SPRAY ICING ON ONEGA VESSEL- A COMPARISON OF LIQUID WATER CONTENT EXPRESSIONS

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ABSTRACT
The hazards associated with ice accretion primarily due to impinging freezing sea spray on ship structures are considered among serious safety concerns for ships operating in the colder regions. An accurate sea-spray icing-estimation model to evaluate the ice accumulation during operations in these regions can make marine operations safer. The accuracy of the present icing models for estimating icing on ships is substantially dependent on the incoming spray flux generated by the wave-ship interaction. In order to illustrate this, the vessel icing incident of the fishing vessel ONEGA is considered, which capsized after encountering heavy icing. In this study, the ONEGA vessel is modeled using a stability-calculation program. Then assuming the vessel to maintain minimum stability criteria prior to icing, the minimum likely amount of ice accumulation in the exposed locations that destabilized the vessel is estimated. This estimation is compared against another method used to evaluate ice thickness over the period ONEGA was accreting ice. The latter method utilizes the operational weather forecasting model used by MET Norway - "Marine-Icing model for the Norwegian COast Guard (MINCOG)". The MINCOG model uses spray-flux estimations based on past empirical observations mainly obtained from fishing trawlers. The spray-flux consists of important elements like the liquid-water content (l_{wc}) and the spray-generation frequency. An analysis is carried out applying different formulations for these two elements proposed by different researchers to see the variation in evaluating the total ice accumulation. After noticing the difference in results in total ice thickness from the stability and the icing-model methods used in this study, it is concluded that more investigation and field measurements are needed concerning the neglecting of the contribution of wind-generated spray in the spray flux formula used in MINCOG. Accordingly, multiple real-time spray measurements to develop a more suitable spray-flux formulation may improve the ice accumulation estimation over a longer time period.
Keywords: Sea Spray icing, Spray flux, Ship stability

NOMENCLATURE
AIS - Automatic Identification System
B_{ice} - Center of Buoyancy after ice accretion
BM_l - Longitudinal metacentric radius (m)
BM_t - Transverse metacentric radius (m)
B_o - Center of Buoyancy when no ice accretion
B_φ - Center of Buoyancy after heel
E - Collision efficiency of the droplets
G_o - Vessel center of gravity when no ice accretion
G_{ice} - Vessel center of gravity after ice accretion
GM - Metacentric height (m)
GZ - Righting Lever (m)
h - Altitude of an object over the deck of the vessel (m)
H_s - Significant wave height (m)
I_l - Longitudinal moment of inertia (m^4)
I_t - Transverse moment of inertia (m^4)
K - Keel of the ship
KMl - Longitudinal metacentric height from keel (m)
KMt - Transverse metacentric height from keel (m)
LCB - Longitudinal center of buoyancy (m)
LCG - Longitudinal center of gravity (m)
l_{wc} - Liquid-water content (kg m^{-3}) of spray
MCT - Moment to change trim one unit (t m)
MFV - Medium sized fishing vessel
M_{ice} - Metacenter after ice accretion
M_o - Metacenter when no ice accretion

M_φ - Actual metacenter when heel
N - Spray frequency (s^{-1})
n_1 - normal vector towards freezing plate
N_φ - False Metacenter
ϕ - Angle of heel (°)
Q_c - Convective heat flux (W m^{-2})
Q_{cond} - Conductive heat flux (W m^{-2})
Q_d - Heat flux from incoming water droplets (W m^{-2})
Q_e - Evaporative heat flux (W m^{-2})
Q_f - Heat flux released by freezing (W m^{-2})
Q_r - Radiative heat flux (W m^{-2})
R_w - Spray-flux (kg m^{-2} s^{-1})
TCB - Transverse center of buoyancy (m)
TCG - Transverse center of gravity (m)
t_{dur} - Spray duration (s)
t_{int} - Time interval between a ship and wave collision (s)
TpCm - Weight to change the immersion with one unit (t cm^{-1})
V - Absolute wind speed (m s^{-1})
VCB - Vertical center of buoyancy (m)
VCG - Vertical center of gravity (m)
V_d - Droplet velocity in coordinate system following ship
V_{gr} - Relative speed between the ship and wave groups (m s^{-1})
V_r - Relative speed between ship and an oncoming wave (m s^{-1})
z - Height above the deck of an MFV (m)
λ - wavelength (m)

