Ship Superstructure Icing Climatology of Coastal Eastern North America

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ABSTRACT

Superstructure icing occurs when bow-generated spray freezes on decks and bulkheads. Most common to smaller vessels, icing hinders deck activity, increases draft, decreases freeboard, and raises center of gravity. Forecasts of icing potential may allow vessels to avoid hazardous areas. This report develops a synoptic climatology of superstructure icing in eastern North American coastal waters from a database maintained by the Atmospheric Environment Service of Canada. Ships with 5 cm or more of accreted ice were selected from the database, providing a sample of 117 superstructure icing incidents. Eighty percent of cases occurred behind cold fronts, with a mean distance behind cold fronts of 1600 km. Mean distances of cases from the nearest closed low are about 1000 km. Ship headings during icing are typically into the true wind in low to moderate sea states, with air temperatures averaging –8°C. Synoptic patterns found in this sample of ship icing cases are similar to those of other east coast Northern Hemisphere locations investigated by the Soviets and Japanese.

INTRODUCTION

Ship superstructure icing occurs when spray, generated mainly from bow–wave collisions, freezes on decks and bulkheads. Most common to fishing trawlers and other smaller vessels because of their low freeboard and greater motion in the sea, icing hinders deck activity, increases draft, decreases freeboard, and raises center of gravity. In extreme cases seaworthiness is sufficiently reduced that trawlers capsize, sinking with loss of life because ice-encased life rafts cannot be used to abandon ship. The superstructure icing threat to larger ships is probably less serious because of their greater length and freeboard, which tend to reduce superstructure wetting. Nevertheless, even on large vessels with greater stability margins, icing can reduce ship operating efficiency.

Superstructure icing, as is the case with most forms of atmospheric icing, such as freezing rain and rime, requires two concurrent processes to accrete (Ackley, 1985). Liquid water must be delivered to the ice accretion surface in droplet form in a quantity sufficient to cause an increase in ice thickness, and the atmosphere must be able to freeze some of the arriving water. When little water is delivered, or when the air/sea temperature is high, icing rates decrease. Icing rates also decrease when too much water is delivered to the superstructure. Too much spray reduces freezing rates because sensible and latent heat cannot be removed quickly enough from the large volume of water to freeze, and the water has sufficient thermal energy stored in its large mass to ablate previously accreted ice. Therefore, maximum ice accretion rates usually occur under conditions of moderate to severe cold and moderate water delivery to ship surfaces (Itagaki, 1990).

The ability to accurately and reliably forecast potential ice accretion rates may reduce the icing hazard because ships could seek shelter, be routed around hazardous forecast areas, or operate in a manner so as to minimize accretion potential. However, the complexity of the process makes modeling difficult. Empirical methods have been used by the U.S. National Weather Service (Feit, 1985) and the U.S. Navy (Mertins, 1968). Numerical methods are under development (Overland, 1990; Ryerson, 1989; Vefsnmo et al., 1988; Zakrzewski, 1987). However, modeling alone is, at times, not sufficient for forecasting because numerical information of sufficient quantity and quality required to use such models is frequently not available. Under these data-poor conditions, and even under conditions when data quality is good, forecast meteorologists can be aided by using synoptic weather patterns to generate forecasts and warnings.

The Soviets and Japanese have been active in studying the synoptic weather patterns associated with ship superstructure icing in their waters. Soviet studies of synoptic patterns associated with superstructure icing (Stallabrass, 1979, 1980; Borisenkov and Panov, 1974; Borisenkov and Pchelko, 1972; Shellard, 1974; Vasil'yeva, 1966) indicate that most intense icing usually occurs behind lows following cold front passage. This intense zone usually begins some distance behind the cold front, rather than immediately after passage. The Japanese concur, citing similar patterns in the Okhotsk Sea and Sea of Japan in the vicinity of the Kuril Islands (Sawada, 1966, 1975). This post-cyclone pattern should hold for other icing areas in similar geographic locations with regard to sea/land position. Makkonen (1984), however, questions the validity of synoptic studies for forecasting ship icing, stating that surface conditions do not necessarily reflect synoptic patterns, and suggesting that the range of potential patterns is so large as to evade meaningful classification.

