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Climatological Study to Determine the Impact of Icing on the Low Level Windshear Alert System

VOLUME I: Analysis

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September 1989

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16. Abstract

The climatological study was performed to determine the impact of icing on the performance of the Low Level Windshear Alert System (LLWAS).

This report presents the icing statistical profile in the form of data tables and histograms of 106 LLWAS sites. The icing statistical data were derived using freezing rain and freezing drizzle hourly reports obtained from the National Climatic Data Center magnetic tape records. The meteorological data cover a 24 year history of the time period between January 1, 1965 to December 31, 1988. The statistics include: icing reports and duration (actual time of freezing precipitation in hours), glazing duration (an extension of freezing weather following precipitation up to a 48 hour limit), freezing duration (combination of both icing and glazing with and without weighting). Also presented is the ranking of all LLWAS sites based on the above listed parameter combinations including a contour map showing icing intensity of all site locations. Finally, the extent of the freezing effect on windshear sensors is demonstrated by using a graph from field test measurements collected during a period of light freezing rain.

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PREFACE

The work described in this report was performed in support of FAA's Low Level Windshear Alert System (LLWAS) program. This program is designed to improve windshear sensor performance used in LLWAS under icing weather conditions. The work was sponsored by the Office of Weather Sensor Programs, APS-340. The work was performed by the Transportation Systems Center's Surveillance and Sensors Division, DTS-53.

This report provides an icing statistical profile for each of the 106 LLWAS sites and the ranking of all these sites. Ranking is based on icing, glazing and freezing severity statistics based on hourly meteorological data reports made available by the National Climatic Data Center (NCDC), Asheville, NC. The data covered a 24 year time period between January 1, 1965 and December 31, 1988.

The author wishes to thank Craig Goff of the Office of Weather Sensor Programs (APS-340), for sponsoring this effort and for providing valuable technical advice. Continuous technical support was provided by Edward A. Spitzer (DTS-53), Chief of Surveillance and Sensors Division, and John F. Canniff (DTS-53), TSC's Project Manager for the program.

Valued support was provided by the Systems Resource Corporation technical staff: Robert D'Errico for technical information and support in the initial phase of the magnetic tape reduction effort; David C. Burnham for setting up the QUATTRO spreadsheet used in the data presentation; and especially Brian Berkwitz for developing all data reduction computer programs and reducing magnetic tapes.

The author wishes to express special thanks to Eve Rutyna and Stephanie Levy, both of EG&G Dynatrend, for editing and preparing this report.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32) (5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0		1		2		3		4		5		6		7		8		9		10					
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

TABLE OF CONTENTS

Section | Page

Volume I: Climatological Study - Analysis

1.0 INTRODUCTION 1
- 1.1 Background 1
- 1.2 LLWAS Sensor Problem 1
- 1.3 Purpose 1
- 1.4 Objectives 1
- 1.5 Definition of Icing Concerns 2
- 1.6 Summary 3

2.0 METHODOLOGY 5
- 2.1 Climatological Data Source 5
- 2.2 Data Reduction and Analysis 5

3.0 RESULTS 9
- 3.1 Geographical Distribution of Icing 9
- 3.2 Icing Severity Ranking 11

4.0 CONCLUSIONS 17

5.0 RECOMMENDATIONS 17

APPENDICES

APPENDIX A: AIRPORTS WITH LLWAS SYSTEMS A-1

APPENDIX B: WORCESTER TESTS B-1

1.0 INTRODUCTION

1.1 BACKGROUND

The FAA has identified the 110 airports (listed in Appendix A of Volume I) where Low Level Windshear Alert Systems (LLWAS) have been, or will be deployed to detect windshear hazards for approaching and departing aircraft. The purpose of the LLWAS is to detect and warn of microbursts and frontal generated wind shear events.

1.2 LLWAS SENSOR PROBLEM

Icing can affect presently used LLWAS wind sensors, which may slow down or stop and thereby affect the integrity of the LLWAS system. This problem can last for an extended period of time. In response to complaints from FAA field personnel about LLWAS icing problems, TSC conducted a two-year test of the performance of commercially available anemometers under icing conditions and found several that were not affected by icing.

1.3 PURPOSE

The FAA is considering the feasibility of retrofitting the LLWAS with an icing-resistant, low maintenance sensor design which will continue to operate effectively under severe icing conditions and can be retrofitted into the existing LLWAS with a minimum of impact. The purpose of this study is to assess the severity of icing at the 110 LLWAS airports with the goal of determining which airports would warrant icing-resistant anemometers.

1.4 OBJECTIVES

The objectives of this study are:

A) Provide a statistical profile of icing precipitation events for the 110 LLWAS airports.

B) Generate a climatological database and develop icing criteria, based on the derived statistics, to rank the LLWAS sites according to their icing severity.

1.5 DEFINITION OF ICING CONCERNS

The decision was made to limit the study to icing caused by freezing liquid precipitation, either rain or drizzle. Sticking snow was excluded from the study for two reasons:

A) The current LLWAS sensors are of the propeller/vane type are generally not affected by snow. Snow is, however, an important consideration for cup anemometers which tend to become filled with snow and slow down.

b) The available historical weather data clearly detail the occurrence of freezing rain and drizzle, but do not explicitly distinguish sticking snow from non-sticking snow.

The effects of icing on anemometer performance can last well beyond the actual duration of an icing event. The ice accumulated during the event can last until the temperature goes above freezing and/or there issufficient solar heating. The study examined the significance of persisting ice by defining the following specific terminology:

A) *Icing* is defined as the actual period of ice accumulation as given by the weather observations.

B) *Glazing* is defined as the expected duration of the accumulated ice after accumulation has stopped. For simplicity, the algorithm used to define glazing used only temperature, not solar heating. The glazing period after an icing event was continued until the temperature went above freezing or 48 hours had elapsed, whichever came first. The 48-hour limit would allow for manual deicing of the wind sensors, solar heating, evaporation, or any

other way of removing the ice.

C) *Freezing* is defined as the total period of icing and glazing for an event.

The analysis assumed that the LLWAS anemometers would be affected soon after icing was reported and would be affected until the glazing period was over. Appendix B presents some data from the earlier icing field test that supports this assumption. Thus, the expected impact of icing on the LLWAS system will be represented by the frequency and duration of icing/glazing events.

1.6 SUMMARY

The results of the climatological study are presented in two volumes. Volume I (with Appendices A and B) compares the icing severity for different airports. Volume II describes the details of the data processing and presents the icing statistics for each individual airport.

The climatological study results provide an up-to-date 24-year statistical profile of icing for 106 LLWAS sites. Meteorological data were not available for the following four LLWAS sites:

Cedar Rapids Municipal Airport, IA
Ft. Lauderdale International Airport, FL
Sarasota-Bradenton Airport, FL
Monroe Regional Airport, IL

However, data for these sites can be inferred from nearby sites.

The following data are presented:

A) A complete 24-year hourly icing, glazing and freezing history for each LLWAS site in the form of yearly summary tables and histograms. (Volume II, Appendix B).

B) A climatic map indicating icing contours based on total icing duration. (Volume I, Section 3.1).

C) Data tables and histograms of ranked LLWAS sites based on five parameters: number of yearly icing events, icing duration, glazing duration, freezing duration, and weighted icing and glazing duration. (Volume I, Section 3.2)

2.0 METHODOLOGY

This section describes the methodology of the study. Details, such as tape formats, weather codes and data reduction procedures are presented in Appendix A of Volume II.

2.1 CLIMATOLOGICAL DATA SOURCE

The climatological data used in the study were "Surface Airways Hourly Observations," obtained from the National Climatic Data Center (NCDC) in the form of library tapes. With few exceptions, all library tapes contained hourly observations a period of 24 years, from January 1, 1965 to December 31, 1988. The tapes did not specify the actual time within the hourly reporting interval at which freezing rain or drizzle began. Thus, the smallest observation interval is one hour.

2.2 DATA REDUCTION/ANALYSIS

The data reduction procedures identified freezing rain and drizzle events and the presumed following glazing period. A data file was generated for each airport including all the weather data from the events, including the intensity of the freezing precipitation (light, moderate or heavy), the temperature and the wind speed and direction. This condensed data file was used in subsequent statistical analyses and was also used in another study to define the "worst case" icing conditions which an icing-resistant anemometer must withstand.

