ICE ACCRETION ON SHIPS WITH SPECIAL EMPHASIS ON BALTIC CONDITIONS

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SMHI Rapporter

METEOROLOGI OCH KLIMATOLOGI

Nr RMK 7 (1977)

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C O N T E N T S

SUMMARY

Since the middle of the 1960-ties, ice accretion reports have been collected from ships travelling in the Baltic. The data from these reports have been processed and the relation between ice accretion and meteorological and oceanographic parameters have been studied. The investigation comprises merchant vessels of a size typical for the Baltic.

This report presents the results from the icing campaign. It contains a general description, including factors causing icing, the freezing process etc. Results from other investigations have been studied and comparisons made. Forecasting of ice accretion is diskussed and the method now used at SMHI is described. Finally some comments are given on how to avoid or decrease the ice accretion.

SAMMANFATTNING

Sedan mitten av 1960-talet har nedisningsrapporter från fartyg som trafikerat Östersjön samlats in av SMHI. Rapporterna har bearbetats och samband mellan nedisning och vissa meteorologiska och oceanografiska parametrar har studerats. Undersökningen har omfattat handelsfartyg av typisk storlek för Östersjön.

Rapporten visar resultaten från nedisningskampanjen. Den innehåller dessutom en allmän beskrivning, vilken omfattar faktorer som orsakar nedisning, frysprocessen etc. En del tidigare arbeten har studerats och jämförelser av resultat har gjorts. Nedisningsprognoser diskuteras och den metod som nu används vid SMHI beskrivs. Slutligen ges en del kommentarer om metoder att undvika eller minska nedisning.

1. INTRODUCTION

During the winter season ice accretion on ships is a great risk for the shipping in northern open waters (fig. 1 and 2). Many trawlers and small ships have been lost both on the North Atlantic Ocean and in the Baltic*) due to heavy icing.

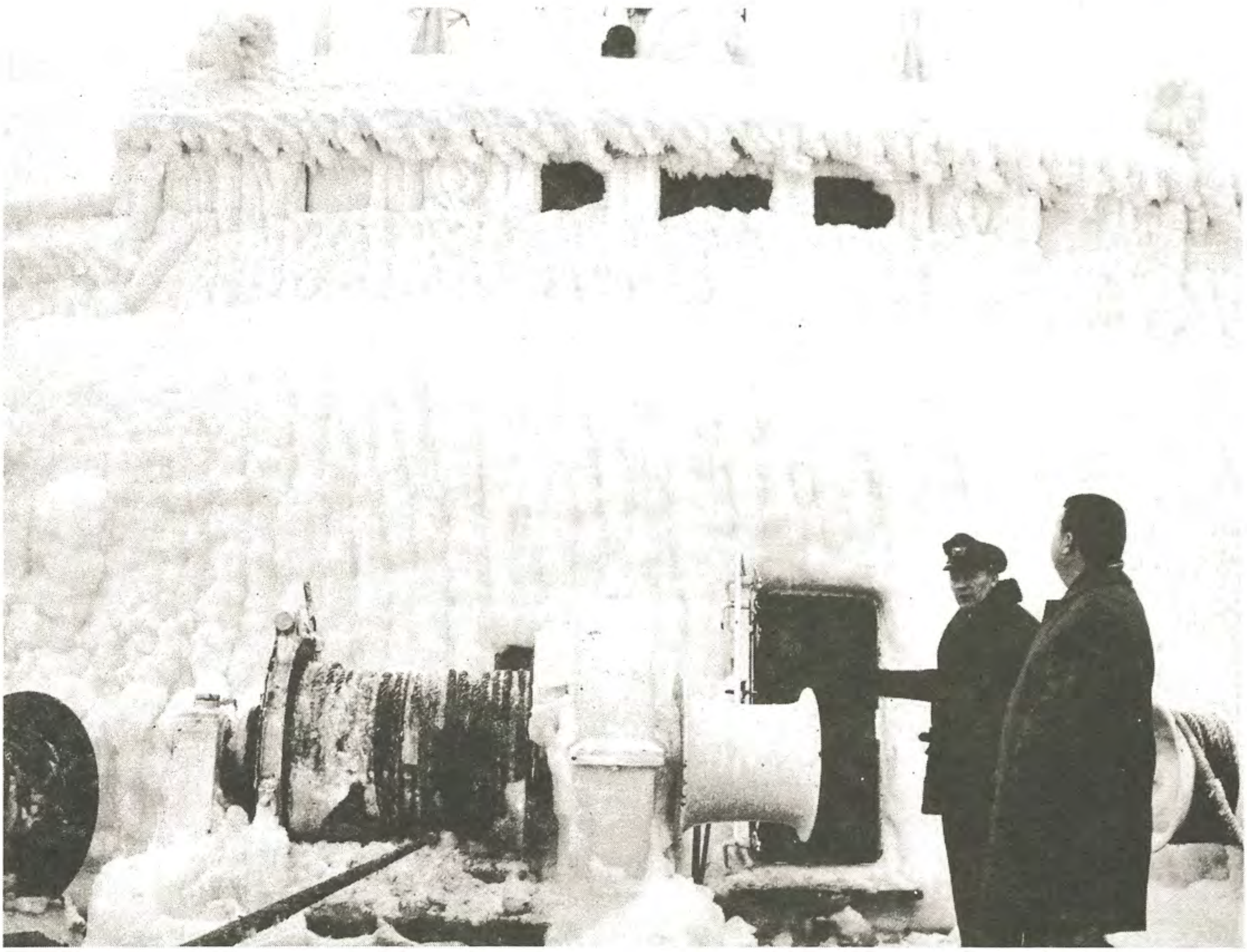

Figure 1.
The ferry m/s Peter Pan had to return to the port at Trelleborg due to the icing covering the windows of the bridge. The icing occurred between Trelleborg - Sassnitz, 18/1 1972, at south-easterly winds 17 - 22 m/s, airtemp. -5°C and seatemp. +1°C.

*) The Baltic is defined as all the sea area east of Sweden, thus consisting of the Baltic Sea, the Gulf of Bothnia, the Gulf of Finland and the Gulf of Riga.

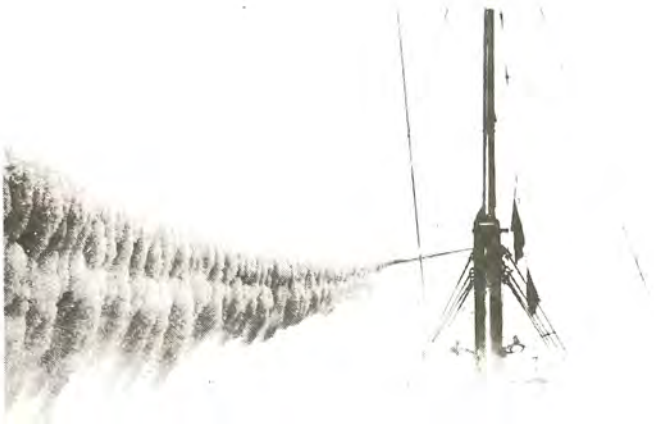

Figure 2.
m/t British Vigilance (about 16 000 dwt) in Gävle harbour.
The icing occurred in the southern and central Baltic Sea at winds between NW and NE and up to 30 m/s. Airtemp. was estimated -5^{o} to $-10^{o}C$.

The knowledge about ice accretion has increased during the last decades and experience has been gained how to prevent or decrease the degree of icing. Warnings for expected icing are now issued in risky waters. The ships have become larger and more seaworthy. They have been constructed in such a way that the possibilities for icing and its influence on the stability of the ships have decreased. Mother ships offer aid and provide icing warnings to fishing fleets in Atlantic waters. All these factors have decreased the accidents but still the ice accretion is a great security risk. Even if the ship is not lost, the work on board is impeded and risky for the crew due to the ice covering the ship. Great delays also arise when removing the ice in ports before unloading and loading.

Many scientists in the U.S., the U.S.S.R., Great Britain, Germany and Japan have studied the formation growth and characteristics of icing. Methods to prevent or decrease the icing have also been studied. Statistical and theoretical methods to estimate the rate of icing during different weather conditions have been developed. Most studies have treated ocean conditions with saline water while brackish water areas have caught less attention. Russian scientists have published results from the ice accretion in the Baltic and also made some theoretical calculations of the rate of icing.

In the middle of 1960, SMHI started to collect icing reports from ships in the Baltic. The purpose with the campaign was to study the ice accretion on ships further and to compare the ocean results with Baltic conditions. Many similarities but also differences are found and the results give the base for ice accretion forecasts issued by SMHI.

2. METEOROLOGICAL AND OCEANOGRAPHIC DATA

The Baltic (fig. 3) is an inland sea with brackish water. The salinity varies from 15 $^{o}/oo$ in the south to 3 $^{o}/oo$ in the northern Bay of Bothnia. The sea area is rather small and is very much affected by the surrounding land areas. The variations of the sea surface temperature varies from slightly below 0 ^{o}C in the winter up to approximately 20 ^{o}C during the summer. Parts of the sea area is usually covered by ice during the winter.