OBJECTIVE AND APPROACH

Nevertheless, an analysis of synoptic patterns in eastern North American waters might assist land and ship-based forecasters in producing more informative forecasts. If patterns are similar to those described by the Soviets and Japanese, Makkonen's arguments against the idea of universal synoptic patterns for forecasting superstructure icing may not be valid. Therefore, the objective of this report is to develop a synoptic climatology of eastern North American coastal waters for improving forecasting and for improving understanding of storm structures generating severe ship superstructure icing conditions.

The Atmospheric Environment Service (AES) of Canada has compiled a ship icing data base covering the years 1970 through 1986 (Brown and Roebber, 1985). The data base includes approximately 7300 reported superstructure icing events from sources such as the U.S.S.R., the Pacific Marine Environmental Lab, National Oceanographic and Atmospheric Administration, World Meteorological Organization, U.S. Air Force Global Weather Central, National Oceanographic Data Center, and the U.S. Navy. Though not all records are complete, most include ship position, time, surface weather (including wind, temperature, pressure, humidity, and cloud cover), sea state, ice accumulation, ice type and a classification of the relative icing rate. Statistical summaries of the database on the coasts of Canada have been done by AES, but they do not include synoptic analyses. Unfortunately, the type of ship experiencing icing is not reported; only its identification number is listed in the database. This presents some problems with the analysis, because the rate of ship icing in any given set of conditions varies significantly with ship physical characteristics (length, freeboard, hull shape) and operations being conducted.

Synoptic weather charts were obtained for this study through the U.S. Air Force Environmental Technical Applications Center from the National Climate Data Center on microfilm for the locations and times of selected icing reports in the AES data base. These were compiled into synoptic classifications using methodology used by Ryerson (1988) to develop a synoptic climatology of atmospheric icing on New England mountaintops.

ANALYSIS

A database was created for synoptic analysis from the AES master database. A total of 117 ship icing cases were identified in the Atlantic Ocean and Gulf of St. Lawrence (Fig. 1). Most cases were located less than 400 km from shore.