1. INTRODUCTION

Commercial fishing is rated as one of the most dangerous occupations [1], [2]. With increased seafood demand and trade, leading to substantial monetary gains, fishing vessels are often tempted to operate in severe weather conditions. In 2019, 671 fishing vessels were operating in the Arctic Polar Code area, making 41% of the total ships there, sailing an aggregate of 4.82 million nautical miles [3]. One such significant hazard that fishing vessels encounter while operating in cold regions arises from ice accretion. Icing not only possesses a safety hazard for crew working on the vessel, it may also damage communication and safety equipment or other critical and essential machinery. The maneuverability of the vessel can be reduced, subsequently barring it from taking evasive actions to minimize the accretion and its impact, such as changing its heading to face the sea from astern. More threatening is that icing can eventually destabilize and capsize the vessel. When a vessel accumulates ice on the topside, the center of gravity is shifted upwards, consequently reducing the metacentric height. Thus, the righting lever, which determines the restoring moment to bring back the vessel to its initial state when heeled, is gradually reduced, and therefore the vessel loses its capability to upright **(Fig. 1)**. The smaller vessels have less residual stability compared to the larger vessels, and thus a lower amount of ice accretion can destabilize and make them more prone to capsizing due to sea-spray icing. Also, the smaller fishing vessels with lower freeboards and large superstructure relative to the rest of the ship frequently encounter waves at their resonance frequency. This can lead to increased spray events when slamming with high motion amplitude, and the spray can cover the entire vessel [4].

A catastrophic ship icing incident in the Arctic waters was the sinking of fishing vessel ONEGA, which led to the loss of 17 lives on 28 December 2020 while fishing west of Yuzhny Island in the Novaya Zemlya Archipelago. There were 19 crew members onboard, out of which only two were rescued, one found dead, and 16 were not found [5]. According to "The Commission of the Federal Service for Supervision of Transport" from the "Ministry of Transport of the Russian Federation" [6]: the vessel apparently encountered heavy ice accumulation, which reduced the initial vessel stability. The investigation mentioned about the unjustified risk admitted by the captain of the vessel when deciding on line-hauling in difficult hydrometeorological conditions. The stormy weather and the presence of an open hatch for retrieving fish using a fishing tackle led to the ingress of seawater into the premises of the vessel located on the main deck. This water ingress added to the initial negative stability and a sharp increase in heel, leading to the sinking of the vessel.

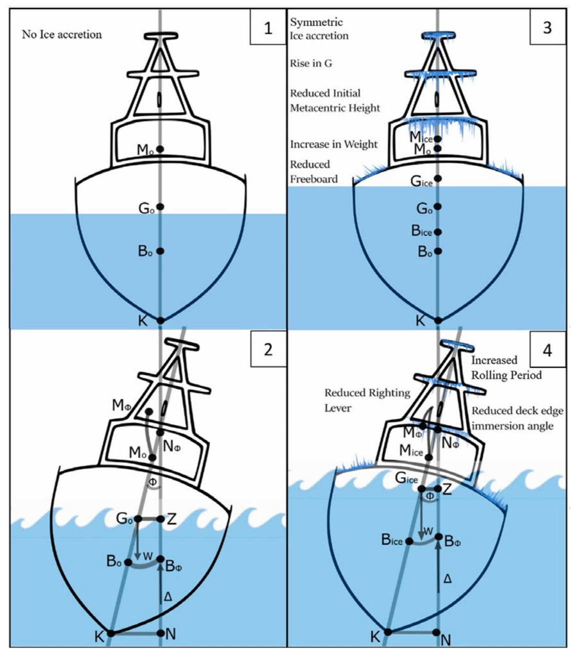

FIGURE 1: VESSEL WITH NO ICE ACCRETION IN CALM WEATHER (1) VESSEL ABLE TO UPRIGHT INSTANTLY WHEN HEELED (2) VESSEL WITH REDUCED STABILITY DUE TO ICE ACCRETION (3) VESSEL RIGHTING ABILITY REDUCED WHEN HEELED (4) [7]

The ONEGA incident has two particular aspects: first the ice accumulation factor that led to the catastrophe, and the second is the safety-related actions admitted by the captain and the ship crew. This study will only focus on the first part. There are mainly two types of ice accretion attributed to vessel icing: atmospheric icing and sea-spray icing. The first type is the atmospheric freshwater icing emerging from the accumulation of snow, fog droplets, and freezing raindrops. The second type is the saline seawater icing emerging from sea spray, where the ocean is the source of the impinging droplets, which freeze when they come in contact with exposed surfaces across the vessel. The past observations on ships indicate sea spray as the main contributor towards vessel icing. Sea spray alone attributed to 90% ice accretion from the Zakrzewski and Lozowski study [8] from more than 4,000 observations from [9] and [10] data. Samuelsen and Graversen [11] analyzed icing event data from 17 different medium-sized and large-sized ships around Arctic waters of Northern Norway and the Svalbard archipelago between 1980 to 2006. They found 83.6% purely sea-spray icing events, 9.9 % sea spray along with atmospheric events, and 6.5% from fog events. Again, there are usually two methods of sea spray generation; the first is the sea spray generated by the ship wave interaction. This is considered the primary contributor to marine ice accretion and is often perceived as the only water source in icing models. The second is the wind-generated sea spray produced by the strong wind shearing droplets off a wave crest (spume droplets) and bubbles bursting in breaking waves creating atomized droplets (film and jet droplets). Though some models [12]–[15] considered the contribution of wind-generated spray in ice accretion on offshore platforms, but several others neglected its contribution for modeling icing on ships [16]–[18], as it is regarded to be a minor contributor.

