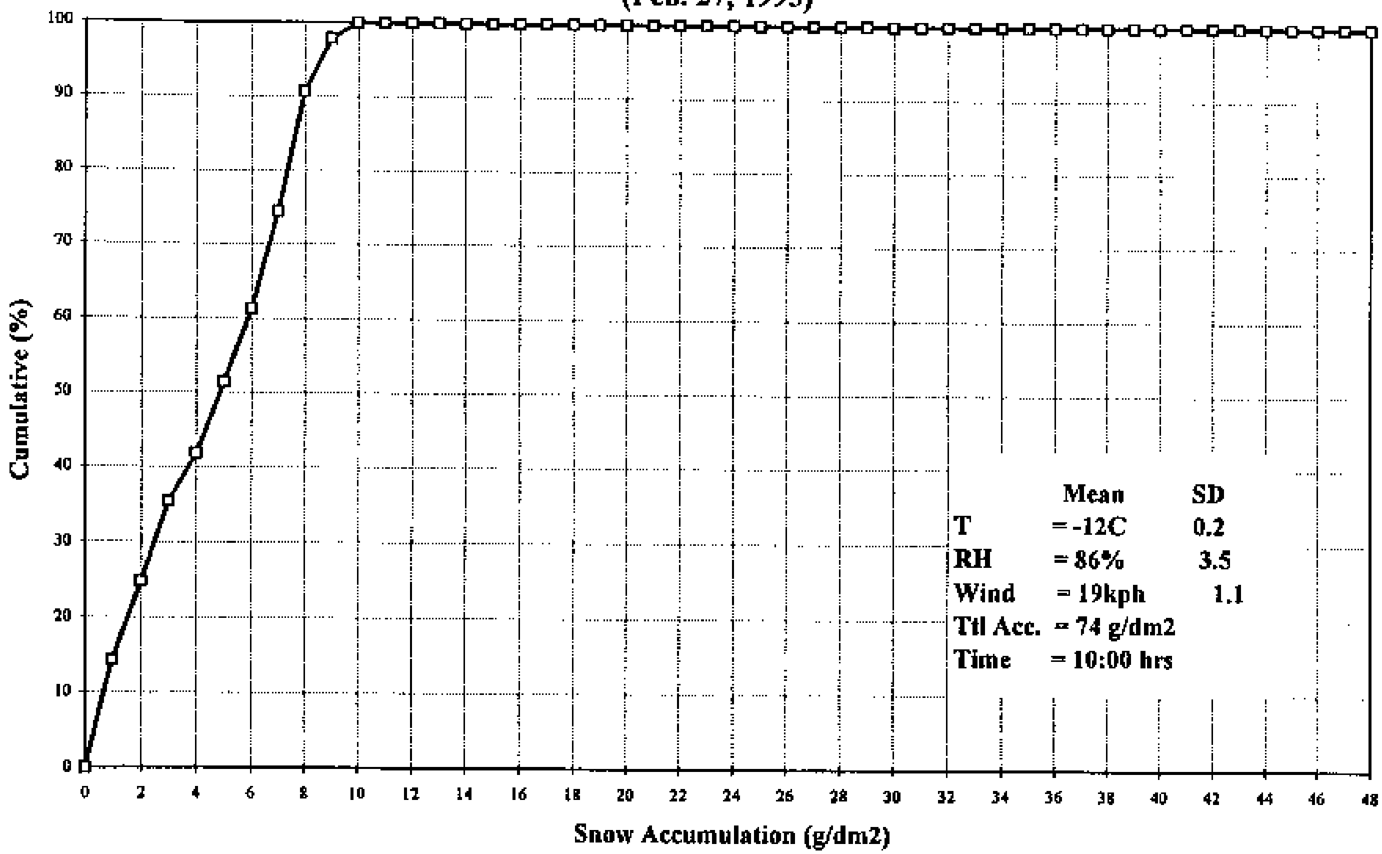




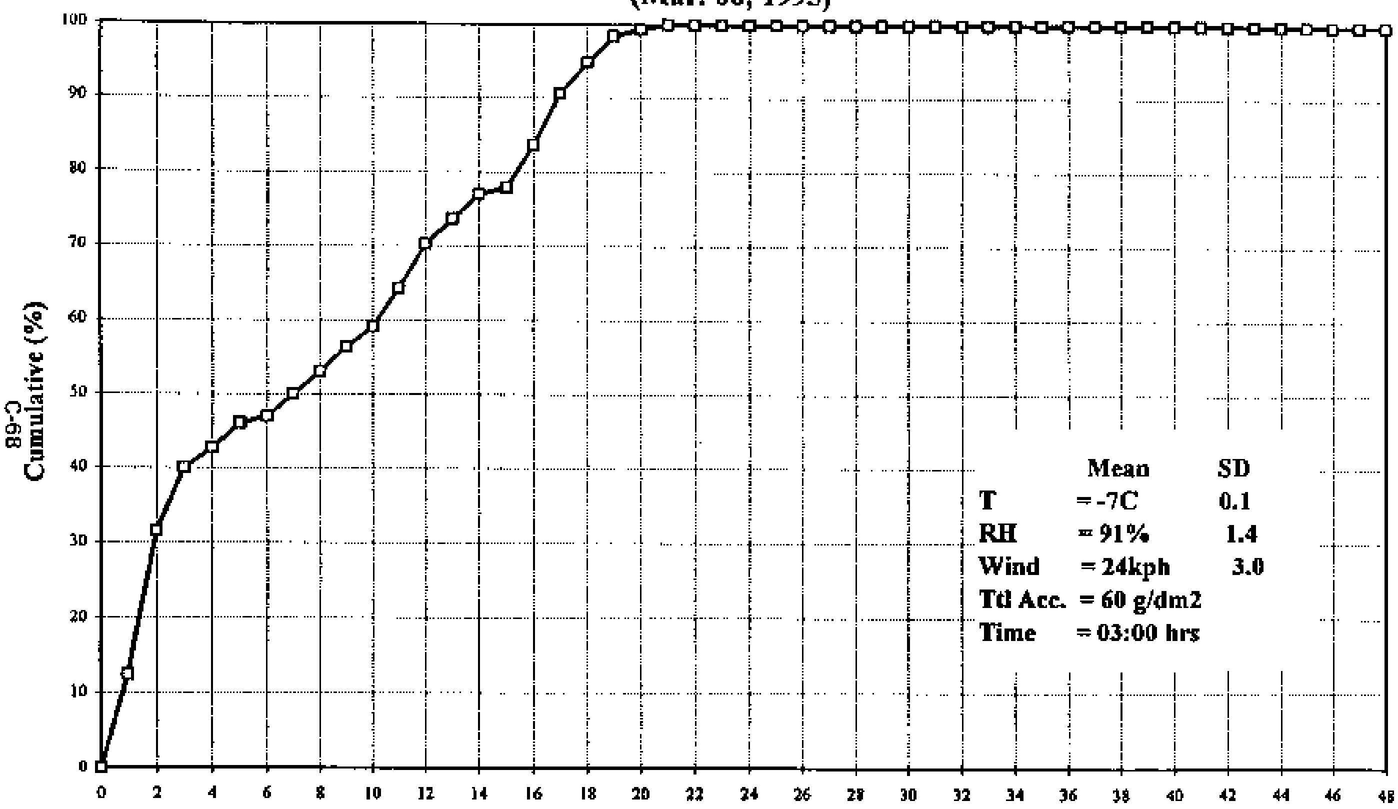
18/8/95 15:44

950224.XLS

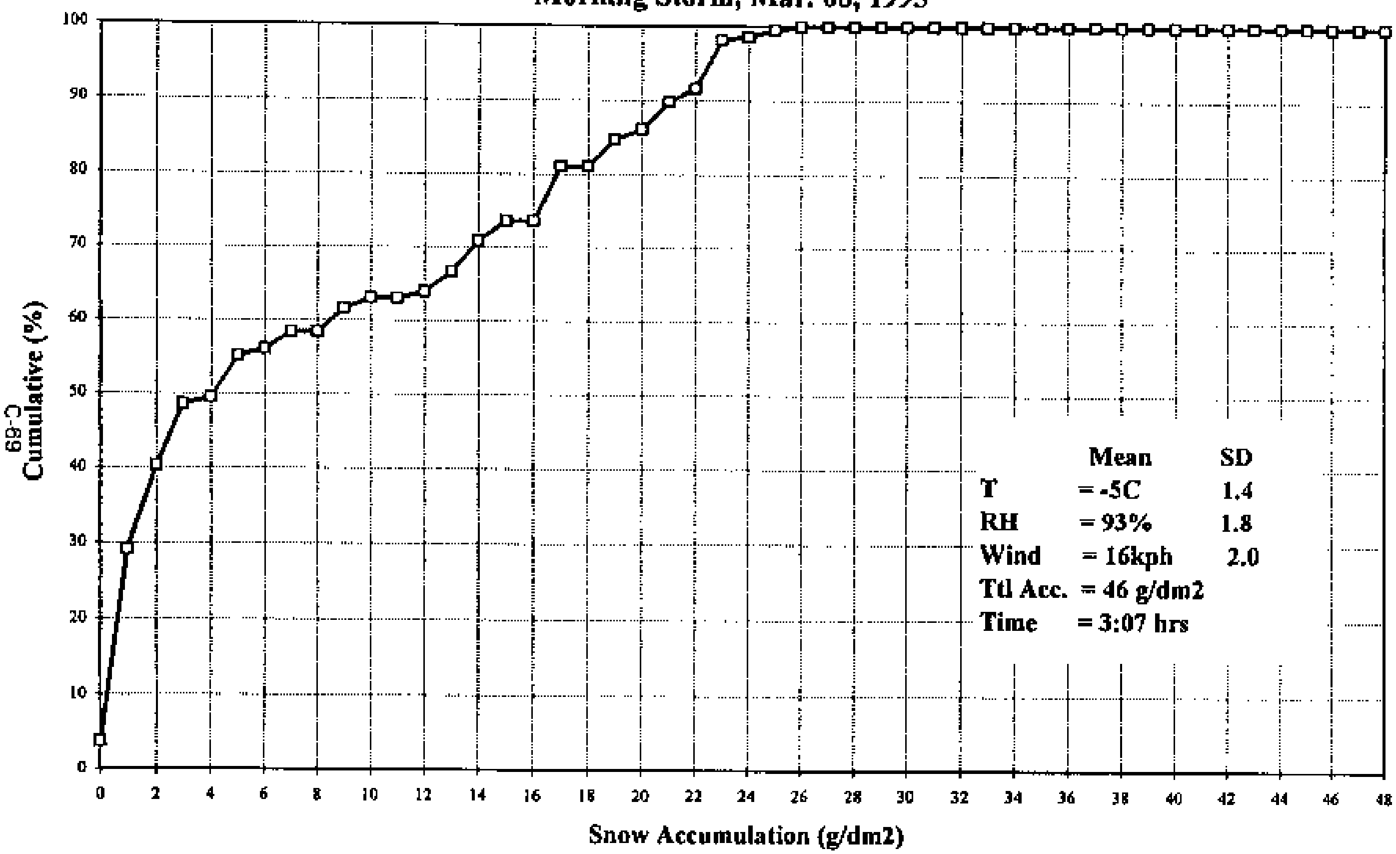
Distribution of Snow Accumulation For 45 min. at Every 3 min. (Feb. 27, 1995)



Distribution of Snow Accumulation
For 45 min. at Every 3 min.
(Mar. 06, 1995)



