High Latitude, West Coast Mountaintop Icing

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ABSTRACT

Numerous studies have characterized in-cloud mountaintop icing at North American midlatitude locations. This paper describes mountaintop icing at a high-latitude West Coast location, Site Summit, near Anchorage, Alaska. Icing was monitored at an elevation of 1189 m with a Rosemount ice detector. Data from the 1989–90 winter season at Site Summit are compared to icing conditions at two East Coast sites. Site Summit had 102 icing events during the year with an average duration of 7.5 hours per event. Peak icing intensity occurred in the late fall and early winter, with icing rates averaging 0.11 g/hr-cm of ice detector probe length and peaking at 1.06 g/hr-cm of probe length. An overview of weather conditions during icing events is also presented from measurements from nearby rawinsondes.

INTRODUCTION

Mountaintop icing has been studied extensively in New England (Ryerson,1988, 1990), Quebec (McComber et al., 1990), and the Sierras (Berg, 1988). Several of these studies have dealt specifically with the climatology of icing, including icing intensity and frequency and the synoptic conditions producing icing events (Ryerson, 1988, 1990; Berg, 1988). In addition, a related multiyear project, WISP—Winter Icing Storm Project, is currently being conducted under the auspices of the Federal Aviation Administration (FAA) in Colorado to improve aircraft icing forecasting (Hinkelman, 1989).

A goal of mountaintop icing research at the Cold Regions Research and Engineering Laboratory (CRREL) is to understand mountaintop icing conditions as they occur globally and to develop a more universal understanding of the conditions producing severe icing conditions within climatic regimes. This paper presents a summary of icing conditions observed during the first year of observations at Site Summit, a subarctic, West Coast mountaintop near Anchorage, Alaska. Measurements are compared to East Coast midlatitude icing conditions on Mt. Mansfield, Vermont, and Mt. Washington, New Hampshire.

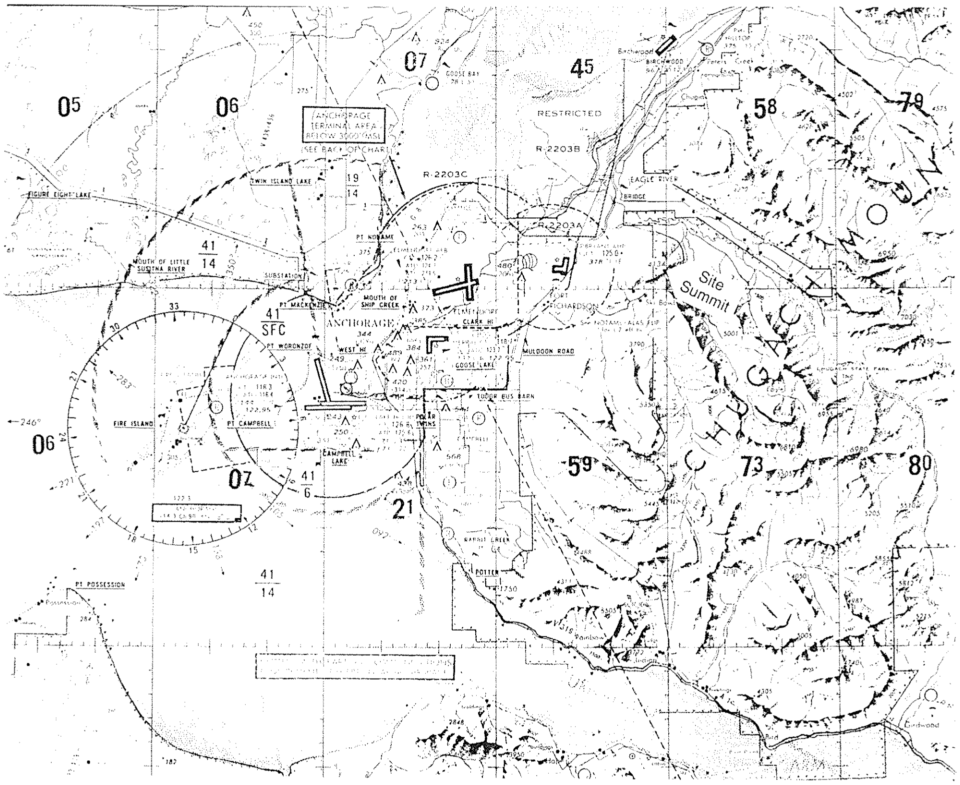


Figure 1. Location of Site Summit, Alaska.