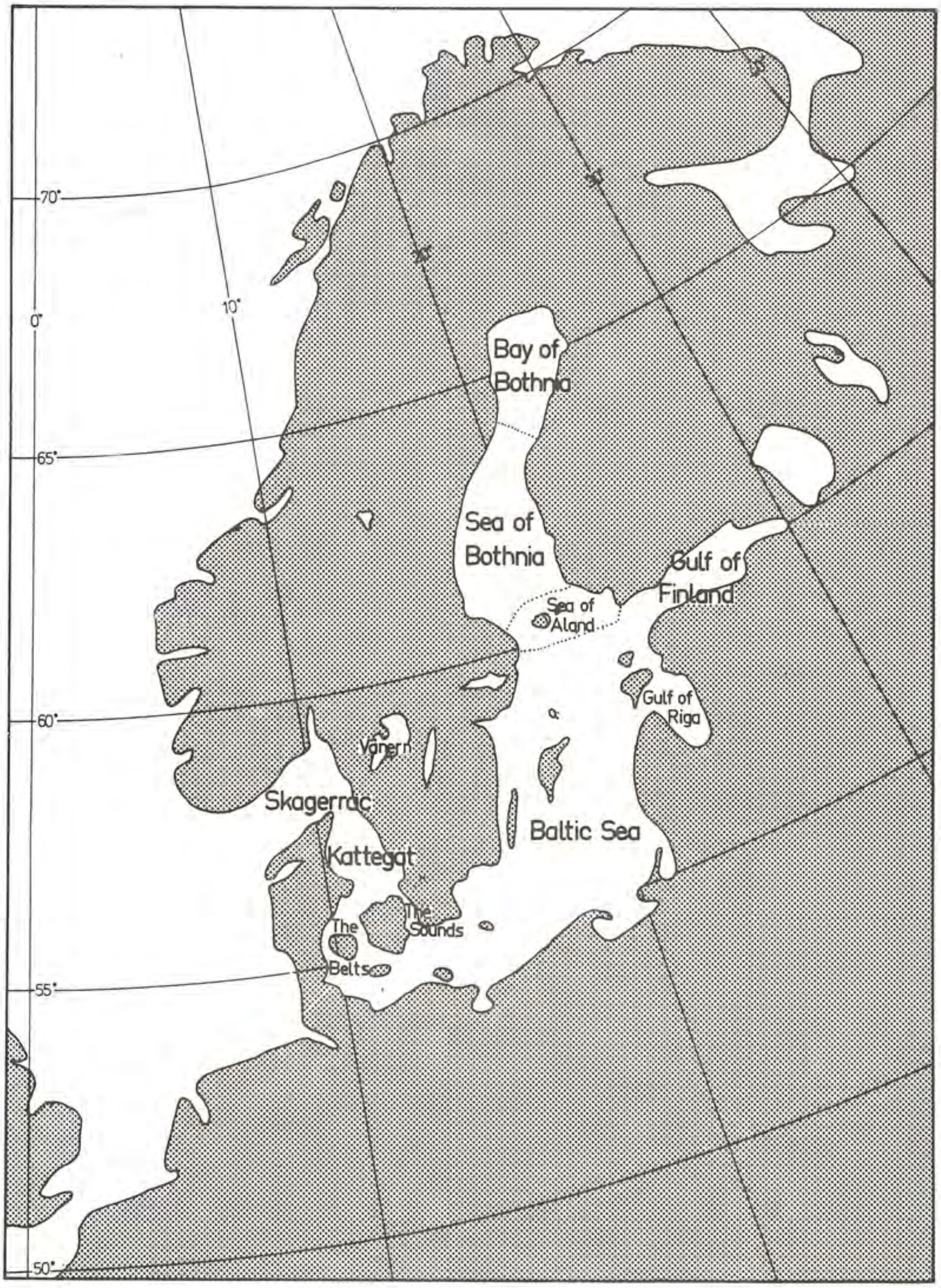

Figure 3.
Map of the Baltic.

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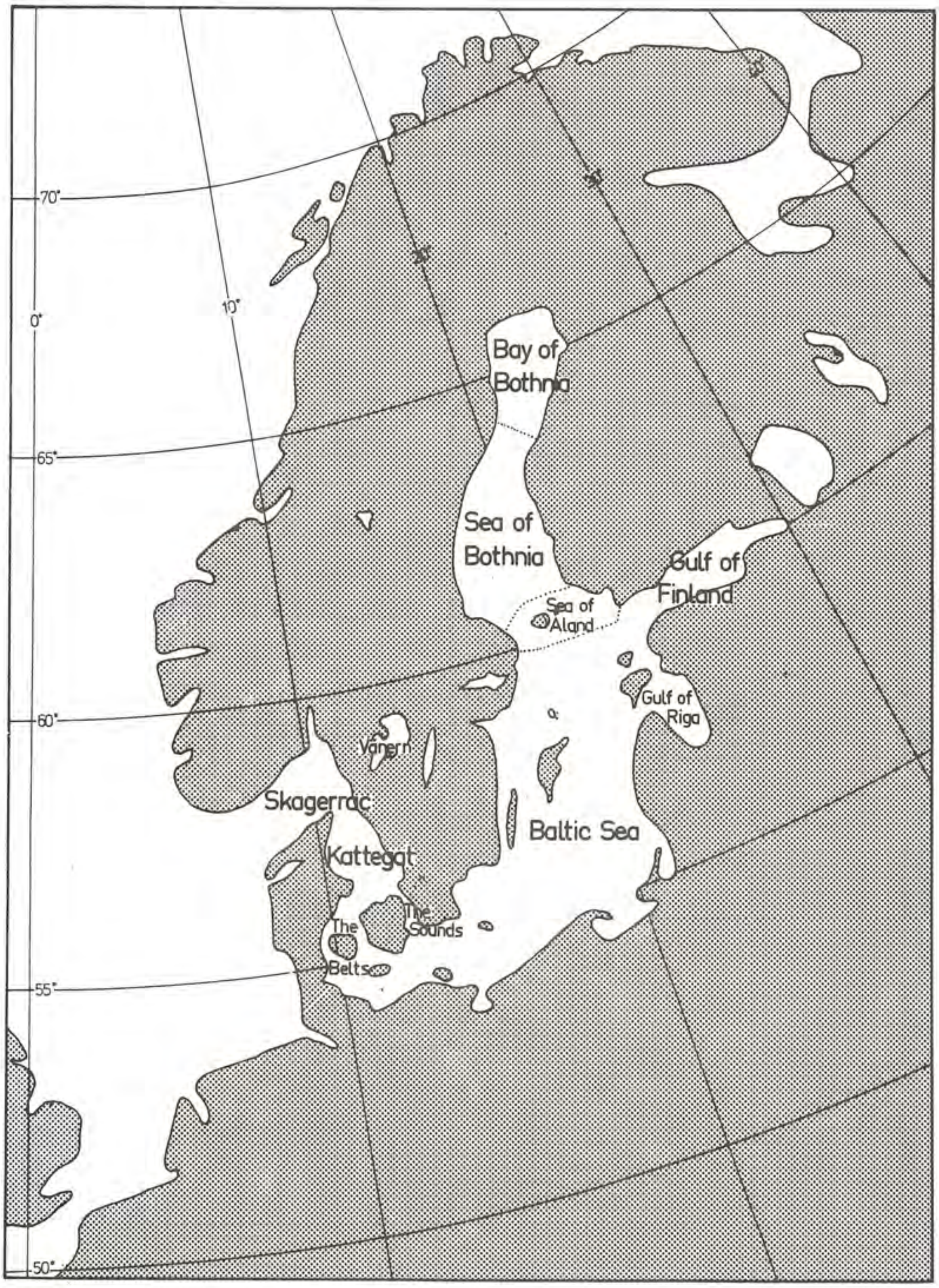

Figure 3.
Map of the Baltic.

Cold air masses are during the winter season moving southward from the Arctic Sea and westward from the European - Asian continent. From November the sea surface temperature normally has decreased (fig. 4) enough to allow ice accretion on ships during intense cold air mass outbreaks. From April the air temperature normally is high enough for icing to be rare.

