U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 308

SUPERSTRUCTURE ICING IN ALASKAN WATERS

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MARCH 1985

INTRODUCTION

For marine purposes ice accretion may be defined as the accumulation of ice formed on 1) exposed structural components of ships or 2) structures above the water surface either on the coast or at sea.

The importance of advising marine interests of the existence and expected location and intensity of ice accretion is twofold.

Safety

The accumulation of ice on small vessels has the potential of causing serious handling problems leading to instability and capsizing. This is particularly true of fishing trawlers which may have tons of fish and water shifting about in their holds. The extra weight of ice on masts and rigging not only makes the vessel top heavy but also increases its "sail area" and hence the affect the wind has on it. This causes difficulties in handling the vessel.

While larger ships have less of a problem with ice induced instability, the accumulation of ice on antennae makes radio communication difficult if not impossible and has a deleterious affect on radar.

On all sizes of vessels ice accumulation presents a real safety hazzard to all working on deck.

Efficiency

During fishing operations the ability to work deck equipment unhampered is of prime importance. Ice accretion of course impedes the efficient use of deck equipment and slows the work.

Larger vessels, particularly container ships, may find that upon reaching the destination port, the deck cargo is ice encrusted to the point where unloading cargo is impossible even though the vessel is safely berthed.. Similarly ice accretion on coastal equipment used for unloading may preclude the efficient discharge of ships cargo, resulting in costly delays.

Over the years a number of efforts have been made to model and establish relationships between ice accretion on ships and meteorological and oceanographic parameters. The purpose of this paper is to summarize the various ways of approaching this problem and to describe the NMC program to produce automated ice accretion forecasts.

SOURCES OF ICE ACCRETION

Ice accretion on ships is a result of the following factors:

1. Fog
2. Precipitation
   a. freezing rain
   b. snowfall
3. Freezing spray

Fog

Two types of fog are common to the marine environment.

1. Advection fog. This is not an expected source of icing since it is formed when warm air flows over cold water and the air temperature can be expected to be above freezing in virtually all cases.

2. Sea smoke. Although this is not a common cause of icing it cannot be disregarded as a source. Sea smoke ranges in thickness from a few meters to several hundred. It occurs when very cold air flows over substantially warmer water. The process for forming ice may be summarized as follows: Relatively warm water evaporates at the surface but condenses into droplets again as it is convectively transported into the colder air. If this overlying air is very much below freezing the droplets will be supercooled and freeze upon impact with the ship. An example of an extreme case is described by Lee (1958) in which a vessel traveling through sea smoke (visibility 200 yds) picked up approximately 26 tons of ice in 10 hours.

Precipitation

Another atmospheric source of ice accretion is freezing precipitation. This occurs in the form of rain or drizzle. Its effect is to glaze the ships surface with a clear hard coating of ice. This type of icing is not considered serious because the accumulated weight tends to remain relatively low and the handling properties of the ship due to increased sail area are not significantly affected. On the other hand the glaze may affect communications and impede the work of deck hands. Precipitation in the form of snow plays a minimal role as a source of ice accretion since most of it generally tends to blow off the ship. The remaining snow is usually not very dense and adds little to the accumulated weight and sail area.

Freezing Spray

Freezing spray is a result of either the action of the wind on the water or the impact of the ship against the waves. In both cases the spray is carried by the wind and exchanges heat with the cooler air. The temperature ultimately reached by the spray is dependent upon the ambient temperature, the amount of time it is being transported, the initial temperature of the spray and the initial size of the spray droplets.

Borisenkov and Panov (1972) statistically analyzed more than 2000 instances of icing on Soviet fishing vessels. Their results are summarized in the table below.

	Spray	Spray with Fog, rain or drizzle	Snow	Fog, rain or drizzle
Northern Hemisphere	89.9	6.4	1.1	2.7
Arctic	50.0	41.0		9.0

Table 1. Percentage frequency of occurance of ice accretion (after Borisenkov and Panov (1972)).

As can be seen their study indicates that the most frequent cause of icing is freezing spray. This supports similar conclusions reached in other studies, e.g. Shektman (1967). The remainder of this note will be concerned with forecasting ice accretion due to freezing spray.

