Marine

FORECASTING OF SUPERSTRUCTURE ICING FOR ALASKAN WATERS*

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ABSTRACT

Methods available for determining the potential for forming ice on ship superstructures are summarized. The National Meteorological Center (NMC) ice accretion forecast system is described and two ice accretion forecast techniques, Overland et al and Wise and Comisky, are evaluated using observations taken in the Alaskan waters. The results of the evaluation indicate that the Overland et al technique is superior.

1. INTRODUCTION

Marine weather at high latitudes is associated with a number of problems unique to the cold regions of the globe. Among these is the hazard created by the conditions of sub-freezing air temperatures combined with strong winds and sea temperatures near freezing. This hazard is called superstructure ice accretion and is defined as the accumulation of ice formed on exposed structural components of ships or structures above the water surface either on the coast or at sea. Advising marine interests of the existence and expected location and intensity of ice accretion is important for both the safety of the vessel and its efficiency of operation.

The accumulation of ice on small vessels has the potential of causing serious handling problems leading to instability and, ultimately, capsizing. This is particularly true of fishing trawlers which may have tons of fish and water shifting about in their holds. There are numerous instances of loss of life at sea directly or indirectly attributable to icing problems. To cite a couple of examples, Shekhtman (2) notes the loss, in the Bering Sea on 19 January 1965, of 10 Soviet vessels due to instability brought on by the accumulation of ice. On 14 January 1980, two of five hands were lost aboard a crabber, the Gemini, when it capsized off the Alaskan coast due to icing induced instability.

The extra weight of ice on masts and rigging not only makes the vessel top heavy but also increases its "sail area," thereby creating difficulties in handling due to the effect of winds. Although the result of such increased windage is not likely to be as disastrous as instability, it is a situation to be avoided.

While larger ships have less of a problem with ice induced instability, they are not immune. The accumulation of ice on antennae makes radio communication difficult if not impossible (3). On all sizes of vessels ice accumulation results in hazardous working conditions on deck. During fishing operations the ability to work with deck equipment in an unhampered manner is of prime importance. Ice accretion, of course, impedes the efficient use of deck equipment and slows the work. Cargo vessels, particularly container ships, may find that upon reaching the destination port, the deck cargo is ice encrusted to the point where unloading is impossible, even though the vessel is safely berthed, resulting in costly delays.

A major obstacle to the development of improved forecast techniques is the lack of accurate and consistent observations from vessels at sea. This is not surprising since ice accretion rates and amounts are greatly affected by such factors as the size and shape of the ship's hull and superstructure, the heading of the vessel relative to the wind and the sea keeping ability of the ship. An example of the type of data needed to permit a full description of the problem may be found in Minsk (4). He reports on objectively measuring ice accretion by exposing an array of cylinders mounted on a drilling rig in the North Aleutian shelf to freezing spray and weighing and profiling the ice at regular intervals. Clearly, this is not appropriate for obtaining observations from commercial vessels.

A number of authors have reviewed the various aspects involved in the icing of the ocean structures. Among them Makkonen (5), Lozowski and Gates (6) and Jessup (7). The reader is encouraged to refer to these papers for a more general view of the subject. The purpose of this paper is to describe the method adopted by the National Meteorological Center (NMC) to produce automated ice accretion guidance forecasts from information available through operational numerical weather prediction models.

2. SOURCES OF ICE ACCRETION

Among the various causes of ice accretion on ships, the most common are fog, freezing rain, snowfall and freezing spray. The relative importance of these factors is discussed below.

In the marine environment two types of fog occur most frequently. The first, advection fog, 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. The second, sea smoke, although not a common cause of icing, 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 (8) in which a vessel traveling through sea smoke (visibility 200 yds) picked up approximately 26 tons of ice in 10 hours.

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.

Finally, the most important of the causative factors is 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.

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Borisenkov and Panov (9) statistically analyzed more than 2000 instances of icing on Soviet fishing vessels. The results are summarized in Table 1.