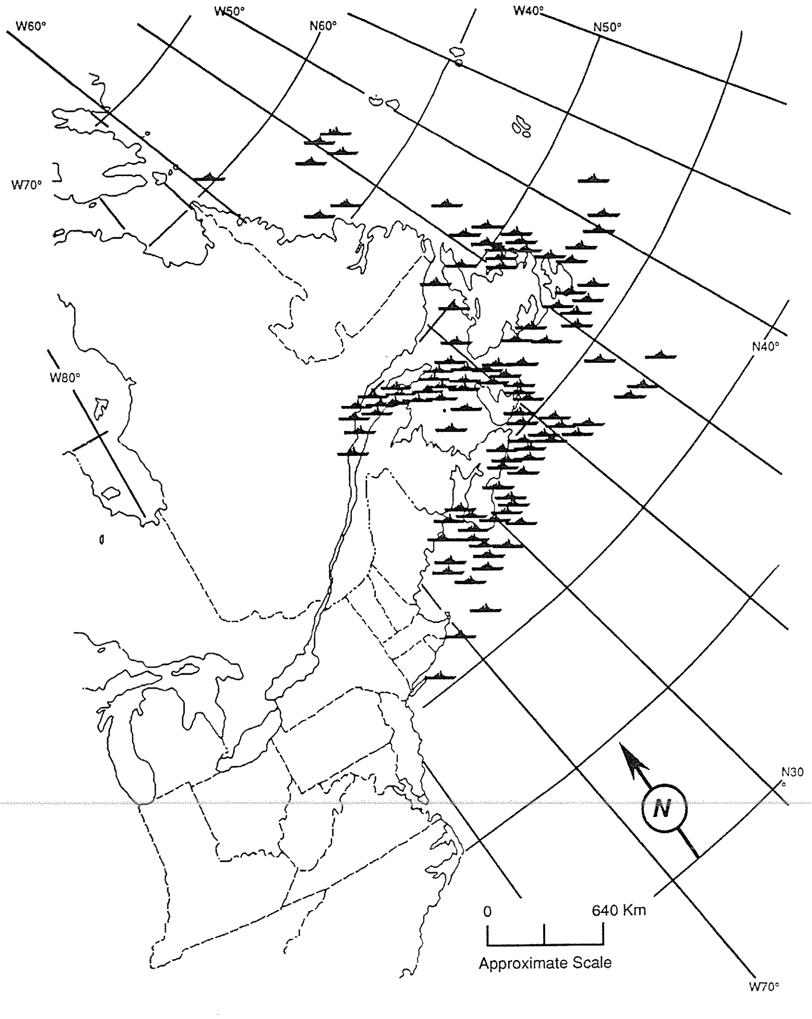

Figure 1. Ship icing cases selected.

Criteria for selection of cases were data source (some were stated by AES to have poor quality), ice type, ice thickness already accumulated on the ship, icing rate, and ship speed. Data from buoys, stationary sea structures and platforms were not selected because superstructure water delivery processes are considerably different for moving ships and stationary structures (Jessup, 1985). Cases with ship speeds greater than 4 knots were chosen to ensure that stationary structures were not included.

Only cases with icing generated from sea spray were selected; cases associated with freshwater sources of ice such as rain or fog were excluded. Cases with ice thickness accumulations of 5 cm or greater were chosen to ensure that a significant amount of icing had occurred. The AES database does not specify the location of ice thickness measurements on each ship, nor does it indicate the distribution of ice on the ship. Ships in icing rate categories of slow and rapid buildup were chosen. Rate of ice accretion was not specifically quantified in the AES database, only categorized as slow or rapid with no intermediate rate classifications. Cases where icing was classified to have ceased or had begun to decay were discarded.

Weather patterns during icing were classified similar to those in Ryerson (1988). Patterns were post cold frontal (PCF), generally with a high to the west, warm front to the south (WFS), multiple fronts or cyclones (MFC), and miscellaneous. Statistical summaries were made of wind direction, wind speed, air temperature, sea water temperature, wave height and direction, swell height and direction, ship heading and speed, and distance to the nearest closed low pressure cell and cold front.

RESULTS

As in Soviet and Japanese studies, a majority of icing cases occurred to the west of low pressure cells and usually at a considerable distance behind cold fronts. Along the eastern North American coast, 80 percent of all cases occurred behind cold fronts. The selected ship icing cases were located an average of 1600 km (1000 miles) behind cold fronts (Fig. 2) (Table 1). There may be several reasons for this large distance. Cold fronts are typically accompanied by large

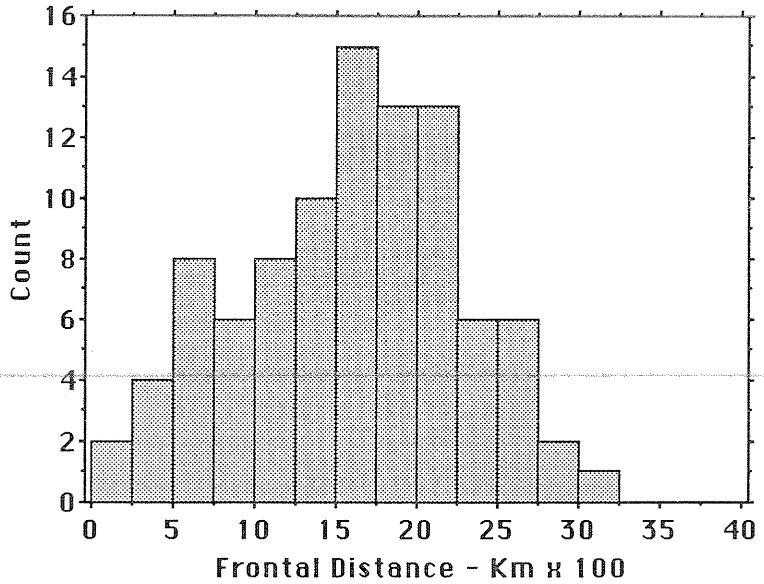

Figure 2. Frequency of cold front distances from iced ships.