FORECAST APPROACHES

Numerical

Employing numerical methods researchers, notably Stallabrass (1979, 1980), have attempted to model the complex and multiple processes related to the accumulation of ice on ships. These processes can be grouped as follows:

1- The generation of liquid water in the air stream passing over the ship. This liquid water may be droplets generated mechanically or by atmospheric processes such as rain or fog.

2- The kinematics and associated process of the droplets striking the ship. This includes droplet trajactory and collection efficiency.

3- The thermodynamic processes related to ice accretion. This includes latent heat release, convective evaporative heat transfer and the exchange of thermal energy between the droplets and accretion surface.

Little use has been made of numerical models in an operational setting due to the complexity of the models and the simplified assumptions that must be made about the structure upon which the ice forms.

Empirical Approach

This approach has enjoyed more success operationally. Sawada (1962) developed an ice accretion nomogram for use in the Sea of Japan. The graph is based on data obtained by Japanese vessels. It provides icing estimates by category i.e., light, moderate or heavy. The graphs do not consider sea temperature and are based on wind speed and surface air temperature, fig. 1.

Mertins (1968) studied nearly 400 observations taken by trawlers in the Northeast Atlantic. The study resulted in series of nomogams which provided guidance for forecasting the severity of ice accretion. The charts required sea surface temperatuire as well as wind speed and air temperature, fig. 2.

Wise and Comisky (1980) combined the Mertin charts into a single nomogram. The new nomogram was then modified based on climatological differences between the Northeast Atlantic and the Northeast Pacific. In addition they integrated some 50 quantified icing reports from the northeast Pacific region. The end result was a diagram constructed purely on an empirical basis without recourse to a derived functional relationship between variables (see Figure 3).

NMC ICE ACCRETION FORECAST PROGRAM

The nomograms described above were not designed as forecast aids but rather as guides to icing potential if a certain set of conditions occur in a particular, rather localized, area. In some cases the graphs were distributed to vessels so the ships masters themselves, using wind and temperature input from marine broadcasts, could determine their chances of being involved in an icing situation. The graphs were also made available to forecast offices so that under appropriate conditions mention of icing potential could be put in the marine forecast. In either case the graph is generally not used until it is recognized that an icing situation is developing. Furthermore, because of time limitations, the graph is normally used at only one or two locations of particular interest.

By applying the nomogram at multiple locations and by using forecast input as well as analyses it can be used not only to evaluate and quantify the present posibility of icing but also to alert the forecaster to forecast potential icing situations. In addition used this way the areal extent of icing can be defined.

Because of the impact of this phenomena upon marine interests as well as the increased attention given to the northeast pacific marine area with the establishment of NOAA Ocean Service Centers at Seattle, WA and Anchorage, AK the Marine Products Branch at NMC decided that this was an appropriate region to begin an experimental ice accretion forecast program.

The approach was to apply the Wise and Comisky nomogram at 2.5 degree intervals of latitude and longitude in the Gulf of Alaska. The result is a contoured chart of grid point values, Fig. 4. A series of charts such as these can indicate to the forecaster the areal extent, movement and growth of the ice accretion area. As mentioned previously the nomogram was developed based upon data obtained from trawlers. It therefore must be emphasized that the values on the contoured chart should also be considered most appropriate for trawler type vessels. Adjustments for vessels differing in configuration should be made by the individual ships master.

As previously indicated the nomogram is not based upon a mathematical functional relationship between variables. Therefore, in order to apply the nomogram as part of an objective forecast scheme a decision tree algorithm was developed which uses 4 tables of ice accretion rates based upon 5 categories of wind speed. Each wind category is represented by a given wind speed as follows:

category	wind range	representitive speed
1	0-20 kts	0 kts
2	21-30 kts	25 kts
3	31-40 kts	35 kts
4	41-53 kts	45 kts
5	> 53 kts	55 kts

Note that category 1 is represented by a wind speed of zero kts. Although some spray is, of course, generated at speeds less than 20 kts, the nomogram indicates that ice accretion rates for winds in this category will be effectively zero, regardless of air or sea surface temperature. On the other hand, the nomogram indicates that ice accretion will occur for categories 2 through 5. Thus, a 17 by 11 matrix of ice accretion values was constructed for each. The matrix was filled by obtaining ice accretion rates from the nomogram for values of air temperature from 0-32 deg F in 2 deg intervals and values of sea surface temperature from 28-48 deg f also in 2 deg intervals. These are values for which the nomogram is valid.