This paper focuses on assessing the amount of ice accumulation that presumably destabilized the ONEGA vessel, which ultimately led to its capsizing. Firstly, the minimum ice-accretion thickness that decreased the initial stability is estimated by modeling the vessel using a hull-modelling program DelftSHIP. Next, another method is used to compare this estimate utilizing the Marine-Icing model for the Norwegian Coast Guard (MINCOG) [18]. The model is adjusted to estimate the total ice accumulation throughout the voyage for ONEGA until it capsized. This model is chosen as it is tested and verified against icing data set from ship types in Arctic waters. The model has delivered higher verification scores than previously developed ship-icing models and nomograms [19], and it is also the present operational model for providing sea-spray-icing forecast at the Norwegian Meteorological Institute. The spray-flux term used in the MINCOG model consists of the liquid water content (l_{wc}) i.e., the amount of water in a unit volume of dry air, and the spray-generation frequency. Samuelsen et al. [18] used Zakrzewski [16] l_{wc} formula derived from Borisenkov et al. [20] data from MV Narva (length 39.5 m) and Horjen et al. [21] data from Endre Dyrøy (length 63.6 m). They inferred that the spray-flux from the formulation derived from Horjen et al. [21] data is underestimated for low waves. For the spray-frequency calculation, it is assumed that every fourth wave-ship interaction creates a spray event for the KV Nordkapp-class vessel for which the MINCOG model is made. This is adopted according to the observations on a whaling ship [17]. This study also aims to shed light on the use of the empirical formulations in icing models based on a few data sets [20]–[22] from limited observations on medium-sized fishing vessels.

2. ICING ESTIMATION ON ONEGA

2.1 Icing Estimation Using Ship Model

ONEGA fishing vessel was built as a liner/trawler in 1979 by Vaagland Batbyggeri - Vaagland, Norway, and was initially named Remifisk. The vessel was later sold, and the name was changed to ONEGA and owned by Variant Fishing – Murmansk and sailed under the Russian flag.

TABLE 1. ONEGA SHIP PARTICULARS

IMO	7825590
MMSI	273445610
Flag	Russia [RU]
Port of registry	MURMANSK
Classification Society	Russian Maritime Register of Shipping
Hull Description	RS Class notation: KM★ R1 fishing vessel
Gross Tonnage	358 t
Summer DWT	208 t
Length Overall (LOA)	39.51 m
Breadth Extreme	7.7 m

For estimating the weight of ice that destabilized the ONEGA vessel, a 3D model was recreated using DelftSHIP according to the Lines plan, General arrangement plan, and Tonnage calculation. The plans are provided from the archive of the Norwegian Maritime Authority (Sjøfartsdirektoratet) for Remifisk, and to correspond the later modification new mid-ship section is inserted to match the elongation. A 3D DelftSHIP model is shown in **Fig. 2**, and the lines plan is given in the appendix in **Fig. 9**.

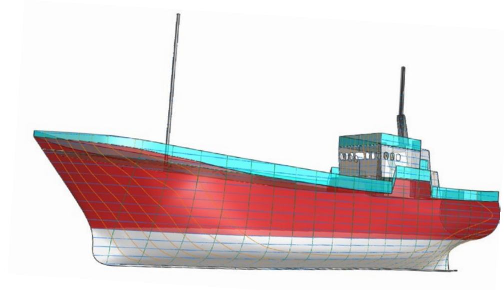

FIGURE 2: 3D MODEL OF ONEGA

All the exposed parts and projected lateral area of the vessel where icing can take place are identified **(Table 2 appendix)**. The identified sections are separated as vertical and horizontal surfaces, as according to Ryerson [23], observation of icing events on USCGC Midgett indicated that the accreted ice thickness on vertical surfaces was ≈ 75% of the ice thickness on horizontal surfaces. Ice density from USCGC Midgett icing events observation varied between 0.69 - 0.92 t m^{-3} [24]. Kultashev et al. [25] observed the density of ice on Soviet fishing trawlers ranging between 0.71 - 0.967 t m^{-3}. Tabata et al. [26] ice density observations from 4 vessels of 121 samples ranged between 0.62 - 0.94 t m^{-3}. Stallabrass [27] considered the average ice density as 0.89 t m^{-3}, and this value was also used by Samuelsen et al. [18] for their MINCOG model, thus this value is considered in this study for evaluating the ice weight.

