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VESSEL ICING IN ALASKAN WATERS - 1979 TO 1984 DATA SET

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Seattle, Washington

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VESSEL ICING IN ALASKAN WATERS - 1979 TO 1984 DATA SET

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ABSTRACT. A set of 85 icing incidents for December 1979 to December 1983 were obtained from the radio log of WBH29, a private reporting station on Kodiak Island. Reports were verified by interviews with the vessel operator and comparison with NOAA sea level pressure, air temperature and sea surface temperature analyses. Icing rates are greater than 2.0 cm hr^{-1} for 30% of the observations and 60% of the vessel event durations are 8 hr or less. The observed icing rates were three times those of a previous study. New icing nomograms are presented based on this new data.

1. INTRODUCTION

Vessel icing is one of the most serious marine meteorological hazards in high-latitude waters. Icing requires the presence of sub-freezing air temperatures, strong winds, and cool sea temperatures. Actual icing potential is a characteristic of each vessel, depending on its design and sea-keeping ability. Differences in vessel type, combined with difficulties in making observations during operations, result in great variability in vessel icing observations for similar meteorological conditions. Our data sets seek to minimize these difficulties by a consistency check through interviews with the vessel operators and comparison with regional meteorological analyses. The data set is the basis of a new icing rate algorithm (Overland *et al.*, 1986) which predicts icing rates greater than three times those of previous nomograms for the same meteorological conditions. We believe this is due in part to the care with which the data set was assembled, in excluding downwind cases, and in defining the duration of isolated icing events.

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2. DATA SET

The observation set consists primarily of fishing vessels, fish processors, tow boats and Coast Guard vessels, which operate in Alaskan waters. Most vessels ranged in length from 20-75 m. A total of 195 icing incidents for December 1979 to December 1983 (Fig. 1) were obtained from the radio log of WBH29, a private reporting station on Kodiak Island. For fishing vessels, the vessel operator who made the report was interviewed to determine the extent of the icing event and provide additional meteorological information and vessel characteristics. For tow boats, the operating logs of individual vessels were consulted. Tow boats were a particularly good source of data because their schedules were not affected by the fishing season or bad weather. U.S. Coast Guard and NOAA vessel reports were concise and usually required little follow up. A final consistency check of the data was made by comparing the individual reports with National Weather Service (NWS) sea-level pressure analyses and air temperature fields.

A total of 85 verified reports were obtained (Table 1 and 2). Reports included date, location, ship's heading and speed, wind velocity, air temperature, sea height, maximum icing rate, total accumulation, and duration of the icing event. For each report, surface wind, sea height, and air and dewpoint temperatures were extracted from NWS Anchorage Forecast Office analyses. Sea surface temperatures were obtained from NOAA regional sea-surface temperature products.

The data were examined for consistency between the vessel observations, the NOAA analyses and the narrative of the vessel operators. In three cases the wind speeds were increased and in six cases the sea-surface temperatures were adjusted based upon the narrative. The air temperatures from the National Weather Service analyzed charts were more regionally consistent than

