

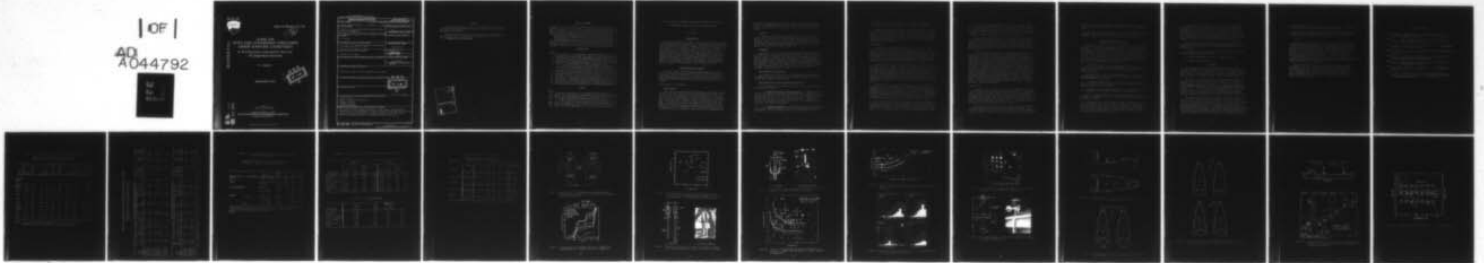
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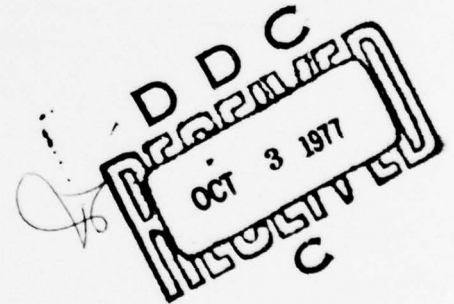
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ICING ON
SHIPS AND STATIONARY STRUCTURES
UNDER MARITIME CONDITIONS
A Preliminary Literature Survey
of Japanese Sources

K. Itagaki

September 1977



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Prepared for
MARATHON OIL COMPANY
By
CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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Preface

This report was prepared by Dr. K. Itagaki, Research Physicist, Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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TABLE OF CONTENTS

Abstract-----	i
Preface-----	ii
Table of contents-----	iii
Introduction-----	1
Reports from Field Studies-----	1
Growth Rate of Ice Thickness-----	1
Questionnaires-----	3
Sea Spray Flux-----	4
Reports from Endangered Ships-----	5
Discussion-----	6
Literature Cited-----	8

ILLUSTRATIONS

Figure	
1. Cross Section of ice accumulated on portside handrail-----	14
2. Percentage of ice accumulation by time-----	14
3. Ice accumulation rate by air temperature and wind scale-----	15
4. Diagram of icing rod, and icing rod installation-----	15
5. Icing gage and icing gage installed-----	16
6. Effect of air temperature and relative windspeed on ice accretion-----	16
7. Effect of angle between waves and ships bearing on sea spray class-----	17
8. Percentage of icing incident by class-----	17
9. Icing incidents by icing indices and wave scale-----	18
10. Sea spray collector-----	18
11. Distribution of sea spray collectors on board ship-----	19
12. Distribution of sea spray flux on forward deck-----	19
13. Distribution of spray flux (kg/m ² /hr) at 30° and 60°-----	20
14. The date and area of icing reported by the Shomei Maru-----	21
15. Theoretically calculated icing rate on a stationary structure--	22

TABLES

Table	
I. Icing rates by position of ice on board ship (Unit ton)-----	9
IIa. Amounts and chlorinities of accumulated ice and brine-----	10
IIb. Results from icing gage, 1963-----	10
IIIa. Ice accumulation measured by weighing method and center of gravity method-----	11
IIIb. Center of gravity and weight measured by weighing method-----	12
IIIc. No. 6 Yahiko-Maru-----	12
IV. Numbers of icings reported-----	13

ICING ON SHIPS AND STATIONARY STRUCTURES UNDER MARITIME CONDITIONS

A PRELIMINARY LITERATURE SURVEY OF JAPANESE SOURCES

by

K. Itagaki

INTRODUCTION

This report contains the results of a literature survey of Japanese sources undertaken as an initial part of the Superstructure Icing Program (SIP) funded by the Marathon Oil Company. Most of the available data were related to ship icing that is primarily caused by sea spray due to the pounding of waves against the ship. This situation is difficult to compare with that of stationary structures such as oil rigs, since a major portion of the sea spray in the latter case would be produced by wind-generated whitecaps, rather than by the pounding of waves against stationary structures. Since fewer parameters are involved in the latter case, theoretical calculations are possible. The results are parallel to those obtained for ship icing, except that the windspeed has to be higher for the stationary structures than for ships.

REPORTS FROM FIELD STUDIES

Extensive studies made through cooperation between the Japanese Maritime Safety Board and the Institute of Low Temperature Science were described by Tabata et al (1963). A major portion of the available field studies was contributed by this group. Since there were some duplications, papers reviewed here will cover the essential parts of the results.

Growth Rate of Ice Thickness

Paper markers

Paper markers were frozen onto the growing ice, using small amounts of water, at 4-hour intervals at several locations on board ship. The cross sections of accumulated ice are shown in Figure 1. The growth rate relative to final thickness, together with the bearing of the ship and the wind direction, is shown in Figure 2. Apparently, the relative angle of the ship to the wind has a strong effect on the icing rate. Table I indicates icing rates by position of ice on board ship. Note that up to 2 ton/hr of icing occurred under rather moderate conditions (air temp ~ -6 to -8°C , windspeed ~ 11 m/s) on a 316-gross-ton vessel. As shown in Figure 3, the Beaufort wind scale and air temperature show

no particular relationship, except that no icing occurred below wind scale 3. Presumably, small ice accumulations in higher winds were lost by being washed from sea water which is warmer than freezing temperatures.

Icing rod

Two aluminum rods were placed on the front face of the ship's bridge. Rod A had an electrical transmitter to measure its weight and was kept in place during the testing. Rod B was replaced with a clean rod every four hours and its weight was measured each time. Figures 4a and 4b show a schematic diagram and photograph of the icing rods. The results of these tests are shown in Table II.

Icing gage

Since brine in the ice may be drained and lost from the icing rod, the total amount of sea spray captured by the object cannot be measured by the icing rod. Therefore, an icing gage was devised, as shown in Figures 5a and 5b, to measure the total amount of the spray captured on the rod (Tabata, 1963). Two sets of icing gages were exchanged every four hours and the amounts and chlorinities of accumulated ice and brine were measured. The results are shown in Table II. The chlorinity shown in column 9 was generally close to that of sea water, indicating that sea spray is the major source of icing.

The structure of accreted ice

The structure of accreted ice was studied by making thin sections from samples collected. The sizes of the crystals were about 0.5 mm and no preferred orientations were found.