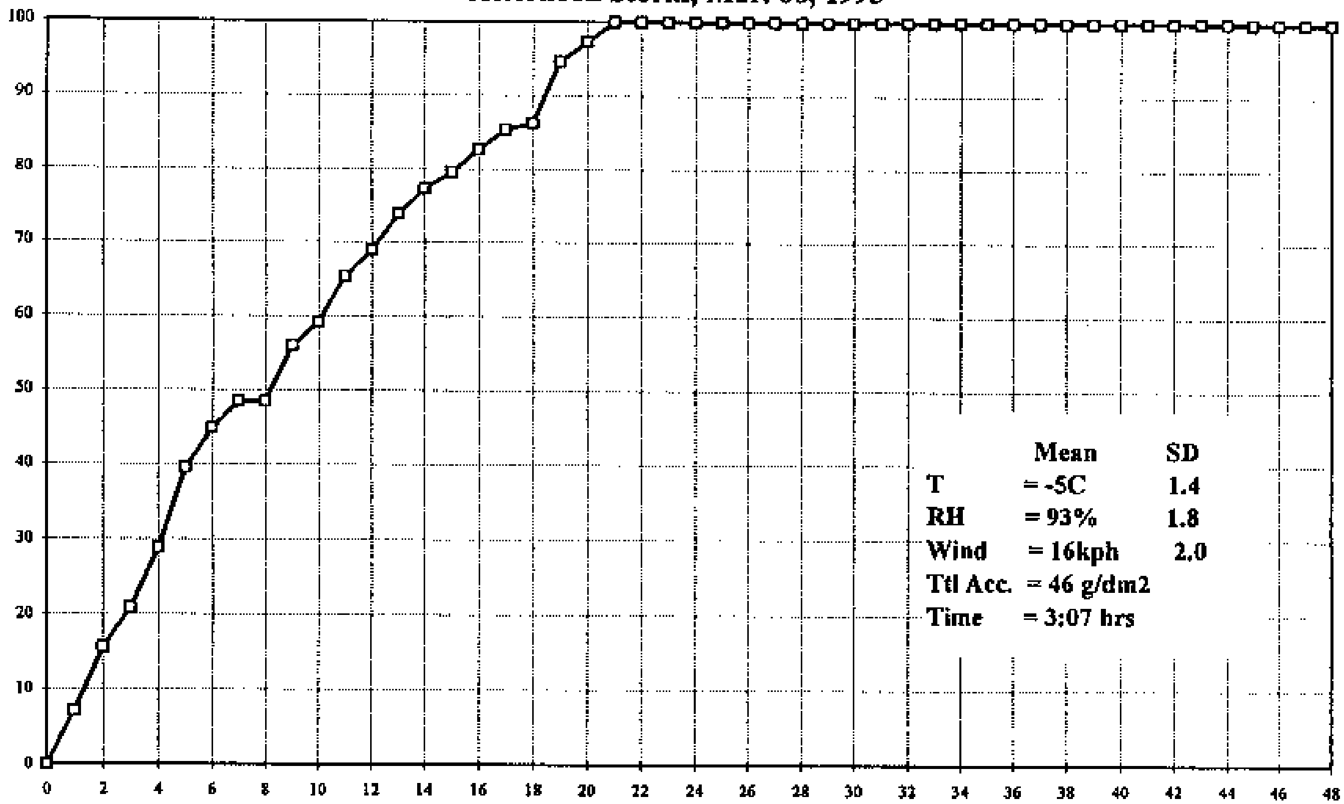
Distribution of Snow Accumulation
For 45 min. at Every 3 min.
Morning Storm, Mar. 08, 1995

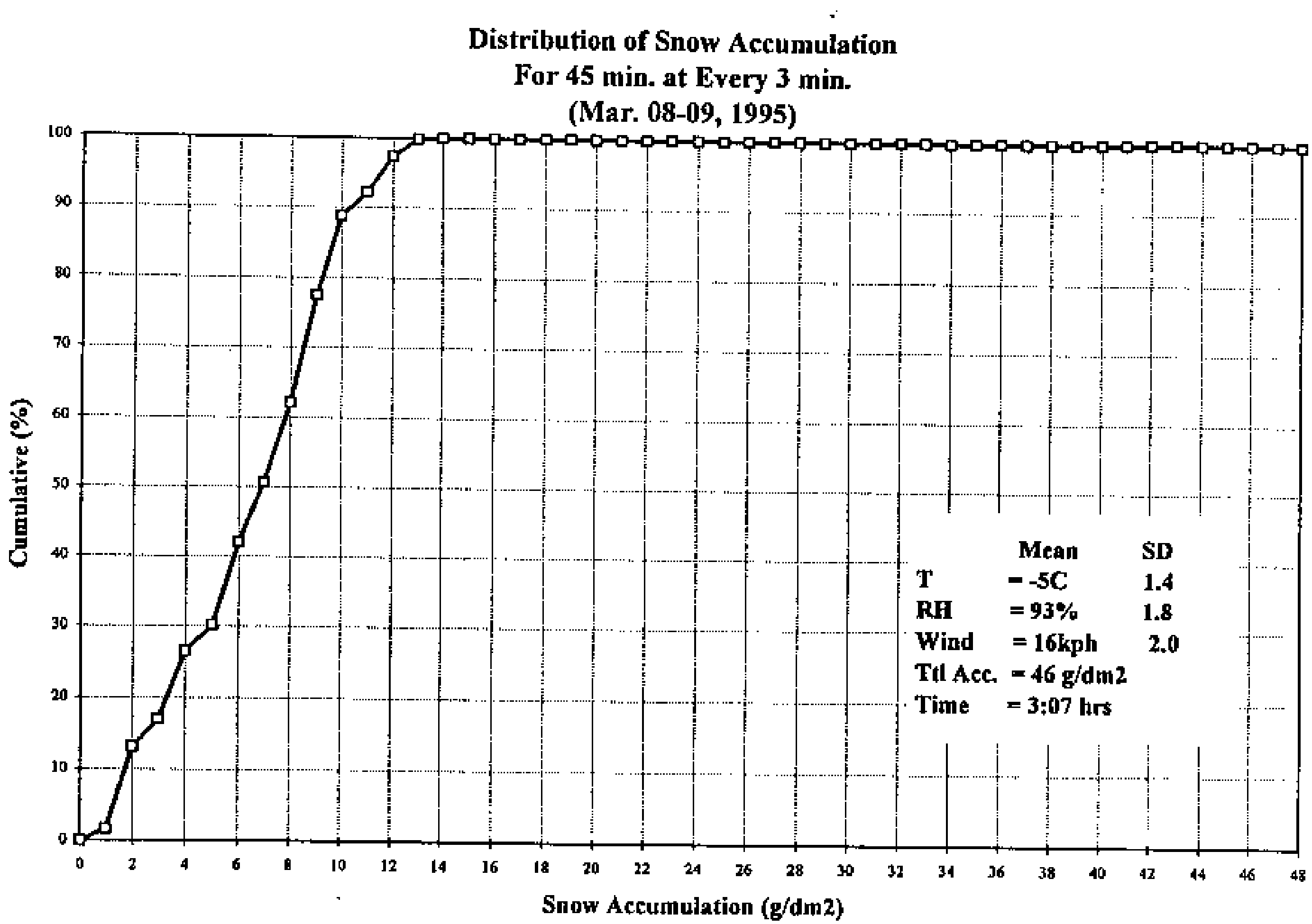


18/8/95 15:55

950308.XLS

Distribution of Snow Accumulation
For 45 min. at Every 3 min.
Afternoon Storm, Mar. 08, 1995

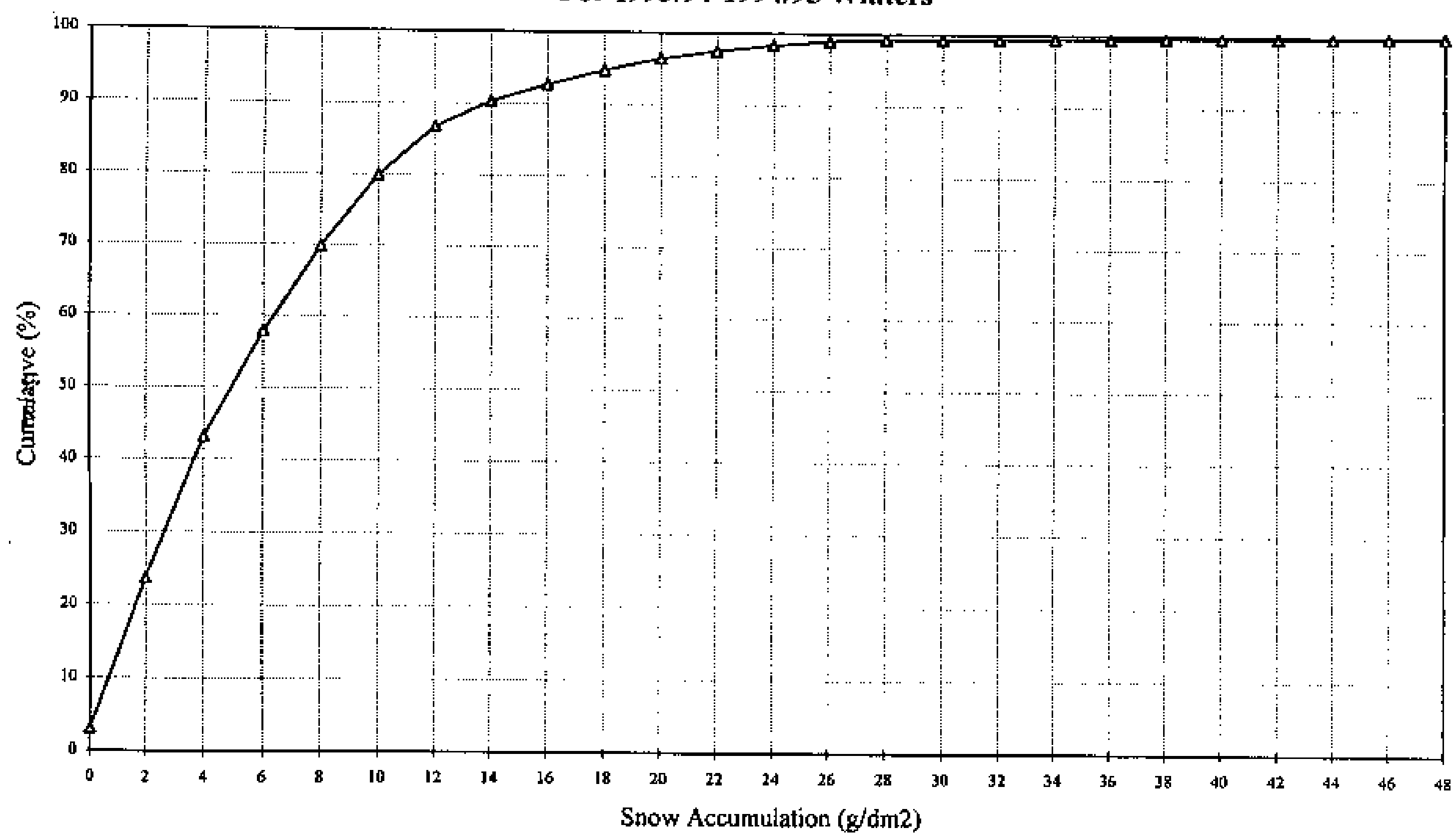




18/8/95 15:55

950308.XLS

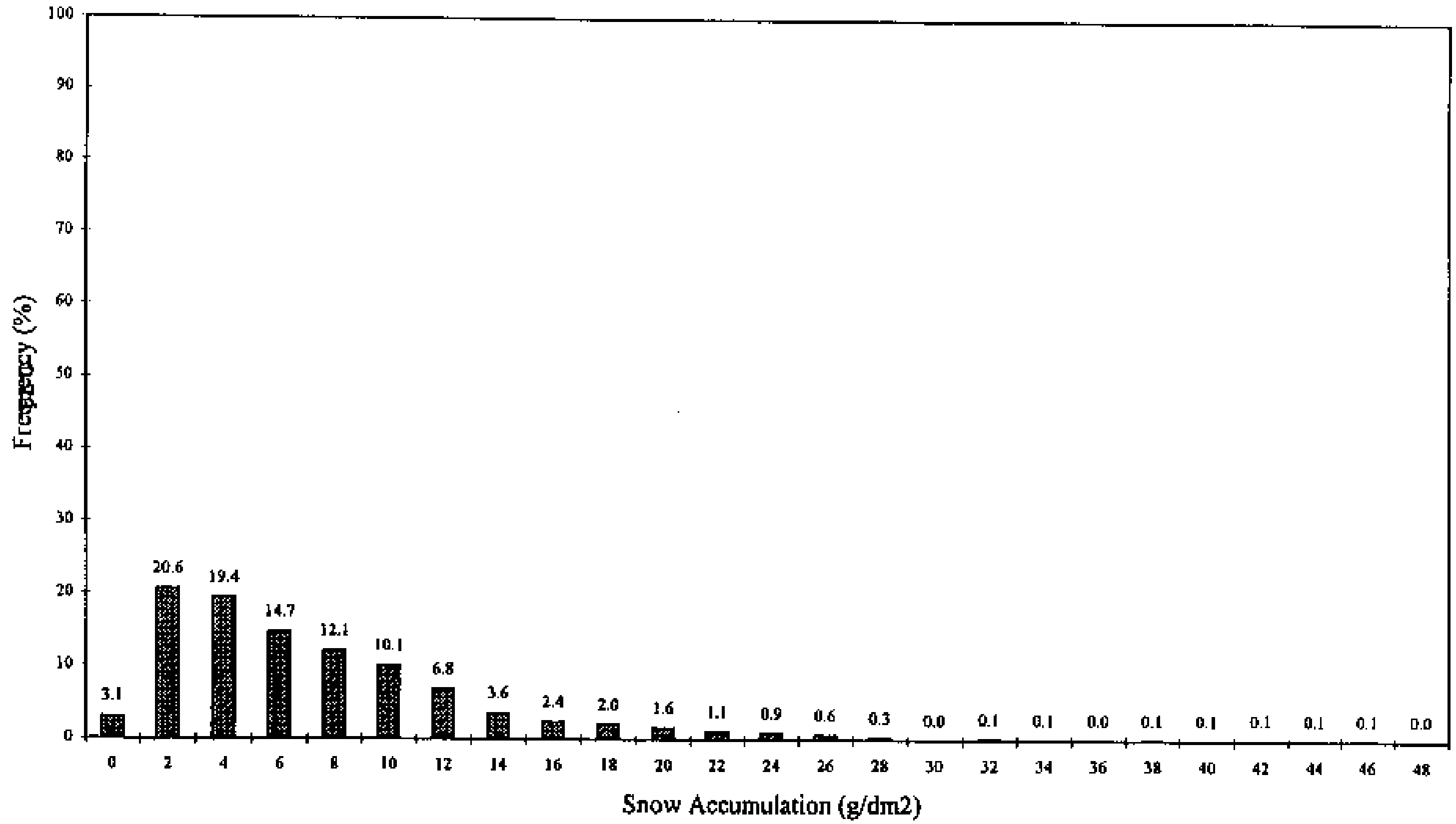
Distribution for Snow Accumulation
For 45 min. at Every 3 min.
For 1993/94-1994/95 Winters