STUDY LOCATION AND PERIOD

Site Summit (61° 15' N, 149° 30' W) is located on the western edge of the Chugach Mountains, approximately 25 km northeast of Anchorage, Alaska. With a summit elevation of about 1189 m, a broad, flat lowland to the west near sea level, and Knik Arm and Cook Inlet to the west and southwest respectively, the observation site (Fig. 1) is similar to that of Mount Mansfield in Vermont (Ryerson, 1988). Mt. Mansfield, though at about 45° N and 75° W, is of comparable elevation, 1220 m, and has no major obstructions to the flow of moisture-laden air to the mountain from the west for over 50 km. Mt. Mansfield also has a significant moisture source lying to the west, Lake Champlain. Although Lake Champlain is a freshwater lake it remains open until late winter, having an average freeze-over date of February 5th (Ludlum, 1985). The Chugach Mountains, to the east of Site Summit, have greater breadth and higher elevations than the Green Mountains of Vermont. However, as with Mt. Mansfield in the Green Mountains, and Mount Washington in the White Mountains of New Hampshire, Site Summit is on the extreme western edge of a north-south trending mountain range.

In addition to the similarity of Site Summit's local geographic setting to that of the two midlatitude study sites, it has other advantages for its use as an icing monitoring location. A continuous supply of electrical power is available from a FAA communications facility at the site. The site is accessible by road during the summer. And, most importantly, nearby Anchorage International Airport is the location of two daily National Weather Service rawinsonde launches that provide free-air measurements of air temperature, relative humidity, air pressure, and wind speed and direction near the observation site.

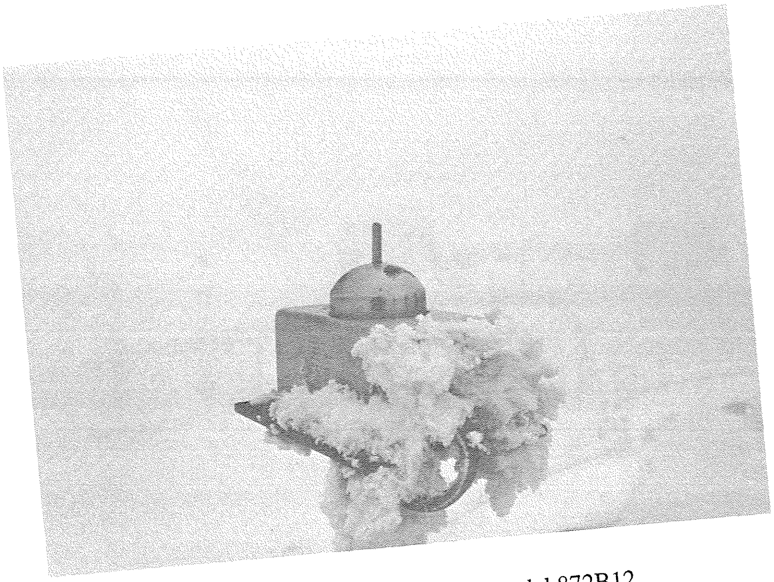


Figure 2. Rosemount ice dectector, model 872B12.

This paper summarizes Site Summit icing and weather observations from September 1989 through August 1990, the first season of observations. Measurements are currently being made and will continue for the next several years.

INSTRUMENTATION

Icing rates were monitored with an 872B12 Rosemount ice detector. The Rosemount ice detector is a 21.0-cm-long, 8.1-cm-wide, 6.4-cm-high stainless steel box topped by a 6.4-cm diam. hemisphere (Fig. 2). A 0.6-cm diam. nickel-plated probe, vibrating axially at a natural frequency of 40 kHz by magnetostriction, protrudes 2.54 cm above the top of the dome. Ice accreting on the probe increases its mass and decreases its vibration frequency; a 133-Hz drop in frequency triggers a 90-second, heated deicing cycle. Only clear or rime ice on the probe causes deicing cycles. Other substances, such as liquid water, do not adhere sufficiently to couple with the probe. Deicing cycle data were recorded by a Campbell CR10 data logger and memory module.

The Rosemount ice detector on Site Summit is mounted on a bracket extending outward from the southwest side of a building so as not to be sheltered from the prevailing winds (Fig. 3). It is located approximately 1.5 m above the structure roof, 7 m above ground level.

Rosemount ice detectors are designed to monitor icing conditions and to initiate automated deicing devices when icing begins. They are thus designed to identify incipient conditions, and are not precision climatological research instruments. As a result, there are no adjustments for calibration or drift correction available to the user, and the measurements must be analyzed and interpreted with care. Despite these drawbacks, the Rosemount ice detector has been found to be the best type of automated instrument for approximating continuous quantitative measurement of icing rates.

Two steps were necessary to prepare the Rosemount data for analysis: 1) deicing cycles were summed per hour and converted to icing rates, and 2) the approximate mass accretion per deicing cycle was experimentally computed for the ice detector models used both in Alaska and the East Coast.