Total amount and center of gravity of accreted ice

The total amount and the center of gravity of ice accumulation were measured by two methods.

1) Method by change in center of gravity: The weight and the center of gravity of the ice can be calculated from the measurements of the center of gravity of the ship before and after the removal of accreted ice and change in the draft. The height of the center of gravity of accreted ice can also be calculated by the change in the period of rolling. The results are shown in Table III(a). This method requires a quiet port for accurate measurements.

2) Method by Weighing: Weighing individual pieces of accreted ice is a more reliable method, although the time and labor required are considerable. Also, this method enables the contributions of ice

accretion in each part of the ship to be assessed. As shown in Table IIIb and IIIc, ice accreted on the upper deck and handrail/bulwark constituted 65% of the total amount of ice accreted on ship.

Using these data, a maximum allowable accretion rate of $5 \text{ kg/m}^2\text{-hr}$ was estimated, which would accumulate up to 50 kg/m^2 of ice during 10 hours of voyage required to reach a safe port. The effects of this amount of icing on ship stability were examined on the Maritime Safety Agency cutters operating in the northern Pacific Ocean, quite possibly exposed to icing conditions. A few of these cutters were found to be unsafe for offshore operation.

Questionnaires

Tabata (1969), who investigated the ship icing and the meteorological conditions on The Maritime Safety Agency cutters, requested the operators of the cutters to fill out questionnaires whenever they operated under possible icing conditions. The items on each questionnaire included the name of cutter, position, speed of cutter, bearings, relative wind direction and speed, air and water temperatures, wave and swell class and their relative directions, estimated ice accretion, weather conditions, and time of initiation and termination of icing.

In addition, sea spray and icing were classified in three steps and included in the questionnaire. These classifications for spray classes 0, 1, and 2 were: no spray, moderate spray, and heavy spray, respectively, reaching to the bridge window. Icing classes 0, 1 and 2 were, similarly, no icing, moderate icing, and heavy ice accretions, respectively. A total of 256 questionnaires were collected the winters of 1963-1967 and covered 12 cutters of between the 270-ton and 1100-ton class. Data analysis was concentrated on the 350-ton class and 450-ton class cutters, since data from other sizes of cutters were insufficient for statistical analysis.

As shown in Figure 6, air temperature and relative windspeed have a definite effect on ice accretion. The following can be deduced from this figure: 1) icing started below -2°C , 2) icing started when relative windspeed exceeded $6 \sim 8 \text{ m/sec}$, and 3) a slight increase in windspeed or decrease in temperature accelerated ice accretion. The angle between waves and ship's bearing is also an important factor for ice accretion, as shown in Figure 7. The smaller the angle, the smaller the ship, or the higher the Beaufort wave class, the more sea spray is observed.

Ono (1974) did some statistical analysis of the ship icing conditions reported by fishing boats and cutters. Icing reports radioed in by ships were documented on the questionnaire forms at the coast radio stations for fisheries. Items recorded were: date, position of ship, name of the ship, tonnage, ship's construction (wooden or steel), type

of vessel, method of fishing, weather, wind direction, windspeed (wind class), relative windspeed and direction to the ship, bearing, speed of ship, air temperature, water temperature, and icing class. The icing class was slightly modified from the previous study as: 0) icing was expected, 1) slight icing was observed, 2) considerable icing was observed, 3) icing was so heavy that deicing was necessary.

During the three seasons between 1970 and 1973, 1358 reports were collected from 154 fishing boats. Icing classes by the year and the month are shown in Table IV. Heavier than moderate icing incidents were reported in about one third of the reports. Pronounced relationships were found to exist between the icing class and the windspeed, wind directions, air temperature and Beaufort wave scale, as shown in Figures 8a, b, c, and d.

Icing is, however, the function of these combined factors. The amount of water that can be frozen is controlled mainly by the sea spray, which is a function of the windspeed, wave class and bearing and speed of the ship. The freezing process of the supplied water is governed by the heat removal, major factors of which are the air temperature, and the windspeed. Since any increase in the wave class, air temperature, or windspeed will accelerate the ice accretion, the product of those factors (the icing index) would be a useful indicator of the icings. The various values of the indices are shown in Figure 9 by a series of dash lines. The cooling factor, i.e. (air temperature) x (relative windspeed) vs wave class, yields these values of the icing index. The reports of icing incidents are also shown in the same graph. The number of the reports are proportional to the size of the circle, and the percentages of icing class reported are shown by the shaded angles. More than 50% of the heavy icing is reported in the regions where the icing is higher than 500, and 100% heavy icing is reported when the icing index exceeds 800.

Sea Spray Flux

Generation of the sea spray is not a simple phenomenon, especially where pounding of waves by the ship's hull is involved. A simple sea spray collector was devised (Tabata 1969) to measure the distribution of sea spray under various conditions. The sea spray was captured by a water-absorbing cylinder (made of toilet tissue), as shown in Figure 10, and the amount was determined by weight after 5 to 6 minutes of exposure. New absorbers were replaced each time. The sea spray collectors were mounted on the upper deck, as shown in Figure 11.

The distribution of the sea spray flux captured by the collectors is shown in Figures 12 and 13 by the relationship of the wave to the ship's bearings. The conditions of their observations were: windspeed 5-9 m/sec, Beaufort wave scale 2-3, wave height 0.6-1 m, and wave length

about 10 m. Although the conditions were quite moderate, considerable differences in sea spray flux by the relative angle and speed can be noted.

Using the classification in questionnaires noted previously, icing conditions under these circumstances were class 0 (not observable), or possibly 1 (moderate), if the air temperature was below -2°C .

REPORTS FROM ENDANGERED SHIPS

According to Sawada (1973), icing can endanger even the 10,000-ton-class ships. The vessel, Shomei Maru (9,390 tons), left Gray's Harbor, Washington, in January 1967, loaded with timber. It encountered heavy icing conditions in the area, as shown in Figure 14. Extremely hard ice had built up to an average of 20 cm (8 in.) in thickness on the fore-castle deck in about 60 hours. The maximum thickness exceeded 50 cm (20 in.). The front window of the ship was covered by 40 cm (16 in.) of ice. The ship listed about 10° to the right (starboard), leaving only a few degrees of safety margin before capsizing could occur. The total weight of ice was estimated to be 200 tons.

In another incident, the vessel Jujo Maru (17,290 tons) reported up to 100 tons of icing in the northern Pacific Ocean. More than 12 hours of ice-removal operations by 60 hands were required before unloading could begin.

From the analysis of the icing data obtained by the observation ship Keifu Maru, at a fixed point 44°N , 140°E , Sawada (1973) derived the following conditions for icing:

1. When water temperature is $3.3 \sim 5.6^{\circ}\text{C}$ and the ship is traveling, icing starts with air temperature below -3°C , windspeed at 8 m/s, and wave height at 1.5 m (Beaufort 5).
2. Severe icing (2 cm/hr) occurs when air temperature drops to -6°C , windspeed is 10 m/s, and wave height is 2 m (Beaufort 6).