18/8/95 12:09

MHIST95.XLS

Histogram for Snow Accumulation
For 45 min. at Every 3 min.
For 1993/94-1994/95 Winters



18/8/95 12:10

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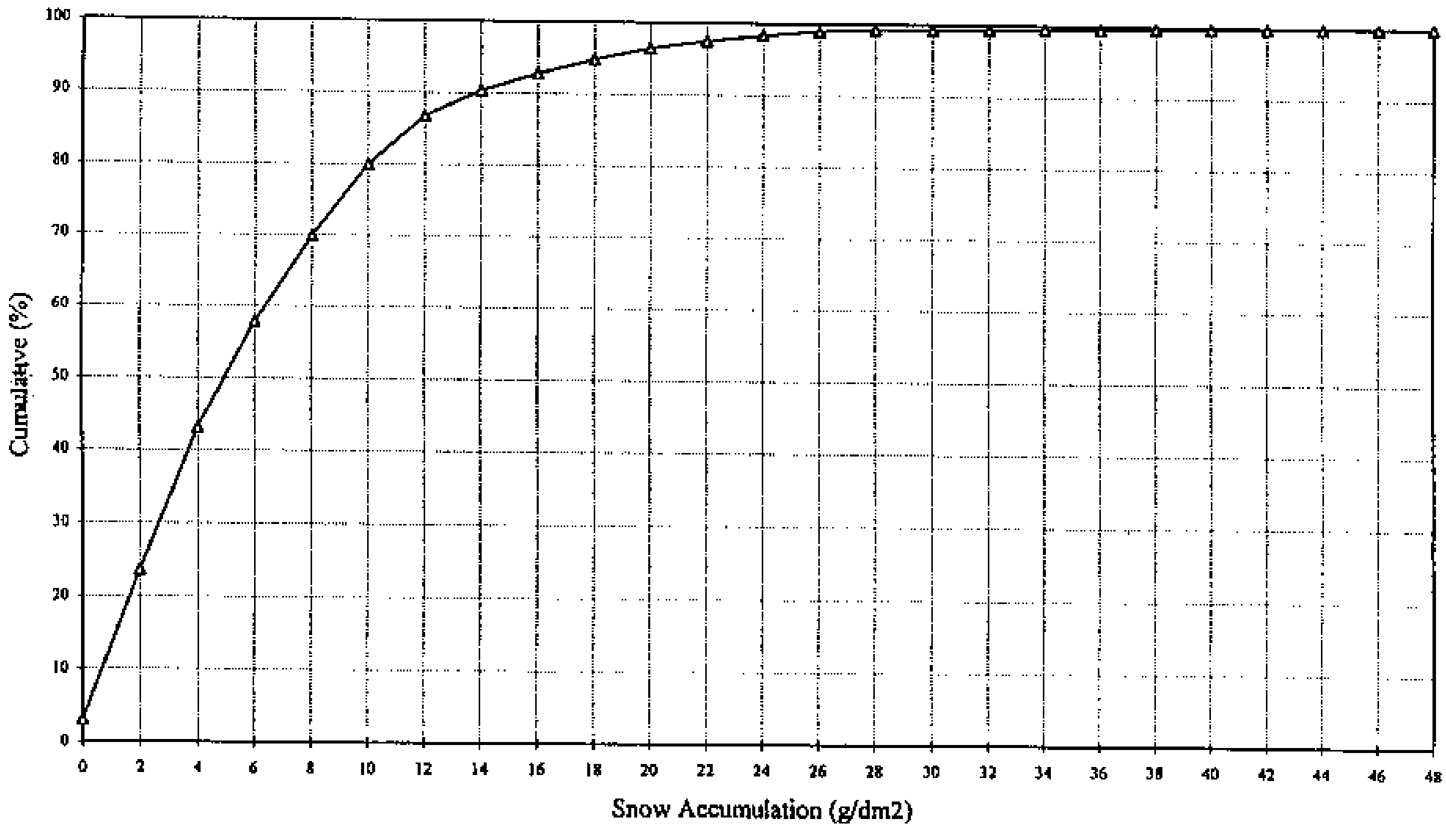
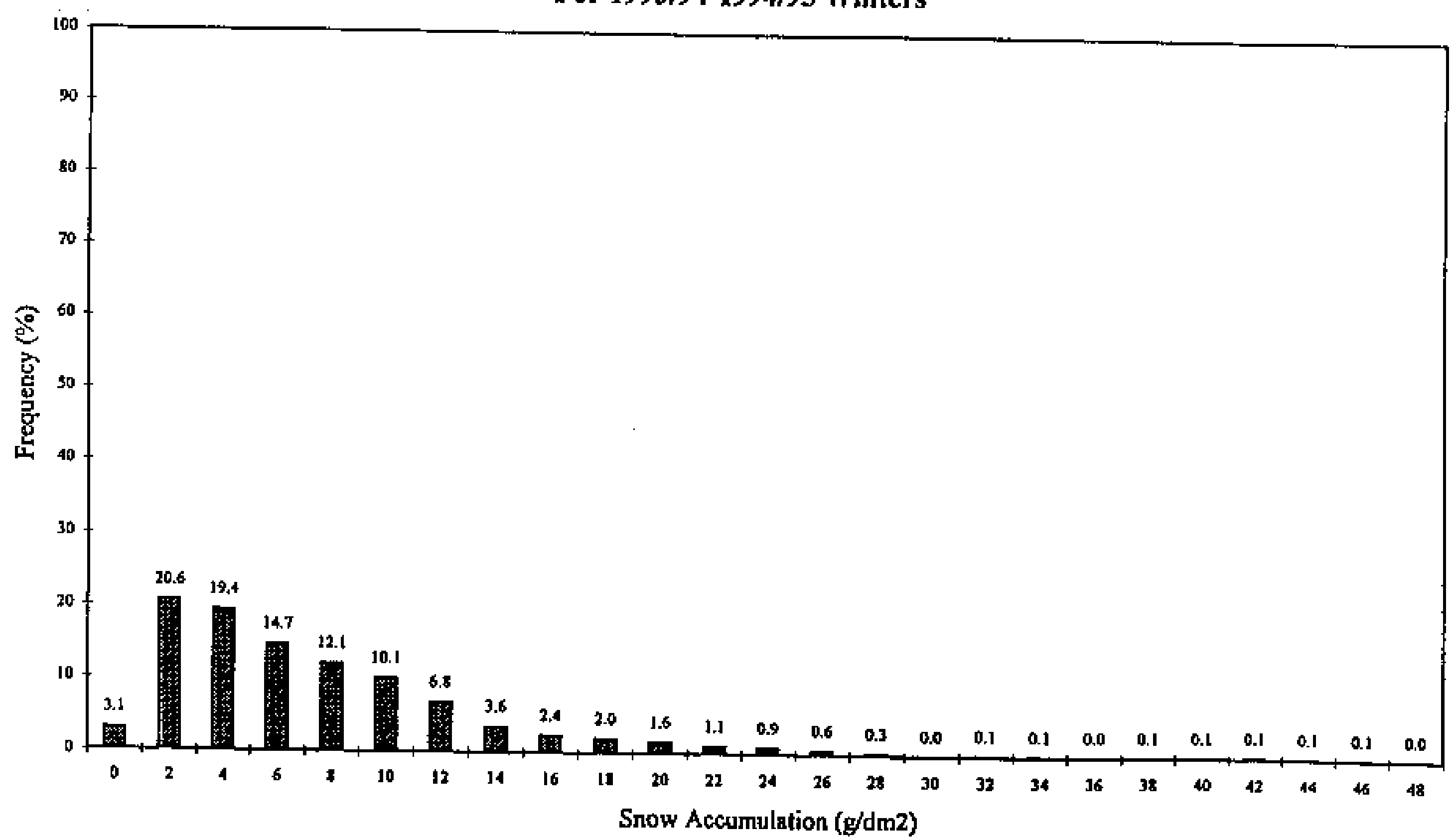
Distribution for Snow Accumulation
For 45 min. at Every 3 min.
For 1993/94-1994/95 Winters



18/8/95 12:09

MHIST95 XLS

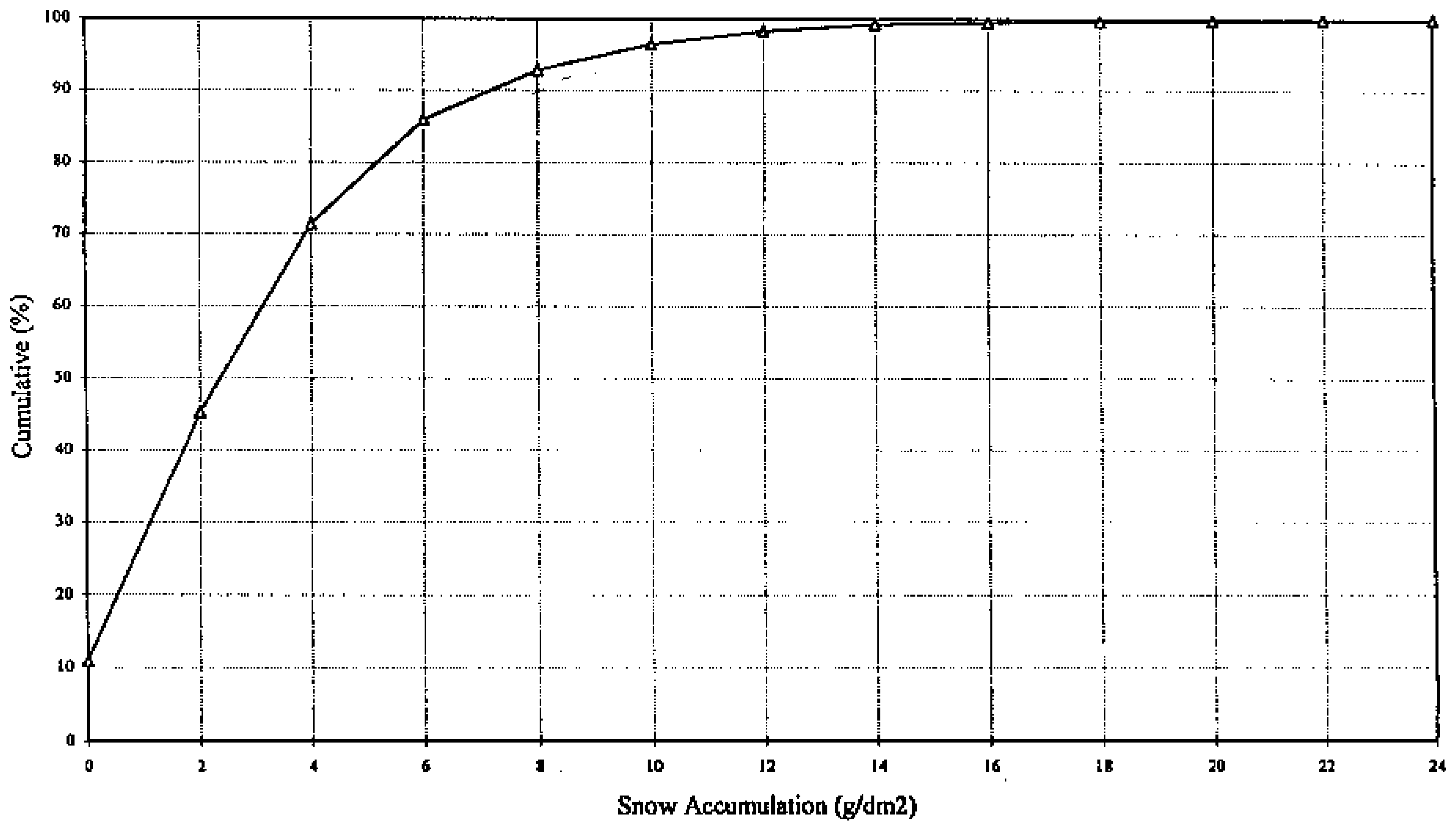
Histogram for Snow Accumulation For 45 min. at Every 3 min. For 1993/94-1994/95 Winters