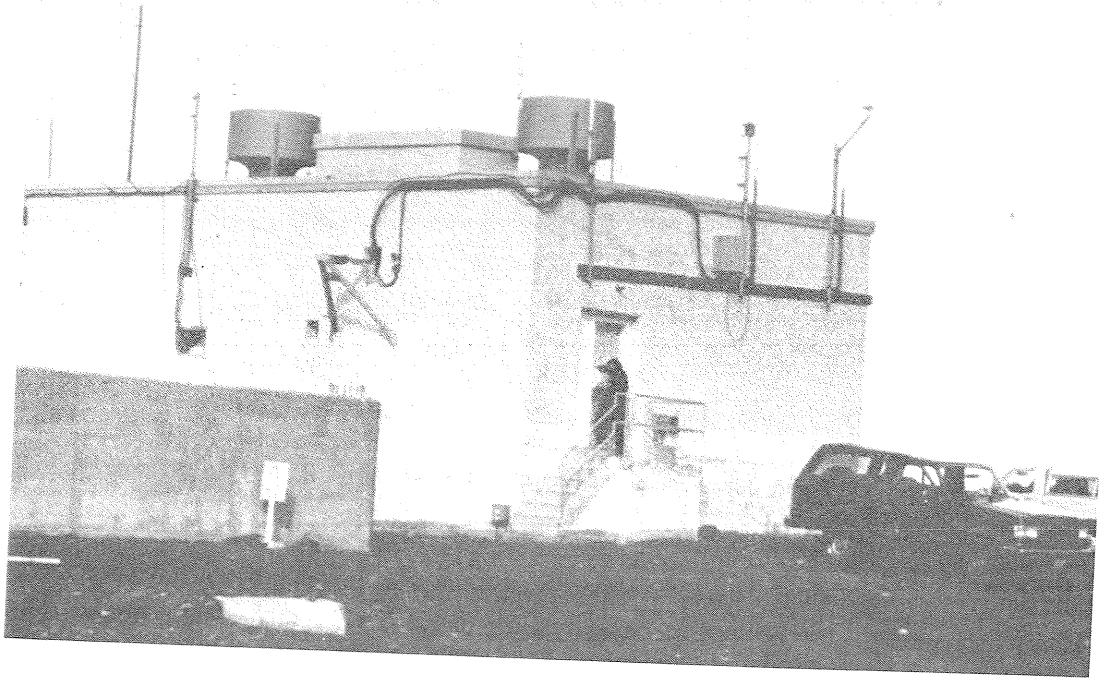


Figure 3. Installation site (top of Site Summit). The ice detector is mounted on the angled bracket on the right side of the roof.

Though the number of accumulated deicing cycles over a period of time, such as an hour, is related to the icing rate, the relationship is not linear. Deicing cycles are fixed at 90 seconds in length. Thus a theoretical maximum of 40 deicing cycles could occur in one hour. As the number of deicing cycles increases, the time available for ice to accrete decreases. Therefore, the icing rate increases more rapidly than the number of deicing cycles. This relationship may be expressed as follows:

$$PC = MC \times (1.0 + [MC/(40.0 - MC)]) \tag{1}$$

where PC is proportional deicing cycles per hour (proportional to the icing rate) and MC is the number of measured deicing cycles per hour (Ryerson, 1988).

Mass accretion per proportional deicing cycle of the Rosemount ice detector was computed by measuring the mass of ice accreting on a rotating multicylinder operated concurrently with the ice detector on Mt. Washington (Ryerson, 1988; Howe, 1991). The mass of ice accreted on the second smallest cylinder of the multicylinder, which has a 0.5-cm diameter similar to the 0.6-cm diameter of the ice detector, was divided by the number of proportional deicing cycles recorded by the ice detector during the multicylinder run. Because the particular ice detector used for this study was still in service on Site Summit, it was not available for calibration. Thus we used a sample of five Rosemount 872B12 ice detectors, the same model as on Site Summit, to approximate the calibration of Site Summit's ice detector. The deicing cycles of the five Rosemount 872B12 ice detectors were recorded during 15 multicylinder runs. Due to differences in the lengths of the multicylinder cylinder and the probes of the ice detectors, the accreted mass was expressed in grams per centimeter of ice detector probe length (g/cm). The mean accretion mass per proportional