However, Sawada observed little ice accumulation when the ship was drifting. Icing may start at higher air temperatures when the water temperature is lower.

As a measure of the icing forecast, Sawada proposed to use an 850-mb isothermal line. Since an 850-mb isothermal line suffers little local variation and preserves its thermal character, it is suitable as a base for the icing forecast. Sawada concluded that icing starts at sea level when the isothermal line at 850 mb is dropped to -15°C and severe icing may occur below -18°C .

As shown above, low air temperatures and the sea spray are the major factors of icing. Although the sea spray is the function of the wind, a moving ship produces more sea spray because of the waves pounding against the bow. The heights of the waves may be a more important factor for the ship's icing. For stationary structures such as an offshore oil rig, most sea spray is supplied by white caps and breaking waves, thus requiring higher windspeeds. Probably a wind strength of Beaufort 8-9 would be required for considerable icing.

Air temperature, on the other hand, may be higher than that required to cause icing on the moving ship, since wind-generated sea spray drops have a longer time to cool down before striking the surface of the structure.

Considering these factors, forecasts of oil rig icing may be made when the following conditions are met:

- 1) 850-mb temperature at the site is lower than -14°C .
- 2) Winds exceed Beaufort 8 - 9.

DISCUSSION

All the data described here were obtained from moving ships. As described elsewhere, sea spray produced by waves pounding on the moving ship's hull was the major source of the icing in the moderate (Beaufort 5-6) condition. It is quite probable that a little rougher sea condition would be required to produce a similar effect on the stationary objects.

The rate of the ice accumulation is highly dependent on the size and the structure of the ship. The smaller the ship or the lower the freeboard, the more the ice accumulates. For instance, a 320-ton cutter (Yubari) accumulated 13.4 tons of ice, or 4.2% of displacement tonnage, while a 74-ton fishing boat (No. 6, Yahiko-Maru) accumulated 4.8 tons of ice, or 7.8% of displacement tonnage, under identical conditions (Table III(b) and (c)). It is interesting to note that the contribution of ice accumulation on the upper deck and the bulwark/handrail accounted for about 65% of the total accumulation in both cases.

The problem of icing rates on stationary structures such as oil rigs and that of icing rates on ships may not be similar because the icings are generated by different processes. The supply of water forming the icing on stationary structures is generated by sea spray from white-caps, whereas that forming the icing on ships is generated by the pounding of waves by the ships. A theoretical approach to icing rate was possible for the stationary structure; the general aspect was parallel to that for ships, except that windspeed had to be higher for the stationary structure. A brief description of this approach will clarify

the major problem area and help to direct future studies. The details will be discussed in a paper in preparation by Itagaki.

The rate of ice accumulation \bar{R} is controlled by three major factors: the mass flux \bar{F} , the capture coefficient \bar{C} , and the proportions of frozen spray droplets captured on the surface \bar{P} , as

$$\bar{R} = \bar{F} \bar{C} \bar{P}. \quad (1)$$

The mass flux \bar{F} at the height of concern would be controlled by the generation of spray by whitecaps, in the present case, and the transport of spray by the eddy diffusion process. Some limited data for the flux are available (Lai and Shemdin 1974, Monahan 1968, and Toba 1961). The capture coefficient \bar{C} is close to unity for the larger droplets such as sea spray. \bar{P} , the proportion of icing to the captured drops, can be derived from Tables IIa and b (Ono 1964). \bar{P} is strongly influenced by air temperature and linearly increases to 100% at around -13°C . This calculated result, shown in Figure 15, agrees with the on-board observations shown in Figures 3 and 6, except that wind level is much higher than indicated by the on-board observations.

The application of this theory is limited by insufficient data, especially for the mass flux \bar{F} at the higher levels, since all the measurements were made close to the sea surface. Measurements of \bar{P} at a more diverse temperature range are also required. With more improved information, we should be able to predict the icing rate, which should be checked again by observations made under a wide range of weather and wave conditions.

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Table I. Icing rates by position of ice on board ship (Unit ton)

[Translated from Tabata et al. (1963, Table 5)]
 (Copyright, T. Tabata; reprinted by permission)

Date of Icing	Location of icing							Total ice accretion	Dura- tion (hr)	Ice accretion per hr
	Fore- castle	Flag- pole and gun	Upper deck Bridge Equip.	Bul- wark star- board	Bul- wark port- side	Other parts				
15 Jan. 1600 hr	0	0	0	0	0	0	0	0		
2000	0.01	0.005	0	0	0	0.009	0.005	0.03	4	0.01
16 Jan. 0000	0.18	0.07	0	0.25	0.003	0.12	0.13	1.75	4	0.18
0400	1.87	0.74	1.00	0.66	0.54	0.63	1.14	6.58	4	1.46
0800	2.47	0.97	1.16	0.66	0.61	1.00	1.44	8.31	3	0.58
1200	2.47	0.97	1.16	0.66	0.61	1.00	1.44	8.31	0	0
1600	2.77	1.09	1.29	0.80	0.61	1.19	1.59	9.33	2	0.51
2000	3.55	1.40	1.68	0.89	0.67	1.64	2.06	11.88	2.17	1.18
17 Jan. 0000	3.55	1.40	1.68	0.89	0.67	1.64	2.06	11.88	0	0
0400	4.94	1.95	1.92	1.10	1.22	1.98	2.75	15.86	2	1.99
0800	6.03	2.36	2.11	2.13	1.59	2.30	3.47	19.99	3.17	1.31

Note: Ice accretion was observed between 1345, 15 January - 0700, 16 January; 1400-1810, 16 January; and 0200-0710, 17 January.

TABLE IIa. Amounts and chlorinities of accumulated ice and Brine

[Translated from Ono (1964, Tables 1 and 2)]
 (Copyright, N. Ono; reprinted by permission)

Table IIa. Results from icing gage, 1962

Date and time	Ice		Brine		Accumulation per hour			Chlorinity in sea spray (0/00)	Cross section accum ice (%)	Mean air temp (°C)	Mean water temp (°C)	Mean rel wind speed (m/s)
	Weight (g)	Chlorinity (0/00)	Weight (g)	Chlorinity (0/00)	Amt of ice (g/hr)	Amt of brine (g/hr)	Amt sea spray (g/hr)					
15 Jan.												
1375-1600	35	-	10	-	15.6	4.4	20.0	-	78	- 5.8	+ 2.0	9.0
1600-2000	90	15.1	20	32.0	22.5	5.0	27.5	18.2	82	- 6.6	+ 1.4	11.6
2000-0000	105	13.2	(890)	(19.6)	26.3	(222.5)	(248.8)	(19.0)	11	- 6.6	+ 0.1	15.6
16 Jan.												
0000-0400	304	14.5	190	29.0	85.0	47.5	132.5	19.7	64	- 9.8	- 0.9	15.5
0400-0700	5	-	0	-	1.7	0	1.7	-	100	-12.6	- 1.3	13.1
1400-1600	30	16.7	0	-	15.0	0	15.0	-	100	-11.4	- 0.8	10.3
1600-1817	95	16.0	10	36.4	43.8	4.6	48.4	18.0	90	-12.7	- 1.0	11.3
17 Jan												
0200-0400	390	-	270	-	195.0	135.0	330.0	-	59	- 7.2	+ 0.5	15.4
0400-0717	335	(10.4)	410	26.0	105.7	129.3	235.0	(19.0)	45	- 6.9	+ 1.5	12.2