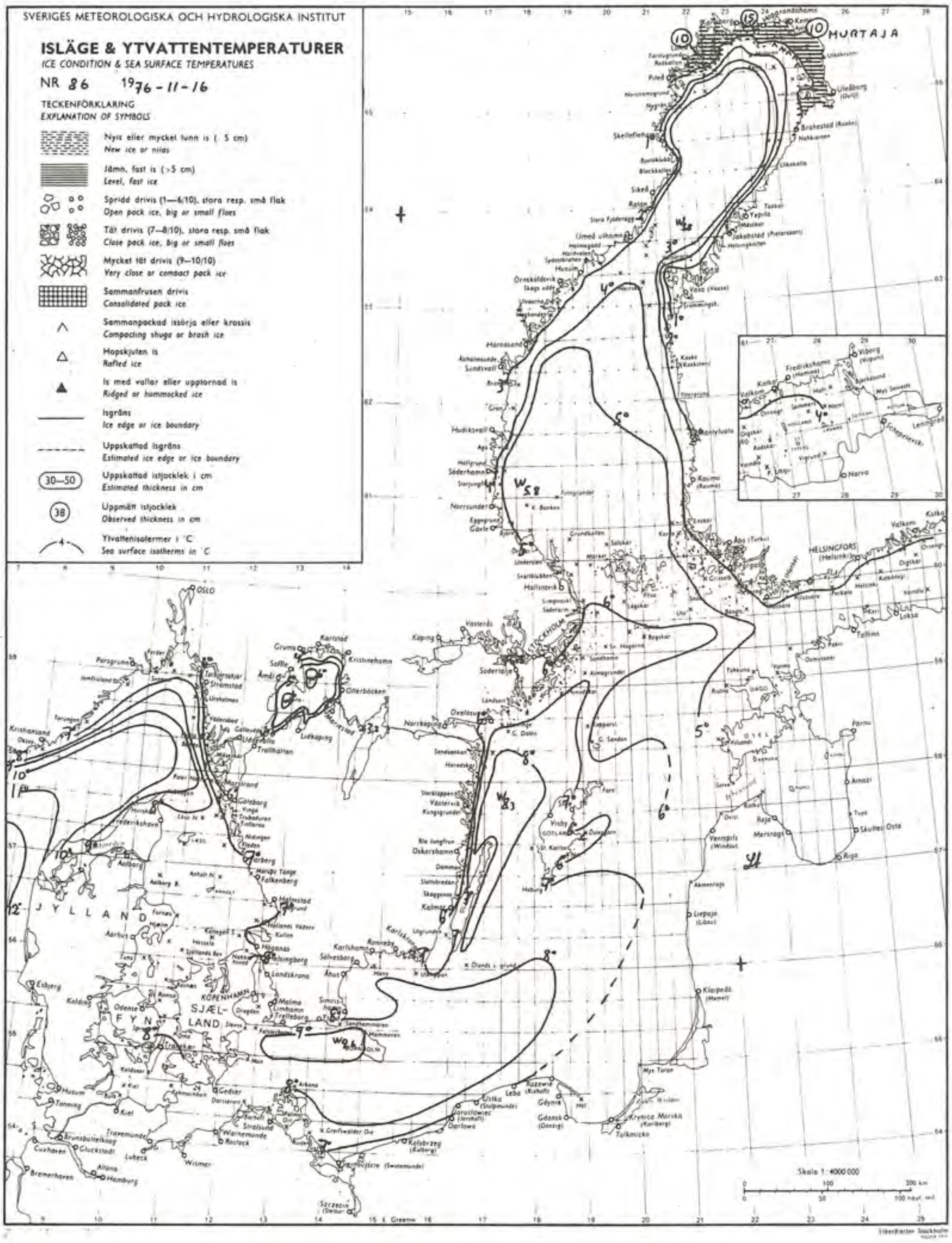

Figure 4.
Sea surface temperature (SST) analysis 16/11 1976.

The frequency of strong winds is rather big during winter (table 1).

Table 1

Number of occasions with wind speeds above 10 m/s during 1973/74 at selected coast stations (4 observations per day are made).

	Nov	*Dec*	*Jan*	*Feb*	*Mar*
Bjuröklubb	*40*	*38*	*24*	*11*	*3*
Holmögadd	*40*	*22*	*36*	*13*	*0*
Örskär	*58*	*46*	*23*	*17*	*4*
Landsort	*50*	*42*	*47*	*22*	*8*

The bottom topography in the Baltic is variable. Wide areas with shoals and banks, narrow straits like the Northern and Southern Quark, islands like Gotland and Åland and surrounding coasts give a special state of sea. Waves formed in deep parts receive a shorter wave lenght when running into more shallow areas. The waves will more easily break and form spray.

3. COLLECTION OF ICE ACCRETION REPORTS FROM THE BALTIC

In the middle of 1960 collection of ice accretion reports from vessels in the Baltic started. In the beginning the reports were very few and incomplete and difficult to treat in an properly way. During the autumn 1969 SMHI initiated a new icing report campaign in the Baltic. Five ships (Västanvik, Nordanvik, Mälarvik, Sunnanvik and Skånevik, later replaced by Östanvik) from Cementa Ltd were engaged. The ships were chosen because they are of a normal size for Baltic traffic (500 - 3000 dwt) and normally run with a speed of 10 - 15 kts. They have low freeboard and are strenghtened for winter navigation and they regularly trade the Baltic.

A drawback is the cargo which consists of warm cement. This seems to make the ice accumulation on deck rather small and the total ice amount has not been incorporated in the study. The ships are equipped with ventilated psycrometer and hull contact sea surface thermometer.

The ice accretion reports have been filled in during the winter season,when the air temperature has been below 0°C. Data on icing or no icing has been noted on a special log (fig. 5). The degree of icing has been estimated in the classes no, light, moderate and severe icing (table 2). The time and positions for the icing has been reported as well as observations of wind, air and sea temperature, waves course, speed, cargo or ballast, total amount of ice etc.

The collection of icing has later been extended to include other types of ship. A similar log as that in figure 5 has been used by the pilots. They have interviewed the captains on board ships with observed ice accretion during the winters 1972/73 and 1973/74. The reports have been mailed to SMHI. The winters were however rather mild and very few icing occasions occurred.

The icing reports have furthermore been supplemented with icing occasions from 1962-68 reported in newspapers, telegrams and letters.

The total data material is thus very inhomogenous. The tonnage and types of ship are variable, from pilot boats and patrol vessels to tankers on 30 000 dwt. More than 300 icing reports are available, 90% of the reports are from merchant vessels of the size 500 - 7000 dwt. Of those 75% are reported by the five ships from Cementa Ltd. In developing the various diagrams only the reports from the merchant vessels have been used. The rest of the material has, however, been tested against the results and coincides rather good.

SMHI
VBM

NEDISNINGSUPPGIFTER
(fartyg)

2b

Fartygets namn ....

Fartygets dödvikt ....tdw. Last, barlast (stryk under)

Destination .... År ...... Månad ....

Fart vid full maskin .... knop.

Fribord höjd ca .... meter (om möjligt)

Dag	Tid	Position		Fart = F = H = S	Nedisning lätt = L måttlig=M svår = S ingen = I	Vind		Temperatur		Våghöjd i meter	Rullningsperiod Stb-bb-stb i sek.
		lat.	long.			riktn.	styrka Beauf.	luft	vatten		

Vilka åtgärder vidtogs för att minska nedisningen? (Kurs- eller fartändring):.....

....

Del av fartyget, som främst är nedisat:..

Mängd is .... ton. (Beräknat på djupgåendet)

Islagrets tjocklek:

På backen .... cm

På fördäck .... cm

På akterdäck .... cm

På bryggans förkant .... cm

På brädgångarna förut .... cm

" " akterut .... cm

" luckor .... cm

Stagens eller vanternas största Ø .... cm

Isutbredning i höjdled på rigg .... meter

Anmärkningar:..

....

....

Formuläret behöver ej nödvändigtvis vara ifyllt i alla delar för att uppgifterna skall ha värde.

....
Underskrift

Figure 5.
Icing logs used by Swedish vessels.

The degree of icing is a difficult parameter to measure. The amount of ice is usually unevenly distributed over the ship and the degree of icing has to be a subjectiv estimation. Different classifications have been made by different authors (table 2).

Table 2

SMHI	*WMO before 1975*	*WMO from 1975*	*MERTIN*
Light 0.5-2cm/12 hours	*0.6-1.2cm/12 hours*	*1cm/3 hours*	*1-3cm/24 hours*
Moderate 1-3cm/4 hours		*1-5cm/3 hours*	*4-6cm/24 hours*
Severe >4cm/4 hours	*2.5cm/4 hours*	*6-12cm/3 hours*	*7-14cm/24 hours*
Very severe		*>12cm/3 hours*	*≥15cm/24 hours*

The degree of icing depends on many factors. In addition to the meteorological and oceanographic conditions factors like the course and speed of the ship, the design, the size etc. are of importance. This study only treats ice accretion in relation to atmospheric and oceanographic conditions and do not take into account other factors. These are however commented upon below.

4. SHORT DESCRIPTION OF ICE ACCRETION

4.1 Factors causing ice accretion

The factors causing ice accretion are mainly,

a) spray
b) overflow of water
c) supercooled fog- and raindrops
d) snow fall

Spray. At air temperatures below 0°C spray is the most important icing factor, Shellard (1974), (table 3). The spray consists of small water droplets. They are formed by breaking waves and the water broken up mechanically by the ship. The spray is then transported in the air by the wind and meanwhile cooled. The rate of cooling depends on the time in the air, the size of the droplets, the air temperature etc. The spray is hitting mainly the wind-ward masts, stays, rigging, derrics, deck machineries and superstructures. At low air temperatures the spray then will freeze to ice.

Overflow of water occurs at violent sea when large water masses are washing over the deck. If the scuppers are kept open from ice, thus allowing the water to run off the deck, the icing have not time to form. Icing already formed on the ship hull or foredeck may quite opposite be loosen or even be melted by the large amount of water. If the water remains on deck a whitish porous slush is formed which may grow rather rapid for every cascade flowing over the ship.