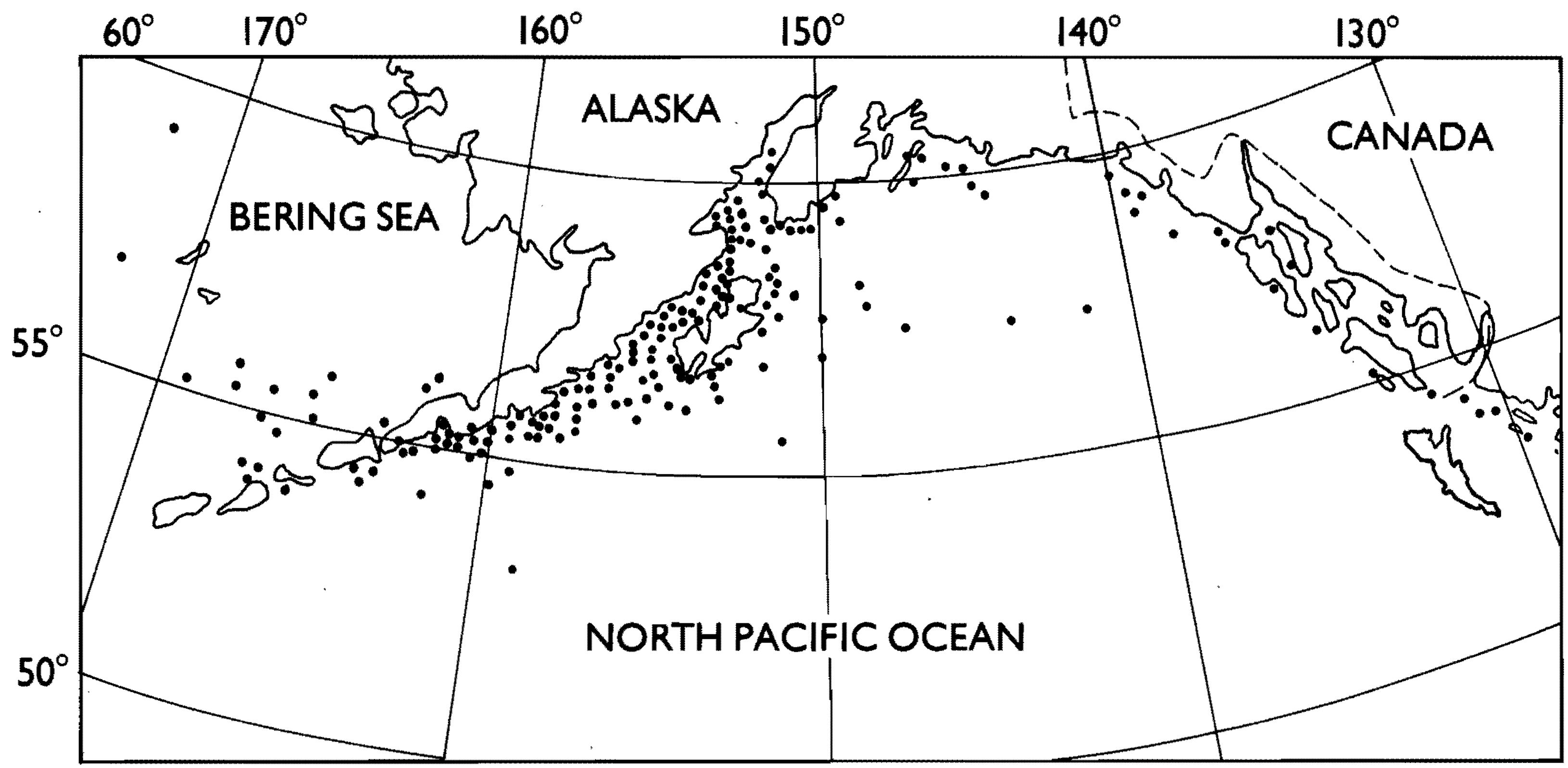


Figure 1.--Vessel icing incidents from December 1979 to December 1984 from the radio log of WBH29 (Peggy Dyson).

those estimated by the vessel operators. Many vessels have uncalibrated thermometers or no thermometers and there were frequent errors in guessing the air temperature by as much as 5°C. A quarter of the ship observations deviated from NWS observations by greater than 2°C. We recommend the NWS air temperature analyses for algorithm development, since errors of a few degrees introduce large errors in freezing rate calculations.

Most captains have very good facility with the Beaufort wind scale. In several extreme cases along mountainous coasts wind estimates from the NWS surface analysis were half the observed winds. The only persistent errors in the captains' winds occurred in moderate wind conditions when they appeared to underestimate wind speed. The maximum reported wind, either from the captain or the NWS analysis, is probably the closest approximation to the regional wind at the time of observation. Errors of a few m/s introduce only modest errors in freezing rate calculations.

It is necessary to define "potential icing rate" in terms of the data set. Potential icing is defined as a sustained icing rate by a vessel which is not actively avoiding icing by heading downwind, slowing speed, or avoiding open seas. Total accumulation of ice divided by duration of the event may systematically underestimate icing rates because the vessel is transiting different conditions, even though observed durations were typically less than 12 hrs. Maximum observed rates have some scatter, are harder to estimate, and do not necessarily represent sustained rates. A good compromise is to define potential icing as the average of the maximum observed rate and the total event rate. In most cases the two rates are similar.

The ship's heading relative to the wind direction shows that most cases with anomalously low icing rates for the meteorological conditions were caused by ships taking less spray while they were heading downwind. We used

Table 1.--Icing reports relative to vessel length (ℓ) in meters for 27 vessels and 84 observations (excluding 1 report from the drill rig OCEAN BOUNTY).

	$\ell < 35$	$35 \le \ell < 55$	$55 \le \ell < 75$	$75 \le \ell$
Number of vessels	12	6	6	3
Number of observations	18	46	16	4
Names of vessels (Number of observations)	Crabber ALASKA TROJAN (3)	Tug JUSTINE FOSS (18)	NOAA RV MILLER FREEMAN (6)	Ferry TUSTAMENA (2)
	USCGC CAPE CORAL (3)	Tug CRUSADER (9)	USCGC SEDGE (4)	USCGC BOUTWELL (1)
	Crabber HERMITAGE (2)	Coastal Freighter SNOW BIRD (8)	USCGC STORIS (3)	NOAA RV SURVEYOR (1)
	Tug SANDRA FOSS (2)	Tug LESLIE FOSS (6)	USCGC CONFIDENCE (1)	
	(8 other crabbers, shrimpers, bottom fishers, USCGC)	NOAA RV CHAPMAN (3)	USCGC SWEETBRIER (1)	
		Conv. Army F.S. PRINCESS TAMARA (2)	USCGC PLANETREE (1)	

Table 2. Icing data set. See footnote for definition of case type.