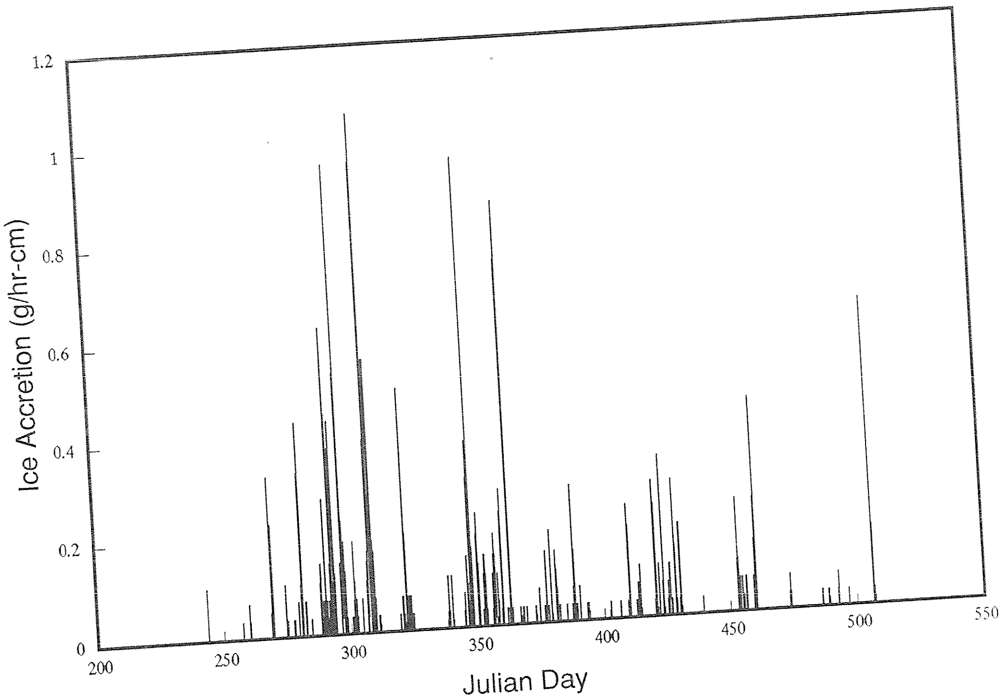


Figure 4. Plot of ice accretion in g/hr-cm for 1989–1990. Note: August is between Julian day 213 and 243; September, 244–273; October, 274–304; November, 305–334; December, 335–365; January, 366–396; February,397–424; March, 425–455; April, 456–485; May, 486–516.

deicing cycle for this sample of five detectors was 0.03 g/cm of probe length. A similar procedure was conducted for the model 871CB1 detector used in earlier studies in New England (Ryerson, 1988). Both models have a 90-second deicing cycle, but the 871CB1 deices after a 200-Hz drop in probe frequency. The 871CB1 accreted ice at a rate of 0.02 g/cm of probe length per proportional deicing cycle.

CLIMATOLOGY OF SITE SUMMIT ICING

Local perceptions of icing conditions on Site Summit varied before equipment was installed. FAA personnel claimed that icing occurred occasionally, and not severely. National Weather Service personnel suggested that very little ice would be observed. Our single year of monitoring shows that atmospheric icing is a relatively frequent, low intensity phenomenon on Site Summit (Fig. 4, Table 1).

Table 1. Rate of ice accretion in g/hr-cm length for Site Summit.

	Icing hours	*All hours*
Mean	0.11	0.01
Maximum	1.06	1.06
Minimum	0.03	0.00
Standard deviation	0.14	0.03
Median	0.07	0.00
Mode	0.03	0.00
Icing hours	615.0	
Hours of data	8760.0	
% of hours icing	7.0	

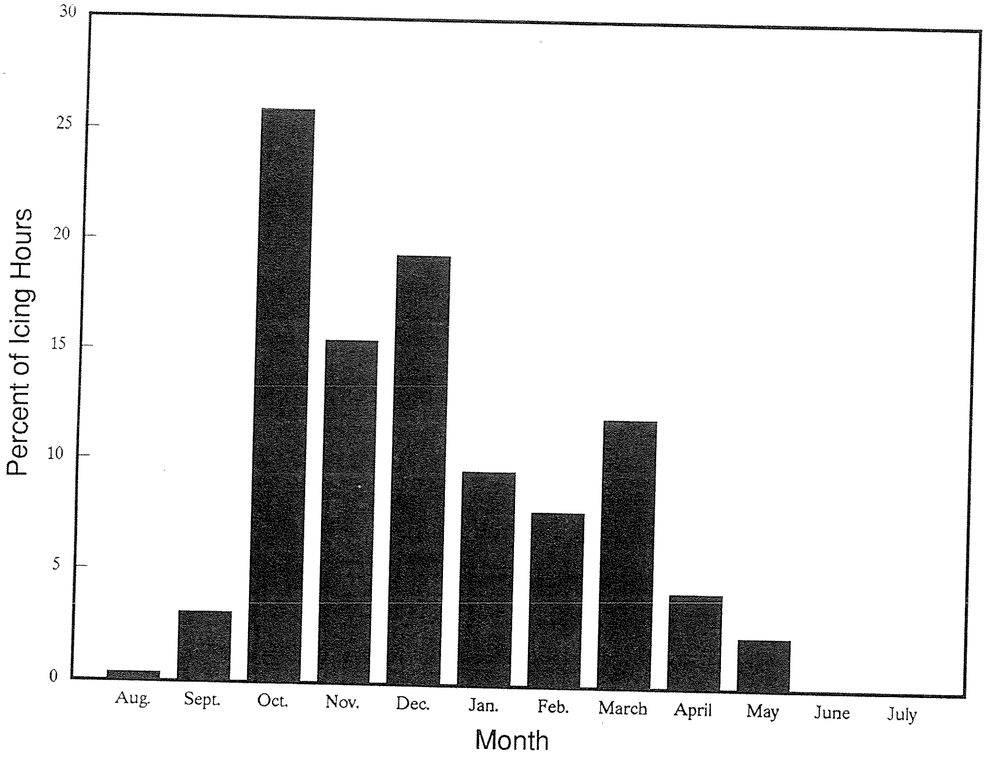


Figure 5. Percentage of total icing hours per month.