According to the classification society of ONEGA – "Russian maritime register of shipping" rules for the Classification and Construction of Sea-Going Ships (Part IV) section 3.5 [28]: corrected initial metacentric height of fishing vessels under loading condition stated shall be not less than 0.35 m. Additionally, the icing allowance has to be accounted for the calculation of weight and center of gravity of the accreted ice in accordance with this rule section 2.4. It is assumed that the vessel was at least maintaining the minimum stability criteria prior to accretion. The last updated draft of the vessel by ship crew was 4.0 m on its Automatic Identification System (AIS); accordingly, these values are applied in the hydrostatic computations. Adding ice loads on the exposed parts (75% on vertical surfaces compared to horizontal surfaces, except the aft deck part where the superstructure shadows sea-spray), the minimum thickness of ice accretion on the ship which reduced its metacentric height (GM) to zero is evaluated. A value till GM zero is computed to estimate the ice thickness even though the vessel could probably withstand a negative GM and oscillate about the angle of loll. This is done as it is mentioned in the investigation [6] that icing was the reason for the initial reduction of GM. Ingress of water through the open hatch was stated to be the ultimate reason for negative stability, and a sharp increase in heel which led to capsizing.

2.2 Icing Estimation Using Icing Model

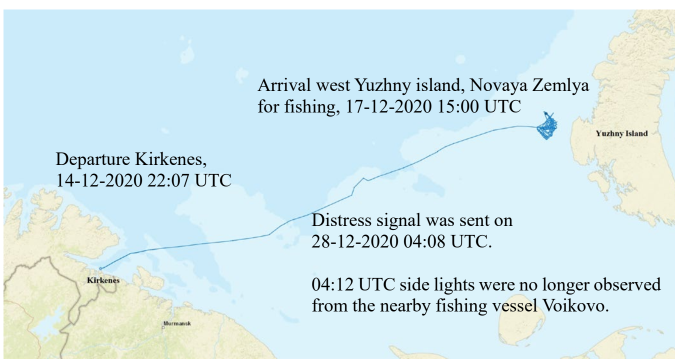

FIGURE 3: LAST VOYAGE OF ONEGA AIS DATA

When plotting the operational hourly forecast data with the vessel position, the MINCOG operational forecast give an icing warning from moderate to severe icing from 19-12-2020 09:00 UTC up until the vessel was lost **(Fig. 4)**. The MINCOG operational version assumes a vessel speed of 5.0 m s^{-1} and a head-on wave and wind direction. The droplet trajectory in the operational version is simplified by adding some drag-force effect by following a straight line from the initial position in the coordinate system following the boat, whereas in reality, the droplets follow a curved trajectory [18]. The output of the MINCOG is an instantaneous icing rate as a warning and is not inferred for integrating the total amount of icing over time. The model only considers the most important heat fluxes ($Q_f = Q_c + Q_e + Q_d + Q_r$), which is reasonable for continuous icing; for a more precise calculation Q_{cond} will have a certain effect for periodic and unsteady spray events [29]. For simplicity, the

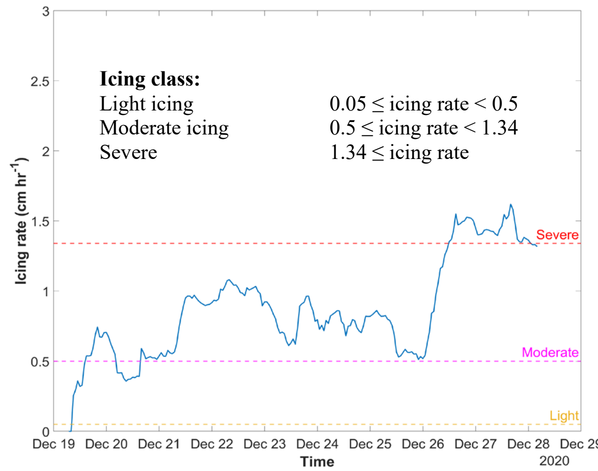

FIGURE 4: ICING RATE DURING VOYAGE OF ONEGA ACCORDING TO MINCOG OPERATIONAL VERSION

model assumes constant spray icing using a time-averaged spray-flux, which does not distinguish the periods with or without spraying for heat-flux estimation [18]. The spray-flux (R_w) in this model is expressed as [18]

$$R_w = E \cdot V_d \cdot n_l \cdot l_{wc} \cdot N \cdot t_{dur} \qquad (1)$$

where E is the collision or collection efficiency of the droplet and is considered unity, V_d is the 3D droplet velocity, n_l is the normal vector for the tilting plate, l_{wc} is the spray liquid-water content and averaging terms $N \cdot t_{dur}$ is the spray-frequency multiplied by the duration of spray.