Supercooled fog or rain. This type of icing on ship is of less importance, as the increase of weight is rather small. The icing makes however the work onboard very hazardously as ladders and passages become slippary.

Snow fall is also of less importance. Dry snow usually blow off the ship and the density of the snow is rather small. If the snow is wet or if it becomes wet by spray it may remain onboard and later freeze to ice and contribute to the ice weight.

Table 3. Percentage frequency of icing intensity on ships according to cause (Data for 1965-66 - after Shekhtman).

Icing intensity	*Cause of icing*					*Number of cases*
	Spray	*Spray and Fog*	*Fog*	*Spray and Precipitation*	*Precipitation*	
Fast growth	*82*	*12*	*2*	*4*	*0*	*52*
Slow growth	*90*	*5*	*2*	*1*	*2*	*303*
No change	*94*	*0*	*2*	*2*	*2*	*54*
All cases	*89*	*5*	*2*	*2*	*2*	*409*

4.2 The freezing process

The formation of the icing on different parts of the ship has been studied in detail by a.o. Tabata et al (1963), Ono (1964). They studied the freezing process with two kinds of icing gauges. One, which consisted of a rod suspended in an electric weight gauge and one consisting of a small rod and a collector for the brine formed during the freezing.

Their measurements show that the ice accretion varies depending on the size of the water droplets (in reality the weight of the spray) and the wind speed (fig. 6).

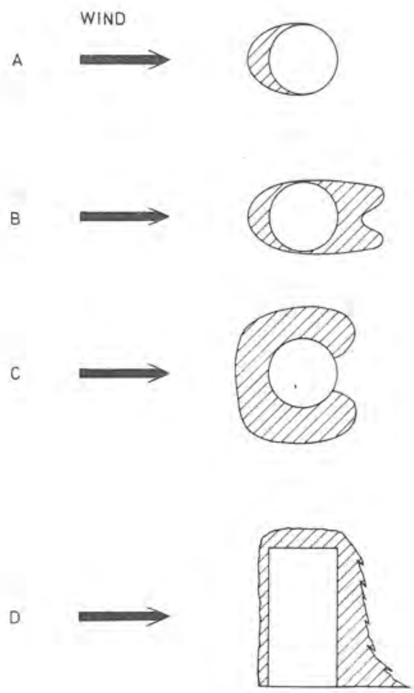

Figure 6.
Formation of the icing on an icing rod with different size of the water droplets.

With small droplets and low wind velocity, every droplet freezes immediately when captured by the gauge and before further droplets arrive. The icing forms mainly on the windward side and the brine is frozen into the droplets (fig 6a).

With somewhat bigger droplets and stronger wind, all droplets do not freeze before the arrival of further droplets and the water moves down - wind and down-ward before freezing. A typical configuration of the icing is shown in fig. 6b and 6d.

When the droplets are further increased more water can blow out on the sides and move down before freezing. The shape will then be more wing like (fig. 6c).

When the sea water freezes the ice crystals will not contain any salt. A liqiud with increasing salt content will form, a so called brine. Some of it will be captured in so called brine pockets in the ice but the rest will drain out. By measuring the chlorinity in the collected brine, Tabata et al (1963) concluded that the temperature of the growing ice accretion is relatively high compared to the air temperature, $-2^{\circ}C$ to $-4^{\circ}C$. The air temperature thus has to be below $-2^{\circ}C$ for icing to occur in ocean water. In the brackish water in the Baltic icing seems to appear already at temperatures between 0° and -0.5° C.

One part of the unfrozen brine is draining down or blown away in the wind while another part is frozen into the ice in so called salt cells as mentioned above. Also air bubbles are caught in the ice, which due to these factors show up a rather porous and whitish appearance. When the accretion process is finished the ice temperature will ajust to the surrounding air temperature.

The hardness of the ice depends on the brine volume which in turn depends on the temperature and salinity. The hardness will increase when the temperature and salinity decreases. This is also a well known fact when trying to force sea ice.

The crystal structure and orientation is unevenly distributed and the individual particles are small about 0.5 mm in diameter.

The ice accretion on deck is mainly formed of big droplets or sea water washing the deck, while the icing higher up, for instance on the bridge deck and the masts, is formed of small, often supercooled droplets from which a part of the salt is draining away. One could from this conclude that the density of the ice varies with height. Measurements by Tabata et al (1963) however give no unambigous picture. In cold chambers the expected results are reached but in more realistic conditions other factors like differences in air temperature, droplet temperatures and size, collision intensity etc. affect the density of the accreted ice.

4.3 The distribution of icing on ship

The amount of accreted ice and the distribution varies a lot due to factors like the course and speed of the ship towards waves and wind, the height and lenght of waves. Tabata (1969) has shown results from field studies with Japanese patrol vessels. The vessels were equipped with icing gauges on different places and were travelling in different directions against the waves and also with different speed. The icing rate and distribution is shown in fig. 7. The amount of icing is relatively small due to rather calm conditions but they still show a higher icing rate when travelling with an angle of 30-60° towards the waves than when heading the waves. The figures also show that the icing rate decrease considerably with lower speeds and this also agrees with experience. From the figures it is also seen that the ice accretion is unevenly distributed when travelling with an angle towards the waves.

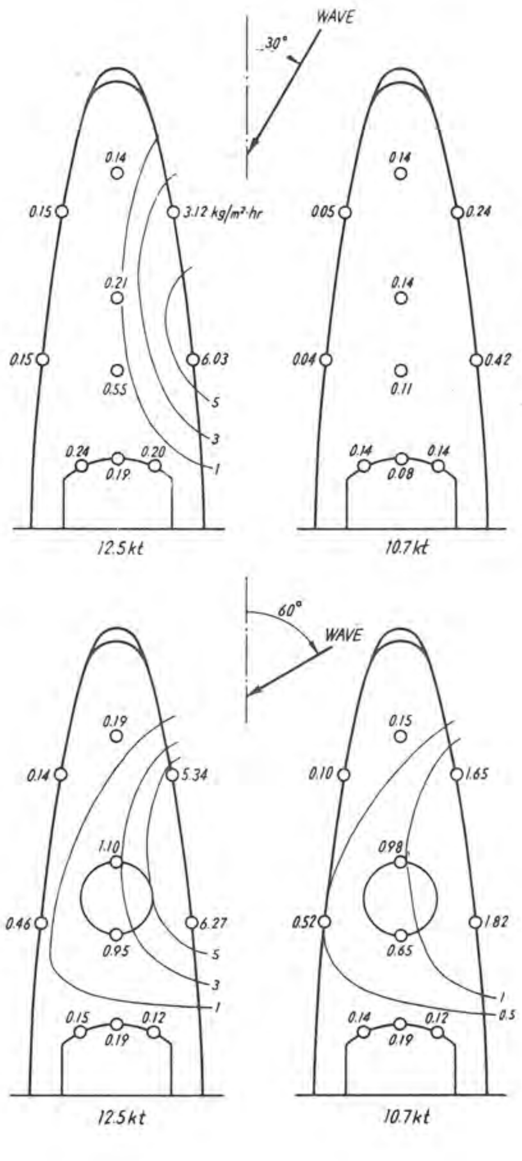

Figure 7.
Distribution of icing at Japanese patrol vessels dependent on course and speed.

Field studies on fishing vessels of type SRT and SRTH in the USSR, Panov, Moltjanov (1972) show that the intensity of the spray (and also the icing rate) has a maximum when the angle between the course of the ship and the waves is 30-40° (fig. 8). They also show that the maximum occurs at larger angles when the speed increases and that the intensity increases when the ship's speed is increasing.

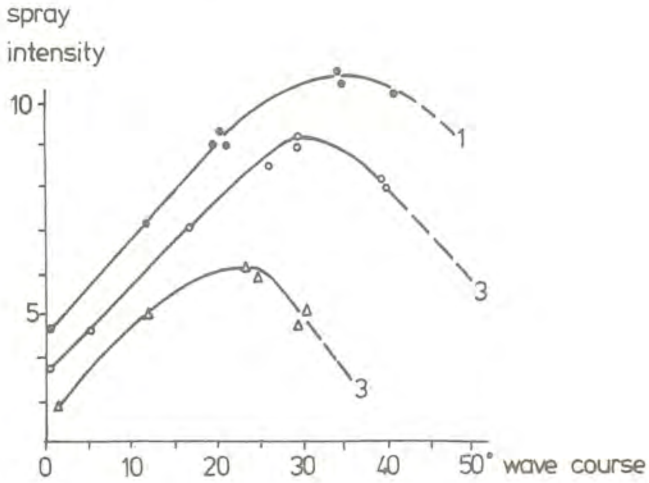

Figure 8.
The relation between the intensity of spray and wave course towards the ship and the speed of the ship, 1) 8.5 kts, 2) 7.0 kts and 3) 5.5 kts.

Panov, Moltjanov (1972), also shows a relation between the spray intensity and the course and height of the waves (fig 9). It is seen that the maximal spray intensity was observed at an angle of 20° between wave and ship's course for a waveheight of 3 - 3.5 m while maximum occurred at about 40° for 1 - 1.5 m waveheight.