The statistical analyses provided data on:

A) The frequency of occurrence each year of the types and intensities of freezing precipitation. Light rain and light drizzle were more or less equally likely. Moderate freezing precipitation was rare and heavy freezing precipitation (rain only) extremely rare. Histograms for each airport show the yearly frequency of

each icing condition. Figure 1 shows a sample icing report histogram for Buffalo, NY.

B) The total icing and glazing duration and the number of events, both on a yearly basis and averaged over the 24-year period. The yearly icing and glazing data are presented as histograms for each airport (see Figure 2 for Buffalo, NY). The 24-year data are presented as histograms comparing all airports.

The 24-year averaged data will be presented in this volume. The yearly data are presented in Volume II.

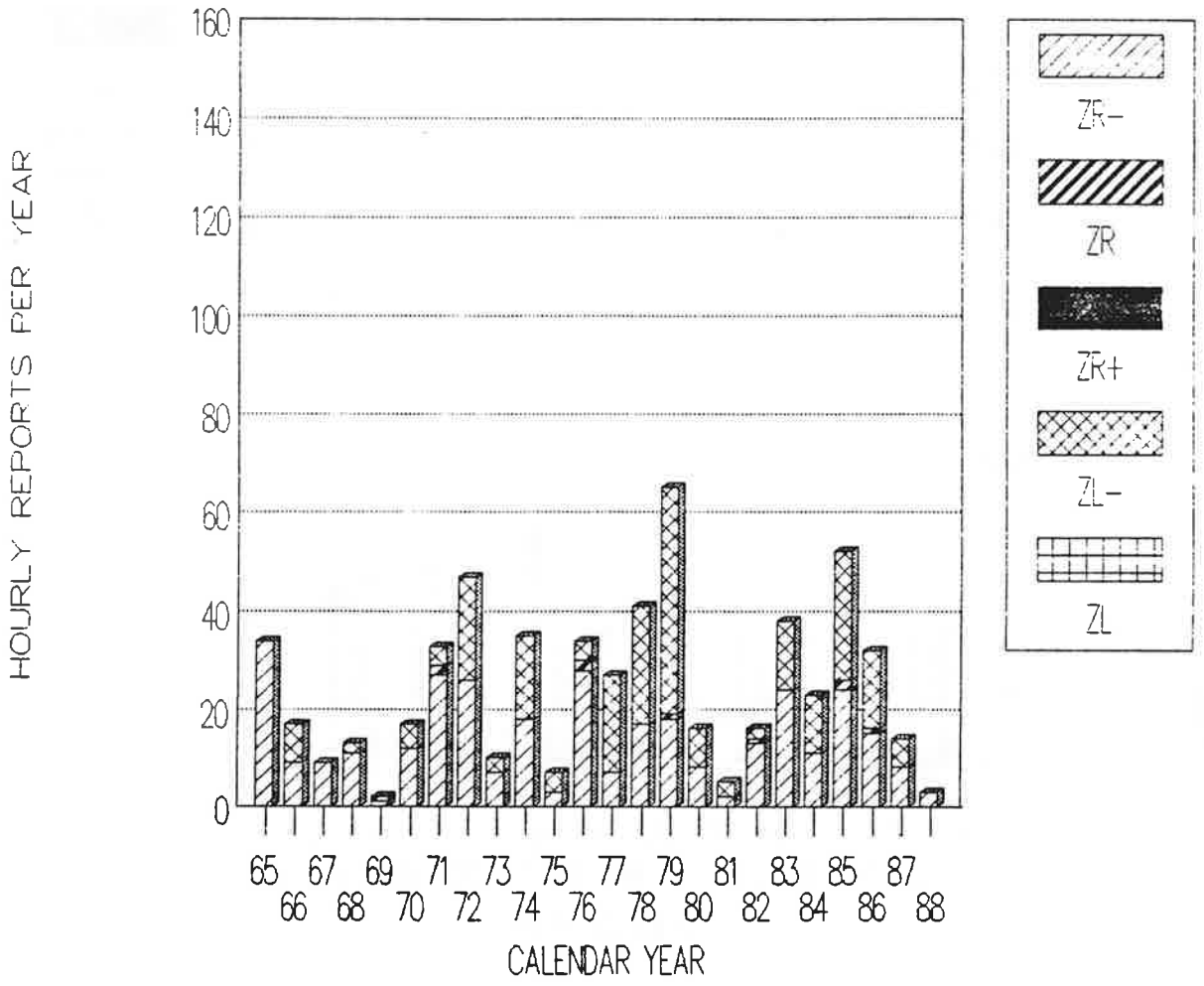


FIGURE 1. BUFFALO, NY ICING REPORTS 1965-1988

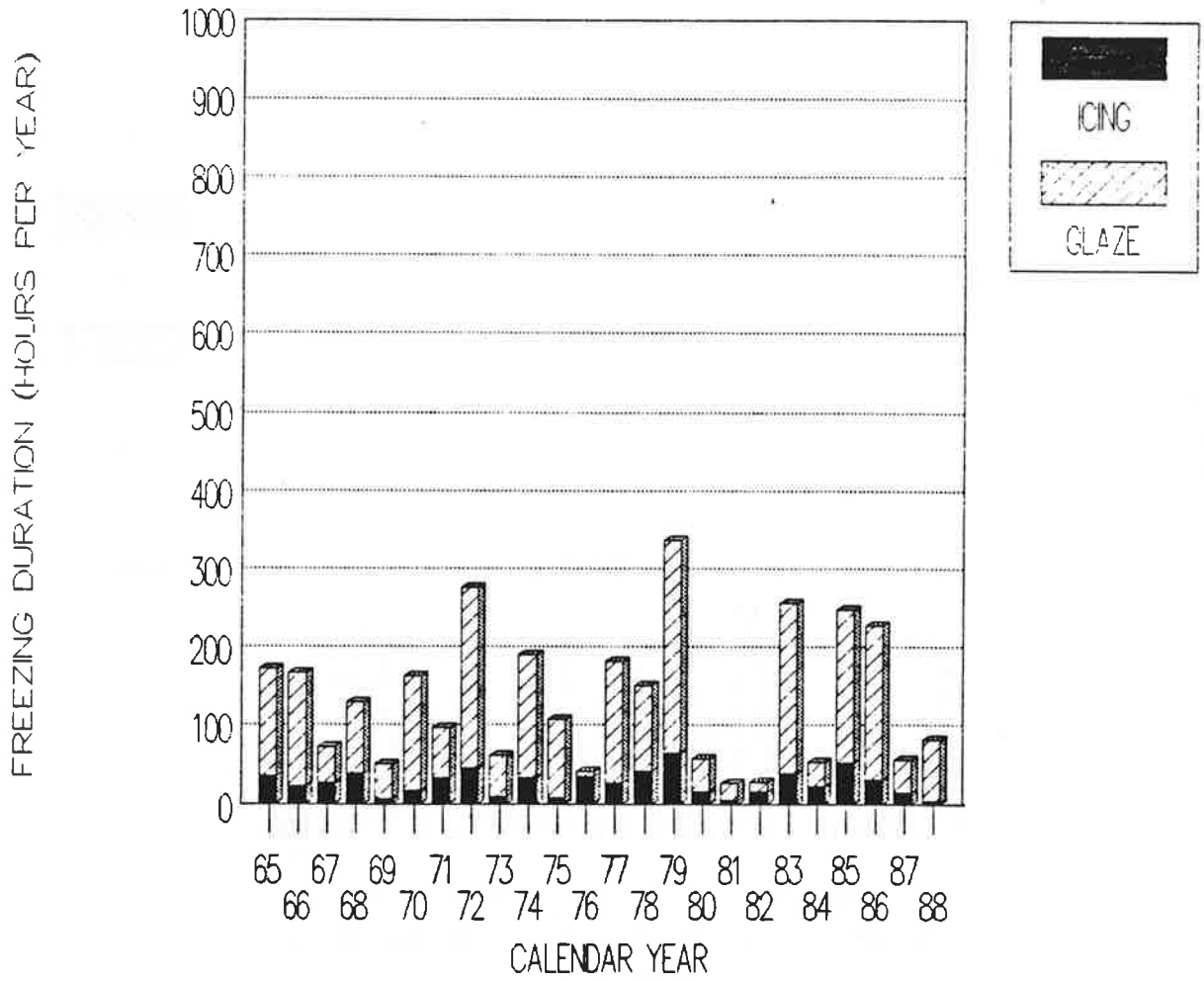


FIGURE 2. BUFFALO, NY FREEZING DURATION 1965-1988

3.0 RESULTS

This section presents the 24-year icing climatology for the LLWAS airports.