18/8/95 12:10

MHIST95.XLS

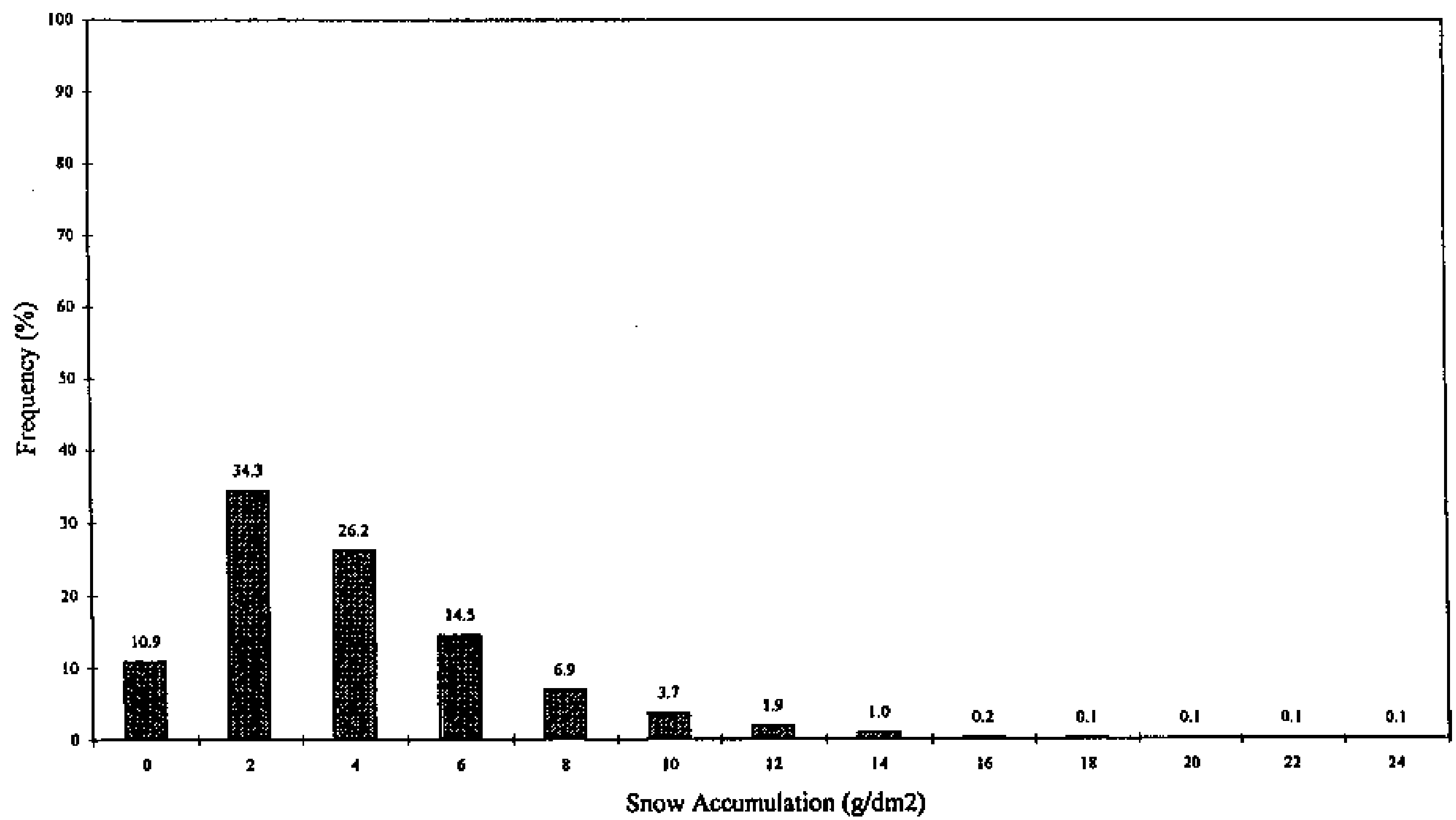
Distribution for Snow Accumulation
For 21 min. at Every 3 min.
For 1993/94-1994/95 Winters



17/8/95 13:55

MHIST95.XLS

Histogram for Snow Accumulation
For 21 min. at Every 3 min.
For 1993/94-1994/95 Winters



17/8/95 12:10

APPENDIX D

AES STUDY

FREQUENCY OF OCCURRENCE OF WATER EQUIVALENT PRECIPITATION RATES AS A FUNCTION OF AVERAGING TIME, TEMPERATURE AND TYPE

Draft

Frequency of Occurrence of Water Equivalent Precipitation Rates as a function of Averaging Time, Temperature and Type

1.0 Introduction

The proposed Holdover Time Tables give the failure time of various types of anti-icing fluids for different precipitation types, temperatures and water equivalent precipitation rates. In order to specify realistic precipitation rates in these tables, the cumulative probability distribution of rates averaged over the different holdover times must be determined. This report presents these distributions using data collected from an experimental site situated at Pearson International Airport established in 1995 with Dryden Commission Implementation Project funding to study nowcasting of on-ground aircraft icing.

2.0 Precipitation rate measurement

There is no internationally recognized “reference” instrumentation for measuring precipitation rate. Standard automated weighing gauges do not have sufficient resolution to report rate with the minutely time resolution required. Meteorological observers report an “intensity” of precipitation in four categories: very light, light, moderate and heavy. This is based on a broad classification of rate which is inadequate for the nowcasting of the holdover times. The observer also makes climatological measurements of accumulated amounts of precipitation every six hours. In the case of frozen precipitation the amount reported is the “water equivalent” of the melted precipitation.

One of the objectives of the experiment at Pearson International Airport (YYZ) was to evaluate the performance of new technologies designed to measure precipitation rates in both liquid and frozen phases with minutely reporting resolution. Several sensors were evaluated and it was determined that a small Doppler radar called the Precipitation Occurrence Sensor

System (POSS) agreed the best with the observed 6-hourly accumulated precipitation amounts. This study will be reported on elsewhere.

2.1 POSS

The Precipitation Occurrence Sensor System is a small Doppler X-band radar designed by the Atmospheric Environment Service as a present weather sensor for its automatic weather observing stations. It is commercially manufactured under licence by Andrew Antenna, Canada. The sensor reports every minute the occurrence, type, intensity, rate and accumulation of precipitation.

The precipitation rate is estimated using the same method as is done with large-scale precipitation radars. The method, referred to as the “Z-R” method, measures the radar reflectivity factor (Z) to estimate the precipitation rate (R).

3.0 Analysis

The water equivalent precipitation rate is reported by the POSS every minute. These rates are averaged using a “sliding box car “ for the three specified periods used in the holdover time tables: 6, 20 and 35 minutes. The data is then classified into three precipitation types as reported by the meteorological observer at the site: snow, freezing rain of light intensity and freezing drizzle. In the case of mixed precipitation types the data is included in a class if that type is reported as one of the mixed types. The data is further classified into the four temperature ranges proposed in the Holdover time tables: 0 to -3C, -3 to -7C, -7 to -14C and -14 to -25C.

The frequency of occurrence with respect to the average water equivalent precipitation rate is determined. The average is included in these statistics only if at least half the minutes have non-zero precipitation rates. In addition, if there is missing data, then at least have the averaging time must have valid measurements. This approach deliberately excludes intermittent precipitation from biasing the percentile statistics.

4.0 Results

The results are presented graphically in plots of cumulative probability versus precipitation rate averaged over a specified period. The cumulative probability at a specific precipitation rate is the percentage of the dataset with precipitation rates less than that rate. There is one graph for each combination of averaging time and temperature (see Figures below).

Each graph displays a curve for each of the three precipitation classes.

In snow, the 95% percentile of the water equivalent precipitation rate averaged over 6 minutes decreases with temperature from about 1.6 mm/h at 0 to -3C to 0.8 mm/h at -14 to -25C. Similar results were found for the other averaging times.

The 95% percentile for light freezing rain is 4.3 mm/h for a 6-minute averaging time in the temperature range 0 to -3C. Light freezing rain did not occur below -3C.

There were few occurrences of freezing drizzle from this location during the experimental period.

A second set of graphs compares the effect of changing the averaging time for calculating the precipitation rate for snow and freezing rain of light intensity. The cumulative probability curves in snow for the temperature range 0 to -3C are very similar, with the 95% percentile constant at 1.6 mm/h.

In light freezing rain the 95% percentile is also quite constant although other percentiles are more strongly affected.

The averaging time will have the greatest influence when the precipitation rate is variable. This preliminary analysis indicates that the rates in snow are less variable than in light freezing rain.