Table IIb. Results from icing gage, 1963

Date and time	Ice		Brine		Accumulation per hour			Chlorinity in sea spray (0/00)	Cross section accum ice (%)	Mean air temp (°C)	Mean water temp (°C)	Mean rel wind speed (m/s)
	Weight (g)	Chlorinity (0/00)	Weight (g)	Chlorinity (0/00)	Amt of ice (g/hr)	Amt of brine (g/hr)	Amt sea spray (g/hr)					
9 Jan												
1540-2200	49.4	11.5	(773)	19.6	7.5	(117.1)	(124.6)	(19.1)	6	- 1.0	+ 1.5	10.5
2200-0000	52.4	6.3	212.2	22.1	26.2	106.1	132.3	19.1	20	- 2.0	- 0.4	9.7
10 Jan.												
0000-0400	72.3	5.9	(329)	22.0	18.1	(82.2)	(100.3)	(19.1)	18	- 2.0	- 0.1	10.2
0400-1200	439.0	8.7	(977)	24.0	54.9	(122.1)	(177.0)	(19.1)	31	- 3.5	+ 2.4	12.0
1200-1600	356.4	8.9	(634)	25.1	89.1	(158.5)	(247.6)	(19.1)	36	- 5.7	+ 1.0	15.5

Note: Parentheses indicate calculated values assuming chlorinity of respective value of sea spray.

TABLE IIIa. Ice accumulation measured by weighing method and center of gravity method

[Translated from Tabata et al. (1963), Table 3a, b, c]
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Name of ship	Conditions	Methods of calculations	Weight of ice (ton)	G (m)	KG' (m)	KG/D*
<u>Sorachi</u>		Center of gravity	25.22	10.41	4.59	1.12
<u>Yubari</u>		Center of gravity	12.82	16.04	5.41	1.32
		Weighing	13.39	13.07	5.09	1.24
<u>No. 6 Yahiko-Maru</u>		Weighing	5.84	2.99	3.41	1.37
		USSR stds (A) [†]	4.73		3.49	1.40
		(B)	2.87		3.49	1.40
<u>Chitose</u>		Weighing	19.99	7.52	5.12	1.25
	1/3 empty	(A)	12.57		4.48	1.07
		USSR stds (B)	6.29		4.48	1.07
		(A)	12.76		4.44	1.06
	Empty	USSR stds (B)	6.38		4.44	1.06

[†]USSR Standard A applies north of 66°30'N or south of 60°S; standard B applies to winter conditions of other areas.

*D=Draft

TABLE IIIb. Center of gravity and weight measured by weighing method

Position of iced surface	<u>Yubari</u>				<u>Chitose</u>			
	Weight of ice (ton)	% to total weight of ice	Center gravity of ice above base line, (m)	KG'/D	Weight of ice (ton)	% to total weight of ice	Center Gravity of ice above base line (m)	KG'/D
Upper deck	5.238	39.1	4.71	1.15	8.788	44.0	4.60	1.12
Bulwark/hand rail	4.279	32.0	5.33	1.30	3.919	19.0	5.34	1.30
Bridge	0.385	2.9	5.66	1.38	2.109	10.5	6.67	1.63
Engine room casing	-	-	-	-	0.036	0.2	4.56	1.11
Boat and davits	0.137	1.0	6.50	1.59	0.643	3.2	5.26	1.28
Machine gun	1.666	12.4	5.51	1.34	2.187	10.9	5.31	1.30
Bow flagpole	0.056	0.4	6.96	1.70	0.176	0.9	7.00	1.71
Upper deck equip	1.627	12.2	4.88	1.19	2.132	10.7	4.98	1.21
Total	13.388	100.0	5.09	1.24	19.990	100.0	5.12	1.25

TABLE IIIc. No. 6 Yahiko-Maru

Position of ice surface	Weight of ice (ton)	% to total weight of ice	Center of gravity of ice above base line(m)	KG'/D
Upper deck	1.739	29.7	2.88	1.16
Deck house	0.460	7.9	4.12	1.65
Outside of bulwark	2.058	35.2	3.54	1.42
Inside of bulwark	0.320	5.5	3.29	1.32
Top of bulwark	0.573	9.8	4.00	1.61
Hatch	0.556	9.5	3.12	1.25
Mast and boom	0.138	2.4	4.65	1.87
Total	5.844	100.0	3.41	1.37

TABLE IV. Numbers of icings reported

[Translated from Ono (1974, Table 1)]
 (Copyright, N. Ono; reprinted by permission)

		Nov	Dec	Jan	Feb	Mar	Sum	(%)
1970-1971	ICING 1	14	52	57	72	32	227	69.6
	2	1	28	14	25	6	74	22.7
	3	0	10	0	13	2	25	7.7
	SUM	15	90	71	110	40	326	
1971-1972	ICING 1	13	92	101	111	41	358	69.2
	2	3	43	32	25	12	115	22.3
	3	1	16	19	6	2	44	8.5
	SUM	17	151	152	142	55	517	
1972-1973	ICING 1	-	48	87	134	74	343	68.0
	2	-	11	17	82	18	128	25.3
	3	-	5	6	20	3	34	6.7
	SUM	-	64	110	236	95	505	

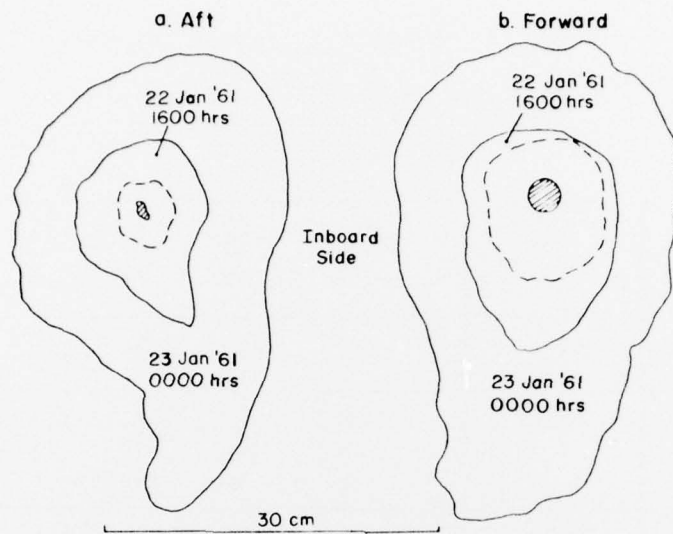


Figure 1. Cross sections of ice accumulated on portside handrail (hatched area). (Tabata et al. 1963) (Copyright, T. Tabata; reprinted by permission.)