Inputs to the decision tree algorithm are the analyzed and forecast spectral model 1000 mb air temperature field and the spectral model 1000 mb geostrophic wind field. The wind field was reduced by 20 percent to account for frictional effects at the ocean surface. The sea surface temperature used was the NMC 2 day composite ship/satellite analysis. Figure 5a, b, c, illustrate the affect that a given set of conditions has on ice accretion rates using the Wise and Comisky nomogram.

Icing cannot be expected to occur at air temperature above 0 degree C. As temperatures fall below 0 degrees the rate of icing tends to increase. This can be seen in Fig. 5a which shows the relationship of icing rate to air temperature for a wind speed of 18 m/sec and a sea surface temperature of 0 degree C. The relationship is non-linear and at extremely low temperatures the increase in icing rate begins to fall off substantially. This is due to the fact that the ocean spray probably freezes into ice pellets before impacting the ship and diminishing the overall collection efficiency.

Figure 5b shows the relationship of icing rate to sea surface temperature for a wind speed of 18 m/sec and an air temperature of -12 degree C. At this air temperature the increase in icing rate is relatively slow until the sea temperature falls below 2^{o} degree C at which point the rate increases substantially. However, the maxium effect of sea temperature is manifested at -2^{o} degree C since this is about the lowest temperature that sea water can reach.

The relationship between winds and waves is non-linear. Because of this it would be expected that a similar relationship should exist between ice accretion rates and wind speed. That is ice accretion rates should increase non-linearly. This is not the case as can be seen in Fig. 5c. Here, the relationship of icing to wind speed for a sea temperature of 0 degree C and an air temperature of -12 degree C is shown to be linear. It is believed that the non-linearity is masked by noise in the data. It should be noted that the icing rate is essentially zero for wind speeds below 10 m/sec.

FUTURE PLANS

During the 1984-85, a series of these charts projected out to 48 hours to Alaska are being transmitted on a routine basis. The forecasts will be verified using observations from ships plying Alaskan waters. These observations will also be used to evaluate, modify and improve the forecast scheme.

Future plans also include expanding the forecast area to the Northwest Atlantic and Great Lakes.

References

Borisenkov, E.P., "Fundamental Results and Perspectives into the Hydro-Meteorological Aspects of Ship Icing". Leuiugrad, Arkt. Autarkt. Nauc-Issled Inst. T298, 1972, pp. 5-33.

Lee, A. "Ice Accumulation on Trawlers in the Barents Sea" London Mar Obsr., 28, 1958, pp. 138-142.

Mertins, H.O. "Icing on Fishing Vessels due to to Spray" London Mar. Obsr Vol. 38, No. 221, pp. 128-130.

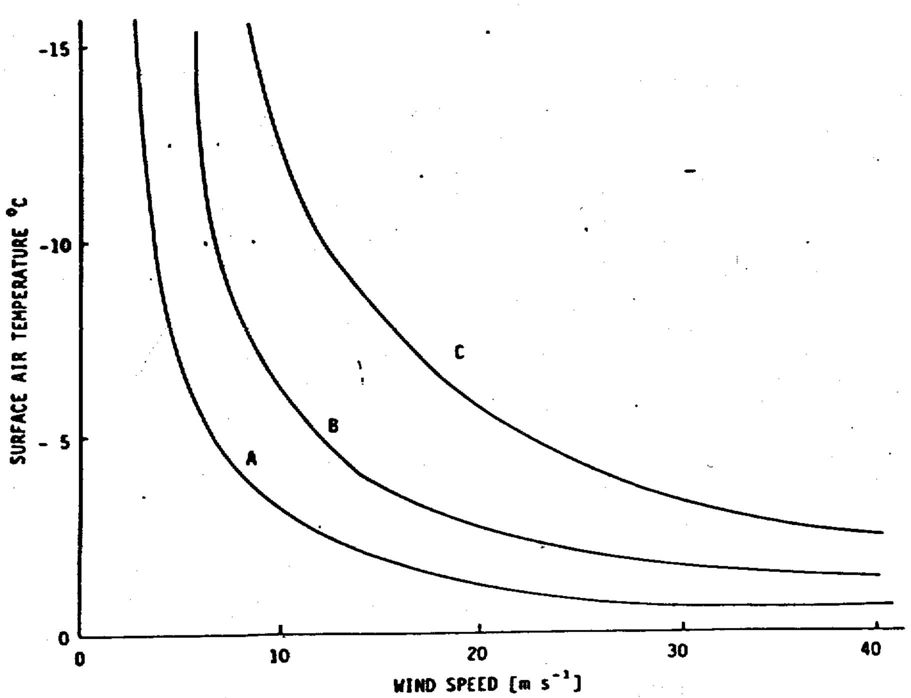
Sawada, T. "Icing on Ships and its Forecasting" Tokyo, J. of Jap. Soc. of Snow and Ice, 24, 1962, pp. 12-14.