In this study, according to the MINCOG model the vessel ONEGA experienced icing over a span of nearly 212 hours; hence the ice accumulation has to be evaluated over this period to be able to compare it with the amount calculated from our stability model. In order to do so, initially, the spray-flux calculation is altered and calculated without the time-averaging term and later considered ice accretion only during every spray event. Without the averaging term $N \cdot t_{dur}$ the spray-flux (R_w) expression becomes:

$$R_w = E \cdot V_d \cdot n_l \cdot l_{wc} \qquad (2)$$

By calculating the icing rate using Equation (2), the ice accumulation for every hour is obtained if the spray-flux was continuous for the whole hour. Then, to compute the ice accretion for only during each spray event, this value is multiplied with the spray duration and the spray-frequency for the vessel voyage speed for that hour taken from AIS data.

The l_{wc} formula used to compute the spray flux is given by Equation (3) Zakrzewski [16], where the constant 6.36 is adjusted slightly by Samuelsen et al. [30] due to a calculation error:

$$l_{wc} = 6.36 \times 10^{-5} H_s V_r^2 \exp(-0.55z) \qquad (3)$$

This formulation is derived from observations from MV Narva, whose dimension nearly matches our vessel ONEGA. The MINCOG model uses spray-frequency as $N = 1/4\, t_{int}$, assuming every fourth wave ship collision creates one spray jet, which is probably suitable for larger vessels as stated by Lozowski [17]. An average value of the observation data from ONEGA sized MFV [31] cited in Zakrzewski [8] shows that spray jet event occurs for every second ship-wave collision. Hence, $N = 1/2\, t_{int}$ is used in our calculation. The spray-duration is expressed as Samuelsen et al. [18]:

$$t_{dur} = 0.1230 + 0.7008\, V_r \cdot H_s \cdot V^{-1} \tag{4}$$

For wind speeds below 5.0 m s^{-1}, V_r is considered constant equal to 5.0 m s^{-1} to avoid impractical large spray-flux value for very low wind speed [19].

The computed ice thickness is integrated for every hour for the period the vessel was accreting ice. It is assumed that the vessel started accumulating ice from 19-12-2020 09:00 UTC until the vessel was lost and is not accounted for any melting or de-icing. It is considered a fair assumption as the air temperature dropped to negative at this time and always remained below -3 °C (**Fig. 5**) during rest of the period, and according to a survivor, "the whole ship was covered with ice" [32]. One thing that should be mentioned is that the data used for the icing model input are from operational numerical forecast models of the Norwegian Meteorological Institute, which may differ from actual measurements at the vessel location.

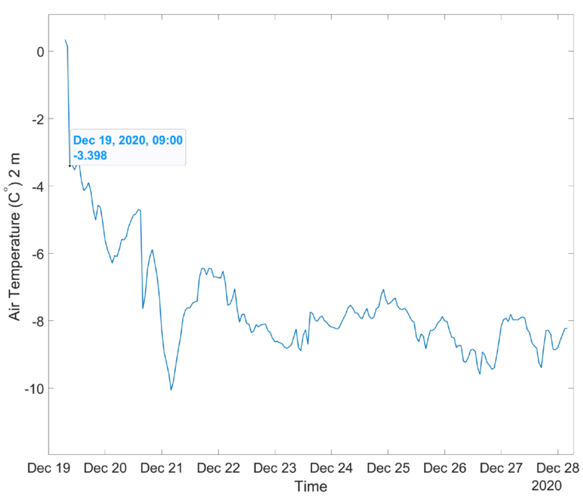

FIGURE 5: AIR TEMPERATURE (2 M) AND SEA WATER FREEZING TEMPERATURE DURING VOYAGE OF ONEGA

3. RESULT AND DISCUSSION

According to appendix **Table 2,** the ice-thickness estimation from the ship-model-stability calculation yields an ice thickness of 27.5 cm on horizontal surfaces and 20.6 cm on vertical surfaces (75%) that are able to reduce the metacentric height (GM) to zero. Next, utilizing the MINCOG model to compute the ice thickness for every hour and integrating the ice accumulation for the entire period, when the vessel began accreting ice until it capsized, yields a 19.4 cm ice thickness value (**Fig. 6**). Though these two ice thickness values from the two methods are comparable, it depends on a few assumptions. One of the key parameters that the output of the MINCOG model is dependent on is the spray flux, which in turn consists of important terms such as the liquid-water content and the spray-frequency. For these terms, several empirical formulae have been proposed:

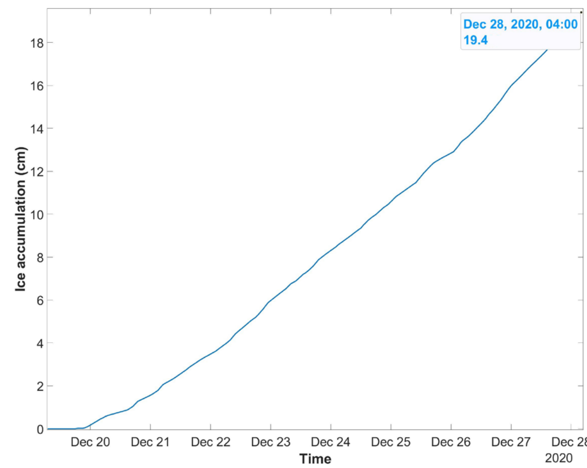

FIGURE 6: ICE ACCUMULATION DURING VOYAGE OF ONEGA FROM MODIFIED MINCOG

The two proposed spray-frequencies ($N = 1/4\, t_{int}$ and $N = 1/2\, t_{int}$) are based on observations from different sized vessel and their spray generation with wave interaction. For l_{wc}, Kachurin et al. [22] proposed a simple relation as a function of wave height, from an observation on an MFV named "Iceberg":

$$l_{wc} = 10^{-3}\, H_s, \tag{5}$$

Stallabrass [27] computed that the l_{wc} is one sixth of Equation (5) [33]:

$$l_{wc} = 1.7\times10^{-4}\, H_s \tag{6}$$

Borisenkov et al. [20] developed an empirical formula from MFV Narva observation:

$$l_{wc} = 2.36\times10^{-5} \exp(-0.55\, h), \tag{7}$$

but the expression did not include any environmental, ship motions or the observed water content terms [18]. This is only appropriate for a specific type of ship under particular sea conditions [34]. Based on this observational data [20], Zakrzewski [16], [30] developed Equation 3 by incorporating significant wave height and relative wave-ship speed terms. Samuelsen [35] formulated an expression that incorporates the physics of Roebber and Mitten [36]

$$l_{wc} = 9.5205\times10^{-4}\, H_s^2 \left(\frac{H_S}{\lambda}\right)^{0.5} V_{gr} \exp(-0.55z) \tag{8}$$

The constant is adapted from the weather information in Borisenkov et al. [20] as in the approach of Zakrzewski [16]. Comparing the results obtained by the different formulae to compute ice accumulation due to sea-spray is done in order to notice the variations in the result when calculating the total ice accumulation through a long period and not considering the dependency of this parameter for icing severity purposes. Fig. 7 and Fig. 8 are presented to show the variation in the ice accumulation in the ONEGA case utilizing the MINCOG model if different formulas are used for these two parameters.