case	month	day	year	approximate latitude (N)	approximate longitude (W)	vessel length (m)	vessel heading (°T)[2]	ship speed (kt)	air temp. (°C) (logged)	air temp. (°C) (NWS)	sea temp. (°C)	wet bulb temp. (°C)	wind speed (m/s) (logged)	wind speed (m/s) (NWS)	wind direction (°T) (logged)	saturation v.p. (mb)	vapor pressure (mb)	event icing rate (cm/hr)	maximum icing rate (cm/hr)	case type[1]	duration (hr)	wave height (m)
1	12	23	79	57.33	156.15	33	999	8	-4.4	-11.1	3.3	-12.8	28	15	000	4.4	1.5	0.8	0.8	d1	3	1.5
2	2	14	82	58.33	154.00	33	999	0	-12.2	-10.0	0.6	-13.7	23	23	315	2.4	1.5	3.4	5.1	1	3	1.8
3	2	14	82	58.60	153.52	33	999	0	-20.6	-20.6	0.0	-21.7	41	31	290	1.2	0.6	6.8	10.2	d1	3	0.6
4	1	23	83	53.17	136.58	21	310	9	-3.9	-3.3	4.7	-5.6	26	26	045	4.6	2.6	2.2	2.5	1	4	1.8
5	1	23	83	59.75	140.75	21	280	9	-2.8	-1.1	4.4	-5.0	20	23	045	5.0	2.1	0.5	0.5	d1	1	2.4
6	12	18	80	56.60	156.50	21	090	10	-15.0	-15.0	4.0	-16.7	26	26	340	1.9	1.0	3.1	3.2	1	5	1.5
7	1	10	80	57.13	152.83	29	040	9	-3.9	-3.9	3.0	-7.2	20	26	340	4.6	1.8	2.0	2.5	o	5	8.2
8	12	19	79	57.83	153.97	29	050	8	-8.9	-8.9	3.5	-10.0	10	10	000	3.1	2.4	0.6	0.9	o	3	2.7
9	2	17	81	58.18	151.50	70	350	10	-7.8	-3.9	3.9	-5.6	8	18	010	4.0	3.4	0.2	0.3	o	3	1.2
10	1	12	80	57.73	148.75	40	097	7	-6.7	-6.7	3.5	-9.0	19	18	315	3.7	1.8	1.3	5.1	d	19	3.1
11	1	14	80	58.00	154.10	40	225	7	-13.3	-13.3	2.5	-14.8	22	20	340	2.2	1.2	1.2	15.2	o	13	4.6
12	1	16	80	58.00	153.83	40	225	8	-12.2	-12.2	2.5	-14.0	18	18	340	2.4	1.3	2.7	5.1	o	6	3.1
13	2	2	80	57.92	154.42	40	240	10	-8.9	-11.7	2.5	-10.0	20	20	345	3.1	1.8	3.6	5.6	o	10	4.6
14	1	18	81	56.50	156.82	40	225	10	-2.2	-3.3	2.0	-3.5	20	13	290	5.2	4.2	0.1	0.3	o	8	4.6
15	1	19	81	55.53	160.00	40	270	10	-2.2	-2.8	2.5	-4.3	14	14	290	5.2	3.6	0.1	0.3	o	8	3.1
16	2	16	81	54.20	166.40	40	085	10	-3.9	-5.0	3.0	-6.1	20	15	045	4.6	3.6	1.3	1.3	o	1	1.8
17	2	16	81	57.72	152.18	40	060	10	-5.6	-6.7	3.0	-7.0	20	18	000	4.0	2.6	0.5	2.5	o	14	2.7
18	2	17	81	55.50	161.50	40	090	9	-5.0	-7.8	3.4	-6.8	13	13	023	4.2	2.6	0.5	1.3	o	10	4.6
19	2	17	81	55.50	161.50	40	090	9	-3.9	-8.3	2.7	-6.0	15	13	000	4.6	2.6	0.2	0.8	o	24	2.4
20	2	14	82	55.50	161.50	40	090	10	-6.7	-6.7	3.8	-8.3	29	14	340	3.7	2.4	0.3	1.3	1	8	3.7
21	2	14	82	56.13	157.80	40	090	10	-12.8	-9.4	3.0	-9.8	23	15	340	3.0	2.7	0.8	2.5	1	10	3.1
22	2	15	82	56.13	157.50	40	070	9	-12.2	-13.3	3.0	-13.6	26	13	000	2.3	1.4	1.3	2.5	1	18	4.6
23	2	25	82	56.00	159.00	40	250	10	-2.2	-2.2	3.0	-5.0	15	10	320	5.2	3.0	0.2	0.5	1	8	1.8
24	3	24	82	54.90	163.07	40	090	8	-6.7	-6.1	3.0	-7.3	18	18	340	3.7	3.0	1.0	5.1	o1	15	4.6
25	12	2	82	55.60	161.50	40	090	10	-2.8	-3.9	5.0	-4.5	9	11	330	5.0	3.3	0.1	0.3	d	7	1.5

[1] d - vessel heading down wind 1 - vessel in a less than fully develp sea o - open ocean

[2] 999 - vessel heading not reported.