Table 1. Percentage frequency of occurrence of ice accretion (after Borisenkov and Panov, 9).

	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

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. Shekhtman (10). The remainder of this paper will be concerned with forecasting ice accretion due to freezing spray.

3. FORECAST APPROACHES

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. Two basic approaches, numerical and empirical/statistical, have been used by researchers to attack the problem of specifying the potential for superstructure icing on ships.

Employing numerical methods, researchers, notably Stallabrass (11, 12), have attempted to model the complex and multiple processes related to the accumulation of ice on ships. These processes can be grouped in three categories as follows:

1. Liquid water must be generated in the air stream passing over the ship. This liquid water may be droplets generated mechanically by the action of the ship against the waves, the action of wind on the water or by atmospheric processes such as rain or fog.
2. The kinematics and associated process of the droplets striking the ship must be accounted for. This includes droplet trajectory and collection efficiency.
3. The thermodynamic processes related to the growth of ice on structures must be formulated. These processes include 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.

The empirical/statistical approach has enjoyed more success operationally. Sawada (13) 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 graph does not consider sea temperature and is based on wind speed and surface air temperature as shown in fig. 1. Mertins (14) studied nearly 400 observations taken by trawlers in the Northeast Atlantic. The study resulted in a series of nomograms which provided guidance for forecasting the severity of ice accretion. The charts required sea surface temperature as well as wind speed and air temperature, (Fig. 2). Wise and Comisky (15) 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 Fig. 3).

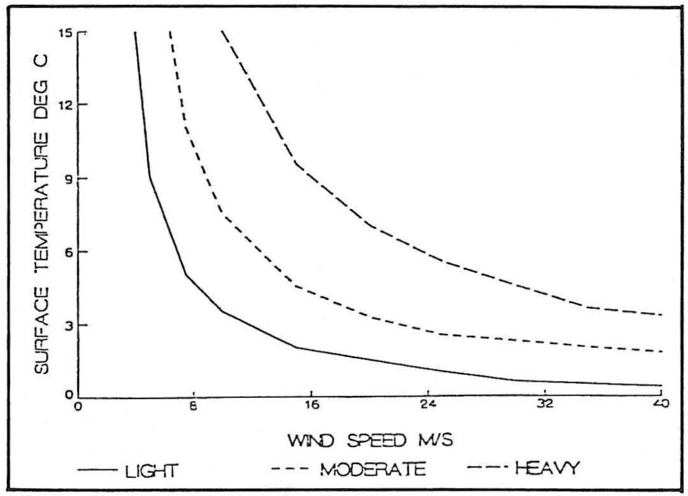

Fig. 1. Relationship of air temperature and wind speed to icing rates (Sawada, 13).