Shektman, A.N. "Hydormeteorological Conditions in the Icing-up of Vessels at Sea" Moscow, Naak.-Issled, Inst. Aerolclim., T.UY p. 45, 1967, pp. 51-67.

Stallabrass, J.R. "Icing of Fishing Vessels: An Analysis of Reports from Eastcoast Waters", National Research Council Canada, Report No. LTR-LT-98, 1979, pp. 34.

Stallabrass, J.R. "Trawler Icing. A compilation of Work Done at N.R.C." Ottawa, Canada, National Research, No. 19372, 1980, pp. 103.

Wise, J.L. and Comisky, A.L. Superstructure Icing in Alaskan Waters, Seattle, NOAA Special Report, P.M.E.L., 1980, pp. 30.



A. Light Icing

B. Moderate Icing

C. Heavy Icing

Fig. 1. Relationship of air temperature and wind speed to icing rates (Sawada 1962).

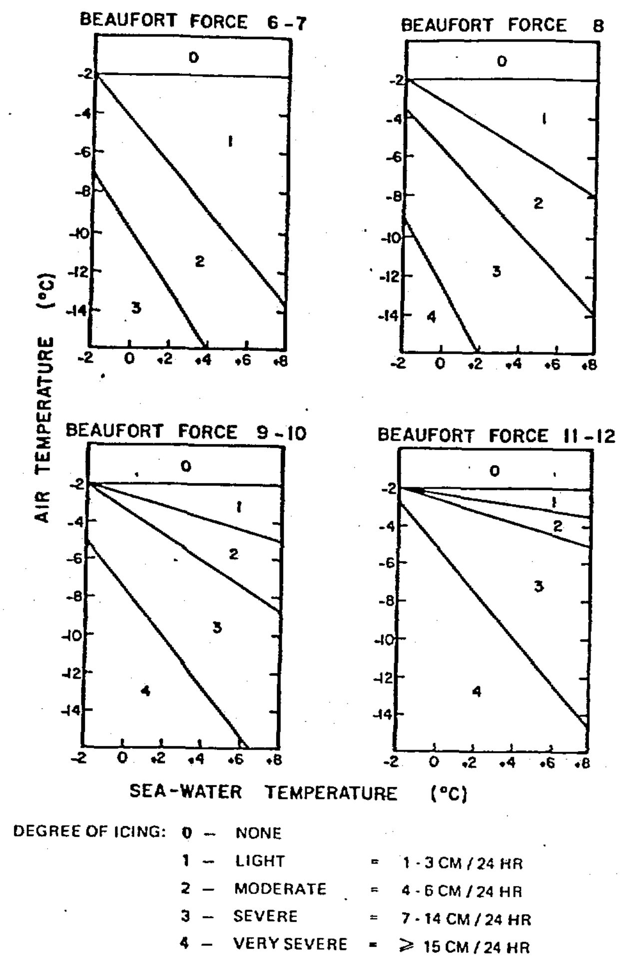
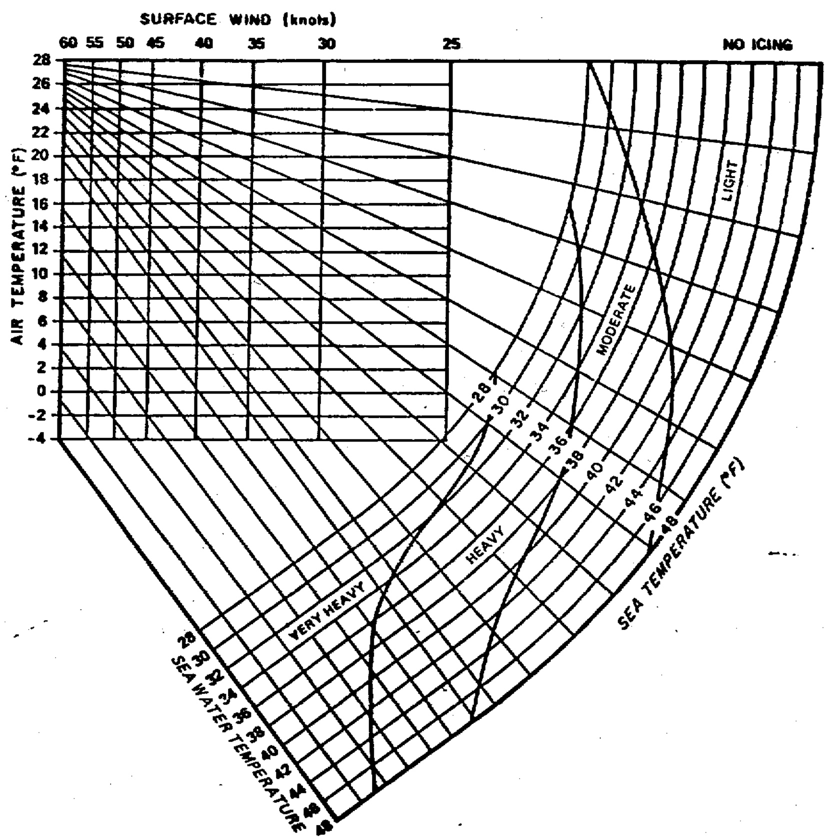