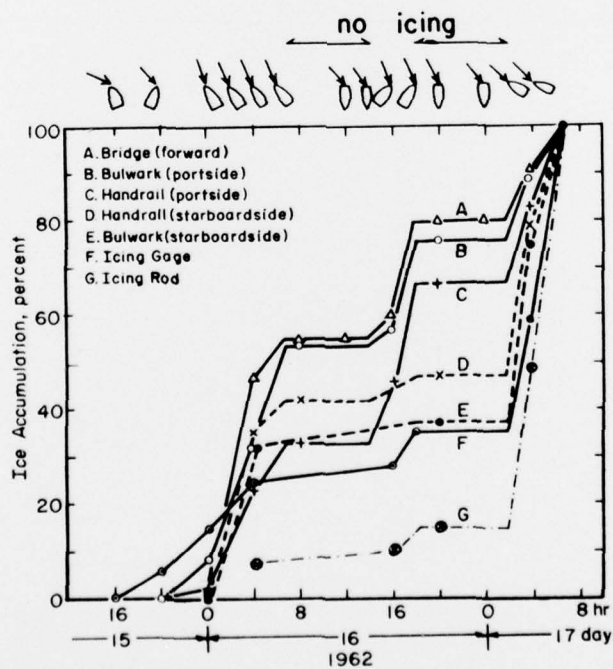


Figure 2. Percentage of ice accumulation by time. (Tabata et al. 1963) (Copyright, T. Tabata; reprinted by permission.)

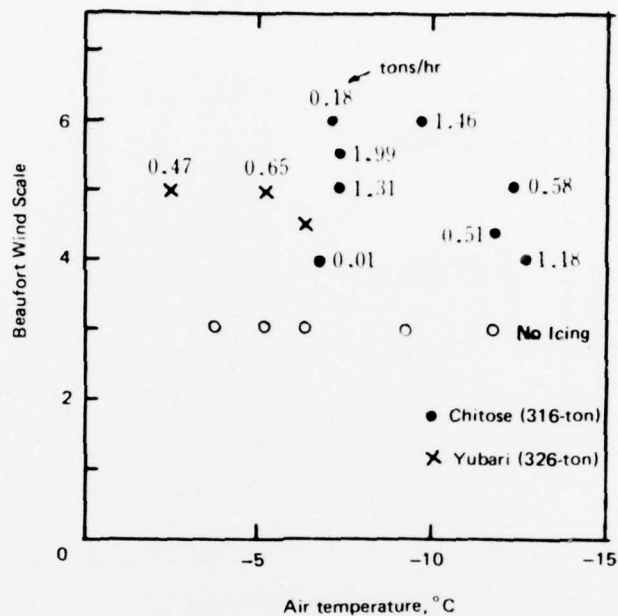
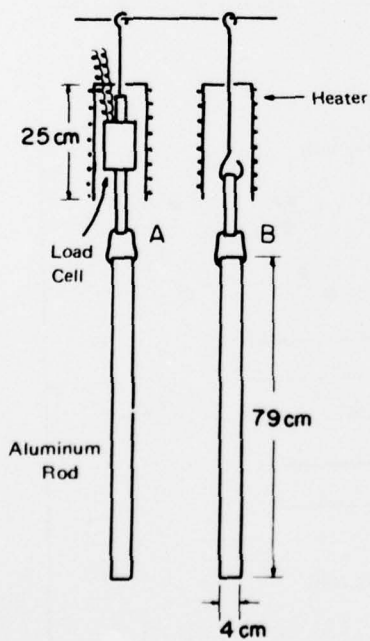


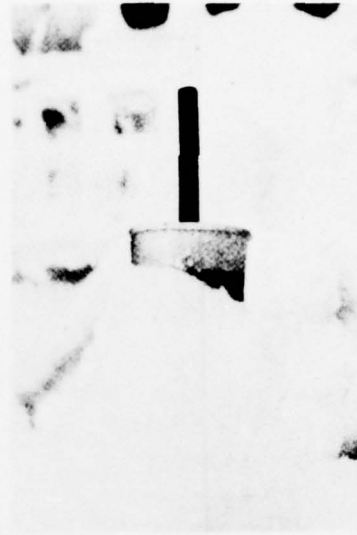
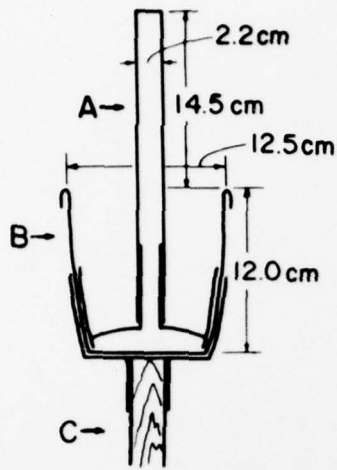
Figure 3. Ice accumulation rate by air temperature and wind scale. Observed on board cutters Chitose and Yubari. (Tabata et al. 1963) (Copyright, T. Tabata; reprinted by permission).



a. Icing rod

b. Icing rod installed

Figure 4. Diagram of icing rod, and icing rod installation. (Tabata et al. 1963) (Copyright, T. Tabata; reprinted by permission.)



a. Icing gage

b. Icing gage installed

Figure 5. Icing gage and icing gage installed. (Tabata et al. 1963) (Copyright, T. Tabata; reprinted by permission).