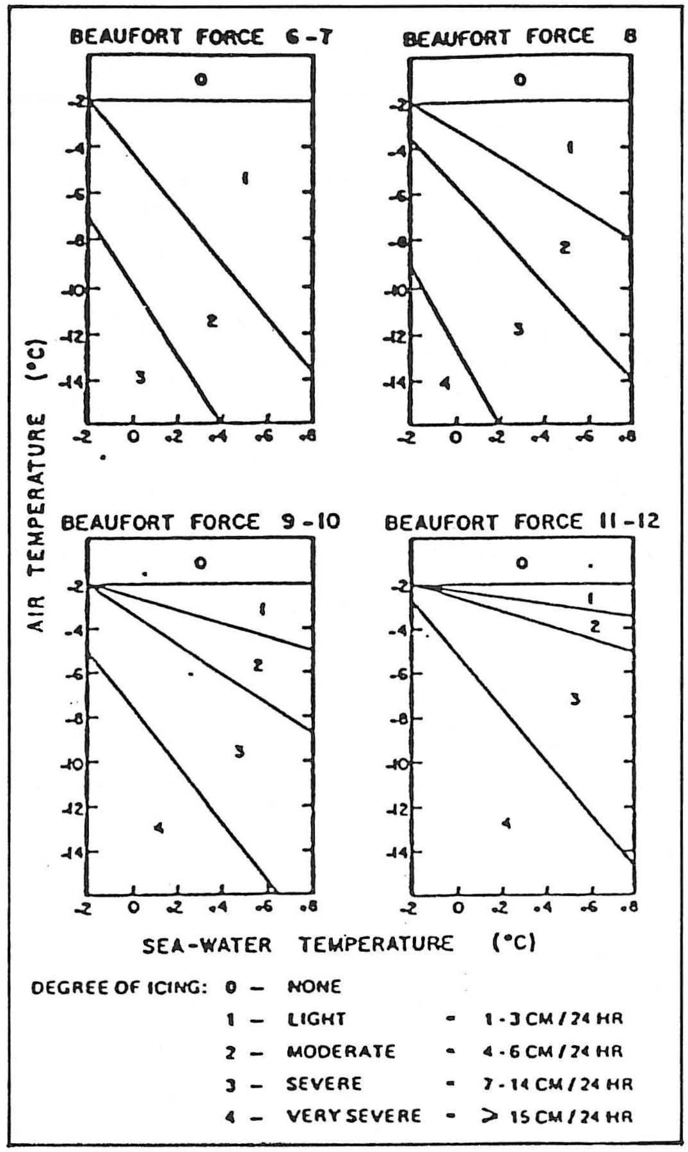

Fig. 2. Mertin's (14) Charts of Icing Rates.

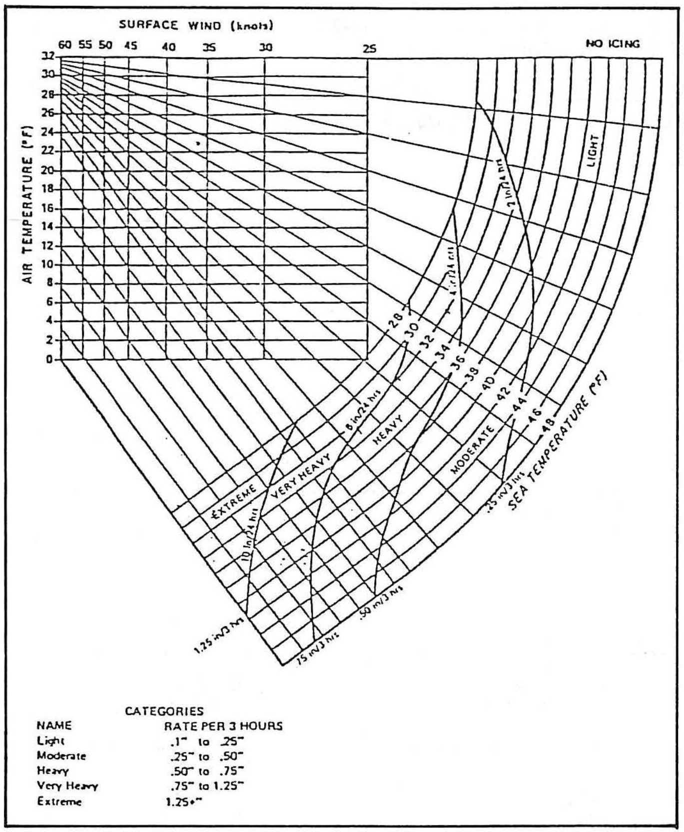

Fig. 3. Wise and Comisky (14) Ice Accretion nomogram.