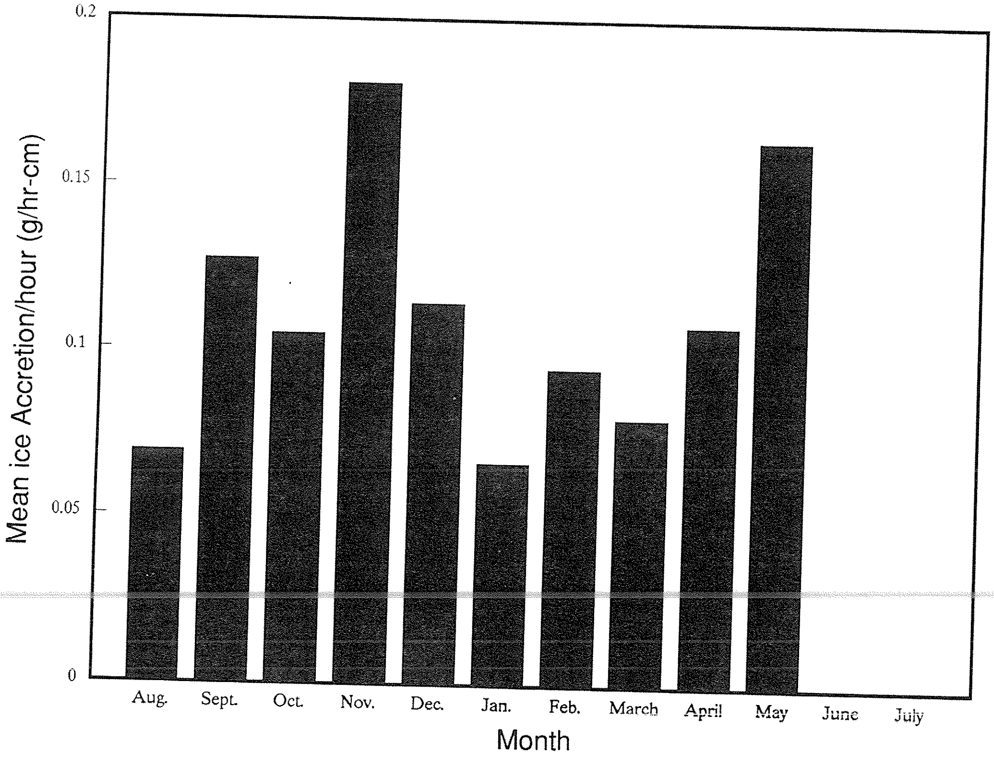


Figure 6. Mean ice accretion intensity per hour.

Icing occurred during 10 months of the 1989–90 monitoring year. There were no icing events during June and July 1990. A total of 615 hours experienced some icing, about 7% of all hours (8760) of the year. Icing frequency and intensity peaked in the late fall, with about 60% of all icing hours occurring from October through December. About 25% of the year's icing hours occurred in October (Fig. 5).

Icing intensity peaks in the fall and late spring (Fig. 6). The average intensity during the year was 0.11 g/cm per icing hour. November and May experienced the most intense icing per hour, averaging about 0.17 g/hr-cm. The maximum intensity recorded, 1.03 g/hr-cm , occurred in early November. Most hours of icing are of very low intensity (Fig. 7). Icing hours were dominated by intensities of about 0.03 g/hr-cm. Icing intensities greater than about 0.30 g/hr-cm of probe length occurred rarely.

Icing events are periods of relatively continuous icing, broken by long periods with no icing. Since there is no established definition of an icing event, we used a definition developed for New England (Ryerson, 1987). This definition is based on the longevity of synoptic events assumed responsible for icing. An icing event begins or ends when a period of seven or more ice-free hours separates hours containing Rosemount deicing cycles. If a break of six or fewer hours can occur with no icing, hours preceding and following the break are considered part of the same event.

There were 102 icing events during the 1989–90 season at Site Summit (Table 2). Though the mean event length was 7.5 hours long, most events persisted for less than 5 hours (Fig. 8). The minimum event length was 1 hour, and the longest event lasted 38 hours (Table 2). Most icing events accreted less than 0.5 g/cm during the event (Fig. 9). The largest amount of ice accreted, over 9.0 g/cm, occurred during an event that lasted 30 hours.