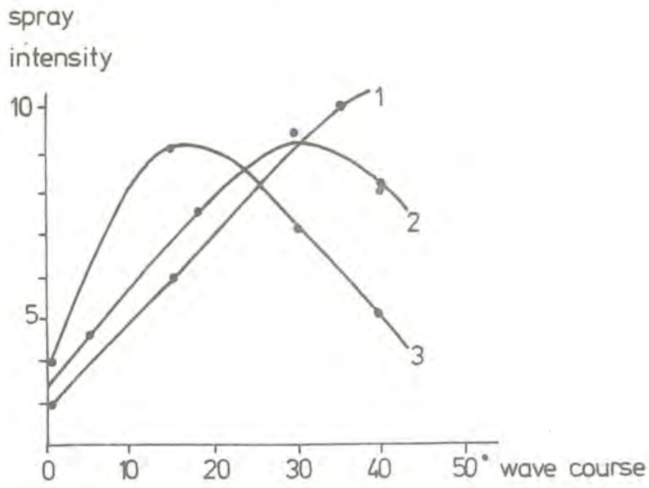

Figure 9.
The relation between the intensity of spray and wave course towards the ship and wave height, 1) 1.0 - 1.5 m, 2) 2.0 - 2.5 m and 3) 3.0 - 3.5 m.

The amount of spray is also affected by the sea characteristics of the ship, like rolling, pitching, ability to steer and to go through waves.

The ice accretion starts forming on the forward part of the ship, mainly on rigging, superstructures, masts etc. which are not washed by water cascades. The stem will gradually sink and the spray will reach higher. This will move the gravitation centre upward and deteriorate the sea worthiness of the ship. If the process continues for a sufficient time the ship will capsize.

The critical amount of icing for a ship to capsize varies from ship to ship. However, London (1957) concludes from model tests that only half of the critical icing amount is required for a ship to capsize if the ice is distributed mainly on one side.

5. RESULTS AND COMPARISONS

Seasonal distribution

The data from the Baltic ice campaign show that most ice accretion cases have occurred during the months November-February (fig. 10). Only a few cases have been reported before November and after the middle of April.

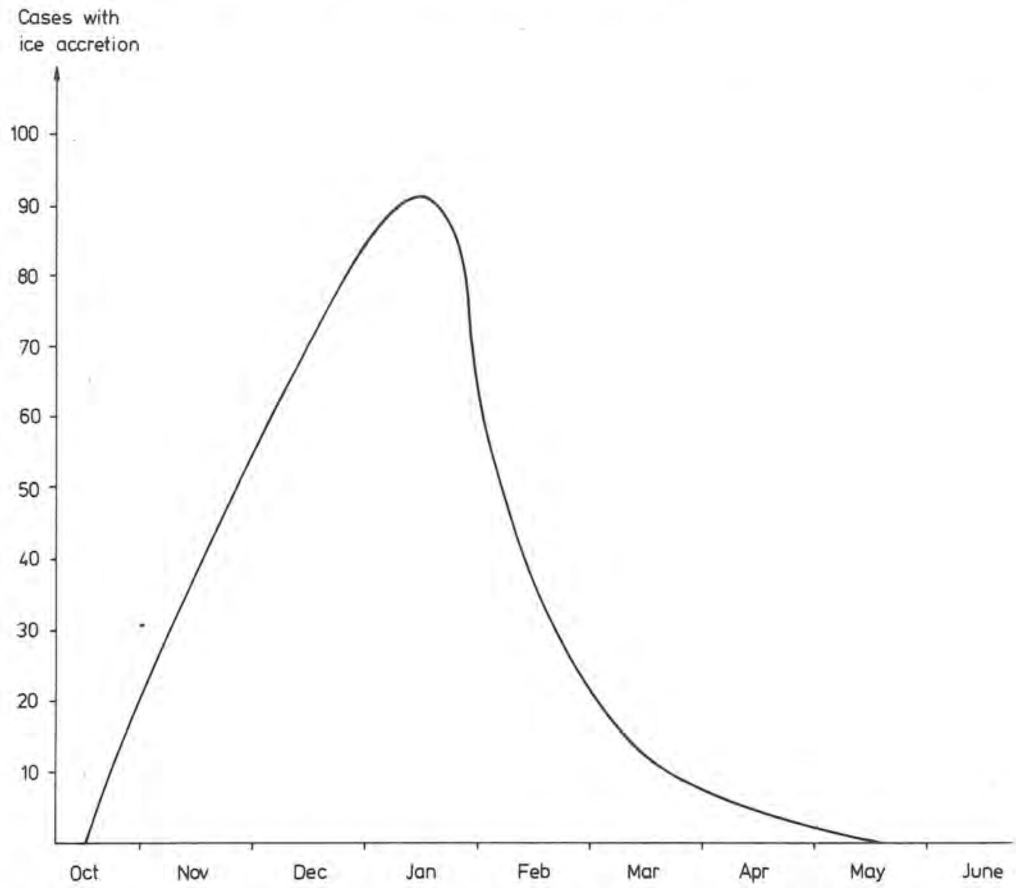

Figure 10.
Distribution of cases with ice accretion during the period October - May in the Baltic.

A rapid increase of the number of cases is observed between November and January. This seems natural as the frequency of strong winds (table 1) in connection with low air temperatures is large during those months and as sea surface temperatures are low. After maximum in January a rapid decrease is seen from the figure. A reason for this is the decreased frequency of strong winds but also of the reason that sea ice normally covers large areas during February and March. (Normally the Bay of Bothnia is covered by ice already in January.)

Dependence on wind direction

The number of icing occasions have been related to the observed wind direction (fig 11). Most cases are reported for winds in the sector northwest to northeast but a maximum is also observed for southeasterly winds. Very few cases have occurred for wind between south and west and no moderate or severe icing has been reported for winds in the sector southeast to west. During the winter those winds generally brings warm air and consequently a decreasing risk for icing. The winds from

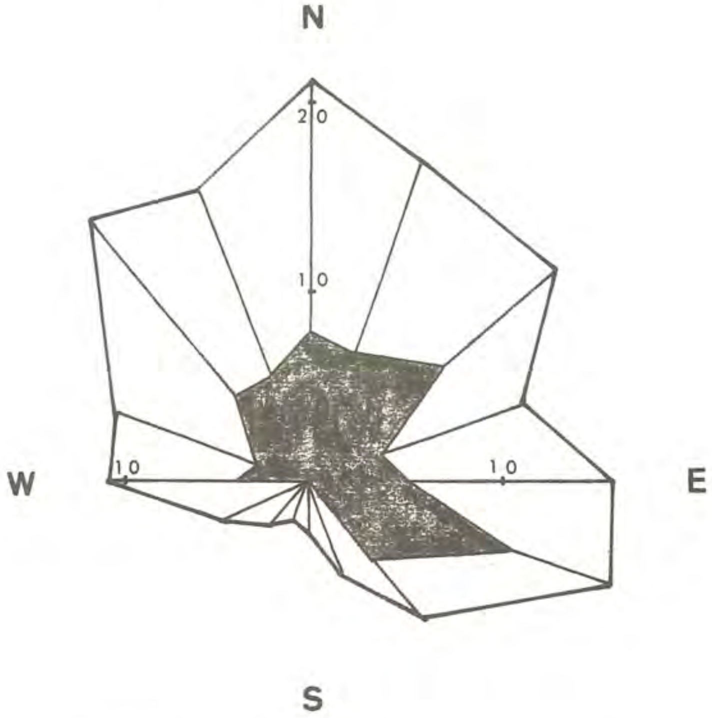

Figure 11.
Distribution of cases with ice accretion at different wind directions. The shaded area shows cases with moderate and severe icing.

northwest to northeast are usually coupled to cold air outbreaks often behind cold fronts but also when lows pass south of Sweden. The southeasterly winds often occur in front of a warm front or in blocking situations with a high over Russia and a low west of Scandinavia. Vasilyera (1971) has shown similar results from 108 icing cases in the Baltic. 20% of the cases occurred at winds between west and north, 38% between north and east, 32% between east and south and only 10% at winds between south and west.

Dependence on wind speed and air temperature

From the collected data the dependence of wind and air temperature on ice accretion have been studied. A diagram showing the degree of icing; no, light, moderate and severe icing, as a function of air temperature and wind has been compiled (fig 12). (The speed and course of the ships have not been taken into account.) The data show few cases with icing for winds below 5 m/s. Moderate and severe icing have occurred when the winds have exceeded 7 respectively 10 m/s. Light icing has been reported for air temperatures as high as -0.0°C to -0.5°C. Moderate and severe icing have occurred with air temperatures below -2.5°C and -4.5°C respectively.