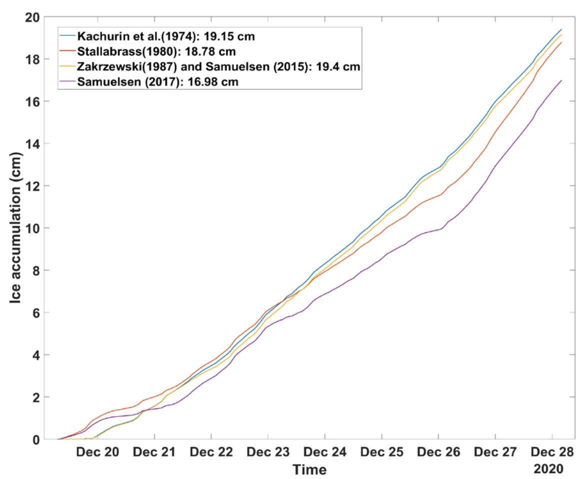

FIGURE 7: ICE ACCUMULATION ON ONEGA CALCULATED BY USING DIFFERENT lwc FORMULAS AND $N = 1/2\ t_{int}$

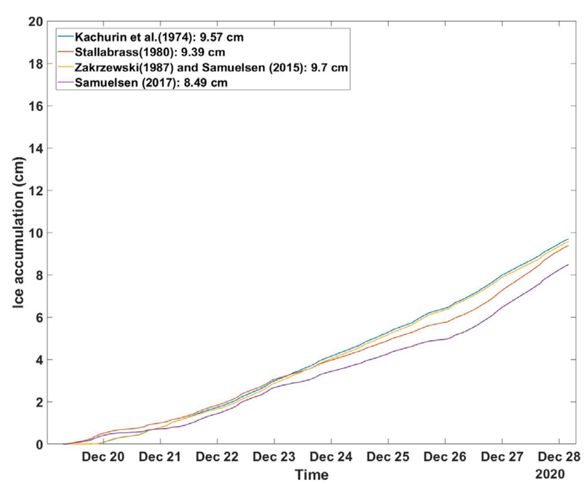

FIGURE 8: ICE ACCUMULATION ON ONEGA CALCULATED BY USING DIFFERENT lwc FORMULAS AND $N = 1/4\ t_{int}$

For the ONEGA case, one plausible reason for lower estimation in the amount of ice accumulation by the MINCOG model method in comparison to icing estimated by ship stability calculation is that the model does not account for wind-generated spray and atmospheric icing. The model is built based on the spray generated from only wave-ship interaction as it is believed to be the most dominating spray-flux source in ship-icing events. Zakrzewski [37] had argued that the wind spray would not affect icing on and above the deck of an MFV. However, his conclusion is based on Borisenkov et al. data [20], who had not recorded spray data for wind speeds over 19 m s^{-1}. CFD models used in Kulyakhtin and Tsarau [14] also show that the contribution of wind spray for icing is low, but since turbulent wind field during the statically unstable conditions plus mountain wave contribution during an actual icing event is likely different from that used in the models, their claim requires further investigations [35]. Nevertheless, at the location where ONEGA was fishing (west of Novaya Zemlya), the contribution of wind-generated spray towards icing should not be ignored. This location is in close proximity to mountains, which is associated with complex wind flow such as gap winds, trapped lee waves and downslope windstorms [38], which may cause wind speed to exceed 30 m s^{-1}. Also, the temperature at the lee side of the mountains may also be extremely low, despite adiabatic warming when descending the lee slope, due to low initial temperature upstream of the mountains in these areas in winter time. Also, the downslope windstorm is associated with the hydraulic jump and type II rotors with rising motion which can generate significant wind-generated sea spray and lift larger droplets to higher elevations which may contribute to vessel icing. Vessel icing events during such a phenomenon have been reported in coastlines of Northern Norway and Svalbard [11] and in the Russian coast of the Black Sea [39]. Shestakova [40] investigated the risks of ship-icing in the Arctic-Russian waters. The investigation found a possibility of frequent hazardous vessel icing events during a downslope windstorm phenomenon on the west coast of Novaya Zemlya, which is regularly observed here, around 138 days per year. The study also found that the ONEGA incident happened during a downslope windstorm, leading to wind gusts up to 32 m s^{-1}.

4. CONCLUSIONS

Vessels operating in cold regions are endangered from the risk associated with ice accretion, mainly due to sea-spray. The icing forecast models deliver a solution by estimating ice accretion rates as a warning for vessels operating in such regions. The accuracy of the models is difficult to verify as it is challenging to acquire accurate observation data during such events. This study aims to provide a comparative overview of the amount of icing the vessel accretes during its voyage compared to the amount calculated by an operational weather forecasting model by adjusting it to estimate accretion for an extended period. The incident of the MFV ONEGA is selected for this purpose. The vessel catastrophically sank on the west coast of Novaya Zemlya. By modeling the ship, an estimate is made for the potential minimum amount of ice accretion from stability calculation that likely destabilized the vessel. Then by adapting the MINCOG icing model the ice thickness is estimated for the duration of the ONEGA voyage in the period the vessel was accreting ice. The ice accumulation calculated from the MINCOG model method for our case is also tested using previous researchers work on liquid-water content and spray-frequency empirical formulas to see its dependency on these critical elements. Though the results from the stability calculation and the icing model are comparable under certain assumptions, the MINCOG method yields to some extent lesser ice accretion thickness than that from the stability calculation. One probable reason is that, like some other ship-icing models, the MINCOG model spray-flux expression does not include the contribution of wind-generated spray. Although some researchers showed its contribution towards vessel icing is negligible, which may be valid in the open sea, observations indicate that its impact may not be neglected in proximity to complex mountainous terrains, especially in locations prone to downslope windstorms. The icing model uses liquid-water content formulation in the spray flux calculation, which is derived from limited observations collected from medium-sized fishing vessels. Also, the spray frequency considered is derived from a limited number of observations and based on the ship speed relative to the surface of an oncoming wave, and not accounting for other vessel parameters. The empirical spray-flux expressions derived by researchers from a few past observation data sets provided valuable contributions for the icing model; however, further investigation and field spray data collection are imperative for scrutinizing the contribution of factors such as wind spray. This may help develop a more appropriate spray-flux formulation to estimate ice accumulation over a longer duration and make the icing model more robust.