Fig. 2. Mertin's (1968) Charts of Icing Rates.



CATEGORIES

NAME	RATE PER 3 HOURS
Light	.05" to .2"
Moderate	.2" to .3"
Heavy	.3" to .75"
Very Heavy	.75+"

Fig. 3. Wise and Comisky (1980) Ice Accretion nomogram.

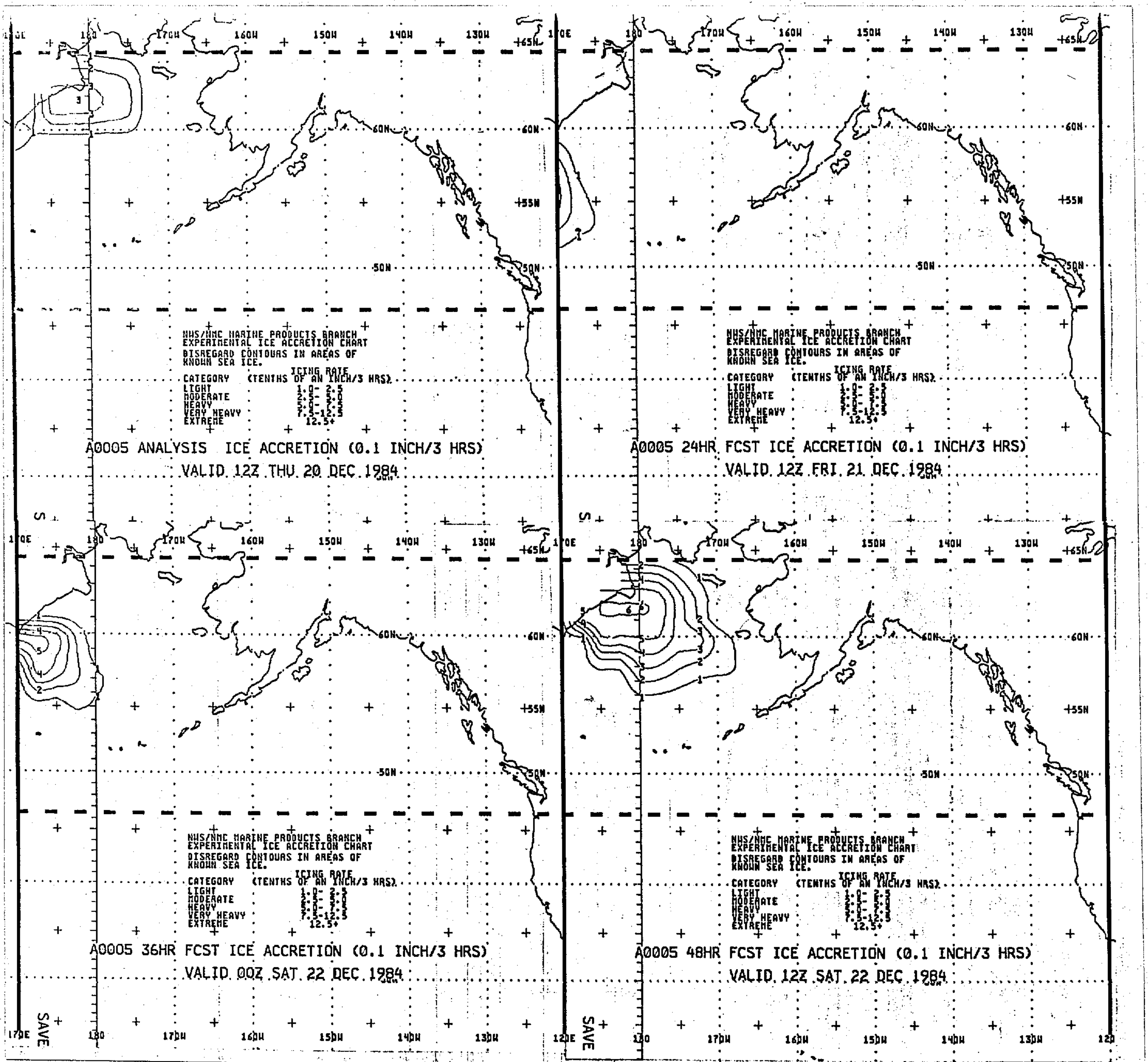
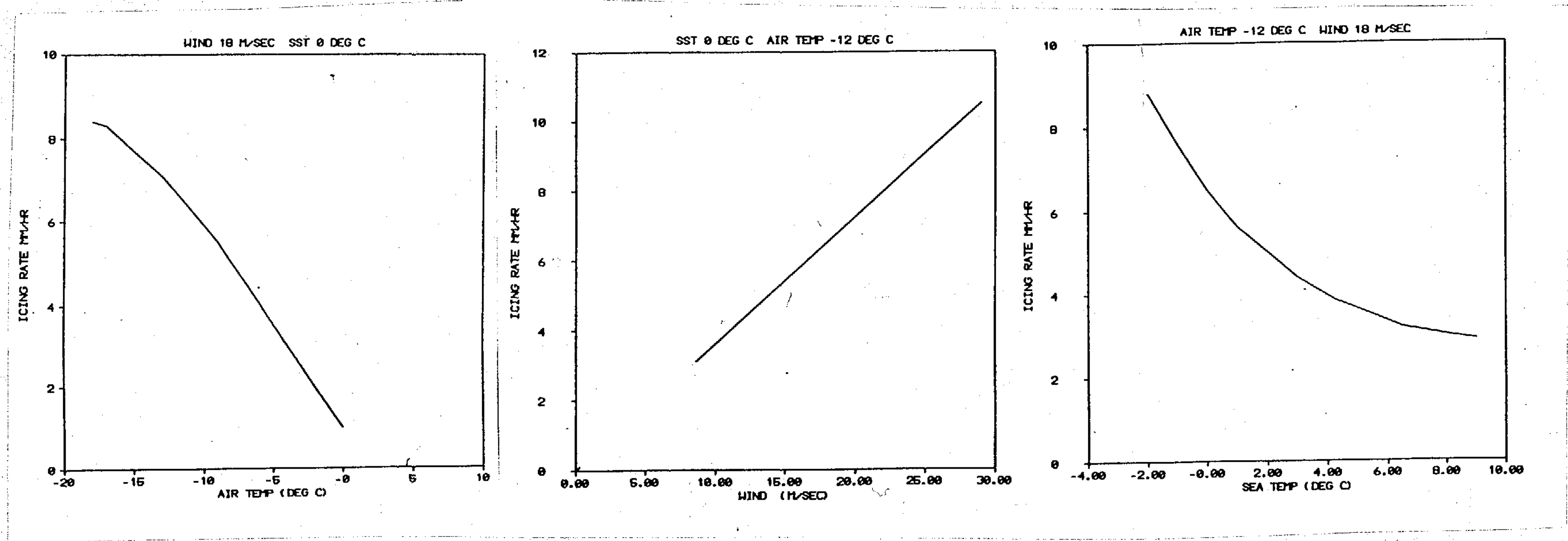


Fig. 4. Contoured Ice Accretion Forecast Guidance Charts. Routinely transmitted to Alaska.



(a) (b) (c)

Fig. 5. Change in icing rate under indicated conditions.