Overland et al (16) used a robust statistical procedure to develop an algorithm which relates meteorological parameters to icing rates. This model will be referred to as the Pacific Marine Environmental Laboratory (PMEL) model and is based on the following relationships:

where $I = A\,P + B\,P^2 + C\,P^3$ (1)

I = Icing rate (cm hr^{-1})

$A = 2.73 \times 10^{-2}$

$B = 2.91 \times 10^{-4}$

$C = 1.84 \times 10^{-6}$

and $P = Va(t_f - t_a)/[1 + .4(t_w - t_f)]$ (2)

where V_a is wind speed (m sec^{-1})

t_f is freezing point of sea water (−1.7 deg C for Alaskan waters)

t_a is air temperature (deg C)

t_w is sea temperature (deg C)

The term $(t_w - t_f)$ in equation (2) varies slowly during the course of the icing season so that it has little effect on a given daily forecast. On the other hand the terms t_a, air temperature, and V^a, wind speed, are both highly variable and subject to forecast error on a daily basis. Fig. 4a shows the relationship of wind speed and air temperature to various values of the predictor function, P, for a sea surface temperature of 1° C and a freezing point of water of −1.7° C. The values of P shown correspond to the break points between light and moderate, P=20.6, moderate to heavy, P=45.2, and the median value of heavy, P=71.4 (Overland et al, 16). As can be seen at very low temperatures a small change in wind speed will result in large changes in icing category while at high wind speeds relatively small changes in temperature result in large icing category changes in icing rates. Fig. 4b relates P to quantitative icing rates.

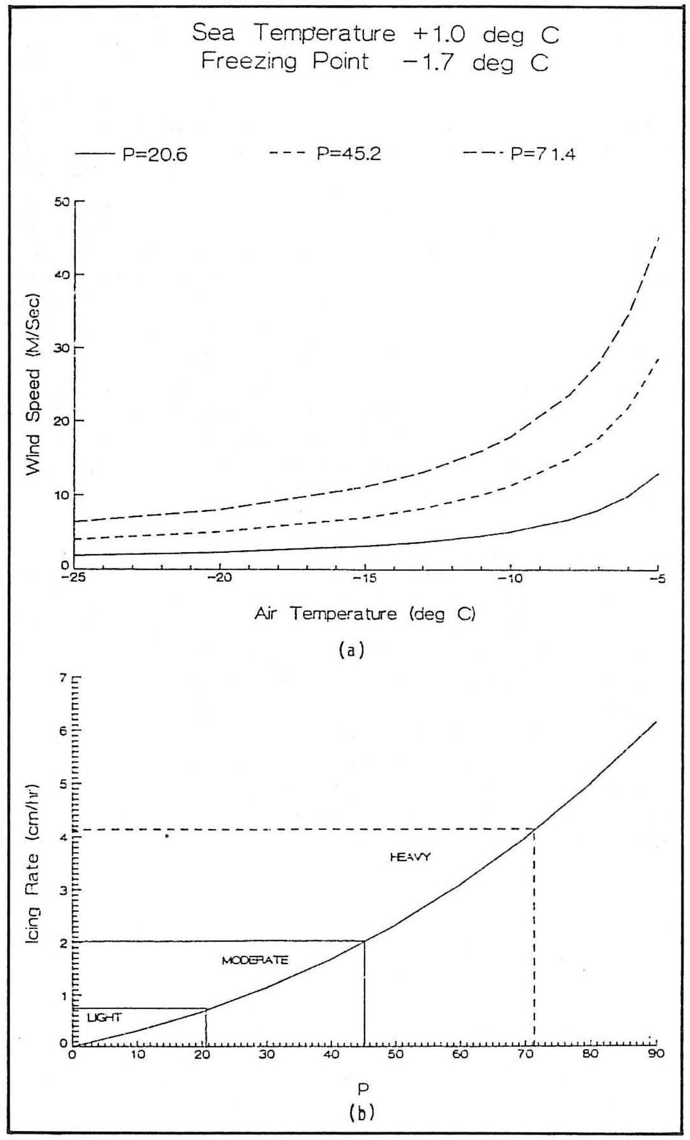

Fig. 4. a) the relationship of wind speed and air temperature to various values of the predictor function, P. b) the relationship of P to quantitative icing rates.