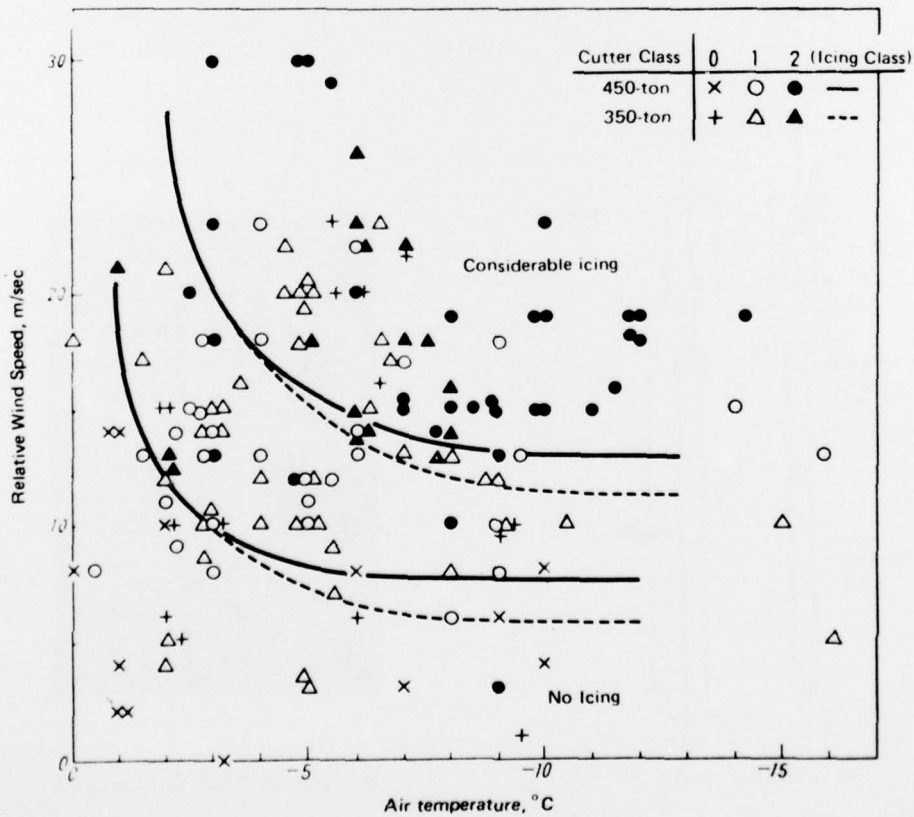


Figure 6. Effect of air temperature and relative windspeed on ice accretion. (Tabata, 1969) (Copyright T. Tabata; reprinted by permission).

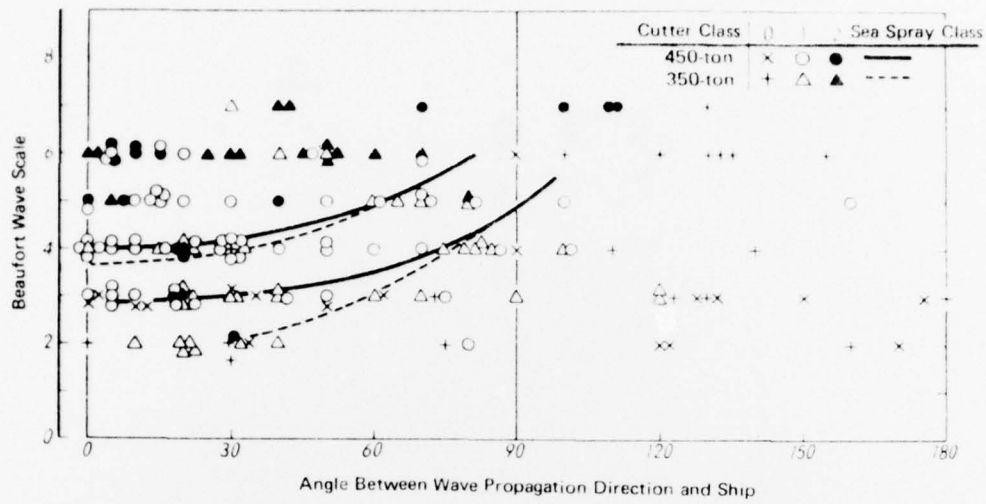


Figure 7. Effect of angle between waves and ships bearing on sea spray class. (Tabata 1969) (Copyright, T. Tabata; reprinted by permission.)

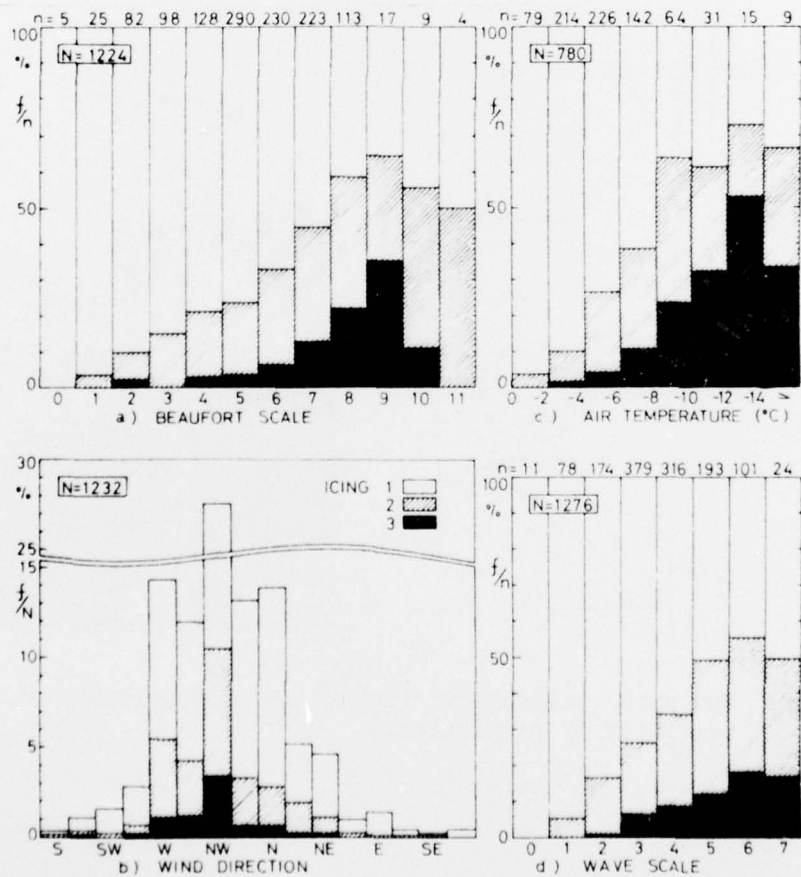


Figure 8. Percentage of icing incident by class. (Ono, 1974) (Copyright N. Ono; reprinted by permission).

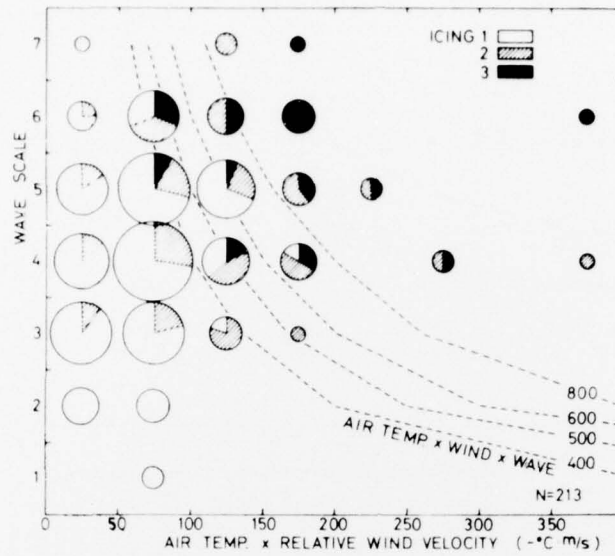


Figure 9. Icing incidents by icing indices and wave scale. (Ono, 1974)
 (Copyright, N. Ono; reprinted by permission).