3.1 GEOGRAPHICAL DISTRIBUTION OF ICING

Figure 3 maps the icing occurrence over the CONUS; the contours show the total number of icing hours in 24 years.

The bottom contour delimits the sites with no reported icing. The next higher line outlines the sites with less than ten hours of icing. Clearly these sites have no significant icing problem; they are located in the deep south and west and are mostly close to the ocean.

The rest of the contours show increments of 100 hours and outline regions with progressively more and more icing. The highest rates (over 1000 hours) are located in the north center of the continent west of the Great Lakes. Fairly high rates project down into the Texas panhandle in the mid continent and down the Appalachian mountains in the East. Coastal areas have relatively less icing than inland areas for the same latitude.

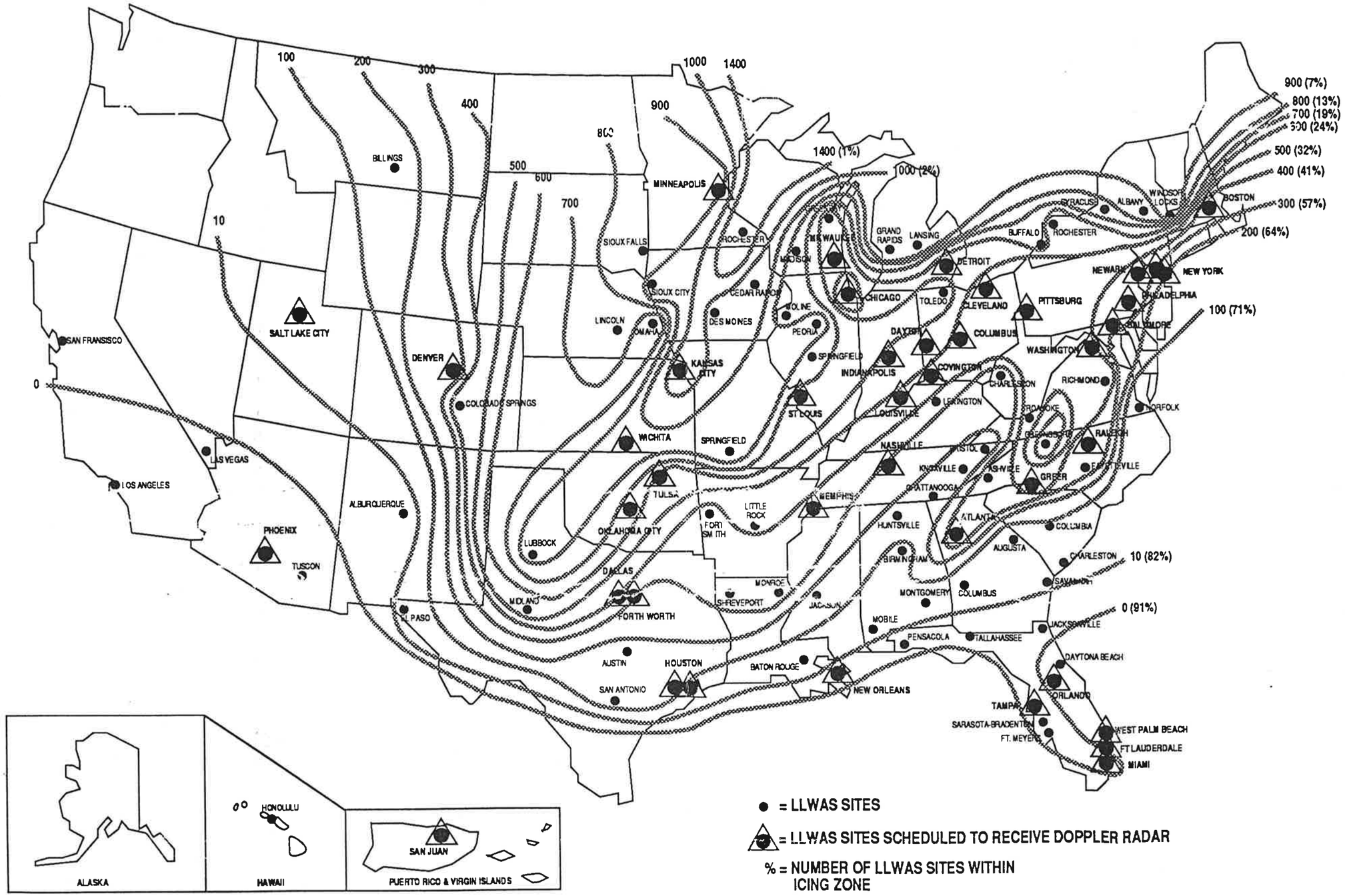


FIGURE 3 ICING CONTOURS MAP BASED ON 24 YEAR ICING STATISTICS - ICING INTENSITY IN CONUS IN TERMS OF TOTAL HOURS PER 24 YEAR PERIOD

3.2 ICING SEVERITY RANKING

Figures 4 through 8 rank the icing severity of the LLWAS airports according to the following criteria:

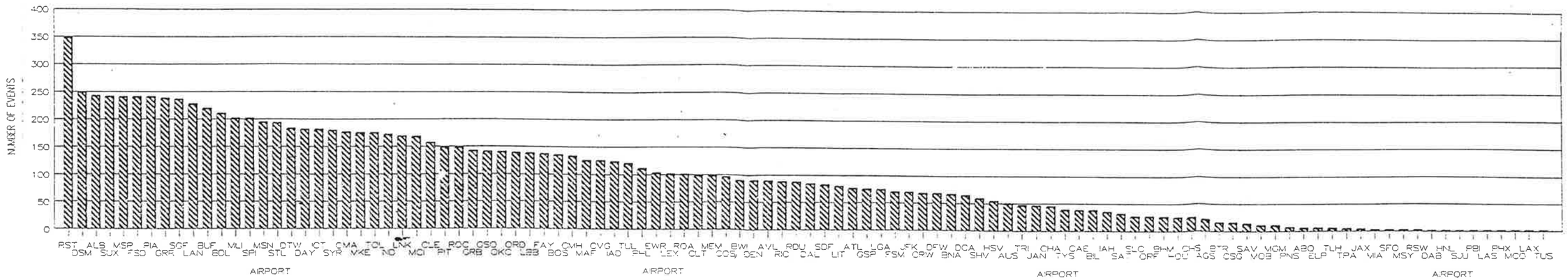
Figure 4	Number of events in 24 years
Figure 5	Total icing hours in 24 years
Figure 6	Total glazing hours in 24 years
Figure 7	Total freezing (icing + glazing) hours in 24 years
Figure 8	Total (icing + glazing/6) hours in 24 years.

The three letter airport codes used in the Figures are listed in Appendix A of Volume I. In all cases Rochester, MN tops the icing ranking. The ranking of the other airports varies some with the criterion selected.

For a first choice, the total freezing criterion (Figure 7.) would appear to be most appropriate since it indicates how long an anemometer might remain out of service due to icing. This criterion gives heavy weighting to glazing since the glazing period is typically much longer than the icing period. This criterion assigns higher severity to the colder parts of the country.

Since the glazing period is somewhat artificially defined, another criterion (for Figure 8) was designed to reduce the weight of glazing so that icing and glazing have roughly equal weight. Note that a reduction in the impact of glazing may be appropriate because microbursts normally occur in the afternoon after solar heating has occurred.

The icing rankings show no sharp break between airports significantly affected by icing and those not affected. The parameters used to rank icing severity decrease continuously from the most affected to the least affected airports. The icing impact reaches an insignificant level for perhaps less than one quarter of the total number of airports.