Table 1. Weather conditions during icing cases sampled.

Variable	*Mean*	*Std. Dev.*	*Minimum*	*Maximum*	N
Wind speed (kts)	31.23	11.22	0	65	117
Air temp (°C)	–7.97	4.53	–20	0	117
Sea surface temp (°C)	1.02	1.97	–1	6	117
Wave height (m)	1.55	1.63	0	10	117
Swell height (m)	1.79	2.22 0	10	117	
Ship speed (kts)	10.35	2.75	8	18	117
Ice thickness (cm)	8.77	5.08	5	29	117
Nearest cold front (km)	1595	674	160	3040	94
Nearest low (km)	1147	483	160	2720	112

Directional frequency of wind, waves, swells and ship headings.

Sample N = 117

	Wind	*Wave*	*Swell*	*Ship Heading*
NNE	6	6	54	10
ENE	0	0	3	4
ESE	1	1	2	4
SSE	2	2	1	11
SSW	1	1	1	31
WSW	26	26	20	33
WNW	66	66	28	26
NNW	15	15	8	9

wind shifts, 90° or more, shifting from southerly to westerly. This creates a confused sea that requires hours to become aligned with the new fetch forming a fully developed sea. Though spray generation is increased by the confused sea state, icing may be delayed by the sea's thermal lag. It is safe to assume that some icing can begin shortly after the cold front passes and temperatures drop below the sea water's local freezing temperature. Since the cases analyzed required a minimum of 5 cm of ice on the ship, icing probably began closer to cold fronts than the 1600 km mean distance. This compares favorably to Soviet and Japanese findings, and supports Minsk's (1977) contention that time is necessary for temperature to drop behind a cold front; therefore, icing occurs a considerable distance behind the front.

Icing cases were located an average of 1150 km (700 miles) from the nearest closed low pressure cell (Fig. 3 and 4) (Table 1). The majority of lows were positioned northeast of the iced ships. This may be a result of the time necessary for a fully developed sea to become established after the low passes. However, the most probable reason is the cold air that follows lows, i.e., behind cold fronts.

Other weather conditions characteristic of superstructure icing off coastal eastern North America were westerly winds and seas, but northeasterly swells (Table 1, Fig. 5). Wind speeds averaged about 31 knots (Fig. 6). Most ship headings were into the wind and waves, but abeam to the swells. Entering waves and wind bow-on assists sea keeping,