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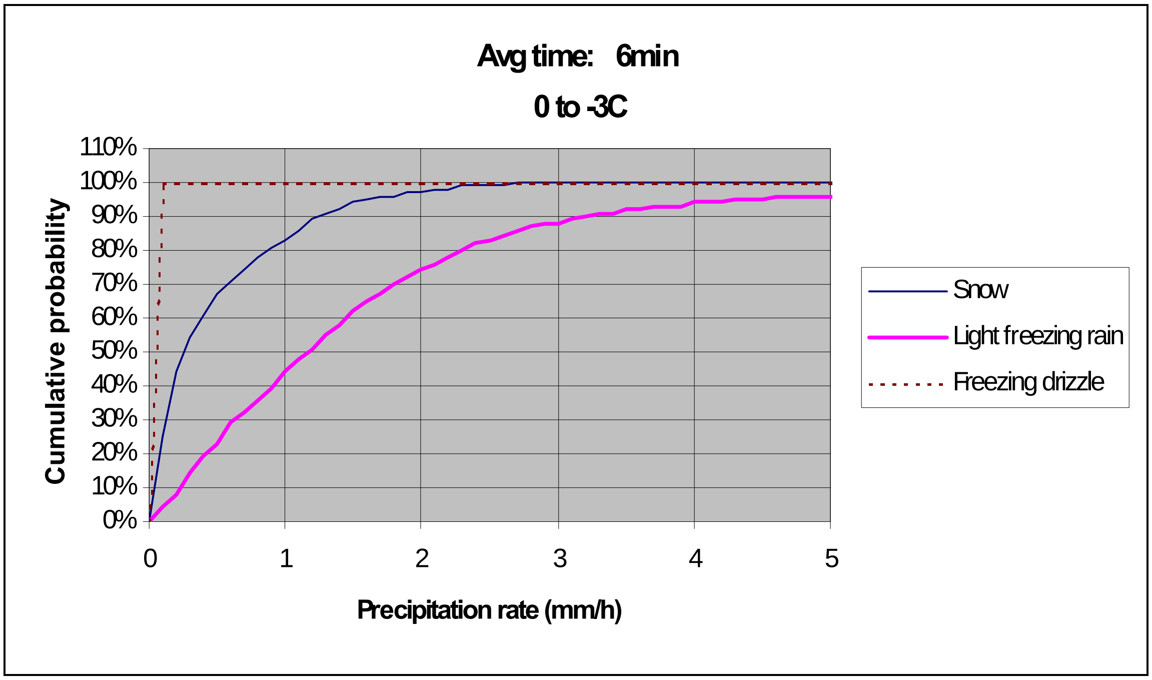
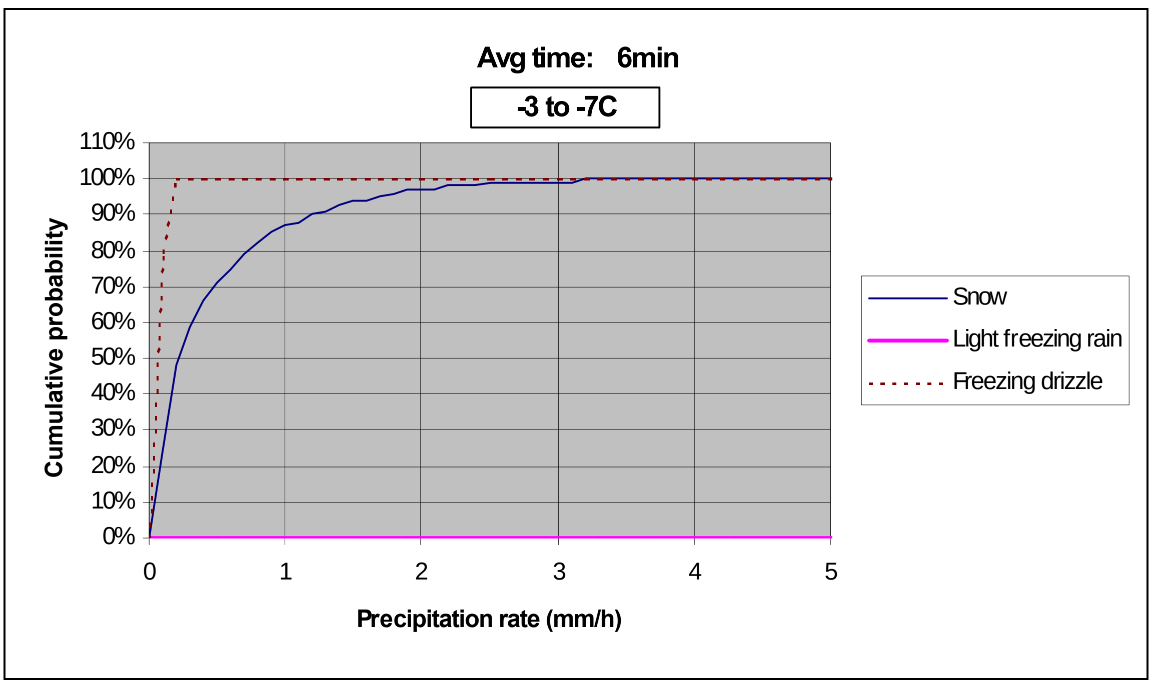
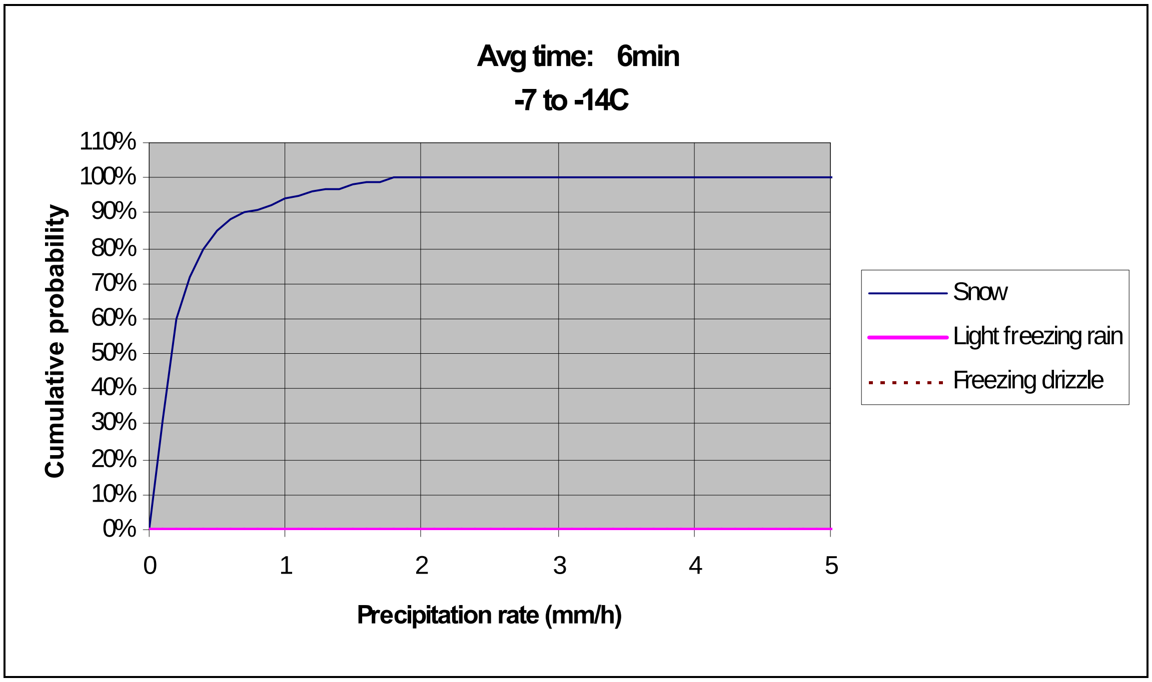
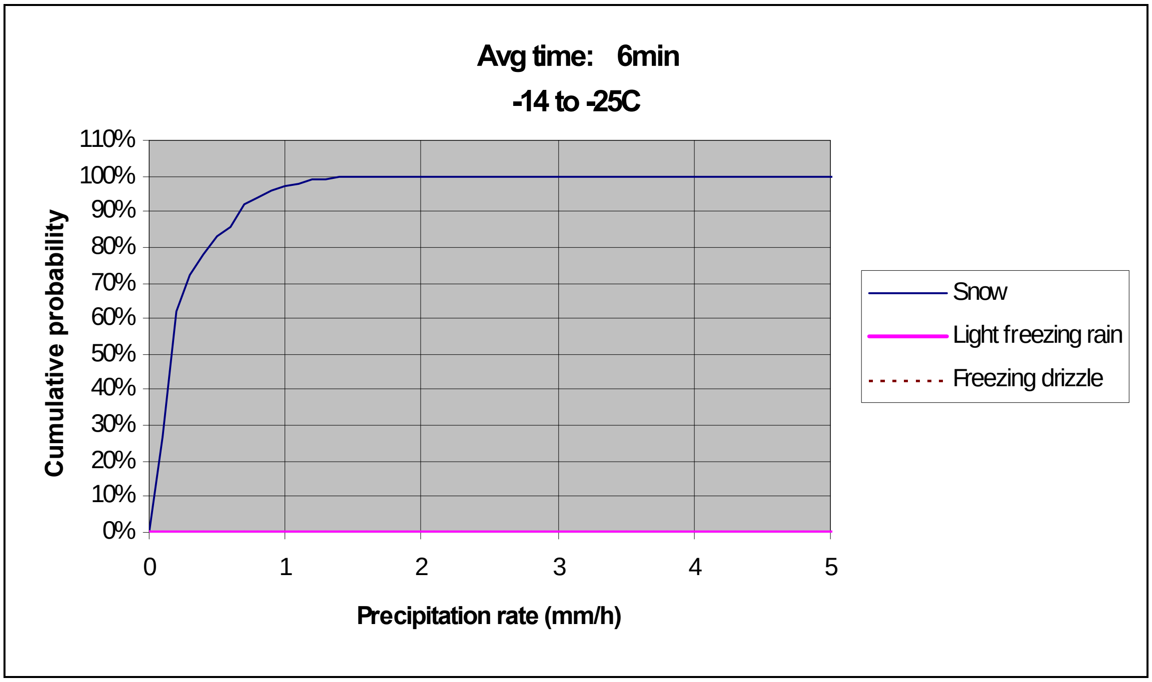
17 Nov. 97


Avg time: 6min
0 to -3C
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative probability
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle

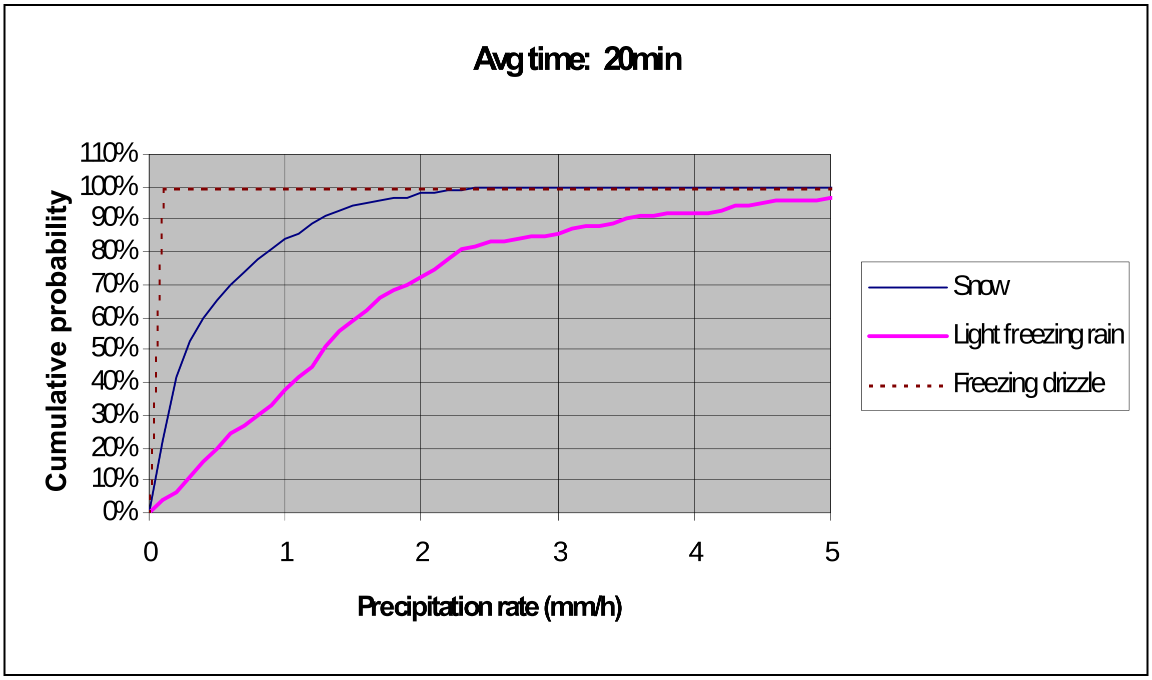

Avg time: 6min
-3 to -7C
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative probability
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle

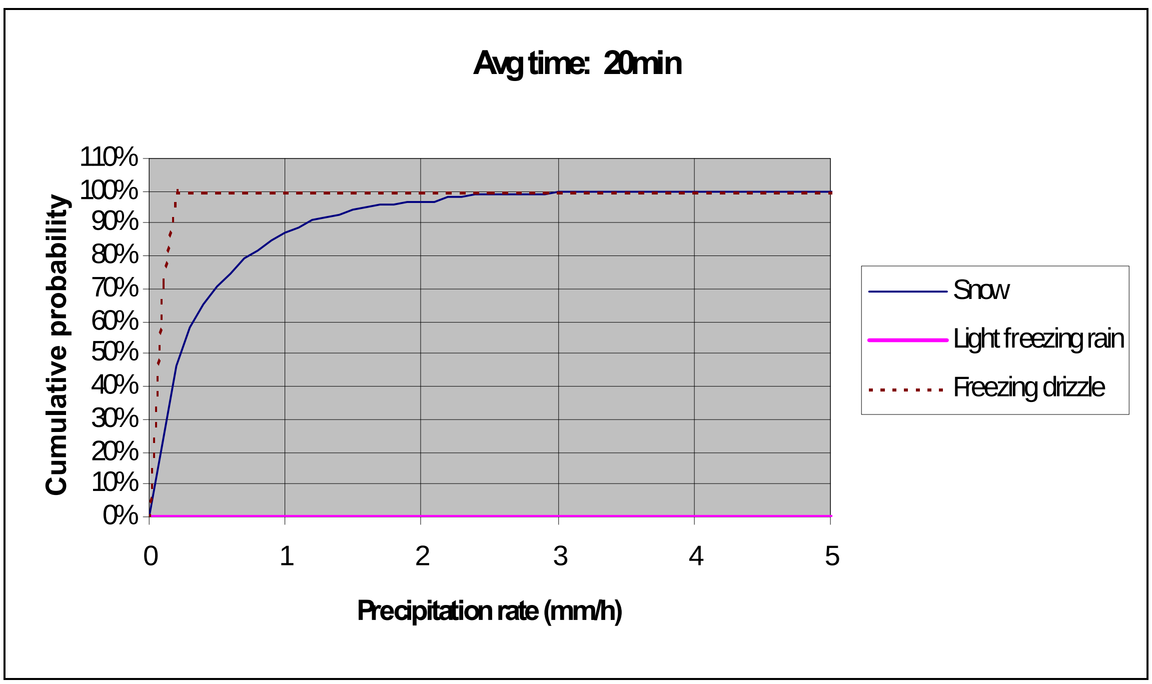


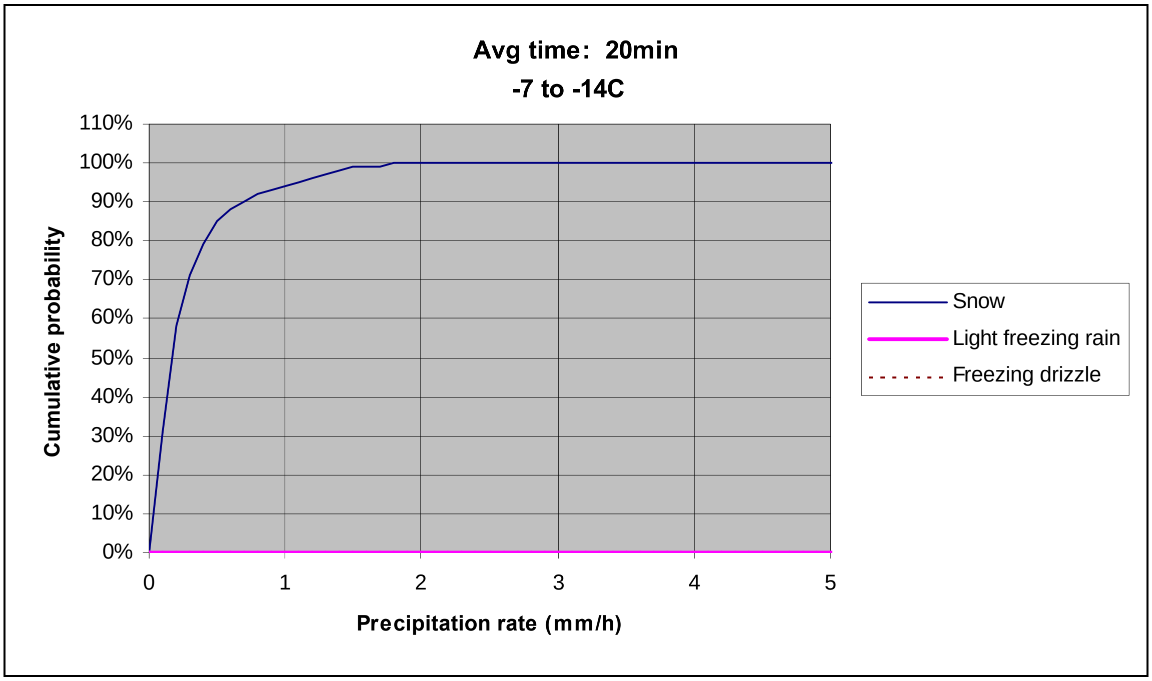
Avg time: 6min
-7 to -14C
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative probability
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle

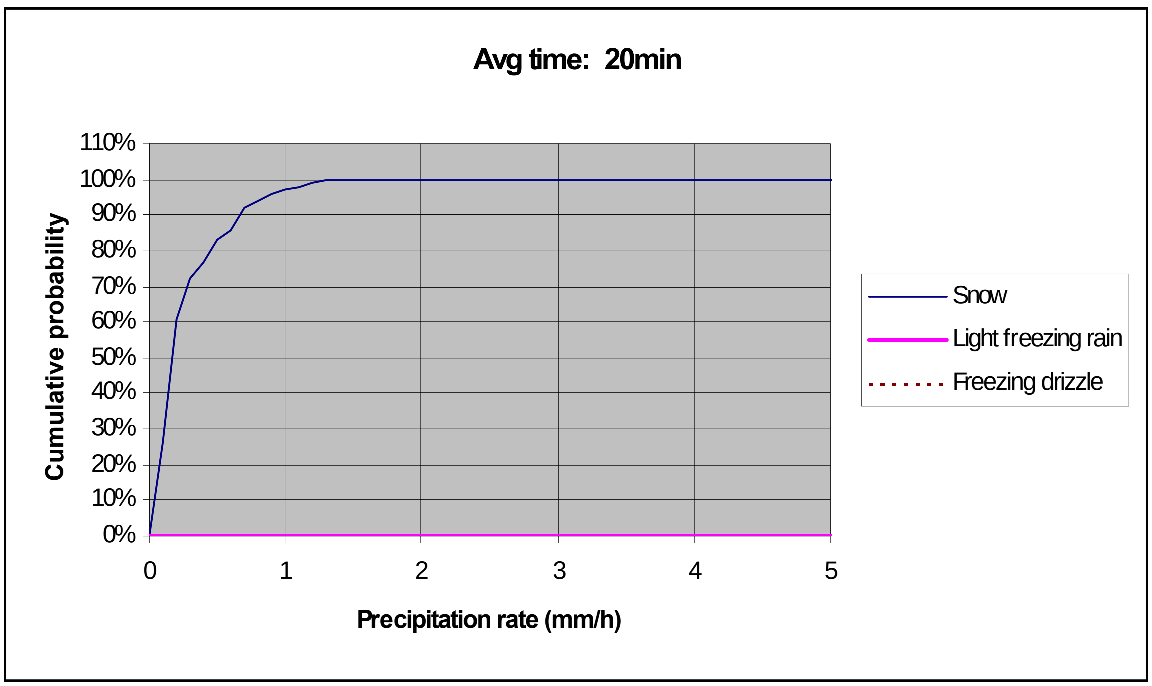


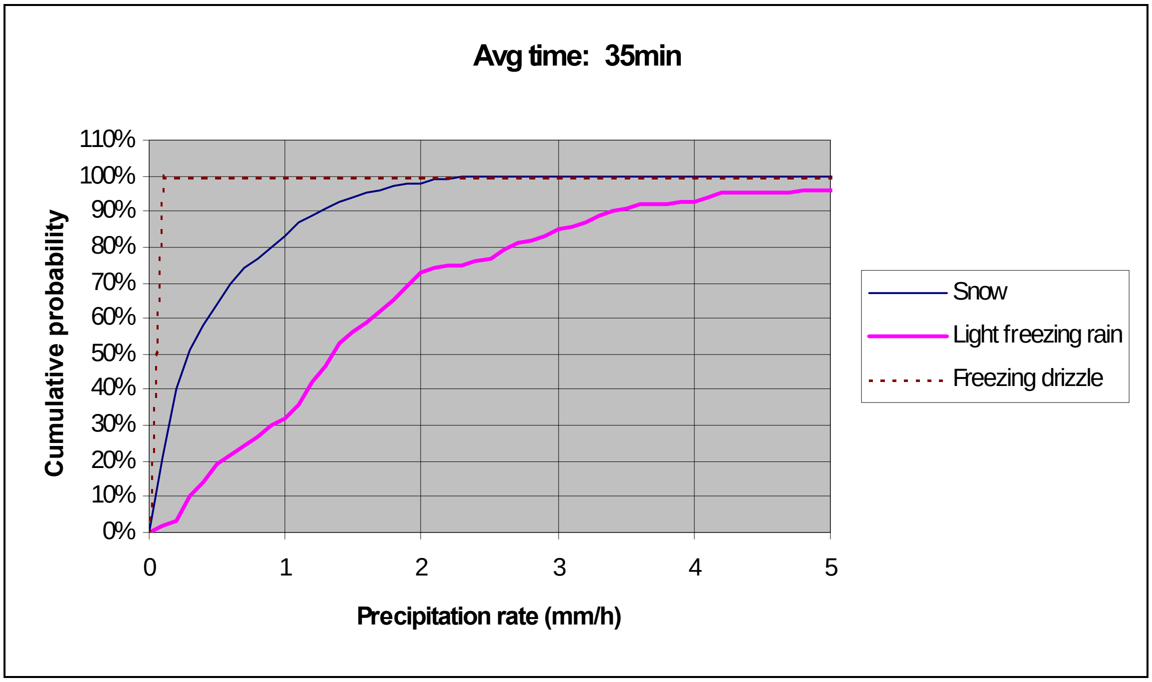
Avg time: 6min
-14 to -25C
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative probability
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle

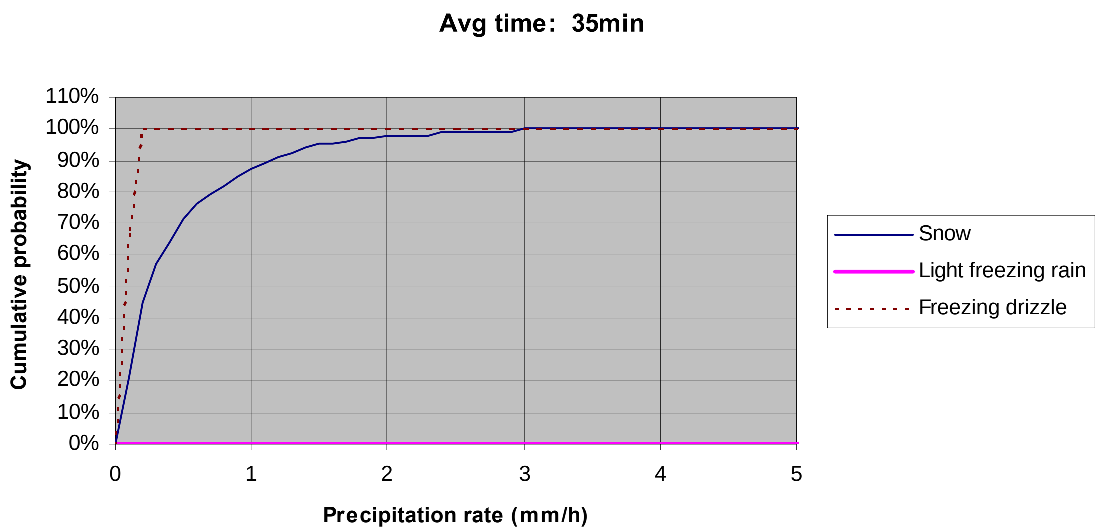

Avg time: 20min
Cumulative probability
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle

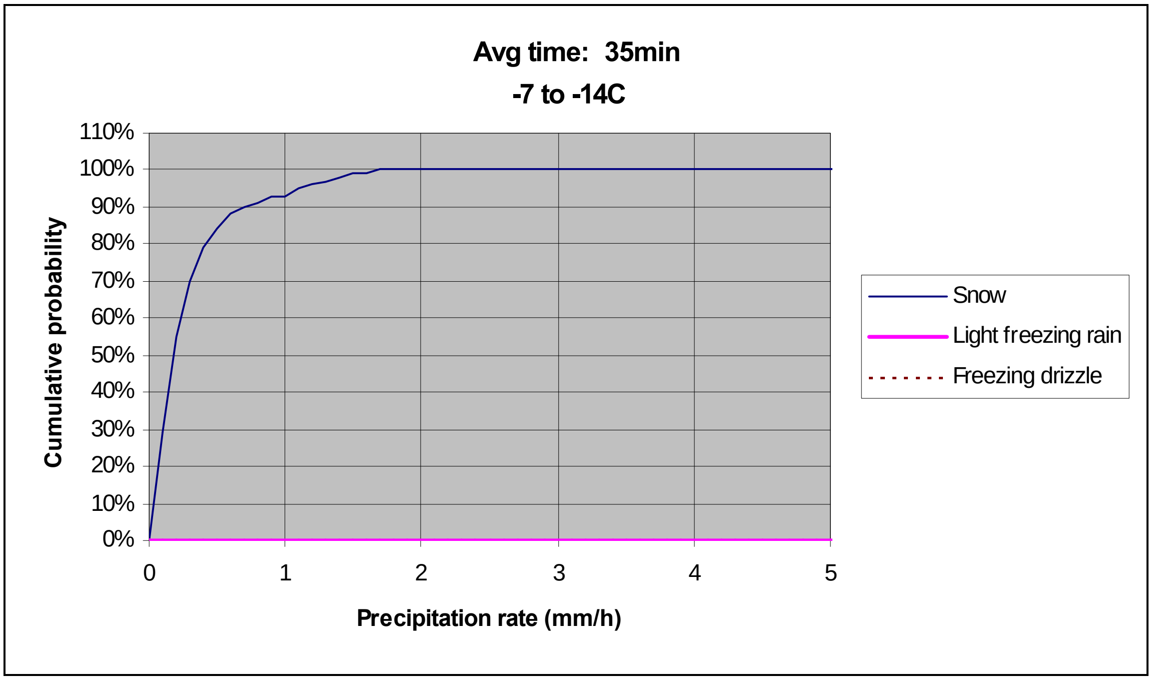

Avg time: 20min
Cumulative probability
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle


Avg time: 20min
-7 to -14C
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
Cumulative probability
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle

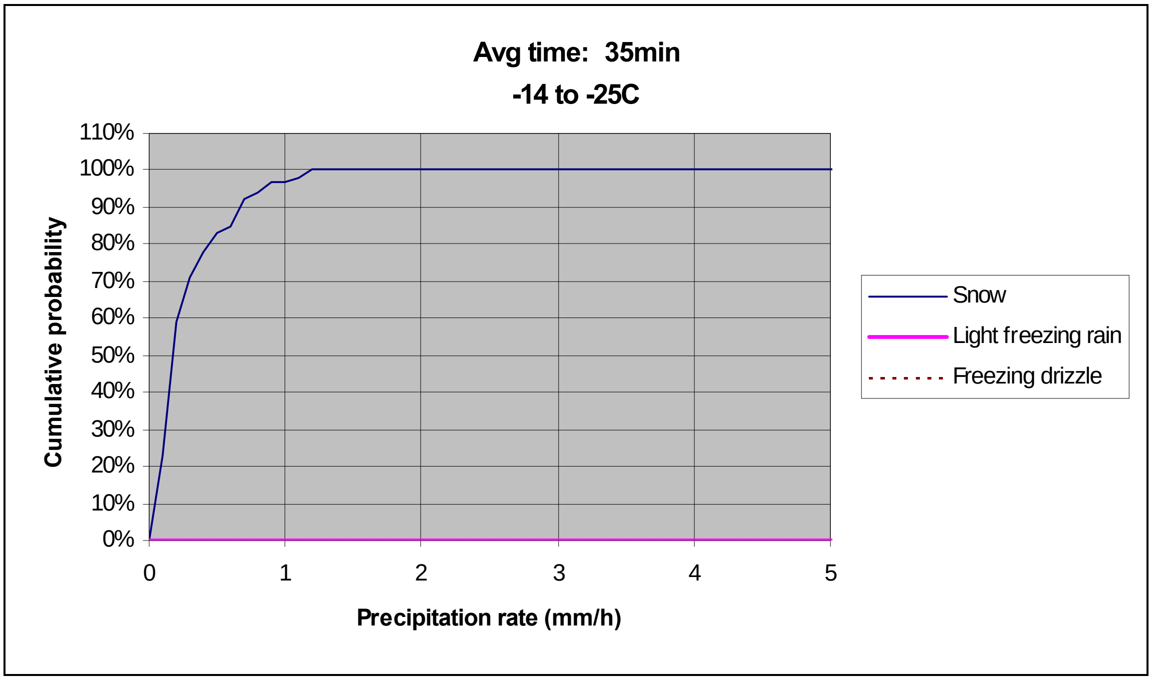

Avg time: 20min
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
Cumulative probability
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle


Avg time: 35min
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative probability
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle

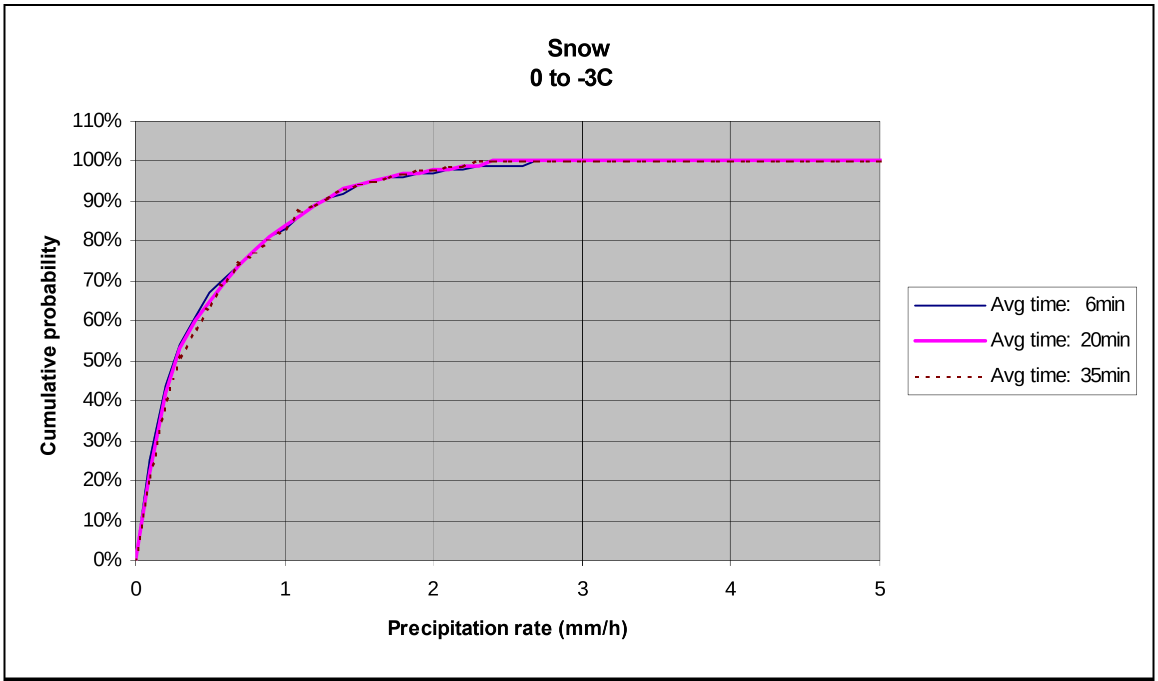

Avg time: 35min
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative probability
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle

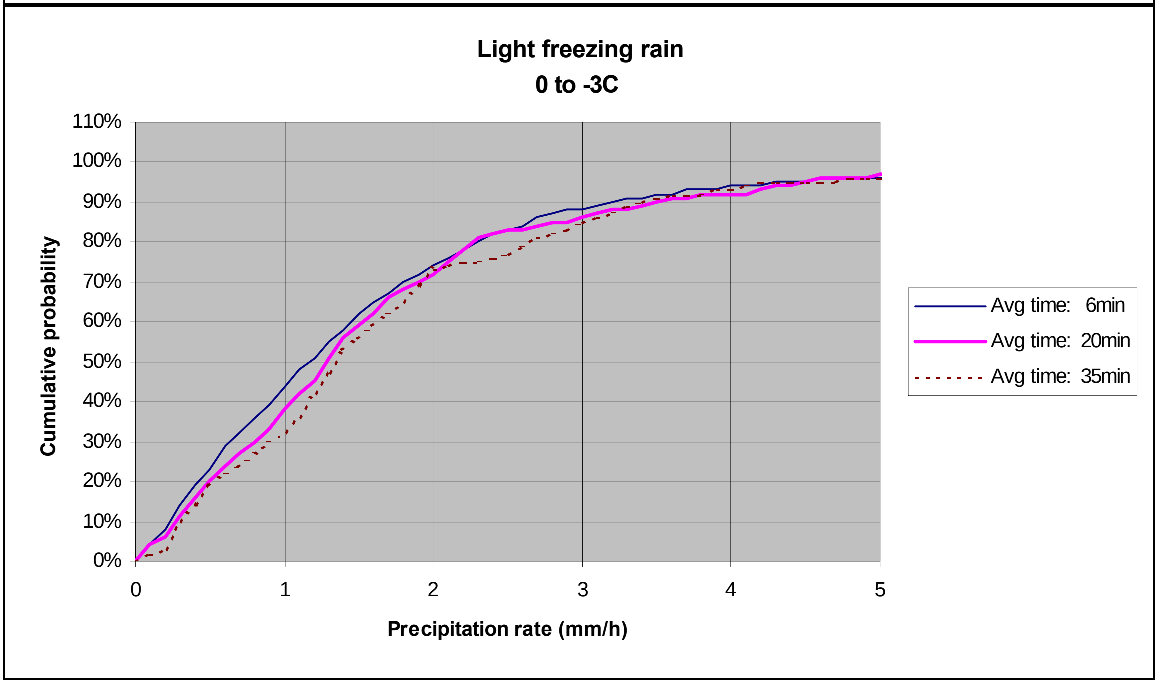


Avg time: 35min
-7 to -14C
Cumulative probability
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle



Avg time: 35min
-14 to -25C
Cumulative probability
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
Precipitation rate (mm/h)
Snow
Light freezing rain
Freezing drizzle

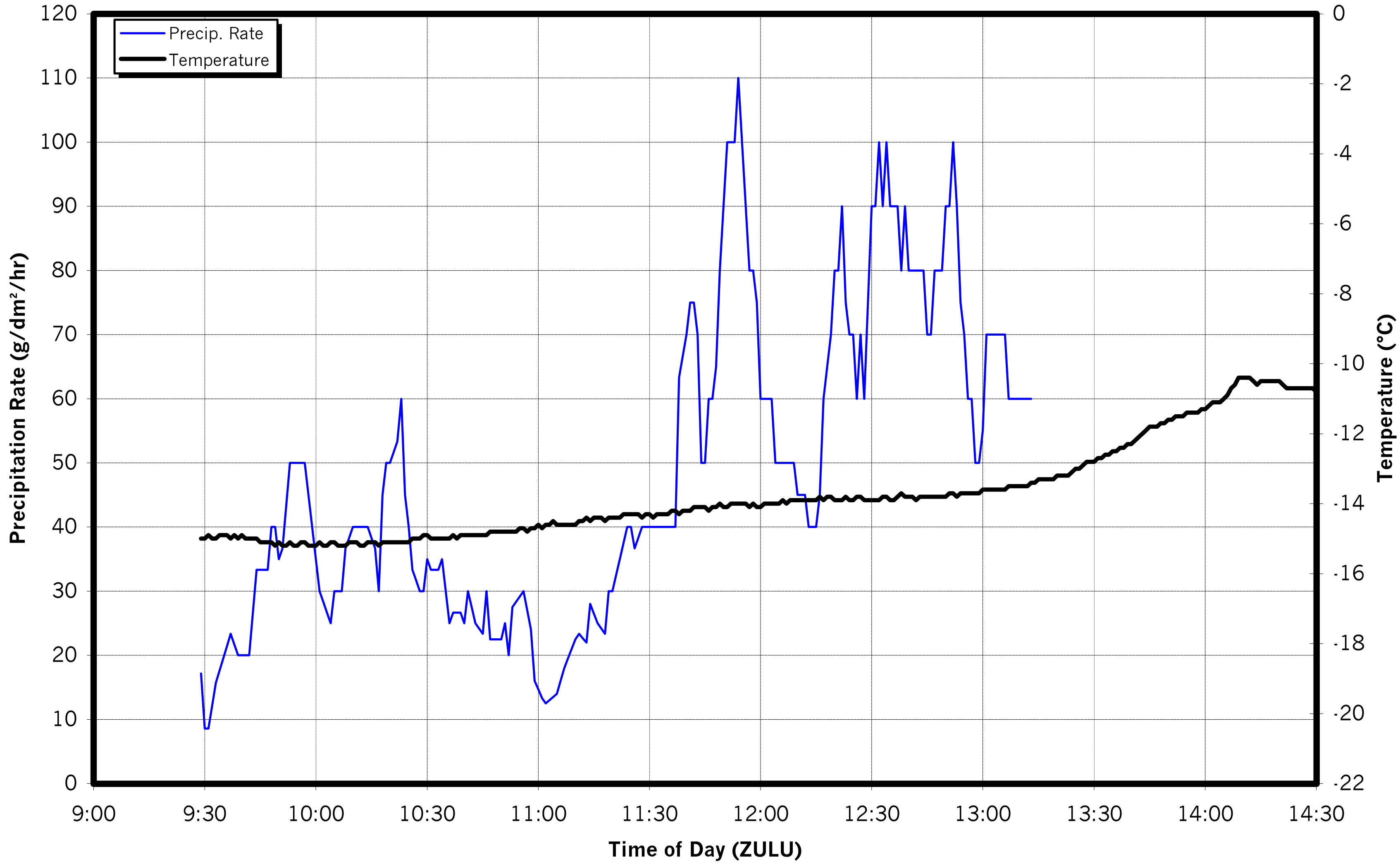

Snow
0 to -3C
Cumulative probability
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
Precipitation rate (mm/h)
Avg time: 6min
Avg time: 20min
Avg time: 35min


Light freezing rain
0 to -3C
Cumulative probability
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
Precipitation rate (mm/h)
Avg time: 6min
Avg time: 20min
Avg time: 35min

APPENDIX E

COLD WEATHER RATE ANALYSIS FOR WINTER 1998/99

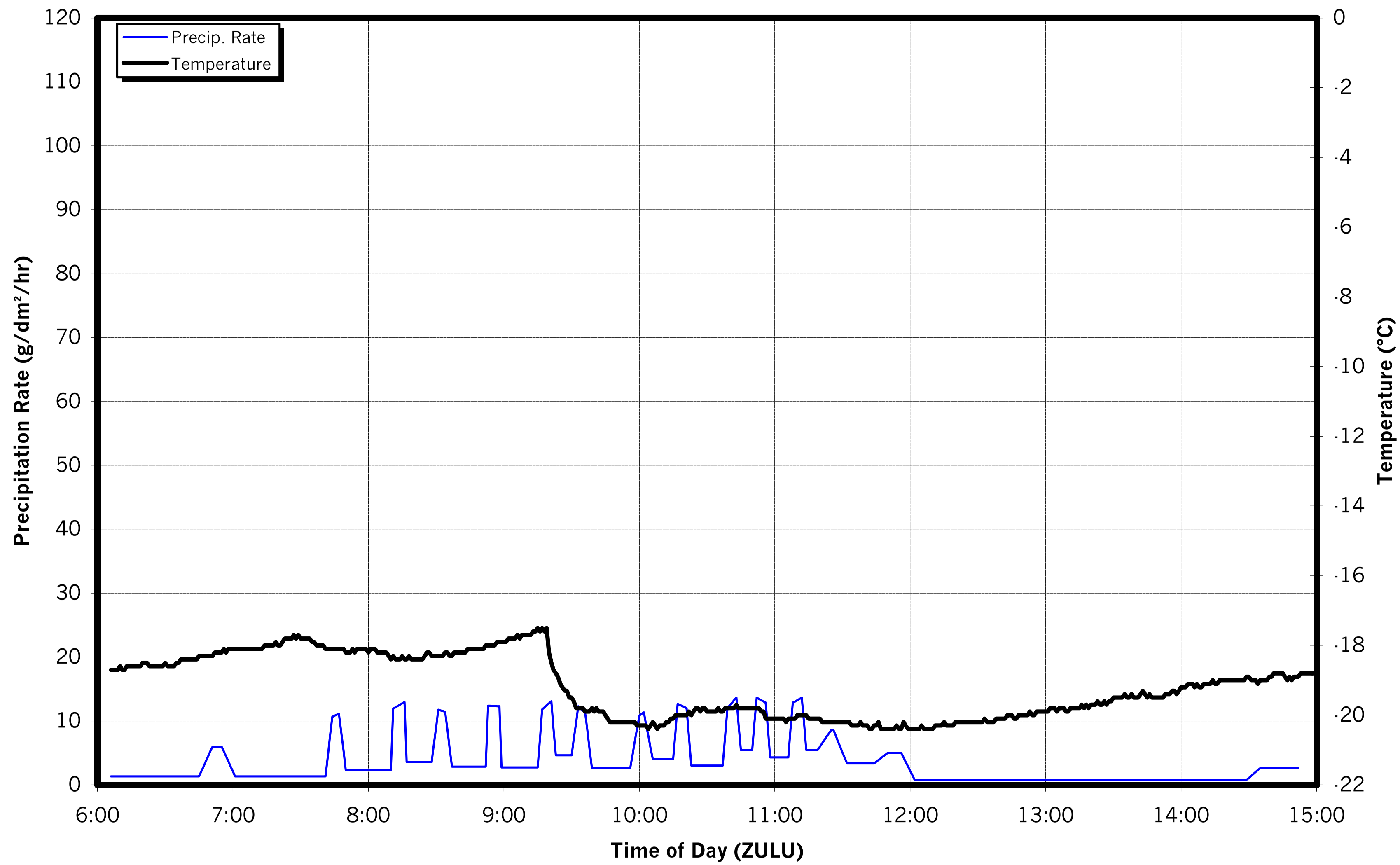
6 MINUTES RATE - EVERY MINUTE
CR21X (Dorval Airport) - January 03, 1999