case	month	day	year	approximate latitude (N)	approximate longitude (W)	vessel length (m)	vessel heading (°T)[2]	ship speed (kt)	air temp. (°C) (logged)	air temp. (°C) (NWS)	sea temp. (°C)	wet bulb temp. (°C)	wind speed (m/s) (logged)	wind speed (m/s) (NWS)	wind direction (°T) (logged)	saturation v.p. (mb)	vapor pressure (mb)	event icing rate (cm/hr)	maximum icing rate (cm/hr)	case type[1]	duration (hr)	wave height (m)
26	12	2	82	55.75	158.00	40	090	10	-3.9	-3.9	5.0	-5.0	15	13	315	4.6	3.3	0.4	1.3	d	24	3.6
27	2	20	83	56.57	165.92	66	300	6	-2.4	-11.1	3.5	-5.1	18	16	025	4.0	2.4	1.2	1.7	o	6	4.3
28	2	20	83	57.00	168.50	66	320	6	-9.0	-10.0	3.2	-9.7	18	13	020	5.2	2.2	0.7	1.7	o	19	4.6
29	1	8	83	58.83	152.35	32	350	8	-12.2	-13.3	3.5	-13.5	17	26	340	2.4	1.5	0.2	1.9	o	19	5.5
30	2	13	83	58.83	152.35	32	005	8	-3.9	-3.3	4.4	-4.7	10	7	020	4.6	3.9	0.1	0.3	o	6	1.2
31	3	12	82	59.25	153.00	37	999	9	-3.3	-2.2	1.8	-4.9	23	11	270	4.8	3.4	0.1	0.3	1	9	2.3
32	3	12	82	59.20	153.55	37	999	4	-5.6	-8.3	1.8	-7.3	15	18	270	4.1	2.6	0.1	0.3	d	14	1.7
33	10	26	83	58.83	153.27	38	010	6	-3.9	-3.9	6.5	-6.0	20	20	315	4.6	2.4	0.2	0.3	o	3	3.1
34	4	17	82	57.67	154.50	39	235	8	-4.1	-4.4	1.6	-7.2	11	13	220	4.6	2.3	0.2	0.3	o	6	2.4
35	4	18	82	57.67	153.48	39	240	8	-5.5	-5.0	1.7	-7.2	11	10	290	4.1	2.4	0.5	0.6	o	8	2.9
36	3	19	82	55.28	161.48	39	230	7	-2.2	-2.2	1.9	-3.3	13	18	320	5.2	4.2	0.5	0.8	o	5	1.8
37	1	8	80	53.75	131.00	43	320	9	-8.9	-6.7	7.0	-7.8	12	20	045	3.2	3.0	0.2	0.3	o	4	0.9
38	1	8	80	53.30	131.00	43	340	9	-7.8	-7.8	6.0	-10.0	15	20	045	3.6	1.3	0.5	1.8	o	10	3.2
39	1	8	80	54.50	132.50	43	270	9	-7.2	-7.2	5.5	-10.0	15	15	045	3.6	1.3	0.9	1.8	o	18	3.2
40	1	9	80	57.00	135.50	43	330	9	-9.4	-7.8	5.0	-11.0	36	20	045	3.0	1.7	1.9	15.2	ol	25	3.1
41	1	10	80	58.25	137.75	43	325	7	-10.6	-12.2	4.0	-13.1	40	20	070	2.8	0.9	4.6	15.2	ol	18	3.1
42	1	10	80	59.00	138.00	43	315	7	-10.6	-12.2	4.0	-14.4	26	20	045	2.8	0.9	1.1	2.5	1	18	3.1
43	1	11	80	59.50	139.75	43	275	9	-11.1	-12.2	3.5	-13.0	20	20	045	2.6	0.9	3.1	3.8	dl	10	3.1
44	1	12	80	59.75	144.00	43	285	9	-13.3	-13.3	2.0	-14.2	20	15	040	2.2	0.9	0.6	0.6	d	6	2.1
45	1	12	80	60.50	146.88	43	290	9	-13.3	-13.3	2.0	-15.0	13	13	020	2.2	0.8	0.2	0.6	d	10	1.2
46	2	16	81	55.30	166.48	66	050	5	-3.9	-2.8	3.3	-5.4	15	13	045	4.6	2.8	0.1	0.1	o	24	2.4
47	2	23	81	58.08	153.97	70	225	10	-1.7	-3.9	2.8	-4.4	8	13	320	5.4	4.2	0.1	0.5	o	6	1.8
48	12	12	79	58.42	134.67	29	999	6	-9.4	-13.9	5.5	-11.2	26	31	090	3.0	1.0	0.4	1.0	dl	3	1.5
49	12	14	79	58.15	134.15	29	999	10	-9.4	-17.8	4.0	-11.4	23	26	000	3.0	0.9	10.2	10.2	ol	1	2.4
50	12	9	79	57.45	133.72	29	999	6	-2.2	-3.3	4.5	-4.1	20	23	000	5.2	3.4	2.0	2.5	1	3	2.1

[1] d - vessel heading down wind   1 - vessel in a less than fully develp sea   o - open ocean
[2] 999 - vessel heading not reported.

case	month	day	year	approximate latitude (N)	approximate longitude (W)	vessel length (m)	vessel heading (°T)[2]	ship speed (kt)	air temp. (°C) (logged)	air temp. (°C) (NWS)	sea temp. (°C)	wet bulb temp. (°C)	wind speed (m/s) (logged)	wind speed (m/s) (NWS)	wind direction (°T) (logged)	saturation v.p. (mb)	vapor pressure (mb)	event icing rate (cm/hr)	maximum icing rate (cm/hr)	case type[1]	duration (hr)	wave height (m)
51	3	14	79	60.97	146.92	20	010	10	-7.8	-5.6	1.0	-8.9	10	10	030	3.4	2.6	0.2	0.3	o	4	1.5
52	12	11	80	59.10	151.70	37	260	5	-12.2	-6.7	3.5	-12.9	31	26	340	5.2	2.2	0.6	0.9	1	24	2.4
53	12	12	79	59.17	151.83	37	999	3	-12.2	-12.2	4.0	-14.0	15	16	330	2.4	1.3	6.4	7.6	o	4	1.5
54	12	20	79	59.75	151.92	37	000	3	-8.3	-9.4	3.3	-9.2	18	14	000	3.3	2.6	0.3	0.6	o	12	1.5
55	12	18	79	59.02	152.83	0	999	0	-10.6	-11.7	6.1	-12.8	35	31	315	1.5	2.8	2.5	5.1	o	9	8.2
56	12	19	79	59.08	151.92	90	000	11	-12.8	-11.1	4.5	-12.2	29	22	295	2.3	1.8	5.1	5.1	o	1	9.2
57	12	19	79	59.00	152.00	90	210	11	-8.9	-10.0	4.5	-11.1	31	10	315	3.1	2.2	2.5	3.8	o	3	3.7
58	12	21	79	59.52	151.72	29	045	10	-6.7	-6.7	4.0	-8.1	32	18	315	3.7	2.9	2.0	2.5	o	5	4.6
59	3	15	80	59.58	150.08	55	065	11	-2.2	-2.2	3.2	-4.5	10	8	330	5.2	3.3	0.3	0.6	o	4	2.4
60	12	10	79	60.00	149.35	29	180	15	-12.2	-6.7	3.5	-8.8	20	20	000	3.7	2.4	0.3	0.3	d	2	1.8
61	12	12	79	59.87	147.33	12	110	13	-12.2	-9.4	4.5	-13.1	20	15	000	2.4	1.9	1.0	1.0	o	8	2.4
62	12	13	79	58.42	134.97	55	999	9	-12.2	-13.3	5.0	-14.0	13	31	000	2.4	1.1	0.3	1.0	d1	5	1.8
63	12	14	79	57.37	133.80	29	350	15	-15.0	-15.0	5.0	-15.9	23	23	315	1.9	1.4	1.7	1.9	o	6	3.7
64	4	17	82	59.07	151.65	55	340	10	-3.3	-3.3	4.0	-4.9	18	18	290	4.8	2.9	0.6	0.6	o	2	4.3
65	2	21	82	59.00	152.50	55	180	10	-8.9	-10.6	3.2	-10.6	17	28	325	3.2	1.6	0.5	1.0	d	5	6.7
66	1	9	83	59.10	151.68	55	270	10	-7.8	-7.8	3.6	-10.0	15	21	340	3.4	1.5	0.3	0.4	1	9	1.5
67	1	9	83	59.17	151.67	55	000	10	-10.6	-13.3	3.6	-13.0	15	18	340	2.7	1.2	5.1	5.1	o	2	2.2
68	2	18	83	54.40	170.71	64	040	4	-3.9	-3.9	3.2	-5.2	17	16	045	4.6	3.3	0.3	1.3	o	12	7.5
69	2	19	83	57.70	152.00	115	275	11	-8.3	-8.3	3.5	-9.7	17	23	310	3.3	2.3	0.3	0.5	o	13	4.0
70	1	8	83	59.18	150.93	38	370	8	-12.2	-12.2	3.5	-13.5	20	20	315	2.4	1.5	1.9	2.5	o	4	2.1
71	1	11	83	59.38	152.00	38	338	8	-9.4	-9.4	3.2	-11.5	24	28	000	3.0	1.5	1.5	2.5	o	5	2.4
72	2	17	81	54.67	162.25	89	060	12	-6.4	-7.8	2.0	-7.0	18	12	035	3.8	2.4	1.0	1.5	o	5	3.7
73	2	1	80	58.65	276.42	66	999	11	-7.0	-6.1	2.2	-8.0	13	15	040	3.6	2.9	1.4	2.5	o	9	3.9
74	3	15	80	57.58	255.50	66	999	5	-10.5	-12.2	2.0	-12.0	19	15	340	2.6	1.5	0.4	0.5	d1	13	1.9
75	2	16	81	55.38	167.78	66	040	4	-7.2	-7.2	2.2	-7.9	14	13	040	3.7	2.9	1.0	1.0	o	8	3.8