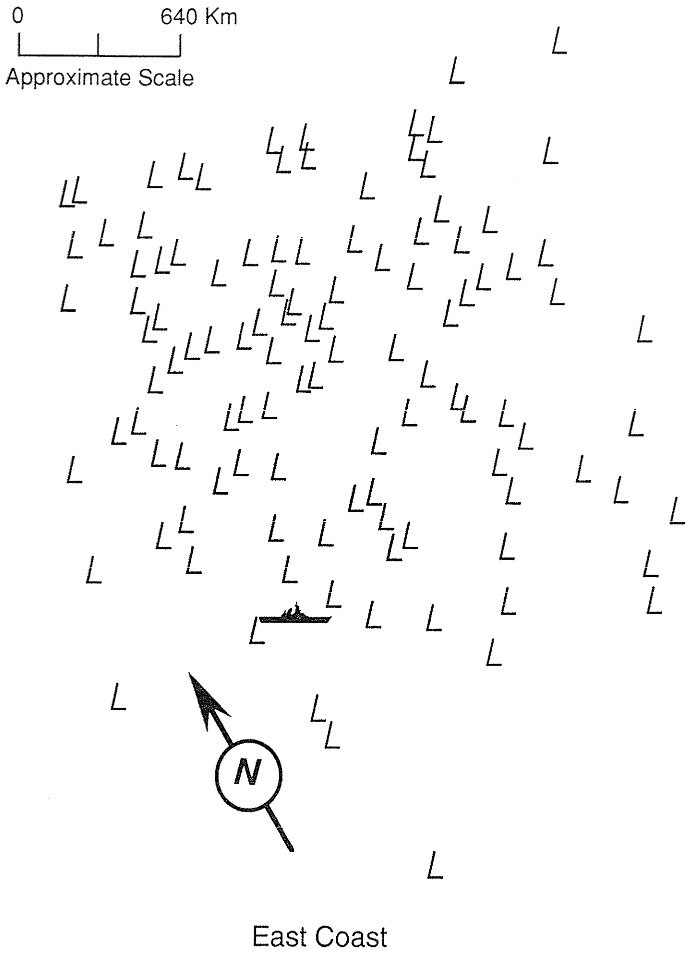

Figure 3. Standardized locations of lows with regard to iced ship location.

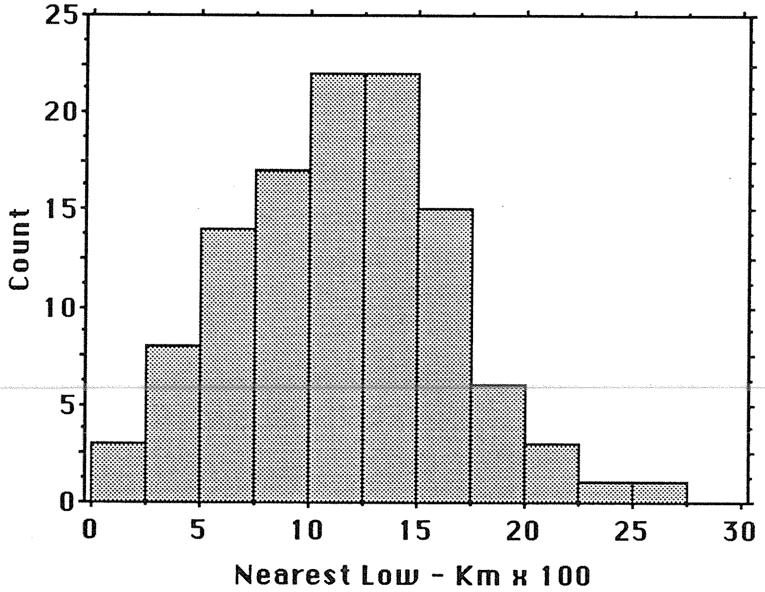

Figure 4. Frequency of distances to lows from iced ships.

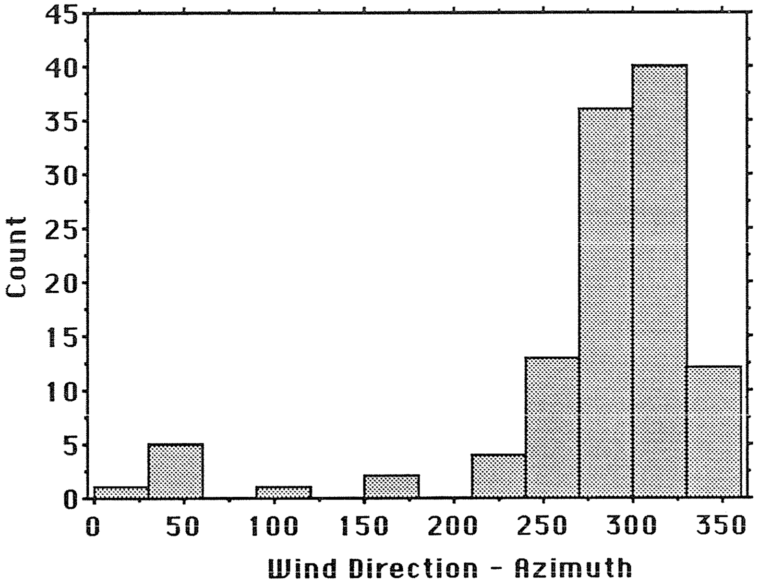

Figure 5. True wind direction frequency during ship icing.