cm1514/report/readac/J03_crx
At: Rate
03/01/01, 9:18 AM

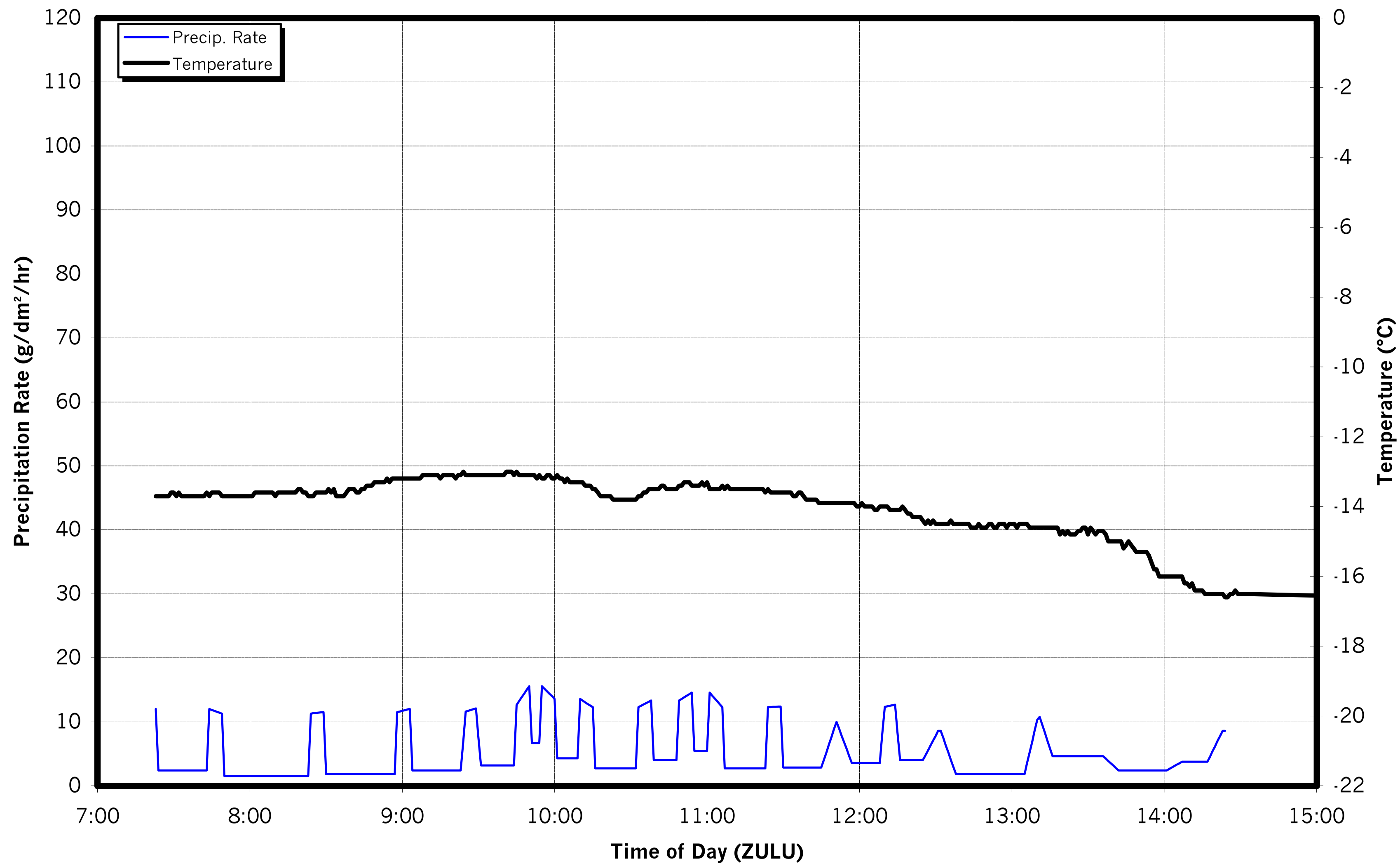
6 MINUTES RATE - EVERY MINUTE

CR21X (Dorval Airport) - January 12, 1999



cm1514/report/readac/J12_crx
At: Rate
03/01/01, 9:20 AM

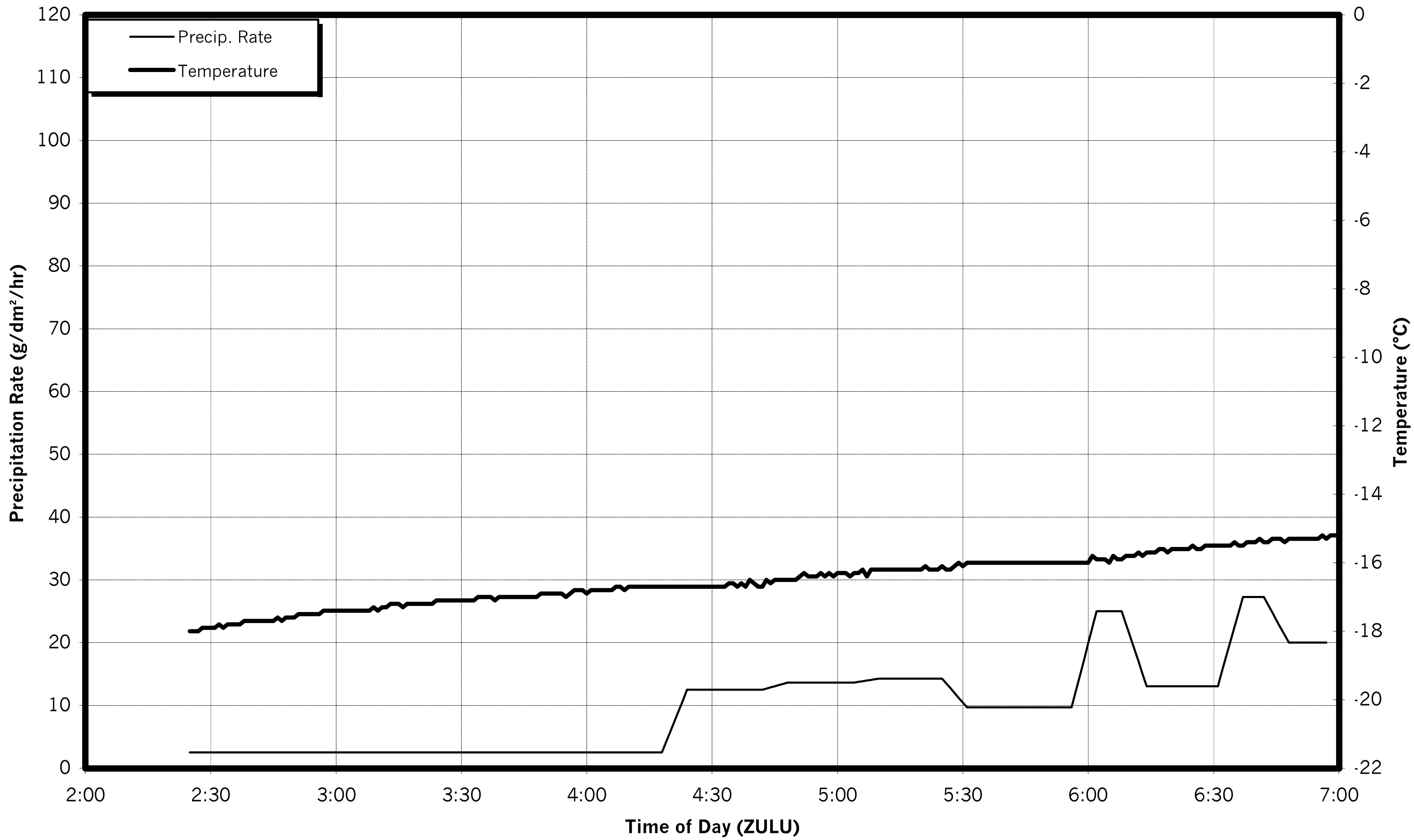
6 MINUTES RATE - EVERY MINUTE
CR21X (Dorval Airport) - January 13, 1999



cm1514/report/readac/J13_crx
At: Rate
03/01/01, 9:22 AM

6 MINUTES RATE - EVERY MINUTE

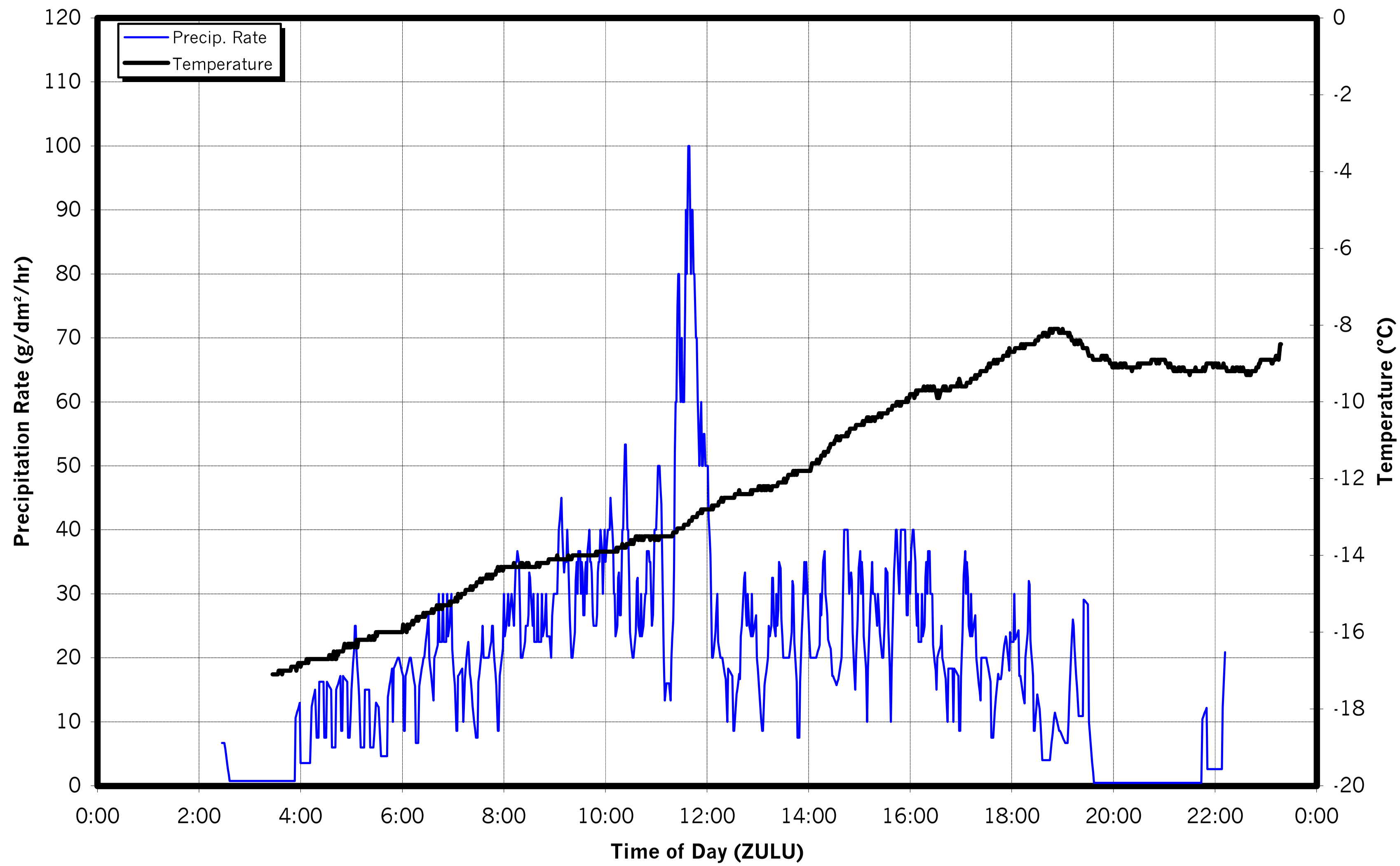
READADC · January 14, 1999



cm1514/report/readac/J14_read
At: RATE
03/01/01, 9:25 AM

CR21X - EVERY MINUTE

January 15, 1999



cm1514/report/readac/J15_crx
At: Rate (2)
03/01/01, 9:26 AM