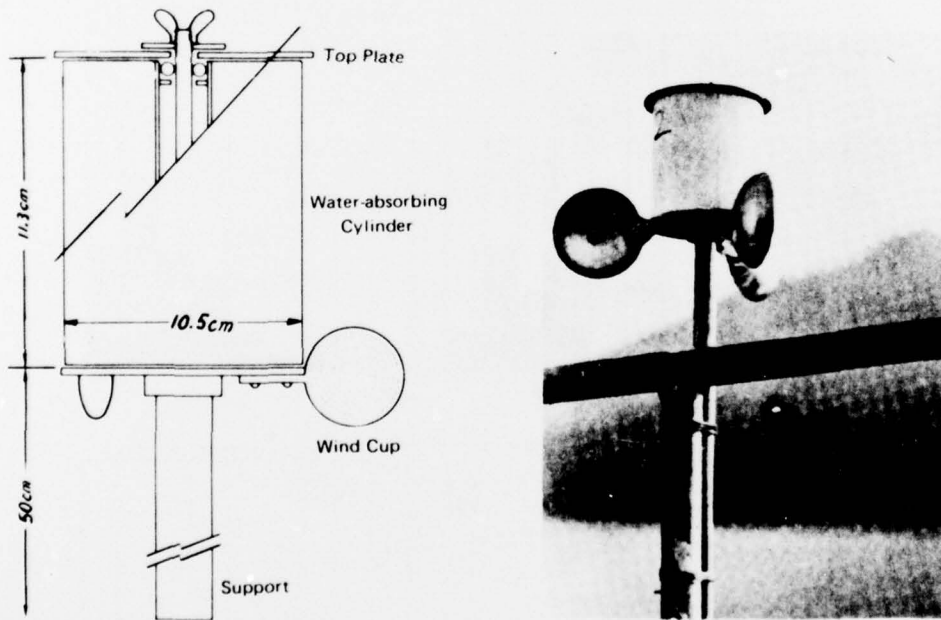


Figure 10. Sea spray collector. (Tabata 1969) (Copyright, T. Tabata;
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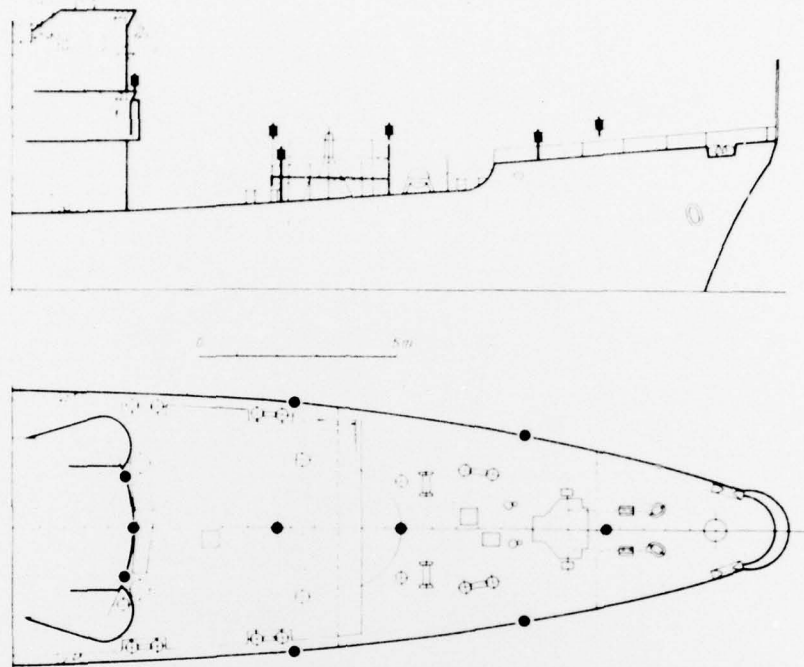


Figure 11. Distribution of sea spray collectors on board ship. (Tabata, 1969) (Copyright, T. Tabata; reprinted by permission).

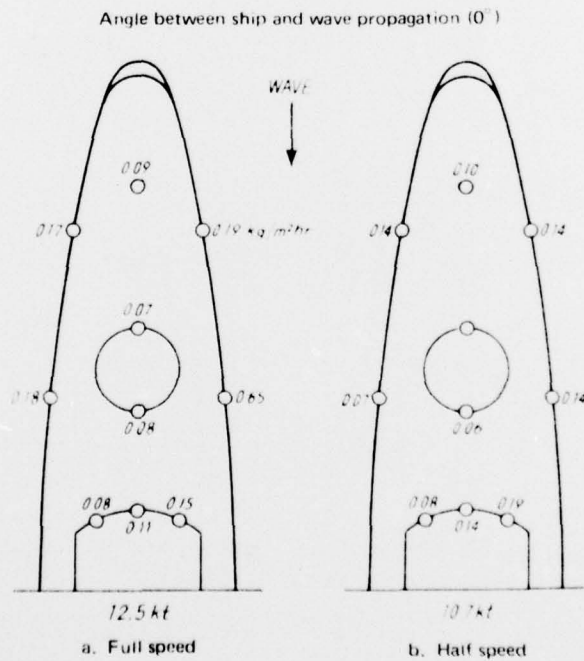


Figure 12. Distribution of sea spray flux on forward deck. (Tabata, 1969) (Copyright, T. Tabata; reprinted by permission).