An important consideration accounted for in the development of this method is that anomalously low icing rates were eliminated by discarding icing reports from vessels which are steaming downwind and hence minimized spray for a given set of meteorological conditions. The PMEL model has also incorporated salinity effects through the prescription of t_f. This is an improvement over previous empirical/statistical approaches because it permits the use of the method in other ocean areas as well as fresh water bodies such as the Great Lakes.

4. NMC ICE ACCRETION FORECAST PROGRAM

The nomograms described above were designed as guides to icing potential if a certain set of meteorological conditions occur in a particular, rather localized, area. It was recognized that by applying such nomograms at multiple locations and by using forecast input as well as analyses it was possible to not only evaluate the immediate icing potential but also to alert the mariner to future potential icing situations. In addition, used this way, the geographical extent of icing as well as the movement of icing areas can be forecast.

Ship superstructure icing is a well known hazard in Alaskan waters and for this reason it was felt that initial efforts to develop a forecast guidance program should begin here. An obvious choice of techniques was the Wise and Comisky (15) nomogram; when the program started, it was the only available method developed specifically for this region.

Since this nomogram was not based upon a mathematical functional relationship between variables, a decision tree algorithm was developed which uses four tables of ice accretion rates (as a function of air and sea surface temperature) based upon four categories of wind speed each with representative speeds of 25, 35, 45, and 55 kt. Wind speeds less than about 20 kt were found not to produce significant ice accretion from freezing spray. For each of these wind categories, a matrix of ice accretion values was constructed. These matrices were filled by obtaining ice accretion rates from the nomogram for values of air temperature from 0° to −20°C and from values of sea temperature from −3° to 10°C. Icing rates were obtained by applying the analyzed and forecast 1000 mb air temperature field and the 1000 mb geostrophic wind field from the spectral atmospheric model of NMC (Sela, 17). The sea surface temperature used was the NMC blended ship/satellite analysis (Reynolds and Gemmill, 18). Ice accretion was computed at 2.5 degree intervals of longitude in the Gulf of Alaska in order to obtain a contoured chart of ice accretion rates. In January 1985, charts of ice accretion guidance forecasts became routinely available, via facsimile, in the Alaskan region.

Shortly after the implementation of these guidance forecasts Overland et al (16) presented a new approach, discussed earlier, to compute ice accretion potential in Alaskan waters. During the 1985–86 winter, this model was tested in parallel with the Wise and Comisky based system, using the same model inputs, with a view to determining which one was more suitable.

5. EVALUATION

A major difficulty in the development and evaluation of ice accretion methods concerns the scarcity of icing observations. In order to mitigate this problem arrangements were made with NWS's Alaskan region to obtain observations of icing events in Alaskan waters. During the period 14–28 February 1986, fishing trawlers in Alaskan waters were requested to report both the occurrence and non-occurrence of icing. The observations were made twice daily, 0200–0300 UTC and 1500–1600 UTC, during the normal course of their voyages. The observations were essentially qualitative, that is, classified only into light, moderate and heavy categories (see Table 2.). For purposes of this comparison, no attempt was made to extract quantitative information from them. It was felt, however, that the data could validly be used to distinguish areas of ice/no ice.

Icing was reported during 5 of the 14 days of the period. The total number of observations was 92 (both occurrences and non occurrences). These observations were compared with the 24 hour forecasts generated using each of the methods. The results of the comparison is presented in Table 3. Four statistics were computed from the contingency tables shown:

$$\text{percent correct} = (H_i + H_n)/N$$
$$\text{power of detection} = H_i/(H_i + M_n)$$
$$\text{false alarm rate} = M_i/(M_i + H_n)$$
$$\text{threat score} = H_i/(N - H_n)$$

where

H_i = number of times icing was forecast and icing was observed
H_n = number of times icing was not forecast and icing was not observed
M_n = number of times icing was not forecast but was observed
M_i = number of times icing was forecast and was not observed
N = total number of observations

Table 2. Example of ice accretion observations taken by Alaskan fishing vessels.