Average hourly icing intensity within events was about 0.07 g/hr-cm, with the most frequent intensity being between 0.025 and 0.050 g/hr-cm (Fig. 10). There is no significant relationship between event length and the hourly average icing intensity observed during the event (Fig.11). The longest event, lasting 38 hours, had an icing intensity

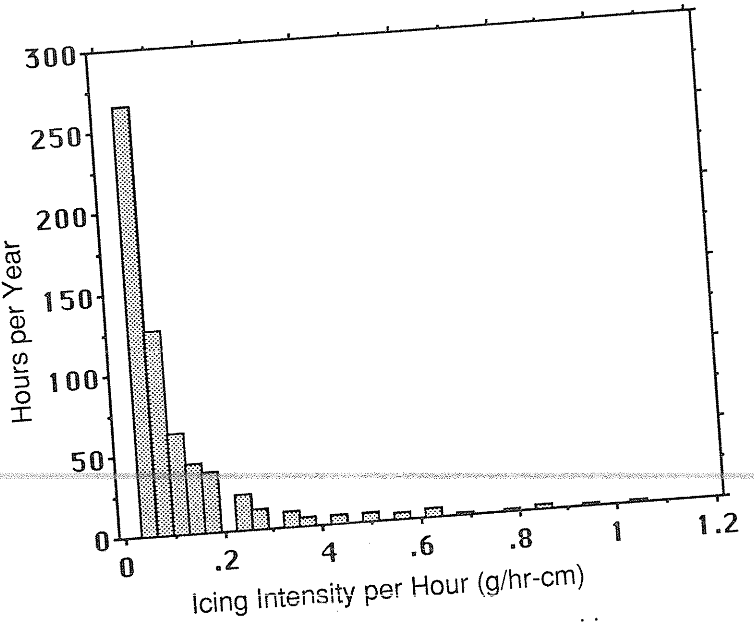


Figure 7. Frequency of hourly icing intensities.

Table 2. Summary of icing events for Site Summit, Alaska.

	Duration of event (hours)	*Total ice accretion during an event (g/cm)*	*Mean ice accretion per hour during an event (g/hr-cm)*
Maximum	38.0	9.02	0.39
Minimum	1.0	0.03	0.02
Mean	7.5	0.68	0.07
Standard deviation	8.6	1.23	0.06
Median	3.0	0.14	0.04
n (number of events)	102	102	102

of only 0.03 g/cm, while the event with the highest icing intensity, 0.39 g/cm, lasted only 5 hours. Though longer events do not produce more intense icing, they generally accrete significantly more ice mass then do short events (Fig. 12).

Weather conditions at Site Summit were not measured in situ, but were derived by interpolating free-air conditions from twice daily rawinsonde flights at Anchorage International Airport (Table 3). Comparison of mean annual conditions, non-icing conditions and icing conditions indicates that icing weather is somewhat more severe than non-icing weather. Atmospheric pressure and temperature are generally lower during icing, and relative humidity and wind speed are higher. Annual and icing wind directions are generally southerly.

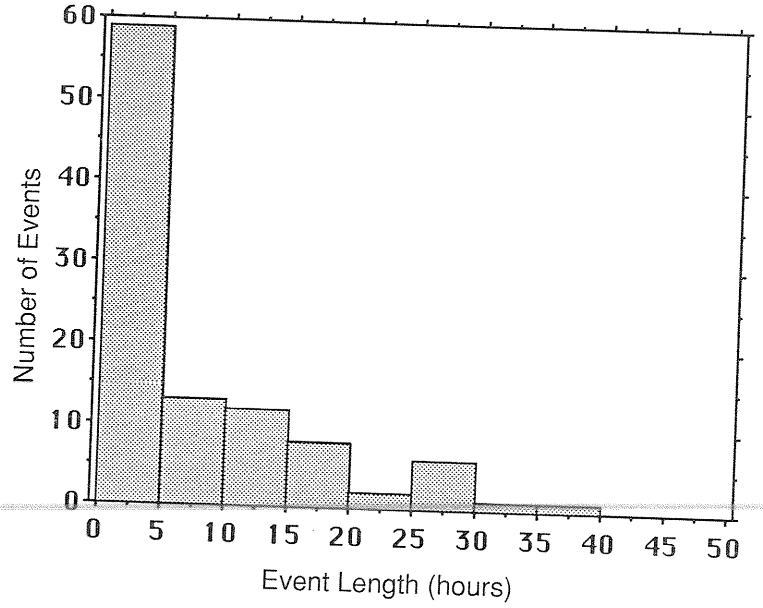
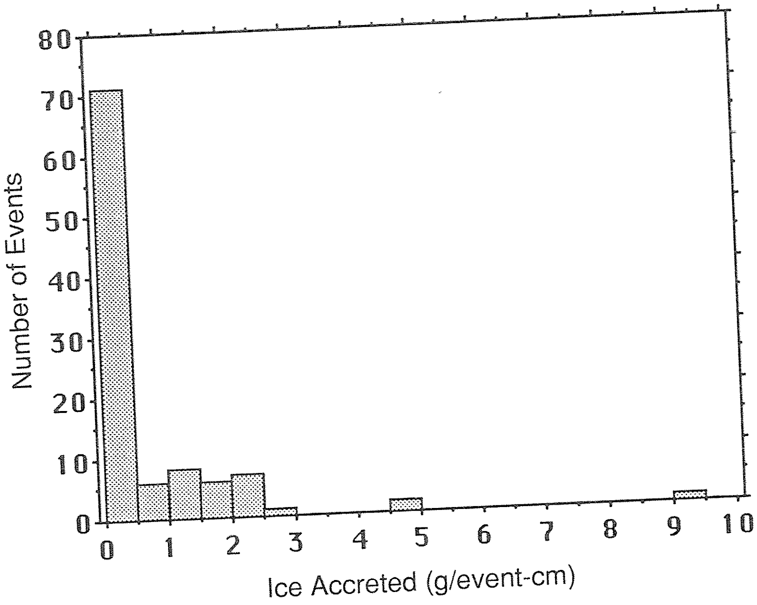