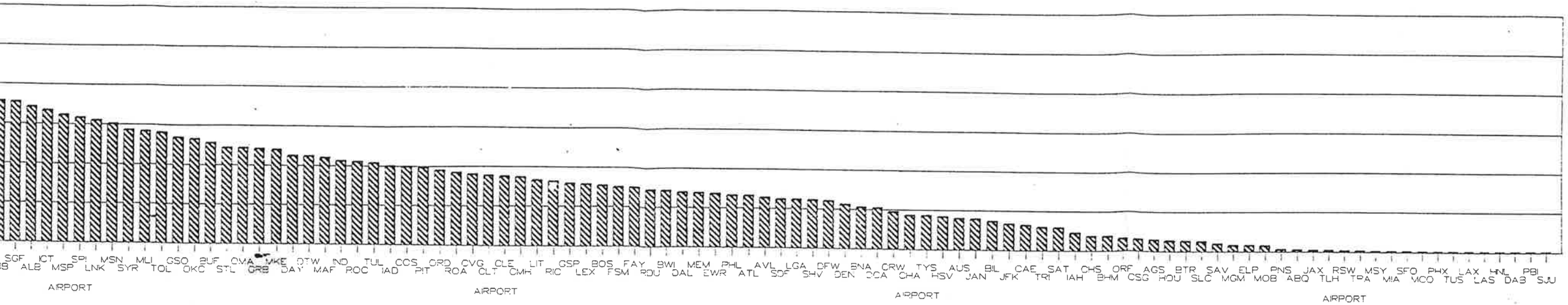


AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
RST	347	1413	7451	6038	2419
DSM	248	985	5612	4627	1756
ALB	241	854	2853	2252	1372
SUX	240	903	5179	4276	1616
PIA	239	900	4898	3998	1566
FSD	239	892	5121	4229	1597
MSP	239	803	5168	4365	1531
GRR	237	917	3747	2830	1389
SGF	235	883	4764	3881	1530
LAN	226	902	4339	3437	1475
BUF	218	636	3225	2589	1068
BDL	209	961	2678	1717	1247
SPI	200	787	4025	3238	1327
MLI	200	705	4019	3314	1257
MSN	193	750	3849	3099	1267
STL	192	606	3266	2660	1049
DTW	182	556	2502	1946	880
DAY	180	560	2867	2307	945
ICT	180	831	3984	3153	1357
SYR	178	713	2426	1713	999
OMA	175	606	4122	3516	1192
MKE	174	597	3393	2796	1063
TOL	174	698	3224	2526	1119
IND	171	528	3154	2626	966
LNK	168	771	4173	3402	1338
MCI	167	1065	3260	2195	1431
CLE	156	435	3417	2982	932
PIT	148	490	2533	2043	831
ROC	147	524	1786	1262	734
GRB	141	600	2998	2396	1000
GSO	140	668	1385	717	788
OKC	139	659	3001	2342	1049
ORD	138	473	2493	2020	810
LBB	137	887	2621	1734	1176
FAY	136	372	1684	1312	591
BOS	134	382	1431	1049	557

AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
CMH	132	431	2279	1848	739
MAF	124	547	2087	1540	804
CVG	124	447	2411	1964	774
IAD	122	498	1173	675	611
TUL	119	518	2712	2194	884
PHL	110	329	1210	881	476
EWR	102	337	1167	889	485
LEX	100	389	1755	1366	617
ROA	99	458	974	516	544
MEM	97	341	1697	1356	567
CLT	97	440	862	422	510
COS	95	496	2472	1976	825
BWI	89	353	1012	728	533
DEN	89	278	1876	1598	544
AVL	88	316	730	414	385
RIC	87	405	1109	704	522
RDU	86	359	1098	739	482
DAL	83	344	855	511	429
SDF	81	308	1541	1233	514
LIT	79	411	1286	875	557
ATL	75	329	777	448	404
GSP	74	394	697	303	445
LGA	73	306	966	660	416
JFK	69	164	969	805	298
FSM	69	373	1343	970	535
CRW	67	235	1182	947	393
DFW	67	300	1249	949	458
BNA	66	262	1220	958	422
DCA	64	257	644	387	322
SHV	58	305	969	664	416
HSV	53	206	802	596	305
AUS	49	197	652	455	273
TRI	46	147	860	713	266
JAN	45	196	814	618	299
CHA	44	214	711	497	297
TYS	38	214	759	545	305

AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
CAE	37	158	344	186	189
BIL	37	182	970	788	313
IAH	34	110	503	393	176
SAT	31	144	314	170	172
ORF	26	75	429	354	134
SLC	26	59	241	182	89
BHM	25	89	441	352	148
HOU	24	64	300	236	103
CHS	24	91	262	171	120
AGS	20	70	273	203	104
CSG	15	71	184	113	90
BTR	15	63	168	105	81
SAV	13	46	148	102	63
MOB	10	34	51	17	37
MGM	10	37	66	29	42
PNS	6	10	92	82	24
ABQ	5	8	49	41	15
ELP	5	36	84	48	44
TLH	4	7	33	26	11
TPA	3	3	3	0	3
JAX	2	7	7	0	7
SFO	1	1	1	0	1
MIA	1	1	1	0	1
RSW	1	3	3	0	3
MSY	1	2	12	10	4
DAB	0	0	0	0	0
HNL	0	0	0	0	0
SJU	0	0	0	0	0
PBI	0	0	0	0	0
LAS	0	0	0	0	0
PHX	0	0	0	0	0
LAX	0	0	0	0	0
TUS	0	0	0	0	0
MCO	0	0	0	0	0

FIGURE 4. RANKED ICING EVENTS



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240	903	5179	4276	1616
226	902	4339	3437	1475
239	900	4898	3998	1566
239	892	5121	4229	1597
137	887	2621	1734	1176
235	883	4764	3881	1530
241	854	2853	2252	1372
180	831	3984	3153	1357
239	803	5168	4365	1531
200	787	4025	3238	1327
168	771	4173	3402	1338
193	750	3849	3099	1267
178	713	2426	1713	999
200	705	4019	3314	1257
174	698	3224	2526	1119
140	668	1385	717	788
139	659	3001	2342	1049
118	636	3225	2589	1068
192	606	3266	2660	1049
175	606	4122	3516	1192
141	600	2998	2398	1000
174	597	3393	2796	1063
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AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
ORD	138	473	2493	2020	810
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CVG	124	447	2411	1964	774
CLT	97	440	862	422	510
CLE	156	435	3417	2982	932
CMH	132	431	2279	1848	739
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FAY	136	372	1684	1312	591
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BWI	89	353	1012	728	533
DAL	83	344	855	511	429
MEM	97	341	1697	1356	567
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PHL	110	329	1210	881	476
AVL	88	316	730	414	385
SDF	81	308	1541	1233	514
LGA	73	306	966	660	416
SHV	58	305	969	664	416
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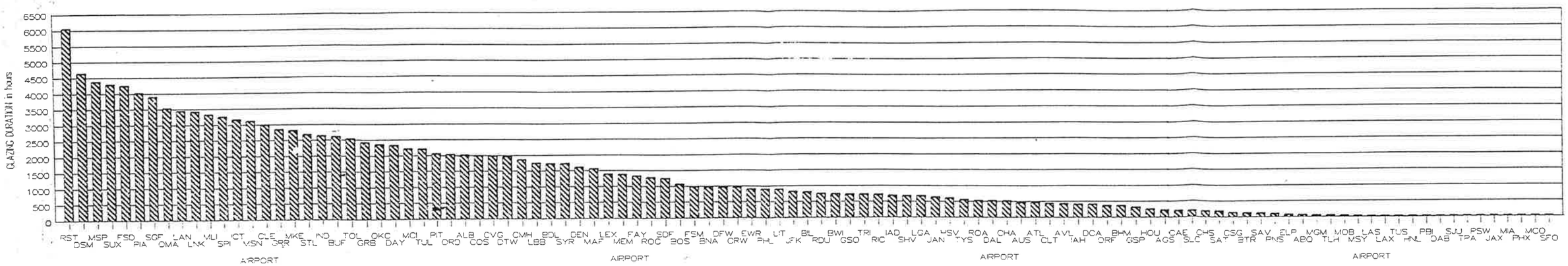
DEN	89	278	1876	1598	544
BNA	66	262	1220	958	422
DCA	64	257	644	387	322
CRW	67	235	1182	947	393
CHA	44	214	711	497	207

AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
CAE	37	158	344	186	189
TRI	46	147	860	713	266
SAT	31	144	314	170	172
IAH	34	110	503	393	176
CHS	24	91	262	171	120
BHM	25	89	441	352	148
ORF	26	75	429	354	134
CSG	15	71	184	113	90
AGS	20	70	273	203	104
HOU	24	64	300	236	103
BTR	15	63	168	105	81
SLC	26	59	241	182	89
SAV	13	46	148	102	63
MGM	10	37	66	29	42
ELP	5	36	84	48	44
MOB	10	34	51	17	37
PNS	6	10	92	82	24
ABQ	5	8	49	41	15
JAX	2	7	7	0	7
TLH	4	7	33	26	11
RSW	1	3	3	0	3
TPA	3	3	3	0	3
MSY	1	2	12	10	4
SFO	1	1	1	0	1
MIA	1	1	1	0	1
LAX	0	0	0	0	0
PHX	0	0	0	0	0
MCO	0	0	0	0	0
TUS	0	0	0	0	0

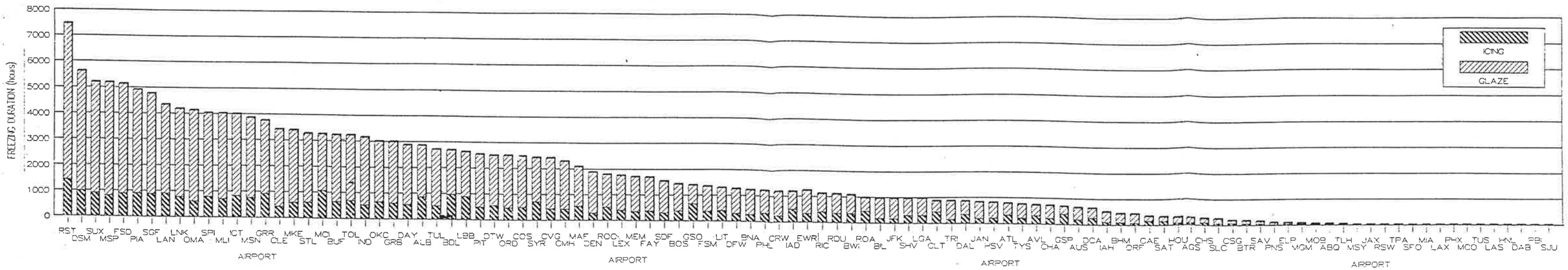


AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
RST	347	1413	7451	6038	2419
DSM	248	985	5612	4627	1756
MSP	239	803	5168	4365	1531
SUX	240	903	5179	4276	1616
FSD	239	892	5121	4229	1597
PIA	239	900	4898	3998	1566
SGF	235	883	4764	3881	1530
OMA	175	606	4122	3516	1192
LAN	226	902	4339	3437	1475
LNK	168	771	4173	3402	1338
MLI	200	705	4019	3314	1257
SPI	200	787	4025	3238	1327
ICT	180	831	3984	3153	1357
MSN	193	750	3849	3099	1267
CLE	156	435	3417	2982	932
GRR	237	917	3747	2830	1389
MKE	174	597	3393	2796	1063
STL	192	606	3266	2660	1049
IND	171	528	3154	2626	966
BUF	218	636	3225	2589	1068
TOL	174	698	3224	2526	1119
GRB	141	600	2998	2398	1000
OKC	139	659	3001	2342	1049
DAY	180	560	2867	2307	945
ALB	241	854	2853	2252	1372
MCI	167	1065	3260	2195	1431
TUL	119	518	2712	2194	884
PIT	148	490	2533	2043	831
ORD	138	473	2493	2020	810
COS	95	496	2472	1976	825
CVG	124	447	2411	1964	774
DTW	182	556	2502	1946	880
CMH	132	431	2279	1848	739
LBB	137	887	2621	1734	1176
BDL	209	961	2678	1717	1247
SYR	178	713	2426	1713	999

AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
DEN	89	278	1876	1598	544
MAF	124	547	2087	1540	804
LEX	100	389	1755	1366	617
MEM	97	341	1697	1356	567
FAY	136	372	1684	1312	591
ROC	147	524	1786	1262	734
SDF	81	308	1541	1233	514
BOS	134	382	1431	1049	557
FSM	69	373	1343	970	535
BNA	66	262	1220	958	422
DFW	67	300	1249	949	458
CRW	67	235	1182	947	393
EWR	102	337	1167	889	485
PHL	110	329	1210	881	476
LIT	79	411	1286	875	557
JFK	69	164	969	805	298
BIL	37	182	970	788	313
RDU	86	359	1098	739	482
BWI	89	353	1012	728	533
GSO	140	668	1385	717	788
TRI	46	147	860	713	266
RIC	87	405	1109	704	522
IAD	122	498	1173	675	611
SHV	58	305	969	664	416
LGA	73	306	966	660	416
JAN	45	196	814	618	299
HSV	53	206	802	596	305
TYS	38	214	759	545	305
ROA	99	458	974	516	544
DAL	83	344	855	511	429
CHA	44	214	711	497	297
AUS	49	197	632	455	273
ATL	75	329	777	448	404
CLT	97	440	862	422	510
AVL	88	316	730	414	385
IAH	34	110	503	393	176

AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
DCA	64	257	644	387	322
ORF	26	75	429	354	134
BHM	25	89	441	352	148
GSP	74	394	697	303	445
HOU	24	64	300	236	103
AGS	20	70	273	203	104
CAE	37	158	344	186	189
SLC	26	59	241	182	89
CHS	24	91	262	171	120
SAT	31	144	314	170	172
CSG	15	71	184	113	90
BTR	15	63	168	105	81
SAV	13	46	148	102	63
PNS	6	10	92	82	24
ELP	5	36	84	48	44
ABQ	5	8	49	41	15
MGM	10	37	66	29	42
TLH	4	7	33	26	11
MOB	10	34	51	17	37
MSY	1	2	12	10	4
LAS	0	0	0	0	0
PBI	0	0	0	0	0
SJU	0	0	0	0	0
PHX	0	0	0	0	0
MCO	0	0	0	0	0
TUS	0	0	0	0	0
LAX	0	0	0	0	0
RSW	1	3	3	0	3
TPA	3	3	3	0	3
JAX	2	7	7	0	7
MIA	1	1	1	0	1
HNL	0	0	0	0	0
DAB	0	0	0	0	0
SFO	1	1	1	0	1

