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AN OPERATIONAL FORECAST SYSTEM FOR SUPERSTRUCTURE ICING*

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1. INTRODUCTION

Ship superstructure ice accretion formed from freezing spray is a hazard unique to the cold regions of the globe. It occurs as a result of sub-freezing air temperatures combined with strong winds and sea temperatures near freezing. 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.

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 capsizing with attendant loss of human lives and economic investment. 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" This increases 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 an adverse affect on radar operations.

During fishing operations the ability to work deck equipment unhampered is of great 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 describe the NMC program to produce automated ice accretion forecasts.

2. FORECAST APPROACHES

The problem of forecasting superstructure icing is basically the forecasting of 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.

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. However, little use has been made of numerical models in an operational setting due to the various simplified assumptions that must be made about the structure upon which the ice forms and the physical processes involved.

In one variation of the empirical/statistical approach nomograms are empirically constructed from icing observations obtained by vessels at sea. These graphs are distributed to users such as fishing vessels, commercial shippers and forecasters. In practice the user is required to have available estimates of future values of air temperature, wind speed and sea temperature. The result is a qualitative estimate of expected ice accretion in terms of light, moderate and heavy rates. This technique has enjoyed more success operationally than the numerical approach and a number of nomograms have been developed. Sawada (1962), Mertins (1968) and Wise and Comisky (1980), figure 1, are good examples of this technique.

A more systematic examination of the problem was done by Overland et al (1986) at the Pacific Marine Environmental Laboratory (PMEL) where a robust statistical procedure was used to develop an algorithm which relates meteorological parameters to icing rates in the following way:

$$I\ (cm\ hr^{-1}) = A(P) + B(P)^2 + C(P)^3$$

where

I=Icing rate

$A=2.73\times10^{-2}$

$B=2.91\times10^{-4}$

$C=1.84\times10^{-6}$

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

where

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

t_f is freezing point of seawater (-1.7 deg C for Alaskan waters)

t_a is air temperature (deg C)

T_w is sea temperature (deg C)

An important consideration accounted for in the development of this algorithm is that anomalously low icing rates were eliminated by discarding icing reports from vessels which were steaming downwind and hence minimizing spray for a given set of meteorological conditions.

3. NMC ICE ACCRETION FORECAST PROGRAM

The nomograms described above were designed as guides to icing potential under a given meteorological conditions in a particular location. Applying such nomograms at multiple locations by using weather forecasts and ocean analyses produced at NMC it is possible to alert the forecaster 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 predicted.

Ship superstructure icing is a particular hazard in Alaskan waters and for this reason the initial efforts to develop a forecast guidance system were concentrated in that area. An obvious choice of techniques was the Wise and Comisky nomogram which, when the program started, was the only method available developed specifically for this region and this technique could only provide very qualitative type of guidance.

Shortly after the implementation of these guidance forecasts PMEL presented the more quantitative technique, described above, to forecast ice accretion potential in Alaskan waters. After an evaluation of the two methods during the 1985-86 winter (Feit, 1987) it was concluded that the PMEL model was superior and this model was adopted as the basis for operationally producing ice accretion guidance forecasts, see figure 2. These charts are produced once daily using wind and air temperature fields generated by NMC's 1200 UTC atmospheric run along with NMC's blended ship/satellite sea surface temperature analysis. Projections of icing potential for 0, 24,36 and 48 hours are generated.

4. VALIDATION OF NMC ICE ACCRETION FORECAST SYSTEM

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 21 February - 6 March 1987 fishing trawlers in Alaskan waters were requested to report both the occurence and non-occurence of icing. The observations were made twice daily, 02-03 UTC and 15-16 UTC, during the normal course of their voyage. The observations were essentially qualitative and 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 .

The 24 hour forecasts generated at NMC and valid at 12 UTC were compared with observations taken 15-16

UTC. Table 1 below presents the results of the comparison in the form of a contingency table (forecasts vs. observations). Four statistics were computed from this table.

power of detection = $H_i/(H_i+M_n)$

false alarm rate = $M_i/(M_i+H_i)$

threat score = $H_i/(N-H_n)$

where

H_i = number of times ice was forecast and ice was observed

H_n = number of times ice was not forecast and ice was not observed

M_n = number of times ice was not forecast but was observed

M_i = number of times ice was forecast and was not observed

N = total number of observations

The results shown in Table 1 suggest that, with a power of detection of .88, the PMEL method does a credible job in detecting this event. The false alarm ratio is a moderately high .62, however, this is not considered excessive for this hazardous type of event. The threat score of .247 is little changed from the score of .280 computed during the initial evaluation (Feit, 1987).

Table 1. Contingency table based on NMC icing forecasts and observations in Alaskan waters for the period 21 Feb-6 Mar 1987.

		OBSERVATIONS		
		ICE	NO ICE	TOTAL
24 hour forecast	ICE	15	25	40
	NO ICE	2	23	25
	TOTAL	17	48	65

power of detection	.88
false alarm rate	.62
threat score	.247

5. SUMMARY AND CONCLUSIONS

Based on the statistics cited above the NMC medium range forecast model together with the PMEL ice accretion forecast method produces ice accretion forecasts of acceptable quality. Improvements to this system are expected to come about as a result of using finer mesh NMC models and improvements in forecasting such boundary layer parameters as ocean surface wind speed and surface air temperature.

The system will continue to be evaluated in collaboration with the National Weather Service Alaskan region and will be expanded to include all the appropriate northern hemisphere waters.

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