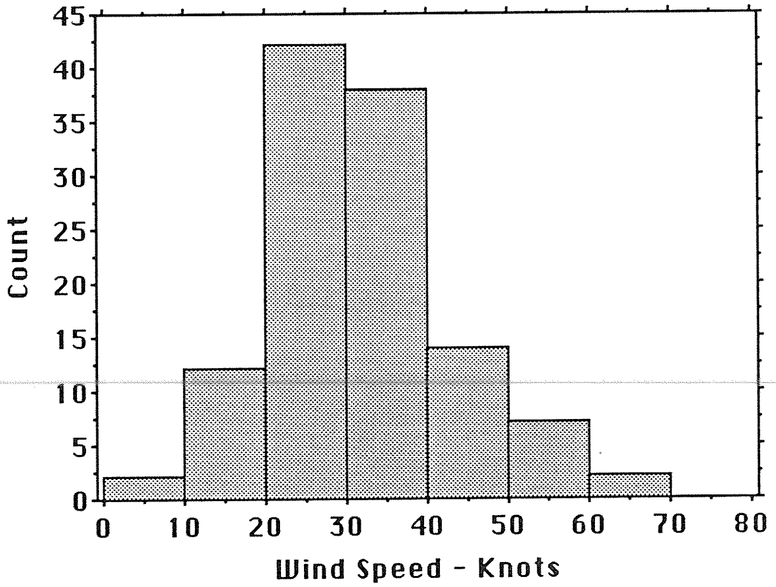

Figure 6. True wind speed frequency during ship icing.

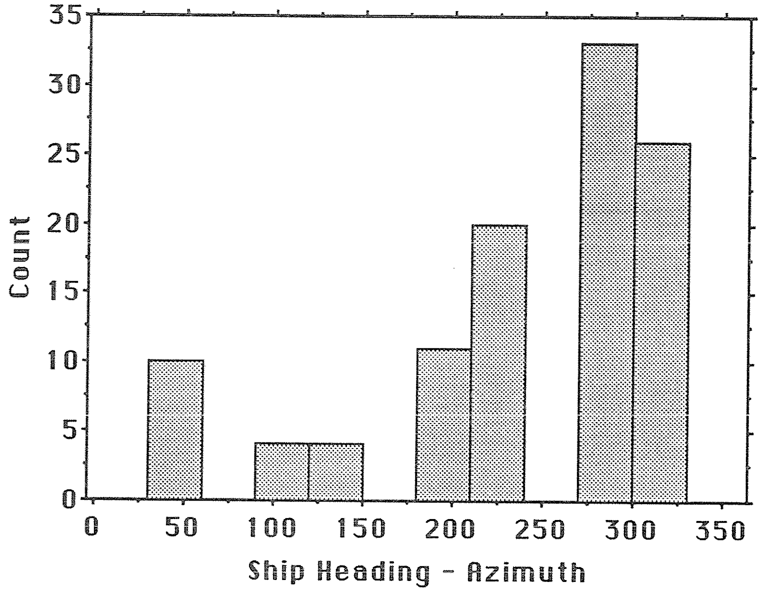

Figure 7. Frequency of ship headings during ship icing.