Name	Location	Weather Information
Guardian	59° 00′ N 150° 48′ W	Brkn, Vsby 15 Wind-W 25 kt 6 ft sea, W 18 ft swell Air 20°F, 28.96 in Lgt frzg spray
Miller Freeman	53° 53′ N 171° 50′ W	Cldy, Vsby 10 Wind-NNE 25 kt Swell-NNE 8 ft Air −0.3°C, Sea 3.2°C 1008.3 mb, falling No ice report
Stacy Foss	57° .0′ N 153° .1′ W	Cldy, Vsby 8 Wind-W 40 kt 4 ft sea, 8–10 ft swell Air 10°F, 971 mb Frzg spray
Sea Hawk	53° 54′ N 166° 32′ W	Blwg Snw, Vis 1/2 Wind-N 35 kt 1 ft sea, 2 ft swell Air 15°F, 29.71 in No icing

Table 3. Contingency tables based on 24 hour ice accretion forecasts using a) the Wise and Comisky model and b) the Overland et al model.

		Wise and Comisky Observations			PMEL Model Observations		
		Ice	No Ice	Total	Ice	No Ice	Total
24 Hour Forecast	Ice	1	9	10	7	18	25
	No Ice	6	76	82	0	67	67
	Total	7	85	92	7	85	92
Percent correct			83.70			80.43	
Power of detection			0.14			1.00	
False alarm rate			0.11			0.21	
Threat score			0.06			0.28	

From this set of observations, the results show the PMEL model is much better in detecting this event. Indeed the power of detection was 1 indicating that every icing event reported was forecast. An examination of the threat score, useful for comparing forecasts of relatively rare events, shows that the PMEL model is substantially better than the Wise and Comisky method. On the other hand there is little difference between models with respect to percent correct. Furthermore, while the false alarm rate using the PMEL model is nearly twice that of Wise and Comisky, in absolute terms this number is still quite small; and considering the hazard imposed by this event on mariners, it is within an acceptable range.

SUMMARY AND CONCLUSIONS

Based on the statistics cited above the PMEL model was adopted as the basis for operationally producing ice accretion guidance forecasts charts in 1987 (see Fig. 5). These charts are produced once daily using fields generated by NMC's 1200 UTC atmospheric run. Projections of 0, 24, 36 and 48-h are generated. Contours of icing rates corresponding to light (.1 to .8 in/3-h), moderate (.8 to 2.4 in/3-h) and heavy (greater than 2.4 in/3-h) are drawn. The charts are considered most suitable for ice forecasts on vessels similar in size and design to Alaskan fishing trawlers.