1 d - vessel heading down wind   1 - vessel in a less than fully develp sea   o - open ocean
2 999 - vessel heading not reported.

case	month	day	year	approximate latitude (N)	approximate longitude (W)	vessel length (m)	vessel heading (°T)[2]	ship speed (kt)	air temp. (°C) (logged)	air temp. (°C) (NWS)	sea temp. (°C)	wet bulb temp. (°C)	wind speed (m/s) (logged)	wind speed (m/s) (NWS)	wind direction (°T) (logged)	saturation v.p. (mb)	vapor pressure (mb)	event icing rate (cm/hr)	maximum icing rate (cm/hr)	case type[1]	duration (hr)	wave height (m)
76	1	10	80	56.08	134.50	50	020	12	-12.2	-9.4	4.0	-11.5	20	18	040	2.4	1.5	5.8	7.6	so	4	2.7
77	1	13	80	56.67	154.25	50	280	12	-5.0	-9.4	4.5	-7.3	15	15	315	4.2	1.9	3.2	8.9	so	18	2.9
78	12	1	80	54.30	131.50	50	130	12	-2.8	-2.8	4.0	-4.9	15	11	090	5.0	3.0	2.5	3.8	so	4	2.4
79	2	11	82	58.00	134.75	50	010	12	-3.9	-6.7	4.0	-6.1	20	23	000	4.6	2.4	5.1	6.4	so	5	1.2
80	2	15	82	56.78	154.28	50	290	11	-15.0	-15.0	3.0	-16.0	26	30	320	1.9	1.1	11.4	15.2	so	8	6.1
81	3	23	82	54.63	159.98	50	260	7	-5.0	-3.3	6.0	-6.0	20	13	340	4.2	3.4	1.1	1.3	so	3	4.0
82	2	23	82	54.42	161.00	50	245	5	-2.2	-2.2	6.0	-3.0	28	15	320	5.2	4.8	1.3	1.6	so	4	5.2
83	3	24	82	54.18	161.75	50	275	7	-3.0	-5.6	6.0	-4.5	26	15	325	5.0	3.1	1.3	1.6	so	10	4.5
84	1	8	84	60.55	151.45	35	020	10	-3.3	-9.4	4.0	-5.7	13	13	020	4.8	2.2	1.0	1.0	o	1	1.2
85	1	13	80	58.00	170.00	70	010	6	-13.3	-12.2	1.0	-11.0	15	13	350	3.4	0.7	1.5	2.5	o	19	3.7

1 d - vessel heading down wind   l - vessel in a less than fully develp sea   o - open ocean
s - we suspect that both icing rates are too large by a factor of three