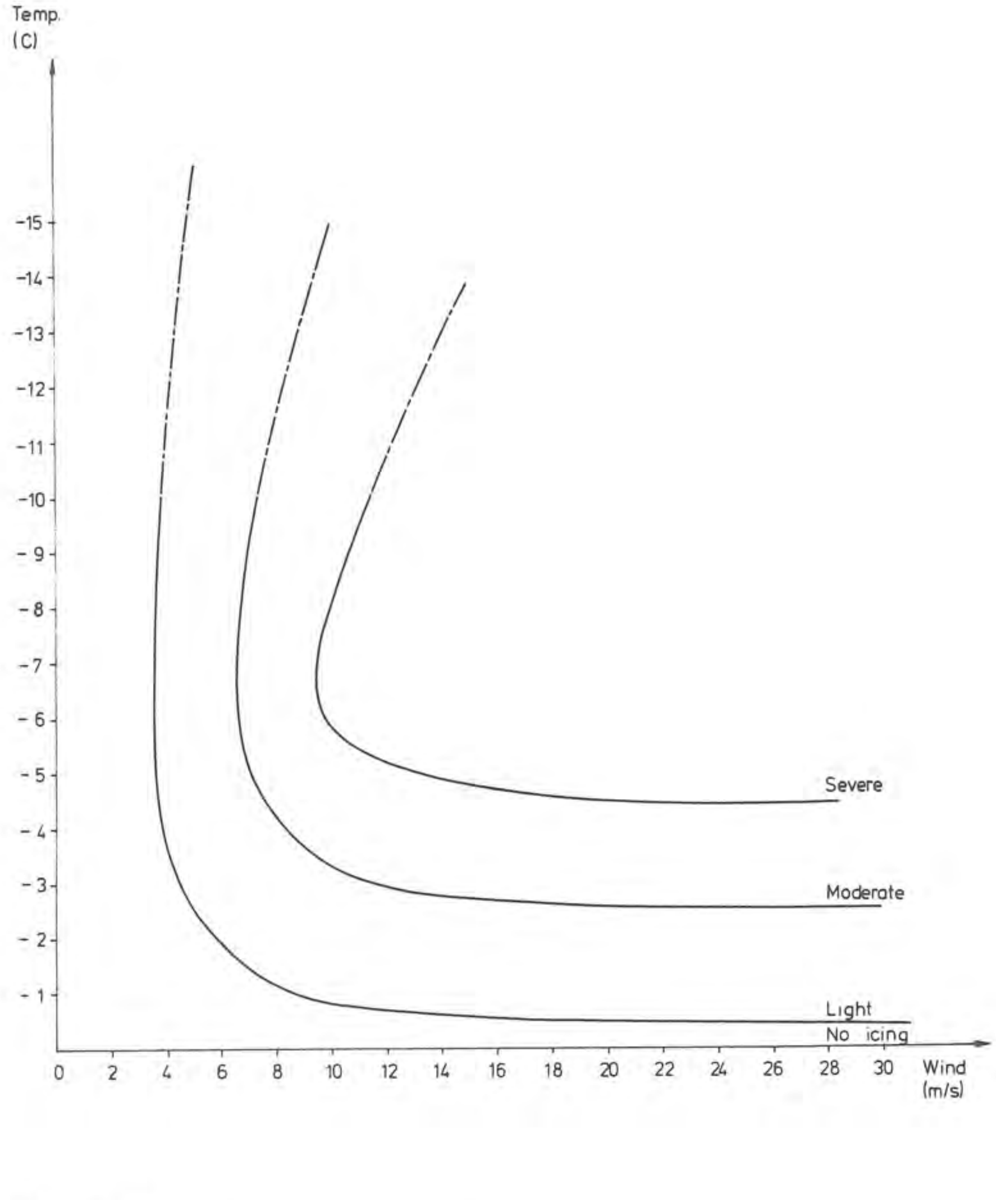

Figure 12.
Relation between icing on ships, air temperature and wind speed.

The speed and course of the ship are of importance for the degree of icing which also has been shown above. The data show for instance two cases of no icing at a wind speed at 22 m/s and critical temperature running with wind from behind. Also some cases with light icing have occurred at winds down to 4 m/s, when the ship has run against the wind with rather high speed. At one occasion two ships have met, one going southward with no icing and the other going northward with moderate icing.

No icing reports have been received for air temperatures below -10.0°C and the curves are consequently a bit uncertain in that region. However, strong winds in connection with air temperatures below -10.0°C are rather rare over open water in the Baltic.

Sawada (1966) has also presented a diagram showing the degree of icing related to air temperature and wind. The diagram is based on data from Japanese patrol and fishing boats. The diagrams (fig 13) show up differences. From our data all forms of icing occur at lower winds and air temperatures. The most extreme difference is seen for -6°C and 10 m/s, where our diagram shows severe icing while Sawada's shows light icing.

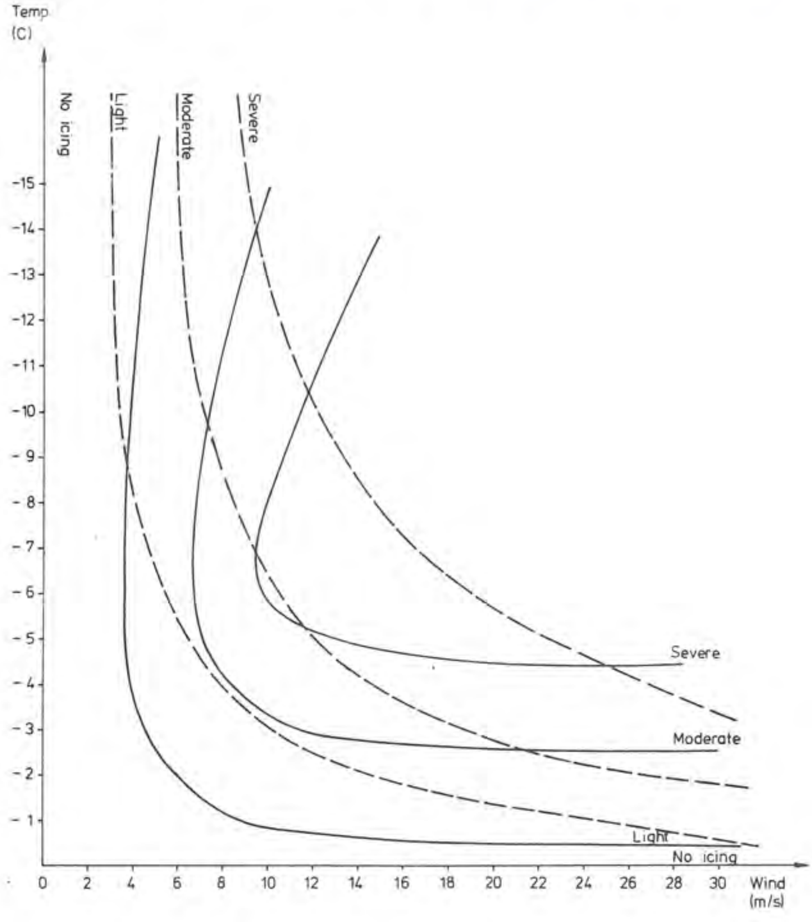

Figure 13.
Relation between icing on ships, air temperature and wind speed. A comparison between Baltic (solid curves) and ocean conditions (dashed curves, after Sawada).

In the outer parts of the diagram Sawada has a larger degree of icing. One reason for the icing at low air temperatures in our diagram may be, that the lower salinity in the Baltic compared to the oceans, gives a freezing temperature for the water very close to $-0^{\circ}C$. Some differences may also depend on different definitions of the degree of icing, which is not mentioned by Sawada in his paper from 1966.

Theoretical studies of the ice accretion and degree of icing have been carried out by Borisenkov, Panov and Moltjanov (1971). They presented an equation for the icing rate.

$$\frac{m_i}{\Delta t} = \alpha \cdot \frac{T_i - T_w + 2.6 \cdot \frac{L_e}{p} \cdot (E_{Ta} - E_{Ti})}{L_i + C_i (T_a - T_i) + C_v (T_i - T_w)}$$

where

$\frac{m_i}{\Delta t}$ = mass (m_i) of water freezing on a unit area during the time interval t.

α = heat exchange coefficient, highly dependent on the form of the accreted surface and wind speed

L_i = latent heat of ice formation

L_e = latent heat of evaporation

C_v, C_i = specific heat of water and ice respectively

T_a = air temperature

T_w = temperature of the water particles

T_i = temperature of the ice formed

p = standard atmospheric pressure at sea surface

E_{Ta}, E_{Ti} = saturated vapour pressure for T_a and T_i respectively

They also gave some examples of the icing rate determined from the equation with different input data. Fig 14 a and b show results with salinities corresponding to that in the northernmost ($0^{\circ}/oo$) respectively in the southern Baltic ($15^{\circ}/oo$) The data used is seen in the figure. The shape of the curves are very similar to those in fig 12.