Figure 8. Frequency of icing event lengths.

Figure 9. Frequency of ice accretion per event.



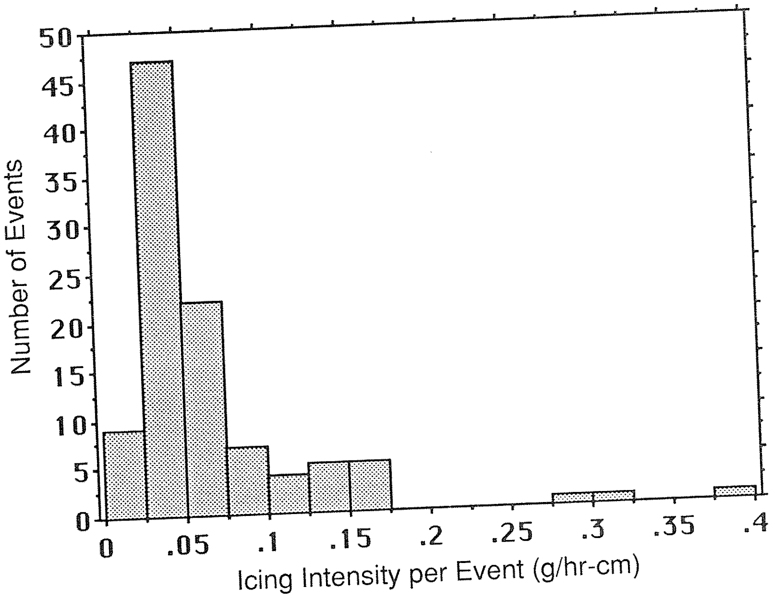
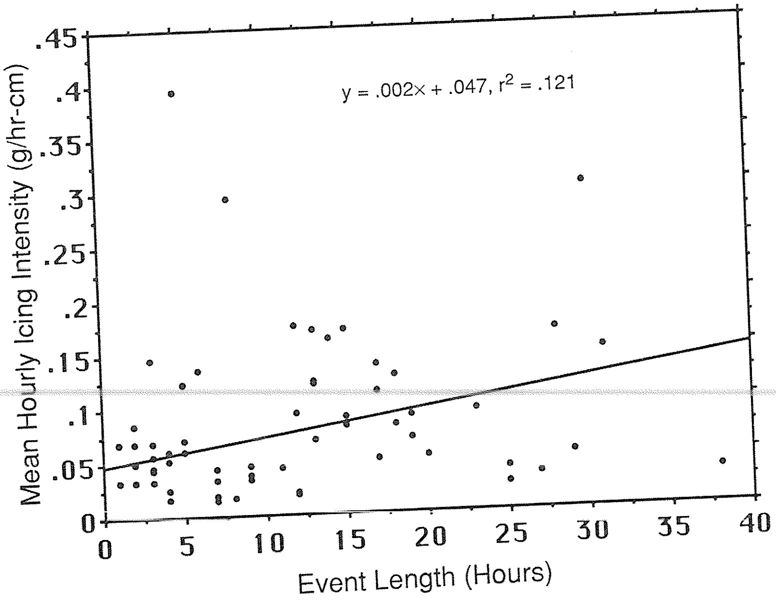


Figure 10. Frequency of mean event ice accretion intensities.

Figure 11. Relation of event length to mean hourly icing intensity.



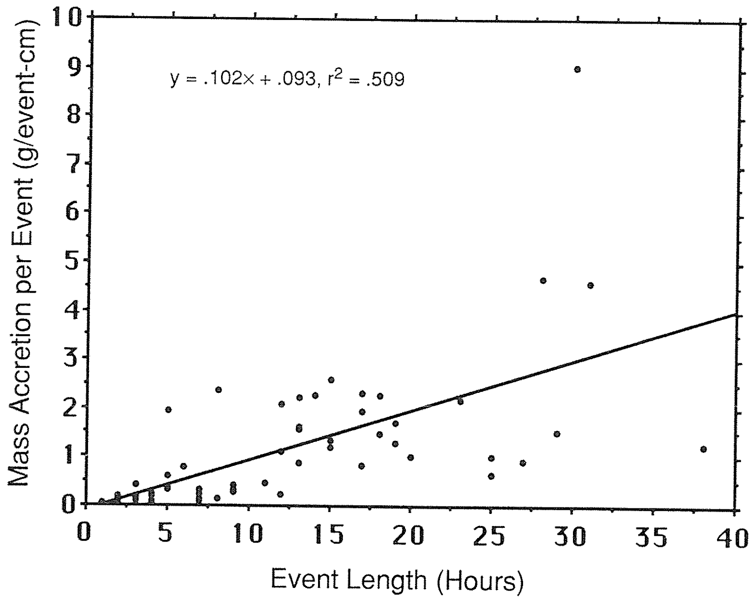


Figure 12. Relationship of event length to ice accretion per event.