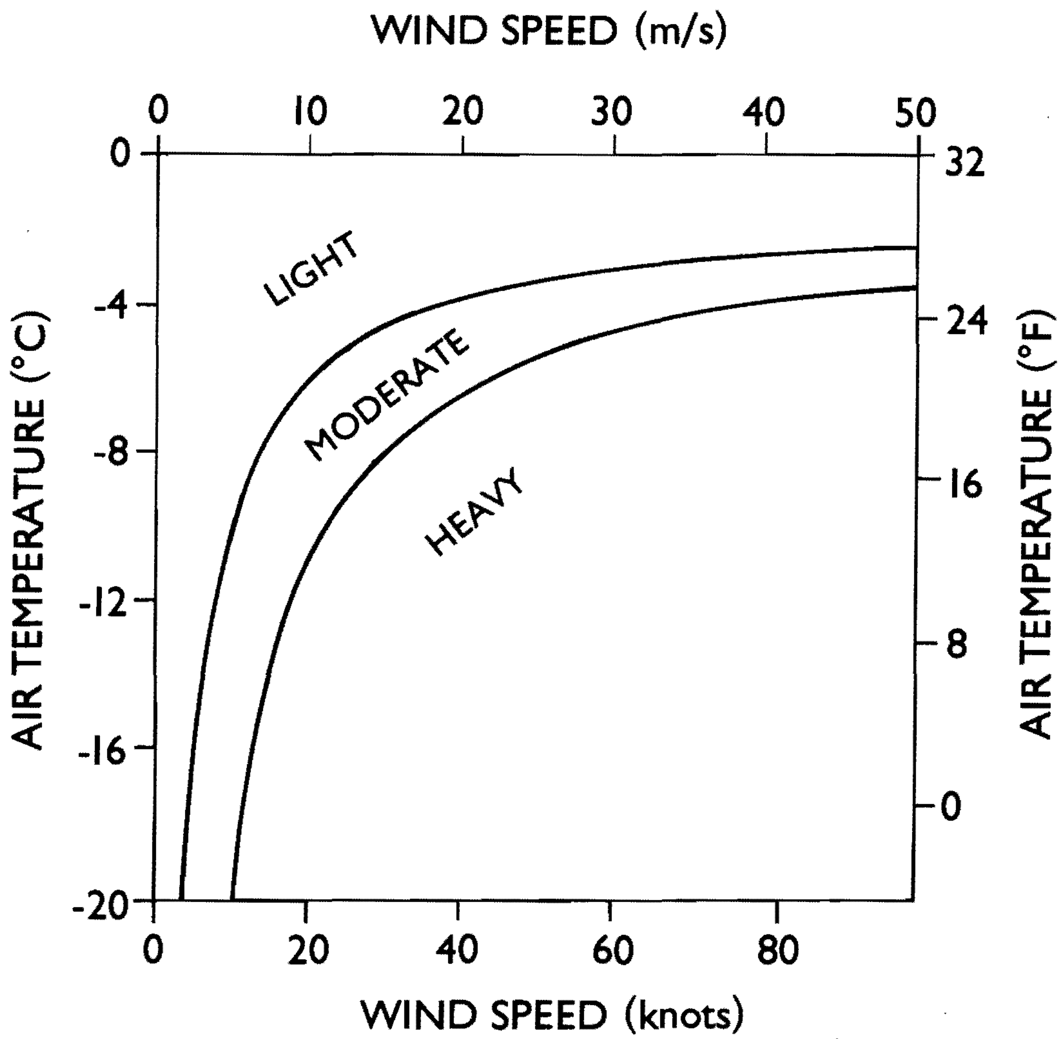
2 999 - vessel heading not reported.

the criteria of 120° or greater off the wind, or a captain's comment in the narrative reports that the vessel was running downwind to identify these cases. The downwind cases have significantly less icing for similar meteorological conditions than vessels abeam or heading into the wind. There are 15 cases meeting the downwind criteria. They are indicated in Table 2 by case type designator "d". Additional low icing cases relative to meteorological conditions were identified for vessels taking less spray because the sea heights were anomalously low in the lee of an island or in an otherwise undeveloped sea. We used the criteria of wave height to wind speed ratio of less than 0.15 m to 1.0 m/s to indicate sheltered conditions; there were 12 non-downwind cases (case type "l") and 7 downwind cases (case type "dl") in this category. We retained one extreme icing case (case 49) which met the wave height criteria but exhibited no other symptoms of lee shore modification. Eight cases (76-83) from one vessel were significantly more severe for the same conditions than any other vessel. These observations are indicated in Table 2 by case type designator "so". There may have been a problem with the definition of icing rate per three hours for this vessel. Of the 85 cases, 58 are considered meteorologically consistent, non-downwind, open-ocean cases of potential icing rate.

3. RESULTS

In general, marine superstructure icing rates for vessels between 20 and 75 m are much worse than had been previously thought (Overland *et al.*, 1986). Previous studies (Wise and Comiskey, 1980) included many cases with vessels headed more than 120° from the wind or with vessels hiding behind headlands. These cases, although valuable tests, must not be included in statistical studies for developing forecast models for worst-case conditions.