FIGURE 6. RANKED GLAZING DURATION

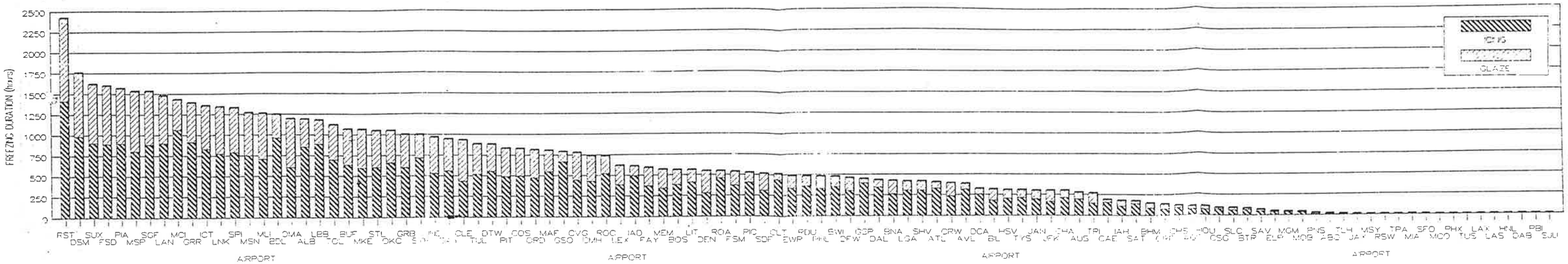


AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
RST	347	1413	7451	6038	2419
DSM	248	985	5612	4627	1756
SUX	240	903	5179	4276	1616
MSP	239	803	5168	4365	1531
FSD	239	892	5121	4229	1597
PIA	239	900	4898	3998	1566
SGF	235	883	4764	3881	1530
LAN	226	902	4339	3437	1475
LNK	168	771	4173	3402	1338
OMA	175	606	4122	3516	1192
SPI	200	787	4025	3238	1327
MLI	200	705	4019	3314	1257
ICT	180	831	3984	3153	1357
MSN	193	750	3849	3099	1267
GRR	237	917	3747	2830	1389
CLE	156	435	3417	2982	932
MKE	174	597	3393	2796	1063
STL	192	606	3266	2660	1049
MCI	167	1065	3260	2195	1431
BUF	218	636	3225	2589	1068
TOL	174	698	3224	2526	1119
IND	171	528	3154	2626	966
OKC	139	659	3001	2342	1049
GRB	141	600	2998	2398	1000
DAY	180	560	2867	2307	945
ALB	241	854	2853	2252	1372
TUL	119	518	2712	2194	884
BDL	209	961	2678	1717	1247
LBB	137	887	2621	1734	1176
PIT	148	490	2533	2043	831
DTW	182	556	2502	1946	880
ORD	138	473	2493	2020	810
COS	95	496	2472	1973	825
SYR	178	713	2426	1713	999
CVG	124	447	2411	1964	774
CMH	132	431	2279	1848	739

AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
MAF	124	547	2087	1540	804
DEN	89	278	1876	1598	544
ROC	147	524	1786	1262	734
LEX	100	389	1755	1366	617
MEM	97	341	1697	1356	567
FAY	136	372	1684	1312	591
SDF	81	308	1541	1233	514
BOS	134	382	1431	1049	557
GSO	140	668	1385	717	788
FSM	69	373	1343	970	535
LIT	79	411	1286	875	557
DFW	67	300	1249	949	458
BNA	66	262	1220	958	422
PHL	110	329	1210	881	476
CRW	67	235	1182	947	393
IAD	122	498	1173	675	611
EWR	102	337	1167	889	485
RIC	87	405	1109	704	522
RDU	86	359	1098	739	482
BWI	89	353	1012	728	533
ROA	99	458	974	516	544
BIL	37	182	970	788	313
SHV	58	305	969	664	416
JFK	69	164	969	805	298
LGA	73	306	966	660	416
CLT	97	440	862	422	510
TRI	46	147	860	713	266
DAL	83	344	855	511	429
JAN	45	196	814	618	299
HSV	53	206	802	596	305
ATL	75	329	777	448	404
TYS	38	214	759	545	305
AVL	88	316	730	414	385
CHA	44	214	711	497	297
GSP	74	394	697	303	445
AUS	49	197	652	455	273

AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6
DCA	64	257	644	387	322
IAH	34	110	503	393	176
BHM	25	89	441	352	148
ORF	26	75	429	354	134
CAE	37	158	344	186	189
SAT	31	144	314	170	172
HOU	24	64	300	236	103
AGS	20	70	273	203	104
CHS	24	91	262	171	120
SLC	26	59	241	182	89
CSG	15	71	184	113	90
BTR	15	63	168	105	81
SAV	13	46	148	102	63
PNS	6	10	92	82	24
ELP	5	36	84	48	44
MGM	10	37	66	29	42
MOB	10	34	51	17	37
ABQ	5	8	49	41	15
TLH	4	7	33	26	11
MSY	1	2	12	10	4
JAX	2	7	7	0	7
TPA	3	3	3	0	3
RSW	1	3	3	0	3
MIA	1	1	1	0	1
SFO	1	1	1	0	1
DAB	0	0	0	0	0
HNL	0	0	0	0	0
SJU	0	0	0	0	0
PBI	0	0	0	0	0
LAS	0	0	0	0	0
PHX	0	0	0	0	0
LAX	0	0	0	0	0
TUS	0	0	0	0	0
MCO	0	0	0	0	0

FIGURE 7. RANKED FREEZING DURATION



AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6	G/6
RST	347	1413	7451	6038	2419	1006
DSM	248	985	5612	4627	1756	771
SUX	240	903	5179	4276	1616	713
FSD	239	892	5121	4229	1597	705
PIA	239	900	4898	3998	1566	666
MSP	239	803	5168	4365	1531	728
SGF	235	883	4764	3881	1530	647
LAN	226	902	4339	3437	1475	573
MCI	167	1065	3260	2195	1431	366
GRR	237	917	3747	2830	1389	472
ICT	180	831	3984	3153	1357	526
LNK	168	771	4173	3402	1338	567
SPI	200	787	4025	3238	1327	540
MSN	193	750	3849	3099	1267	517
MLI	200	705	4019	3314	1257	552
BDL	209	961	2678	1717	1247	286
OMA	175	606	4122	3516	1192	586
ALB	241	854	2853	1999	1187	333
LBB	137	887	2621	1734	1176	289
TOL	174	698	3224	2526	1119	421
BUF	218	636	3225	2589	1068	432
MKE	174	597	3393	2796	1063	466
OKC	139	659	3001	2342	1049	390
STL	192	606	3266	2660	1049	443
GRB	141	600	2998	2398	1000	400
SYR	178	713	2426	1713	999	286
IND	171	528	3154	2626	966	438
DAY	180	560	2867	2307	945	385
CLE	156	435	3417	2982	932	497
TUL	119	518	2712	2194	884	366
DTW	182	556	2502	1946	880	324
PIT	148	490	2533	2043	831	341
COS	95	496	2472	1976	825	329
ORD	138	473	2493	2020	810	337
MAF	124	547	2087	1540	804	257
GSO	140	668	1385	717	788	120

AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6	G/6
CVG	124	447	2411	1964	774	327
CMH	132	431	2279	1848	739	308
ROC	147	524	1786	1262	734	210
LEX	100	389	1755	1366	617	228
IAD	122	498	1173	675	611	113
FAY	136	372	1684	1312	591	219
MEM	97	341	1697	1356	567	226
BOS	134	382	1431	1049	557	175
LIT	79	411	1286	875	557	146
DEN	89	278	1876	1598	544	266
ROA	99	458	974	516	544	86
FSM	69	373	1343	970	535	162
RIC	87	405	1109	704	522	117
SDF	81	308	1541	1233	514	206
CLT	97	440	862	422	510	70
EWR	102	337	1167	889	485	148
RDU	86	359	1098	739	482	123
PHL	110	329	1210	881	476	147
BWI	89	353	1012	728	474	121
DFW	67	300	1249	949	458	158
GSP	74	394	697	303	445	51
DAL	83	344	855	511	429	85
BNA	66	262	1220	958	422	160
LGA	73	306	966	660	416	110
SHV	58	305	969	664	416	111
ATL	75	329	777	448	404	75
CRW	67	235	1182	947	393	158
AVL	88	316	730	414	385	69
DCA	64	257	644	387	322	65
BIL	37	182	970	788	313	131
HSV	53	206	802	596	305	99
TYS	38	214	759	545	305	91
JAN	45	196	814	618	299	103
JFK	69	164	969	805	298	134
CHA	44	214	711	497	297	83

AIRPORT	# EVENTS	ICING	FREEZING	GLAZING	I+G/6	G/6
AUS	49	197	652	455	273	76
TRI	46	147	860	713	266	119
CAE	37	158	344	186	189	31
IAH	34	110	503	393	176	66
SAT	31	144	314	170	172	28
BHM	25	89	441	352	148	59
ORF	26	75	429	354	134	59
CHS	24	91	262	171	120	29
AGS	20	70	273	203	104	34
HOU	24	64	300	236	103	39
CSG	15	71	184	113	90	19
SLC	26	59	241	182	89	30
BTR	15	63	168	105	81	18
SAV	13	46	148	102	63	17
ELP	5	36	84	48	44	8
MGM	10	37	66	29	42	5
MOB	10	34	51	17	37	3
PNS	6	10	92	82	24	14
ABQ	5	8	49	41	15	7
TLH	4	7	33	26	11	4
JAX	2	7	7	0	7	0
MSY	1	2	12	10	4	2
RSW	1	3	3	0	3	0
TPA	3	3	3	0	3	0
MIA	1	1	1	0	1	0
SFO	1	1	1	0	1	0
MCO	0	0	0	0	0	0
PHX	0	0	0	0	0	0
TUS	0	0	0	0	0	0
LAX	0	0	0	0	0	0
LAS	0	0	0	0	0	0
HNL	0	0	0	0	0	0
DAB	0	0	0	0	0	0
PBI	0	0	0	0	0	0
SJU	0	0	0	0	0	0

FIGURE 8. WEIGHTED ICING AND GLAZING DURATION

4.0 CONCLUSIONS

Only nine of the 106 LLWAS airports studied had no records of icing during the 24-year period of the study. The icing severity increased for locations farther north, farther from large bodies of water and at higher altitudes. Roughly 75 percent of the LLWAS airports have a significant amount of icing (approximately 100 hours in 24 years).