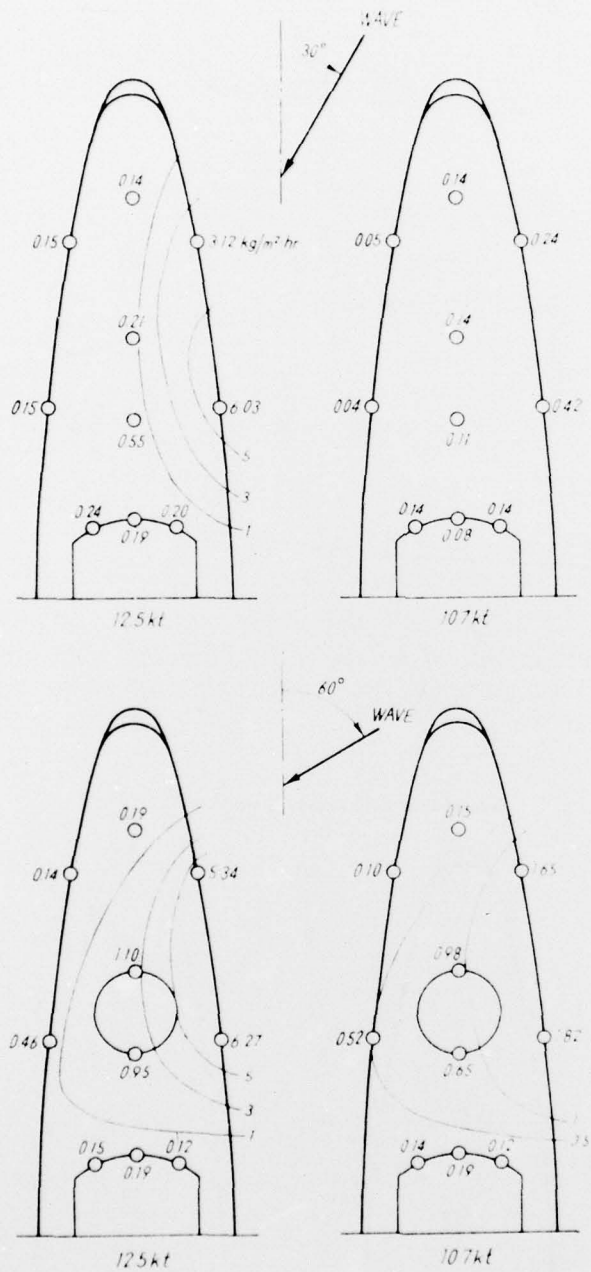
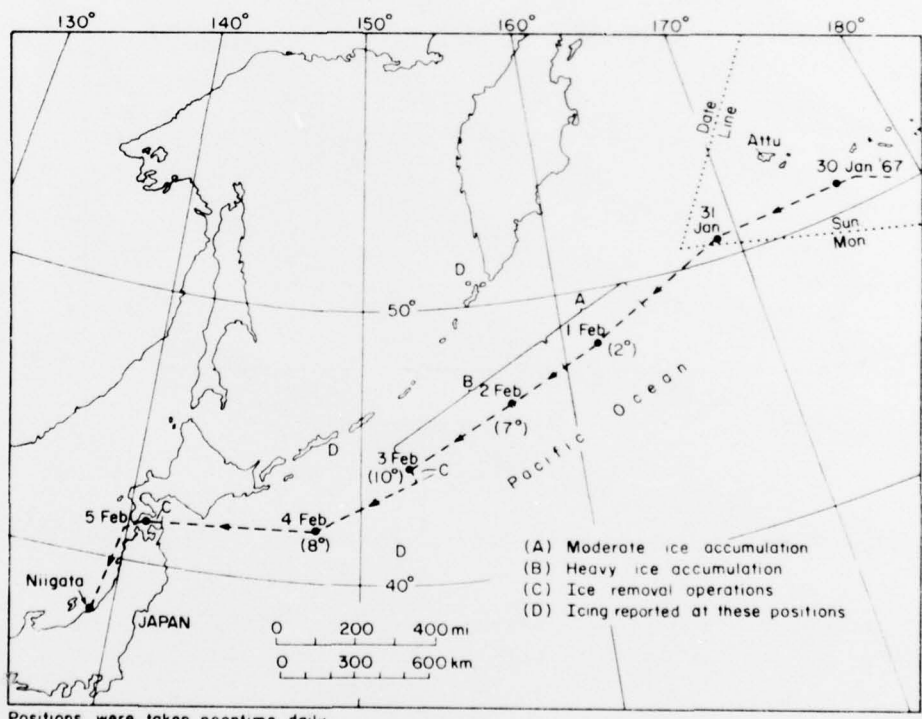
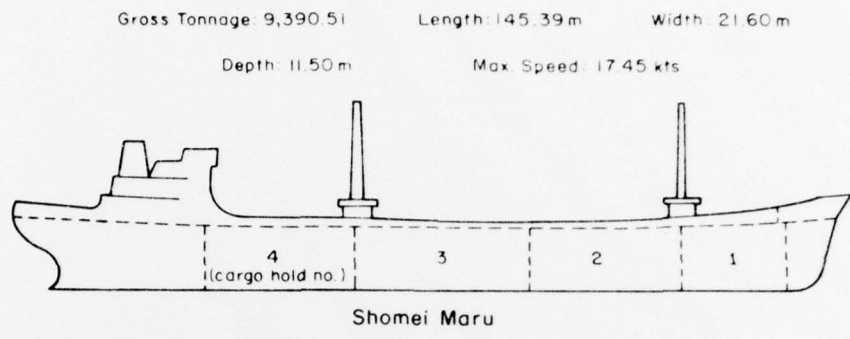


Figure 13. Distribution of spray flux (kg/m²/hr) at 30° and 60° (Tabata, 1969) (Copyright, T. Tabata; reprinted by permission)



Positions were taken noontime daily.
 Figures in parentheses indicate max degree of ships listing.

Figure 14. The date and area of icing reported by the Shomei Maru.
 (Sawada, 1973) (Copyright, the Hakodate Marine Observatory;
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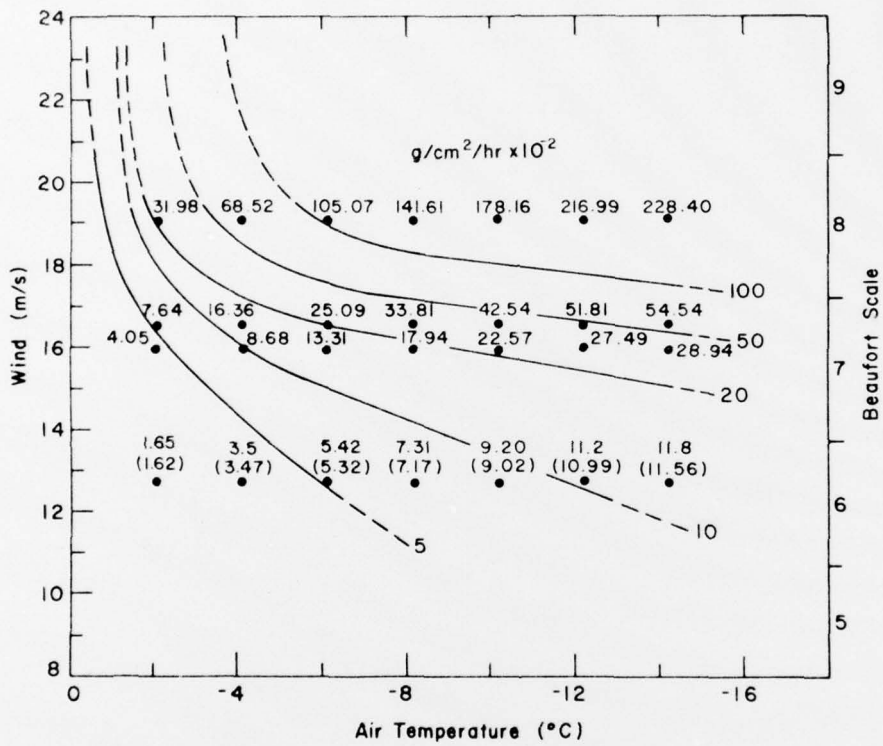


Figure 15. Theoretically calculated icing rate on a stationary structure.