Table 3. Summary of rawinsonde data interpolated to the height of Site Summit*.

	Pressure (mb)	*Temperature (°C)*	*Rel hum (%)*	*Wind speed (m/s)*
All hours (icing and non-icing hours):				
Mean	869.3	–3.1	68.9	7.2
Standard deviation	11.3	7.4	20.6	4.2
Non-icing hours:				
Mean	870.0	–3.0	66.6	6.9
Standard deviation	11.5	7.7	20.8	4.0
Icing hours:				
Mean	864.3	–4.3	83.0	9.5
Standard deviation	8.6	4.0	12.2	4.7

*Data for flights from Sept. 1, 1989 through June 30, 1990

COMPARISON OF SITE SUMMIT AND MIDLATITUDE EAST COAST ICING

Icing on Site Summit, Alaska, was monitored at nearly the same elevation as at Mt. Mansfield, Vermont, 1189 m vs. 1220 m respectively. Mt. Mansfield and Mt. Washington are at a latitude 15° south of and at a longitude 80° east of Site Summit. Site Summit is located in a West Coast subarctic climate according to Trewartha's classification of climate, whereas Mt. Mansfield and Mt. Washington are situated on the East Coast within a humid continental cool summer climate. The winter weather of Site Summit is dominated by marine air from Gulf of Alaska cyclonic activity, with occasional incursions of frigid continental air from the interior. Cyclonic activity is greatest in the fall, decreasing by midwinter through the spring and summer (Landsberg, 1974). Mt. Mansfield's winter climate is controlled by frequent arctic and oceanic air mass changes, and is thus dominated by frontal activity all winter, with slight peaks in the fall and spring.

Mean hourly ice accretion rates on Site Summit are about 2.5 times greater than on Mt. Mansfield, with median and modal rates about 1.5 times greater (Tables 1 and 4). Mean, median and modal hourly mass accretion rates on 1900-m Mt. Washington are about 8, 6, and 5 times greater than those of Site Summit, respectively. The icing records for Mt. Mansfield and Mt. Washington were collected from 1982 to 1986 (Ryerson, 1988). For various reasons, icing was not collected year-round. There are 9868 hours of icing measurements available for these two mountains from this period, with most of the hours occurring from November through May. Icing occurred on Site Summit during about 7% of all hours of the year. For the period of November through May, Site Summit iced about 10 to 12% of the time, Mt. Mansfield about 13% and Mt. Washington 39%.

Only Site Summit and Mt. Mansfield events are compared because of differences in deriving Mt. Washington events. Site Summit experiences approximately 70 icing events during November through May, whereas Mt. Mansfield experiences about 50 events. Mean and median length icing events on Site Summit are 7.5 hours and 3.0 hours, shorter than Mt. Mansfield's 10.9 hours and 7.0 hours.

Temperatures during icing on Site Summit averaged –4.3°C, whereas on Mt. Mansfield temperatures were warmer, averaging –2.6°C. Relative humidities averaged about 70% at Mt. Mansfield, about 13% lower than Site Summit

Table 4. Rate of ice accretion for the two East Coast sites.

	Mt. Washington accretion (g/hr-cm)	*Mt. Mansfield accretion (g/hr-cm)*
Mean	0.87	0.04
Maximum	33.43	0.21
Minimum	0.02	0.02
Standard deviation	1.29	0.03
Median	0.41	0.04
Mode	0.15	0.02
Icing hours	3832.0	1320.0
Hours of data	9868.0	9868.0
% of hours icing	38.8	13.4

during icing. Wind speeds averaged within 2 m/s of one another at the two sites during icing. Wind directions were considerably different, however. Whereas Site Summit's winds during icing were almost southerly, Mt. Mansfield's winds were mostly west-southwesterly.

CONCLUSIONS

Firm conclusions about the icing characteristics at Site Summit cannot be made after only one year of monitoring. However, the mountain is a significant subarctic icing site, with icing conditions generally similar to Mt. Mansfield, Vermont, despite their great geographical separation and regional climatological differences.

Monitoring will continue on Site Summit for several more years to acquire a more representative sample of icing conditions. Site Summit data will eventually be used to build a comprehensive understanding of mountaintop icing weather conditions in disparate climate regions of the world.

ACKNOWLEDGMENTS

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