5.0 RECOMMENDATIONS

The information in this report could be used in two different ways:

A) Retrofit only part of the LLWAS systems with icing-resistant anemometers, then the icing severity criteria developed here could be combined with airport weightings to select, for example, which half of the LLWAS airports should receive icing-resistant anemometers. This approach would be consistent with buying icing-resistant anemometers for the planned LLWAS upgrade and using them to replace the anemometers at the selected airports.

B) Minimize logistical problems by installing the same icing-resistant anemometers were installed at all LLWAS sites. This study shows that the icing-resistant feature would be superfluous at less than 25 percent of the sites. This approach would befurther justified if the new anemometers were easier to maintain than the current units.

APPENDIX A
AIRPORTS WITH LLWAS SYSTEMS

ID	LLWAS AIRPORT NAME	CITY	STATE	VENDOR	REGION
ABQ	Albuquerque International	Albuquerque	NM	FW	ASW
AGS	Bush Field	Augusta	GA	CL	ASO
ALB	Albany County	Albany	NY	CL	AEA
ATL	William B Hartsfield International	Atlanta	GA	FW	ASO
AUS	Robert Mueller Municipal	Austin	TX	CL	ASW
AVL	Asheville Regional	Asheville	NC	CL	ASO
BDL	Bradley International	Windsor Locks	CT	CL	ANE
BHM	Birmingham Municipal	Birmingham	AL	FW	ASO
BIL	Billings Logan	Billings	MT	CL	ANM
BNA	Nashville Metropolitan	Nashville	TN	FW	ASO
BOS	Gen Edward Logan International	Boston	MA	FW	ANE
BTR	Baton Rouge Metropolitan Ryan Field	Baton Rouge	LA	CL	ASW
BUF	Greater Buffalo	Buffalo	NY	FW	AEA
BWI	Baltimore -- Washington International	Baltimore	MD	FW	AEA
CAE	Colubia Metropolitan	Columbia	SC	CL	ASO
CHA	Lovell Field	Chattanoga	TN	FW	ASO
CHS	Charleston	Charleston	SC	CL	ASO
CID	Cedar Rapids Municipal	Cedar Rapids	IA	FW	ACE
CLE	Cleveland - Hopkins International	Cleveland	OH	FW	AGL
CLT	Charlotte/Douglas International	Charlotte	NC	FW	ASO
CMH	Port Columbus International	Columbus	OH	FW	AGL
COS	City of Colorado Springs Municipal	Colorado Springs	CO	CL	AMN
CRW	Yeager	Charleston	WV	CL	AEA
CSG	Columbus Metropolitan	Columbus	GA	CL	ASO
CVG	Greater Cincinnati International	Covington	KY	FW	ASO
DAB	Daytona Beach	Daytona Beach	FL	CL	ASO
DAL	Dallas Love Field	Dallas	TX	CL	ASW
DAY	James M. Cox Dayton International	Dayton	OH	FW	AGL
DCA	Washington National	Washington	DC	FW	AEA
DEN	Stapleton International	Denver	CO	FW	ANM
DFW	Dallas/Forth Worth International	Dallas/Fort Worth	TX	FW	ASW
DSM	Des Moines International	Des Moines	IA	FW	ACE
DTW	Detroit Metropolitan Wayne County	Detroit	MI	FW	AGL

LLWAS LISTING BY AIRPORT ID (cont.)

ID	LLWAS AIRPORT NAME	CITY	STATE	VENDOR	REGION
ELP	El Paso International	El Paso	TX	CL	ASW
ENR	Newark International	Newark	NJ	FW	AEA
FAY	Fayetteville Municipal	Fayetteville	NC	CL	ASO
FLL	Ft Lauderdale/Hollywood International	Ft Lauderdale	FL	FW	ASO
FSD	Joe Foss Field	Sioux Falls	SD	CL	AGL
FSM	Fort Smith Municipal	Fort Smith	AR	CL	ASW
GRB	Austin Struabel Field	Green Bay	WI	CL	AGL
GRR	Kent County International	Grand Rapids	MI	CL	AGL
GSO	Piedmont Traid International	Greensboro	NC	CL	ASO
GSP	Greenville-Spartanburg	Greer	SC	CL	ASO
HNL	Honolulu International	Honolulu	HI	CL	AWP
HOU	William P. Hobby	Houston	TX	FW	ASW
HSV	Huntsville International Carl T. Jones Field	Huntsville	AL	CL	ASO
IAD	Dulles International	Washington	DC	FW	AEA
IAM	Houston Intercontinental	Houston	TX	FW	ASW
ICT	Wichita Mid-Continent	Wichita	KS	FW	ACE
IND	Indianapolis International	Indianapolis	IN	FW	AGL
JAN	Allen C. Thompson Field	Jackson	MS	FW	ASO
JAX	Jacksonville International	Jacksonville	FL	FW	ASO
JFK	John F. Kennedy International	New York	NY	FW	AEA
LAN	Capital City	Lansing	MI	CL	AGL
LAS	McCarran International	Las Vegas	NV	FW	AWP
LAX	Los Angeles International	Los Angeles	CA	FW	AWP
LBB	Lubbock International	Lubbock	TX	CL	ASW
LEX	Blue Grass Field	Lexington	KY	CL	ASO
LGA	LaGuardia	New York	NY	FW	AEA
LIT	Adams Field	Little Rock	AR	FW	ASW
LNK	Lincoln Municipal	Lincoln	NE	CL	ACE
MAF	Midland International	Midland	TX	CL	ASW
MCI	Kansas City International	Kansas City	MO	FW	ACE
MCO	Orlando International	Orlando	FL	FW	ASO
MEM	Memphis International	Memphis	TN	FW	ASO
MGM	Dannelly Field	Montogomery	AL	CL	ASO
MIA	Miami International	Miami	FL	FW	ASO
MKE	General Mitchell International	Milwaukee	WI	FW	AGL
MIL	Quad-City	Moline	IL	CL	AGL

LLWAS LISTING BY AIRPORT ID (cont.)

ID	LLWAS AIRPORT NAME	CITY	STATE	VENDOR	REGION
MUL	Monroe Regional	Monroe	LA	CL	ASW
MOB	Bates Field	Mobile	AL	FW	ASO
MSN	Dane County Regional Truax Field	Madison	WI	CL	AGL
MSP	Minneapolis-St. Paul International	Minneapolis	MN	FW	AGL
MSY	New Orleans International	New Orleans	LA	FW	ASW
OKC	Will Rogers World	Oklahoma City	OK	FW	ASW
OMA	Eppley Airfield	Omaha	NE	FW	ACE
ORD	Chicago O'Hare International	Chicago	IL	FW	AGL
ORF	Norfolk International	Norfolk	VA	FW	AEA
PBI	Palm Beach International	West Palm Beach	FL	FW	ASO
PHL	Philadelphia International	Philadelphia	PA	FW	AEA
PHX	Phoenix Sky Harbor International	Phoenix	AZ	FW	AWP
PIA	Greater Peoria	Peoria	IL	CL	AGL
PIT	Greater Pittsburg International	Pittsburg	PA	FW	AEA
PNS	Pensacola Regional	Pensacola	FL	CL	ASO
RDU	Raleigh/Durham	Raleigh/Durham	NC	FW	ASO
RIC	Richmond International	Richmond	VA	CL	AEA
ROA	Roanoke Regional	Roanoke	VA	FW	AEA
ROC	Rochester-Monroe County	Rochester	NY	FW	AEA
RST	Rochester Municipal	Rochester	MN	CL	AGL
RSW	Southwest Regional	Ft. Myers	FL	CL	ASO
SAT	San Antonio International	San Antonio	TX	FW	ASW
SAV	Savannah International	Sanvannah	GA	CL	ASO
SDF	Standiford Field	Louisville	KY	FW	ASO
SFO	San Francisco International	San Francisco	CA	CL	AWP
SGF	Springfield Regional	Springfield	MO	FW	ACE
SHV	Shreveport Regional	Shreveport	LA	CL	ASW
SJU	Luis Munos Maria International	San Juan	PR	CL	ASO
SLC	Salt Lake City International	Salt Lake City	UT	FW	ANM
SPI	Capital	Springfield	IL	CL	AGL
SRQ	Sarasota/Bradenton	Sarasota/ Bradenton	FL	FW	ASO
STL	Lambert/St. Louis International	St. Louis	MO	FW	ACE
SUX	Sioux Gateway	Sioux City	IA	CL	ACE
SYR	Syracuse Hancock International	Syracuse	NY	CL	AEA