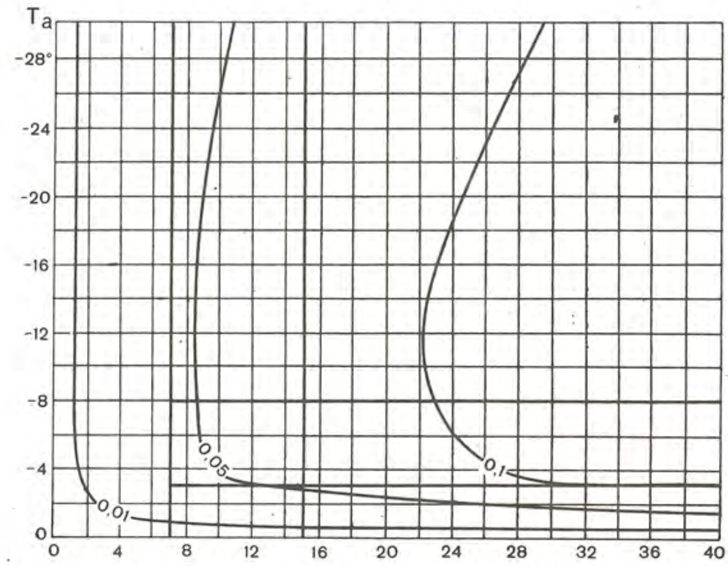

Figure 14a.
The amount of icing (g/h), which may form on a 1cm^2 level surface. $T_a - T_w = 1^\circ C$; $T_a = T_i$; L_i = 80.6 - 94.7 cal/g; L_e = 677; C_i = 0.50 - 0.46; C_v = 1.007; salinity = 0°/oo

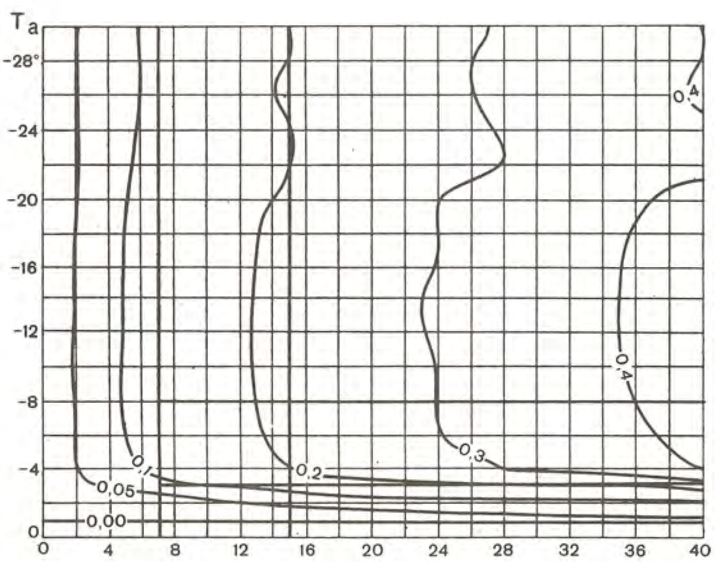

Figure 14b.
The amount of icing (g/h), which may form on a 1cm^2 level surface. $T_a - T_w = 2^\circ C$; $T_a = T_i$; L_e = 646 - 700;
C_i = 0.7 - 18.0; C_v = 0.98; salinity = 15°/oo

From different computations made they draw the following conclusions.

- the icing rates increases with increasing salinity. For example with comparable meteorological conditions the degree of icing should be smaller on Lake Vänern then on Skagerrak.
- an increase of the sea surface temperature will cause a considerable decrease of the icing rate.
- the icing rate has a maximum at temperature around -12^{o}C and is decreasing for lower temperatures. A probable reason is that some of the droplets will freeze before hitting the ship.

The Russians studied the amount of icing formed on a level surface, but they called attention to the fact that the icing amount is considerably larger on cylinder formed surfaces with diameters less than 0.5 m.

Dependence on sea surface temperature

Also from the reports collected from the Baltic it is seen that the sea surface temperature (SST) affects the icing. The rate of icing has not been studied but the distribution of the various degrees of icing versus SST is seen in fig 15. The diagram shows that severe icing mainly occurs for SST lower than 2°C and moderate icing mainly for SST lower than 4°C. No cases with icing have been reported for SST larger than 6°C.

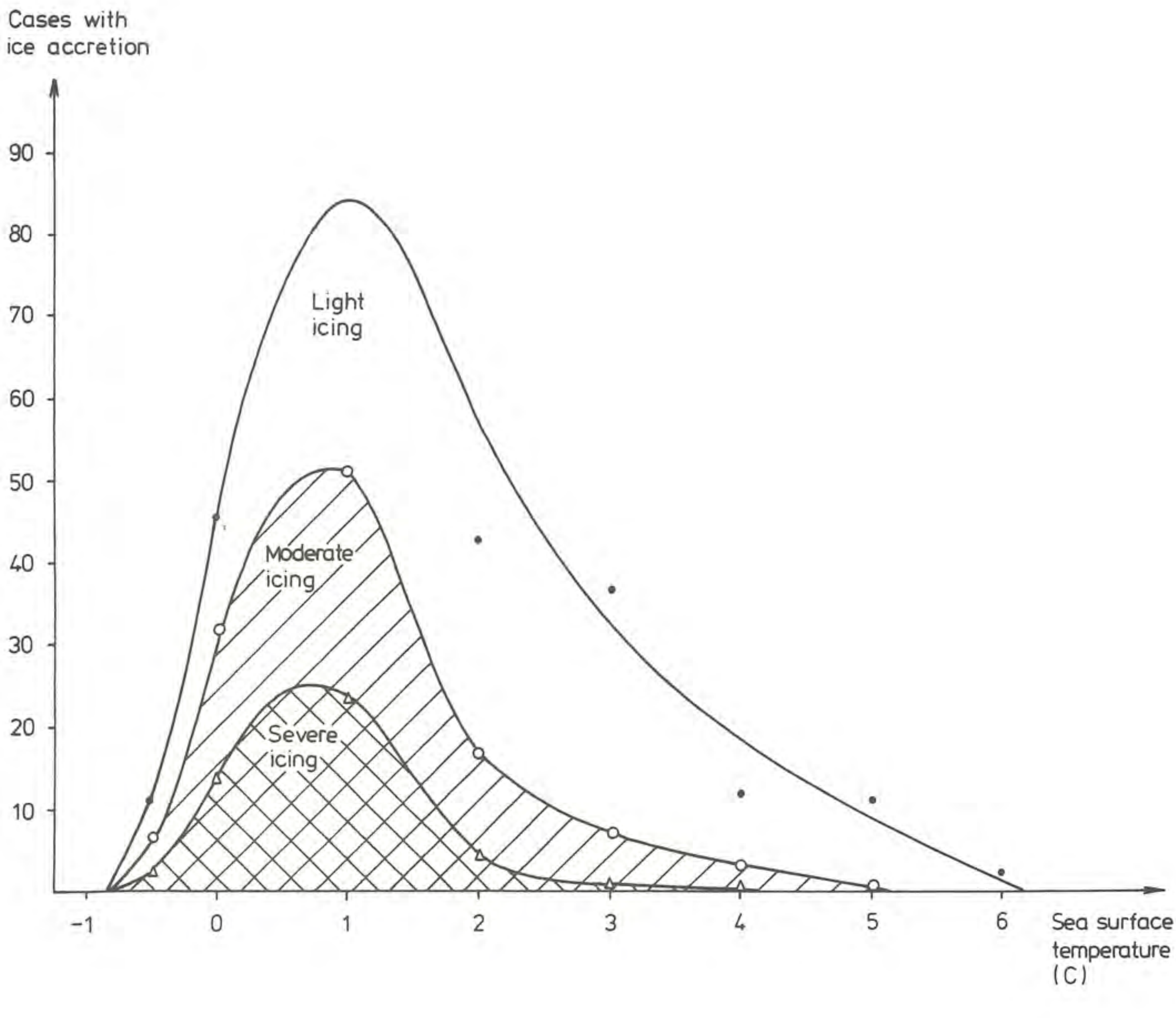

Figure 15.
Relation between SST and cases with ice accretion.

Mertins (1967) has presented icing diagrams on the relation between air temperature, wind and icing rate. He has taken the SST into account (fig 16). The diagrams seen however to underestimate the degree of icing when compared to our diagram (fig 12).

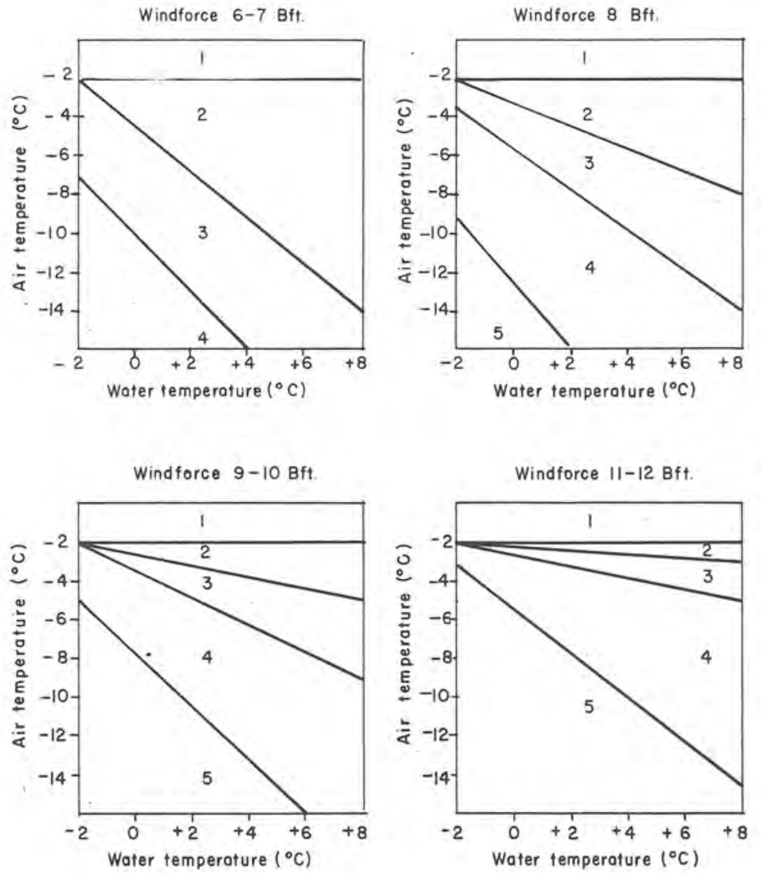

Fig. 3. Diagrams for estimating ice accretion on ships with low speed, as a function of the wind force and air and water temperatures.