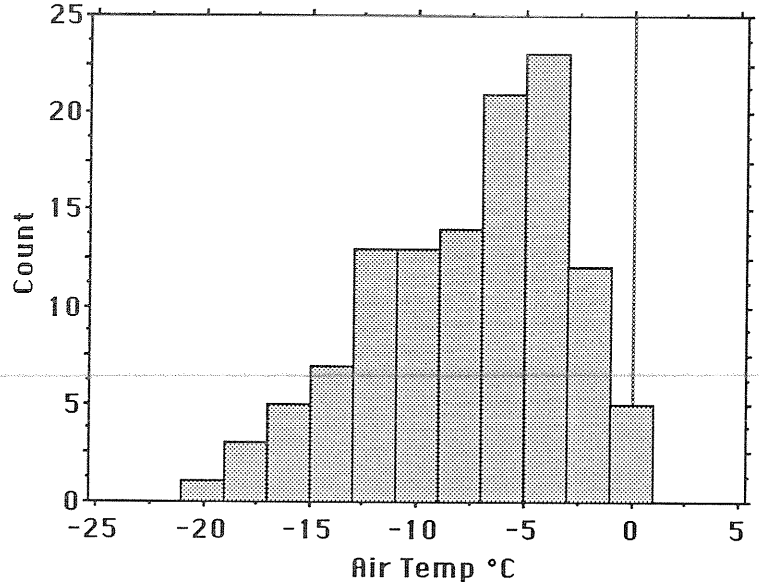

Figure 8. Frequency of air temperatures during ship icing.

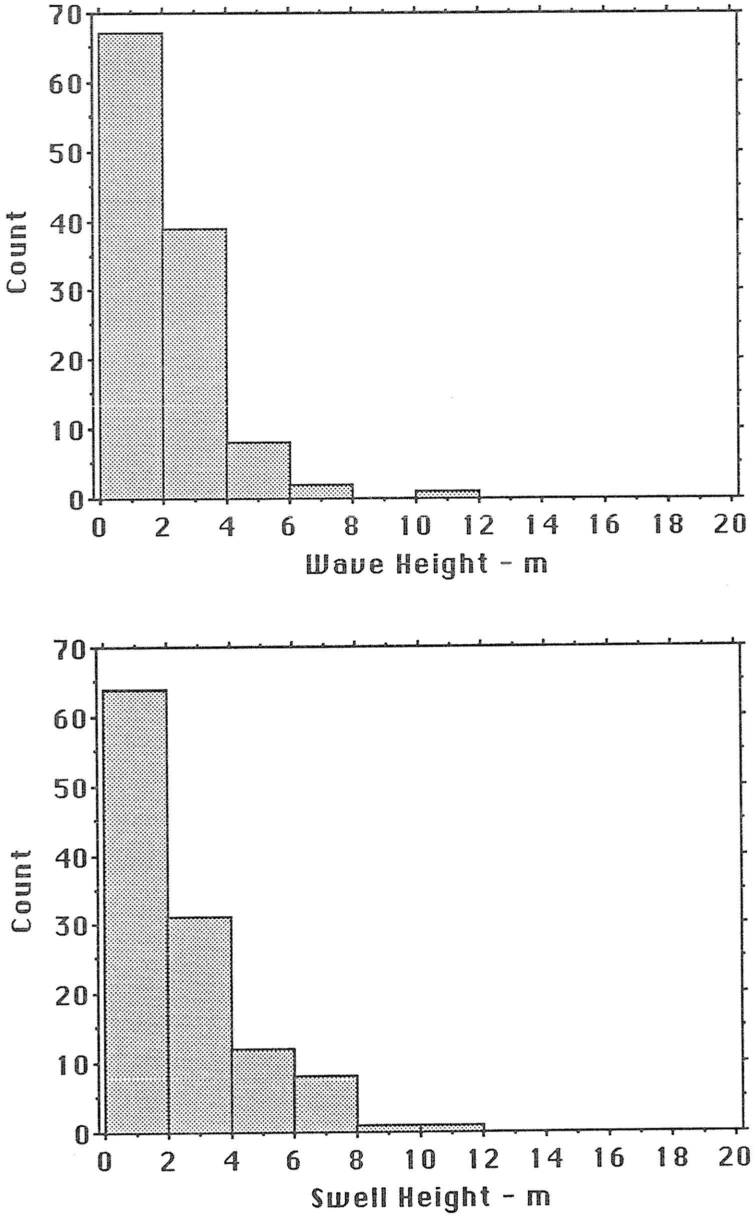

Figure 9. Wave and swell height frequency during ship icing.