LLWAS LISTING BY AIRPORT ID (cont.)

ID	LLWAS AIRPORT NAME	CITY	STATE	VENDOR	REGION
TLH	Tallahassee Municipal	Tallashessee	FL	CL	ASO
TOL	Toledo Express	Toledo	OH	CL	AGL
TPA	Tampa International	Tampa	FL	FW	ASO
TRI	Tri-City Regional	Bristol	TN	CL	ASO
TUL	Tulsa International	Tulsa	OK	FW	ASW
TUS	Tucson International	Tucson	AZ	CL	AWP
TYS	McGhee Tyson	Knoxville	TN	FW	ASO

APPENDIX B
WORCESTER TESTS

The LLWAS systems installed by the FAA at airports have experienced numerous sensor outages attributable to icing. TSC was tasked to evaluate candidate replacement sensors for LLWAS which would continue to function under icing and snow conditions. The test took place at Worcester Municipal Airport in Worcester, Massachusetts. In total, 14 different types of sensors were evaluated during FY87 and FY88.

The Worcester tests concluded that freezing rain and freezing drizzle did, in fact, slow down the speed of the anemometers and eventually some of them were brought to a complete stop under persistent freezing weather conditions. The previous analysis of the Worcester data used 30-minutes data averages. To determine how quickly the icing effect on anemometers occurs, five-minute averages of wind speed were used. Figure B-1 compares the icing performance of three selected anemometers, the first two of which are used in the LLWAS systems:

1) The BELFORT Instrument Company's propeller/vane internally heated sensor, (Loral LLWAS).

2) The R. M. Young propeller/vane heated with lamps (Climatronics LLWAS) and

3) The SUTRON digitized hot-film anemometer.

The icing event shown in Figure B-1 occurred on March 4-5, 1988 and included several periods of light freezing rain reported by the NWS observer. The BELFORT and SUTRON sensors generally agree throughout the event and hence may be used as a standard for evaluating the performance of the R. M. Young sensor.

Figure B-1 shows that the R. M. Young sensor started to degrade at 0618 even before 0630, when the freezing rain was first reported by the observer; at that time, only

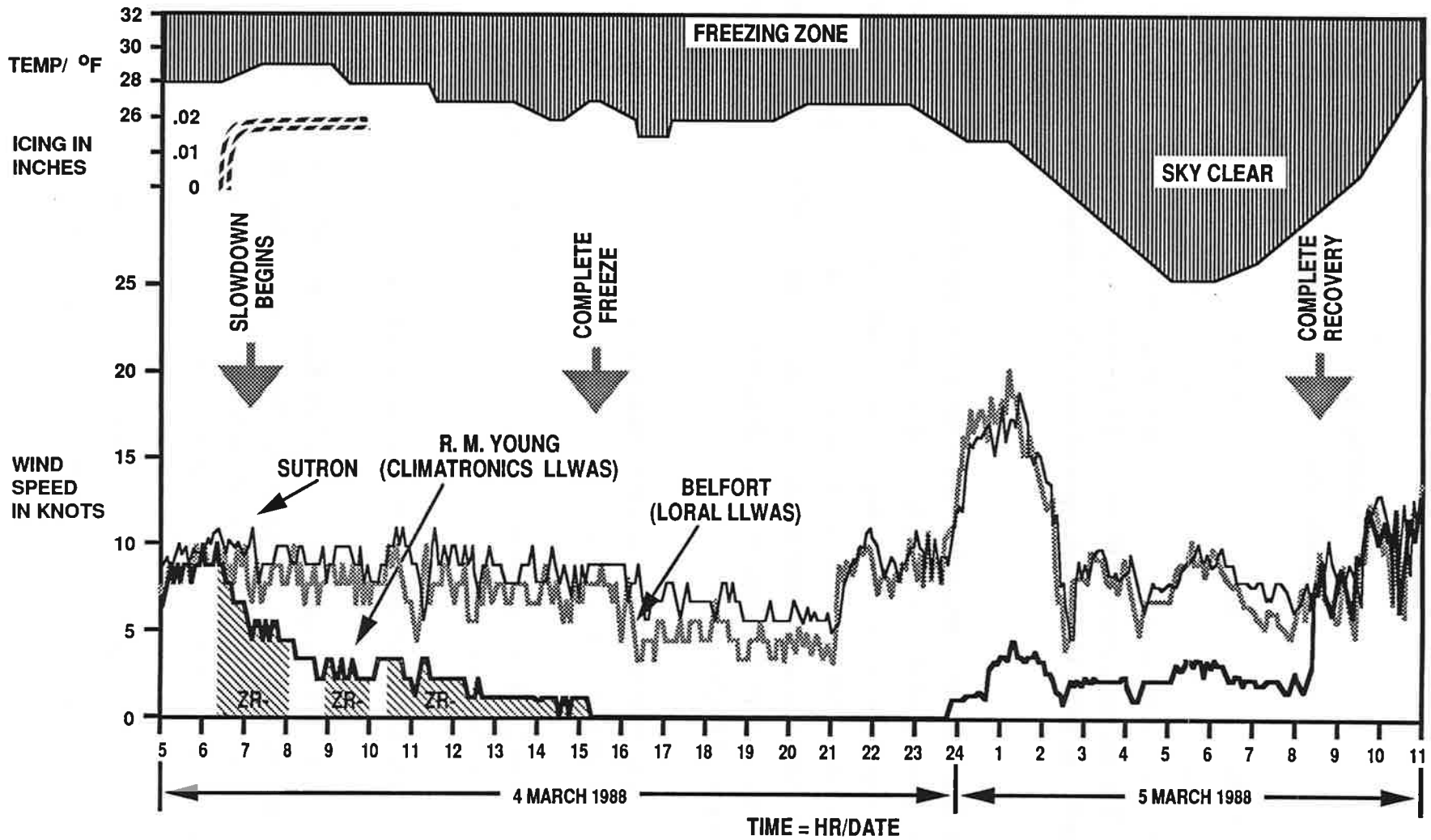


FIGURE B-1: LLWAS SENSOR PERFORMANCE DATA AT WORCESTER AIRPORT, MARCH 4-5, 1988

the icing meters (being tested concurrently with the anemometers) indicated the formation of ice. The raw one-minute data showed that, after icing detectors began to indicate formation of ice, only a few minutes elapsed before the R. M. Young sensor started to slow down and measure about 9-percent low in wind speed.

Summarizing the Worcester data the following may be concluded:

- Anemometer speed may be affected even before the actual freezing rain or freezing drizzle report is made.

- In the event analyzed, light freezing rain slowed down the anemometer soon after rain began. Within 40 minutes, the measured R. M. Young speed was only 50 percent of that measured by the other sensors. Many hours later the R. M. Young sensor completely froze up and remained inoperable during the glazing period after the rain had stopped. Finally, a 21-knot wind restarted the anemometer, but its speed measurement remained very low until the next morning when the radiational heat of the sun cleared the propeller.

- Under normal operating conditions, with no freezing precipitation present, all three sensors performed in satisfactory agreement.