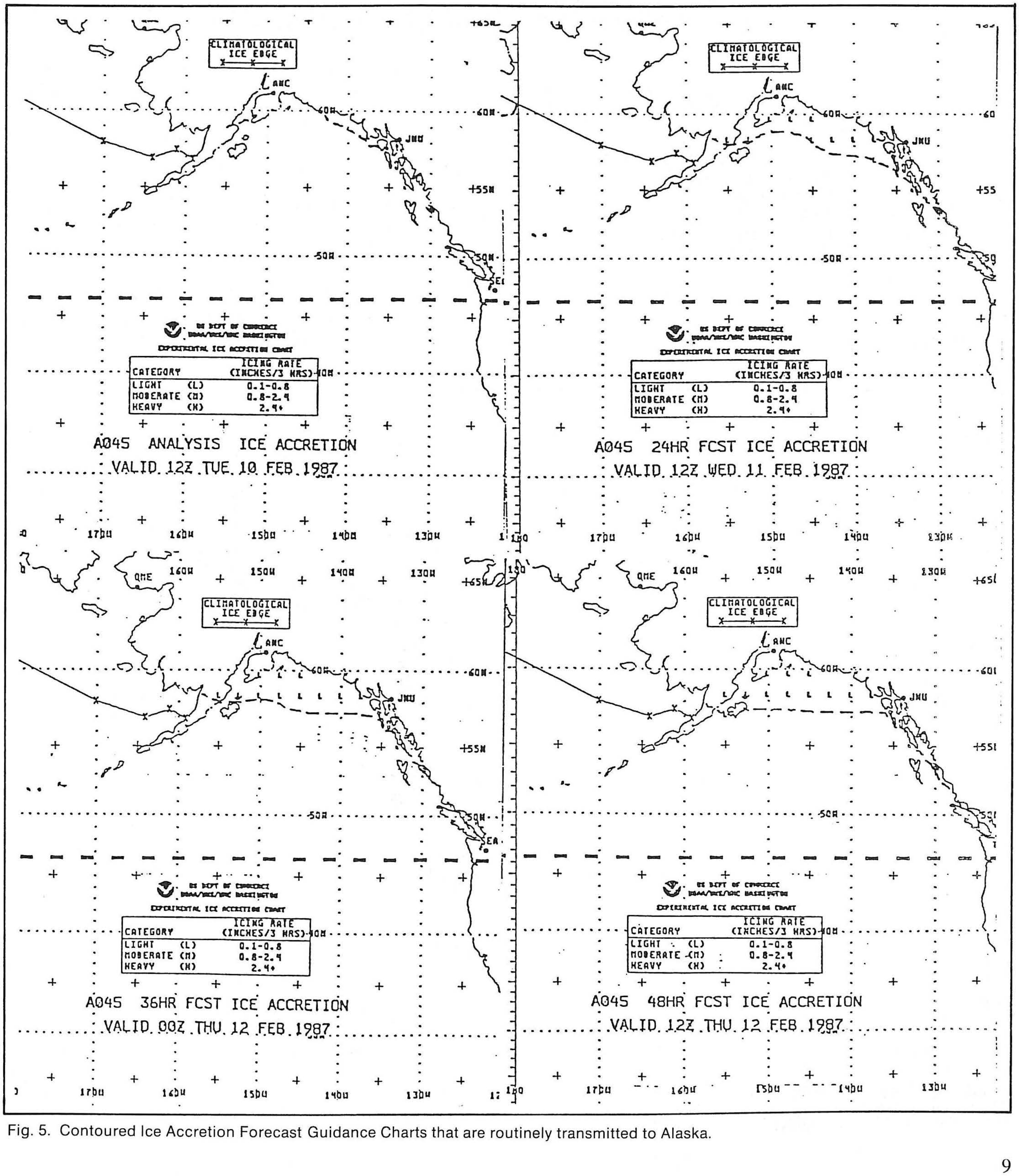

Fig. 5. Contoured Ice Accretion Forecast Guidance Charts that are routinely transmitted to Alaska.

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NOTES AND REFERENCES

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Folklore

"MORE THAN A PAPER MOON. . . ."

by Sue Mroz

The moon has been an endless source of fascination and inspiration for everyone from poets and lyricists to "werewolves" for centuries. Thus, it's not surprising that man has come up with names to identify the various fullmoons, with some of the names seeming quite obvious, and others very unusual.

The following list was sent in by Ralph Hamer, a retired farmer in rural Rockford, IL. He said much of his weatherlore was passed onto him by his father, the late T. Scott Hamer.

January:	"Wolf Moon"
February:	"Snow Moon"
March:	"Sap And Worm Moon"
April:	"Pink Moon"
May:	"Flower Moon"
June:	"Hot and Strawberry Moon"
July:	"Buck Moon"
August:	"Sturgeon Moon"
September:	"Corn Moon"
October:	"Hunter And Harvest Moon" (And Sometimes November Also Goes By Harvest Moon)
November:	"Beaver Moon"
December:	"Cold Moon"