but promotes dangerous icing conditions because large amounts of spray are generated (Fig. 7). The abeam swells cause considerable rolling but, except for encouraging capsizing when sufficient ice accretes to make the rolling moment dangerous, should not promote ice accretion. Air temperatures are low despite the modifying effects of the sea, averaging –8°C, because the air mass source region is continental and most icing cases are 400 km off shore (Fig. 8). Wave and swell heights were very low, less than 1.6 and 1.8 m respectively, probably because the nearshore location of most icing cases made the fetch short (Fig. 9). Finally, the sea surface was quite warm, averaging 1.02°C, perhaps because of warm offshore water (Fig. 10).

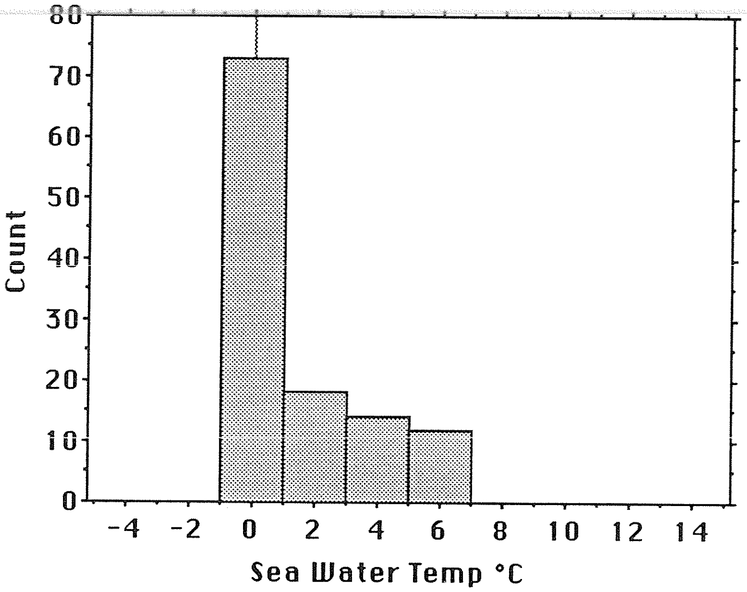

Figure 10. Frequency of sea surface temperatures during ship icing.

Of the remaining synoptic types, eight were warm front to the south (WFS) situations, eight were multiple front or cyclones cases (MFC), and seven were not classifiable. The most threatening ship icing weather pattern off the eastern North American coast is the post-cold-front situation, with decreasing temperatures, westerly winds and seas, and rising pressure.

CONCLUSIONS

Synoptic patterns and weather conditions found in this rather limited sample of North American ship icing cases are similar to those of other east coast Northern Hemisphere sites investigated by the Soviets and Japanese. In general, superstructure icing occurs to the west of cold fronts and southwest of lows, in 20- to 40-knot northwesterly winds, in –3 to –13°C air temperatures, with seas of 1 to 3 m. Water temperatures are usually lower than 3°C, and the majority of ship headings are into the wind and waves.

The importance of the post-cold-frontal situation, i.e., the lee of a cyclone, is contrary to Makkonen's assertion that synoptic patterns are not universal with regard to ship icing, and may not be a useful prediction aid. Cold fronts are one of the easier weather systems to forecast because of the dramatic changes in temperature, wind direction and air pressure that occur along them. In addition, cold fronts are readily observed on weather maps and satellite imagery. Identification of the synoptic conditions producing icing in various regions around the world, and determination if the synoptic conditions are similar, should be of considerable assistance to icing forecasters.

ACKNOWLEDGMENTS

This study would not have been possible without the assistance of Mr. Ross Brown of the Canadian Atmospheric Environment Service, who provided the database. Thanks also to two anonymous reviewers from the Eastern Snow Conference, LCDR P. Longo of the U.S. Navy, and Dr. K. Itagaki of CRREL.

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