Grade of icing –
1 – No
2 – Low 1–3 cm/24 h
3 – Moderate 4–6 cm/24 h
4 – Heavy 7–14 cm/24h
5 – Very heavy 15 cm/24 h

Example –
Forecast:
windforce 9–10 Bft
airtemperature – 8° C
water temperature + 3° C

Expected icing according to diagrams:
heavy icing
7–14 cm/24 h

Figure 16.
Relation between icing on ships, SST, air temperature and wind force. (After Mertin).

6. FORECASTING OF ICE ACCRETION

The results above can be used when preparing icing forecasts or warnings. When issuing an icing warning the meteorologist has to consider the weather conditions. Are they favourable for icing, i.e. will the air temperatures be sub-zero, the wind strong enough and the sea surface temperatures in the right interval (fig 14). If they will, he can use the forecasted wind speed, air temperature and the diagram (fig 12) to decide the degree of icing. As mentioned above the amount of ice accretion is dependent on the ship´s course, speed, size etc., a lot of factors not known by the forecaster. The icing warning shall, therefore, be looked upon as an indication of a probable degree of ice accretion for a "standard" ship. The warnings should then be applicated to the individual ships by the captain, taking into account course, speed, size etc.

From fig 12 is seen that icing occurs already for winds at 3-4 m/s, but the data show very few cases. As the winds during wintertime often exceed this speed and as the temperatures often are below zero, warnings would be issued in almost any sea weather report and they would gradually be ignored. To avoid this the lower wind limit may be put to 6 m/s. The few missed ice accretion warnings should not cause too great problems.

Icing warnings are now issued by SMHI and broadcasted together with the sea weather forecast. The warnings are based on the above mentioned diagrams. Ice accretion warnings are not issued for ice covered areas and not for icing caused by fog or precipitation.

7. THE AVOIDANCE OF ICE ACCRETION

Icing due to freezing spray can clearly be entirely avoided only by keeping away from sea areas with critical air temperature and wind speed. This is obviously not always possible and more realistic is to

- seek shelter in the lee of land until the conditions have changed
- reduce the speed of the ship (fig 7 and 8) or to stop entirely
- choose a course exactly against the waves or if possible run with the waves in order to reduce the amount of icing (fig 7 and 9)
- travel towards a more favourable area where the weather is better or the SST higher

In the Baltic the first alternative is sometimes realistic as the sea area is rather small. It might be possible to avoid the extreme waves by navigating near the lee ward shores or in the fairways in the archipelagoes.

The alternatives above may conflict with each other and with other instructions. However, the additional time spent on a longer route or because of reduced speed may be much less than the time spent in the harbour for removal of the accreted ice.

Tabata (1966) has presented some methods to avoid or reduce the effect of ice accretion. Patrol vessels (350-450 dwt) equipped with
a) anti-icing body mats (for use on ship´s hull, 10 mm)
b) anti-icing deck mats
c) rubber-coated canvas
d) anti-icing paints

have been used during the experiments. Tabata concluded that the anti-icing mats were effective in prevention of icing and made ice removal very easy. Also the rubber-coated canvas gave good anti-icing results. However some drawbacks exist. The mats and canvas are difficult to install, are rapidly worn out or born off and the method is consequently rather costly. The anti-icing effect of the paint were uncertain and further studies were required. Methods, with steam under high pressure and cooling water from the machinery, have been tested for ice removal with various results.

Already accepted methods to prevent or remove ice accretion are,

- already at the design of the ship try to minimize cylinder formed equipment e.g. wire rope rigging and open handrails, Bardarson (1969)
- electrical heating of certain vital parts of the ship like radar antennas, radio masts etc.
- tarpaulins covering certain parts of the deck which will make the ice removal easy

- to use a wooden hammer, which is a very cheap and effective method.

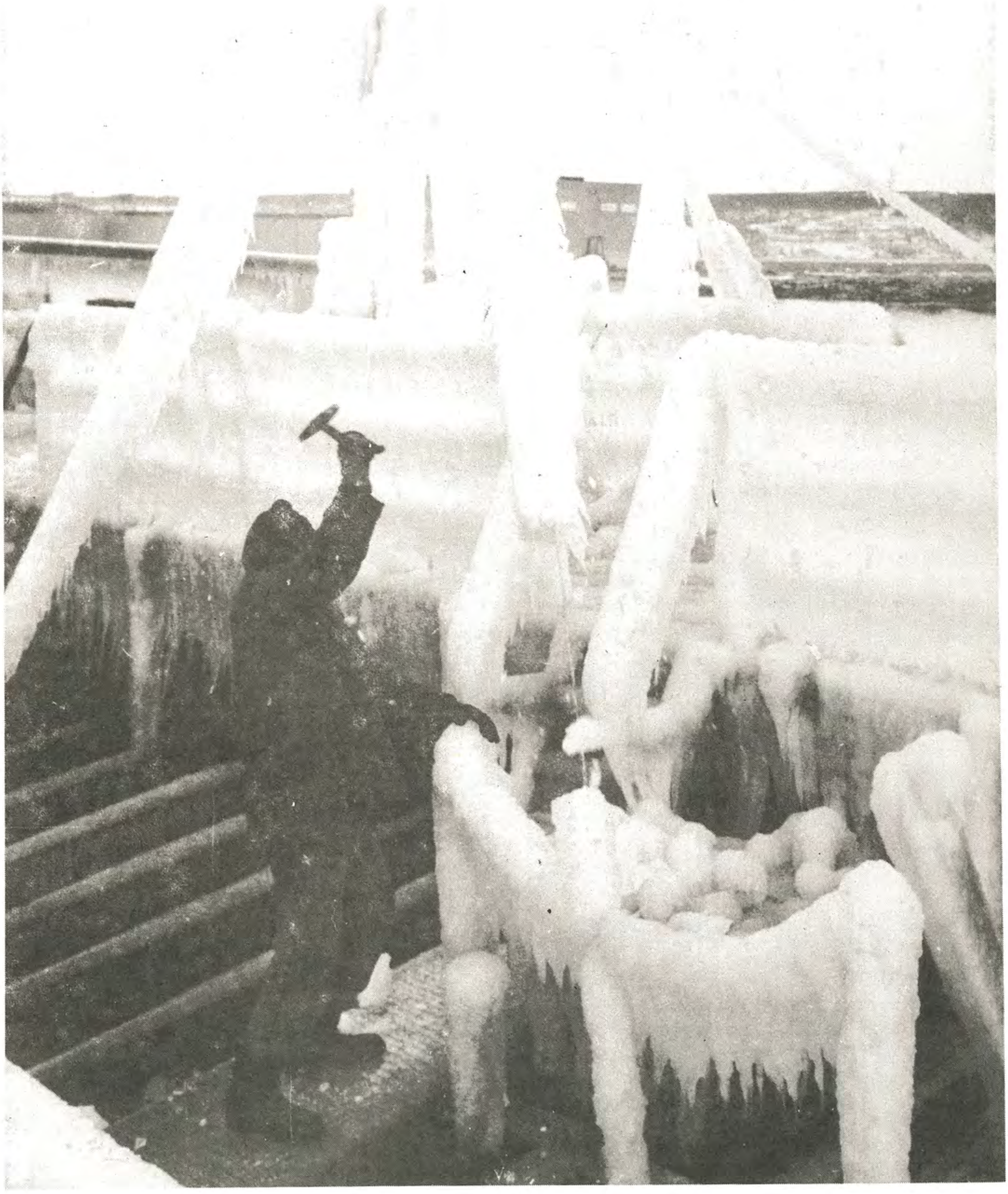

Figure 17.
m/s Alchemist Kiel, 9/12 1971. One very usual method for removal of icing is demonstrated.

evenly distributed. The wind speed is often estimated and not measured, the air temperature has sometimes been estimated from weather maps and the SST has in some cases been estimated from SST maps.

The icing data has been collected from the whole Baltic. In certain areas, which are narrow and rather shallow like Northern and Southern Quark and the entrance to the Sound, icing seems to occur more frequent than elsewhere. Some probable reason may be the more rough sea state in those areas and the limited possibility of changing course.

Icing forecasts based on the diagrams in the report are made and broadcasted during the winter. As mentioned the effect of icing varies from ship to ship. The forecast consequently must be viewed as an indication of a probable risk and serve as an information to the captain when deciding what action to take.

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