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APPENDIX

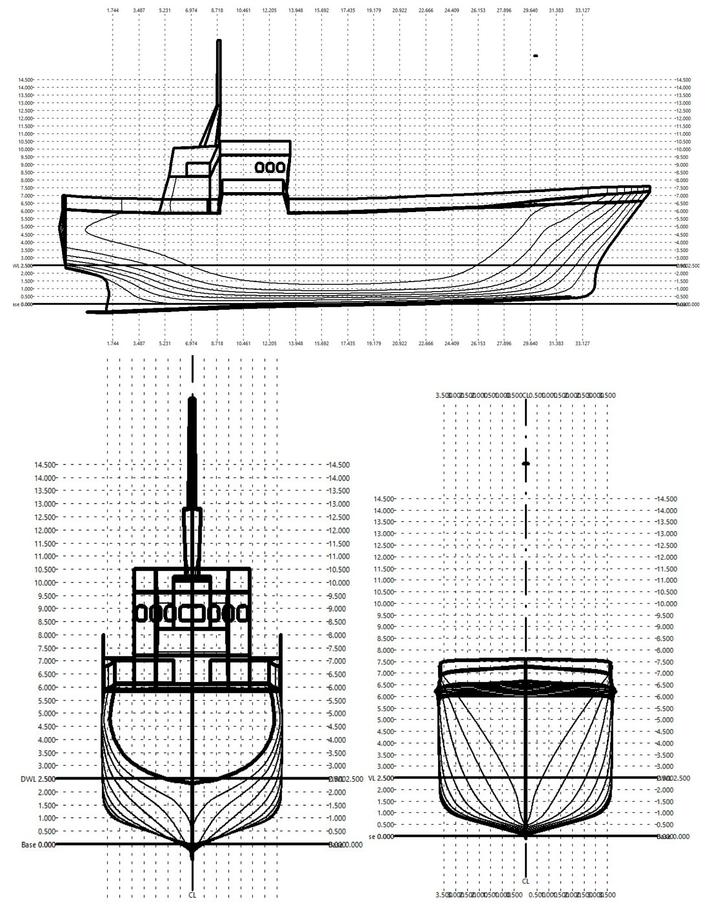

FIGURE 9: LINES PLAN OF RE-CREATED ONEGA DELFTSHIP MODEL

TABLE 2. ICING CALCULATION FROM THE SHIP MODEL

Icing Location	Area	LCG	TCG	VCG	Ice Density	Ice Thickness	Ice Weight	Ice consideration (regulation)	Ice consideration
	m^2	m	m	m	t/m^3	m	t	t/m^2	t
Front deck	160.75	24.368	0.000 (CL)	6.195	0.89	0.275	39.3435625	0.03	4.8225
Bridge access Vertical	6.5	11.148	0.000 (CL)	6.476	0.89	0.20625	1.19315625	0.03	0.195
Bridge access Horizontal	10.91	11.112	0.000 (CL)	7.1	0.89	0.275	2.6702225	0.03	0.3273
Aft deck	61.07	3.206	0.000 (CL)	5.929	0.89	0	0	0.03	1.8321
Accommodation - Aft Horizontal	8.16	7.047	0.000 (CL)	9.174	0.89	0.275	1.99716	0.03	0.2448
Accommodation - Fwd Horizontal	22.47	11.25	0.000 (CL)	9.6	0.89	0.275	5.4995325	0.03	0.6741
Accommodation - Fwd Vertical	17.21	13.182	0.000 (CL)	7.725	0.89	0.20625	3.159110625	0.03	0.5163
Accommodation - Side Vertical	51.68	8.785	0.000 (CL)	8.069	0.89	0.20625	9.48651	0.03	1.5504
Accommodation - Aft Vertical	19.11	6.93	0.000 (CL)	7.797	0.89	0.20625	3.507879375	0.03	0.5733
Railing	66.89	15.495	0.000 (CL)	6.691	0.89	0.20625	12.27849563	0.0075	0.501675
Bridge railing	17.72	10.85	0.000 (CL)	9.807	0.89	0.20625	3.2527275	0.0075	0.1329
Aft mast	9.98	8.61	0.000 (CL)	12.664	0.89	0.20625	1.83195375	0.0075	0.07485
Fwd Mast	11.97	30	0.000 (CL)	11.22	0.89	0.20625	2.197243125	0.0075	0.089775

Draft	FW Displacement	Displacement	LCB	VCB	TCB	KMt	Initial GM (before ice consideration)	KGt(before ice consideration)	Rise in G due to ice consideration	Initial GM (after ice consideration)	KGt (after ice consideration)	KMl	MCT	It	Il	BMt	BMl	TpCm	Final GM
m	t	t	m	m	m	m	m	m	m	m	m	m	t*m	m^4	m^4	m	m	tonne/cm	m
4	715.602	733.492	16.133	2.39	0	3.863	0.35	3.513	3.566827724	0.403827724	3.459172276	35	7.118	1054	23612	1.473	33	2.543	-0.00208612

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