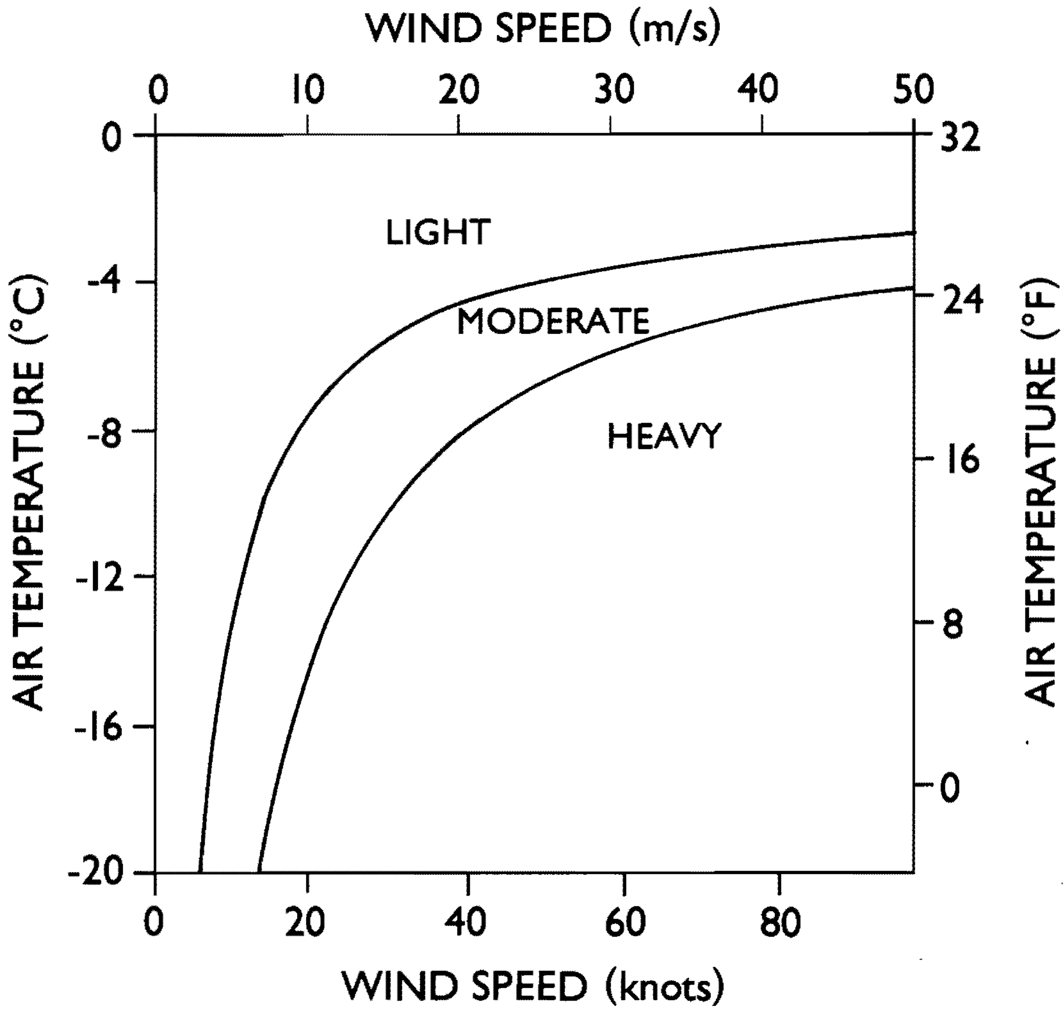
Four graphs (Figures 2-5) show improved nomograms for icing rates for vessels heading into or abeam of the wind for four different sea temperatures. These nomograms are based on the data in Table 2 and on the statistical analysis in Overland *et al.* (1986). Both the rate categories and the icing severity predicted for given environmental conditions are increased from the Wise and Comiskey (1980) study and are based on a much improved data base and improved analysis. We recommend discarding all nomograms from the Wise and Comiskey study and using the present nomograms instead. The new data strongly suggests that vessels under 75 m in length expecting heavy icing conditions must take immediate evasive action either by running downwind or returning to port.



Icing conditions for vessels heading into or abeam of the wind for water temperatures of + 1°C (34°F)

Light Icing - Less than 0.7cm/hr (0.3in/hr)
Moderate Icing - 0.7cm/hr (0.3in/hr) to 2.0 cm/hr (o.8in/hr)
Heavy Icing - Greater than 2.0cm/hr (0.8in/hr)

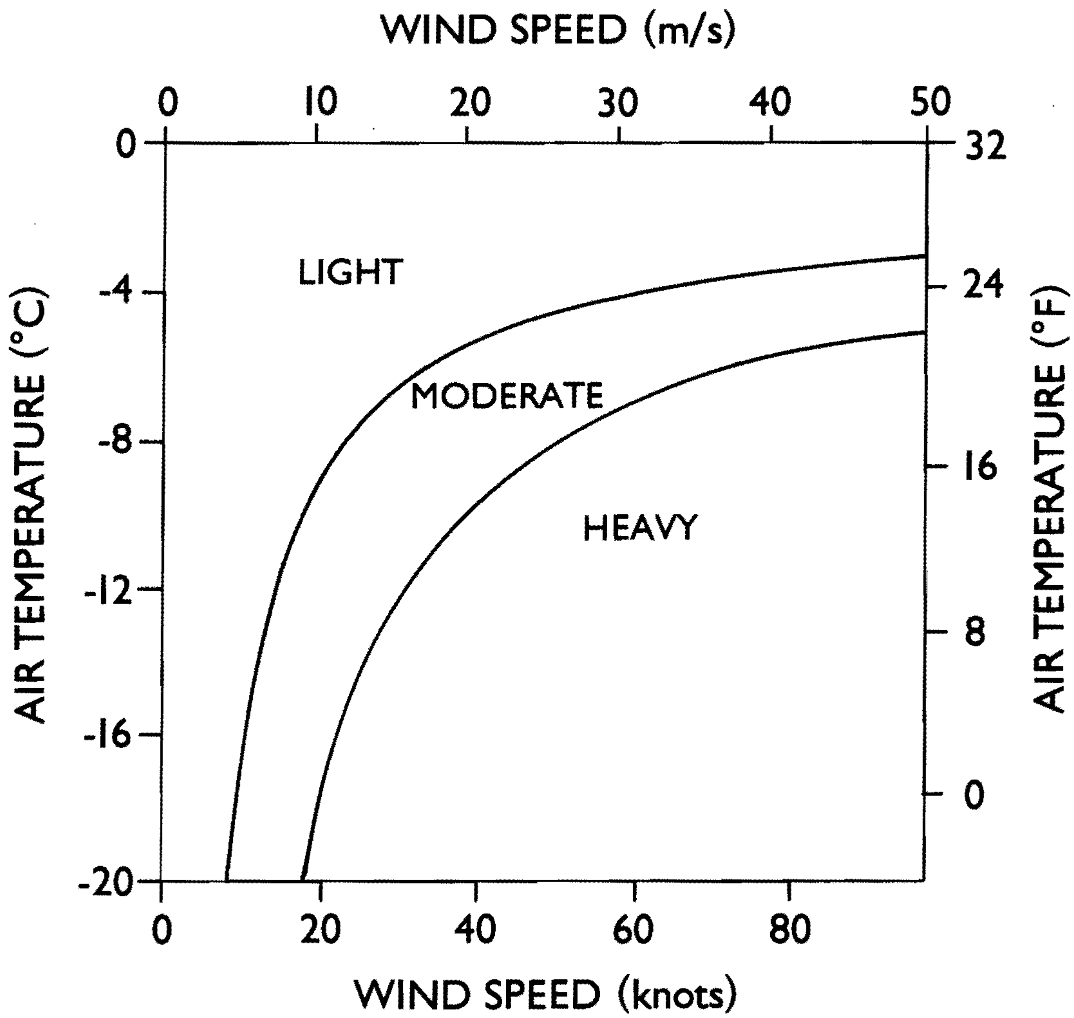
Figure 2.--Nomogram of superstructure icing conditions due to spray for water about 1°C (34°F).



Icing conditions for vessels heading into or abeam of the wind for water temperatures of +3°C (37°F)

Light Icing - Less than 0.7cm/hr (0.3in/hr)
Moderate Icing - 0.7cm/hr (0.3in/hr) to 2.0 cm/hr (0.8in/hr)
Heavy Icing - Greater than 2.0cm/hr (0.8in/hr)

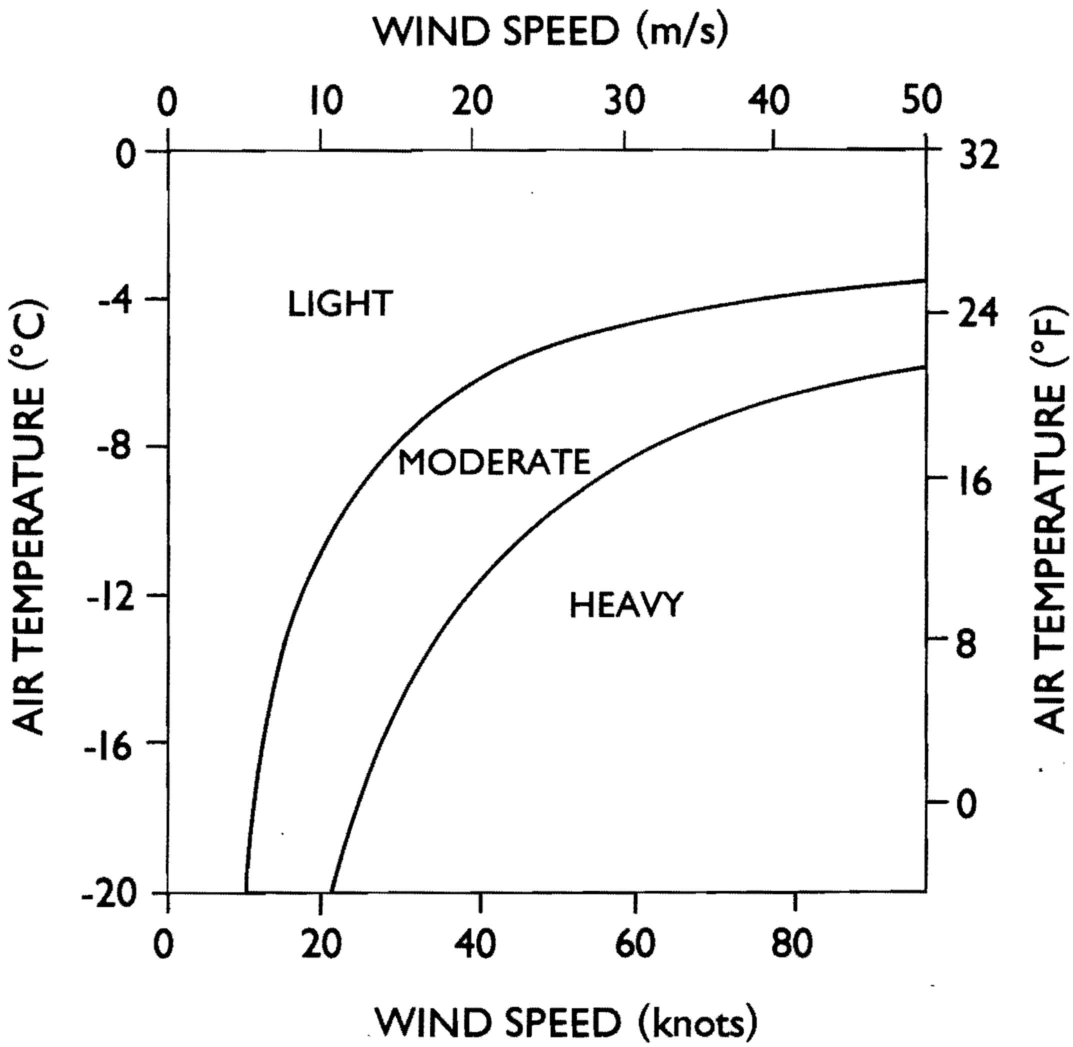
Figure 3.--Nomogram of superstructure icing conditions due to spray for water about 3°C (37°F).



Icing conditions for vessels heading into or abeam of the wind for water temperatures of +5°C (41°F)

Light Icing - Less than 0.7cm/hr (0.3in/hr)
Moderate Icing - 0.7cm/hr (0.3in/hr) to 2.0 cm/hr (0.8in/hr)
Heavy Icing - Greater than 2.0cm/hr (0.8in/hr)

Figure 4.--Nomogram of superstructure icing conditions due to spray for water about 5°C (41°F).



Icing conditions for vessels heading into or abeam of the wind for water temperatures of +7°C (45°F)

Light Icing - Less than 0.7cm/hr (0.3in/hr)
Moderate Icing - 0.7cm/hr (0.3in/hr) to 2.0 cm/hr (0.8in/hr)
Heavy Icing - Greater than 2.0cm/hr (0.8in/hr)

Figure 5.--Nomogram of superstructure icing conditions due to spray for water about 7°C (45°F).

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5. REFERENCES

Overland, J.E., C.H. Pease, R.W. Preisendorfer, A.L. Comiskey (1986): Prediction of vessel icing. *J. Climate and Applied Meteorology* (in press).

Wise, J.L., and A.L. Comiskey (1980): *Superstructure Icing in Alaskan Waters*, NOAA Special Report ERL PMEL, NTIS PB81-135188, 30 pp.