Sea ice impact on naval operations

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Abstract. This paper highlights the icing regime and its impact on the primary naval operations conducted in the Black Sea basin. The article analyzes seawater's phenomenon freezing through the perspective of merchant shipping operations and underlines the impact on underwater or surface warfare. The article figures out the impact on the ship hull, weapons systems, personnel, as well as the tactics aspects of operations or de-icing strategies when ice accrues on ship hull and equipment. The article points out associated meteorological phenomena and brings in attention the importance of meteorological and oceanographic observations in situ or by satellites as a condition for the success of the operation. In the end, the article concludes regarding shortfalls faced during icing periods and give some directions meant to curb the adversary effects of unfavorable icing environment.

1. Background
The Black Sea basin lies between latitudes of 40 - 46°N and longitudes and longitudes of 27 - 41°E [1]. The horizontal exchange of waters with other seas is weak; the Black Sea is connected with the Marmara Sea by Bosporus Strait and linked with the Azov Sea through Kerch Strait; for this reason, referred to as semi-enclosed sea [2], [3]. Moreover, the horizontal exchange of water is low, but the vertical one is reduced [2].

The catchment area encompasses broad regions from Europe and Asia including basins of main rivers the Danube, Dniester, Dnieper, Bug or Don contributing to the significant freshwater influx of about 3 x 10^2 km^3 annually which explain the low salinity of the Black Sea waters of approximately 18 ‰ [2], [4].

The bathymetry of this basin is characterized by an extended shelf in the NW and a narrower one in the SE part, the maximum depth being 2.200 m – S of the Crimea Peninsula [2-4].

From the strategic point of view, the Black Sea region is a hot spot with the concurrence of interests of at least two military powers, namely NATO and Russia [4]. As the Black Sea located in a temperate region, sea ice is likely to occur during the winter season [5].

The present paper will analyze sea ice formation's mechanism emphasizing the freezing of seawater surface and sea spray icing as a result of a combination of meteorological and oceanographic factors [5], [6]. On the sea can, also, be encountered ice of riverine provenience resulted from melting of upward river ice sheets or so-called topside icing due to precipitation rain or snow freezing on decks or upper structures. The present paper will not address these sorts of ice though they have a noticeable impact on naval operations [5-8].

1.1 Freezing of seawater
The formation of sea ice started when certain favorable conditions met. The first condition is the seawater temperature below the freezing point. Knowing that freshwater starts freezing at 0°C while
Seawater with 35‰ salinity freezes at a temperature below -2°C. With its salinity of 18‰, the Black Sea waters have reasonably assessed that start freezing at temperatures lower than -1°C [4, 5].

The two contributors to raising seawater density are salinity and cooling. The waters from the surface with a higher density will sink, and underneath layers will come up, the cycle repeated until the whole colon of water-cooled from the surface up to seabed. Specific to the Black Sea basin is the pronounced stratification of water, the particular case for freezing, being enough to be cooled the upper layer as the lower one, having a different density, will act as a boundary. Shallow waters are susceptible to freeze first as the cooling of the entire colon will occur easier, is the case of the NW part of the Black Sea characterized by a broad shelf [4, 5].

The incipient stage of ice formation commences with the appearance of some ice crystals – frazil ice, which usually floats in a vertical position and gives the sea surface an oily aspect. These crystals further evolve in a greasy layer called grease ice. The next stage represented by small porous bulges with dimensions up to few centimeters – shuga ice. All these sorts of ice encompassed in a broad category: new ice. Further, slightly circular chunks form pancake ice, which can unite together, resulting in an almost continuous sheet – young ice, which can be cracked by wave action. Young ice can further enlarge developing field ice or pack ice. Young ice thickness is ranging from 10 to 30 cm. The next stage of ice development is first-year ice with thickness above 120 cm. Specific to our study area, the Black Sea basin, in the mid-winter, first-year ice can be encountered [5, 7-9].

1.2 Sea spray icing
Sea spray icing is a severe risk for naval operations. Sea spray is an outcome of the interaction between wave and the lower part of the ship (Figure 1) and, in some exceptional circumstances, by heavy wind lift small particles of seawater from the wave crests. The latest way of producing sea spray is less productive than the interaction ship-wave [5, 10, 11].

![](image)

Figure 1. Sea spray result of ship – wave interaction [10]

The ships can sink, capsize, experience excess roll and pitch or become disabled due to the accumulation of ice on decks and superstructures. The accretion of significant loads of ice can lift the center of gravity on a ship enough to result in a destructive loss of stability [7, 10, 12].

Small ships are more prone to be exposed to sea spray, and a somewhat lesser load of ice suffices for destabilization [11].

The icing of sea spray occurs due to the incidence of two categories of factors: environmental and ship features. The environmental factors consist of:

- **wind** – speed, and direction related to vessel;
- **air temperature**;
- **seawater temperature** – related to the freezing point;
Regarding the ship features, the most significant role in the occurrence of spray icing are:
- speed;
- length;
- freeboard;

Not, at last, the handling of the ship and the cold soaking phenomenon can facilitate the icing of seawater spray. The ship is cold-soaked when the quantity of the heat generated is equal with the quantity of the heat lost. The smaller and low freeboard ships are more exposed [6], [7], [11].

2. Methods
This section investigates sea ice's occurrence conditions from spray source and freezing of the surface of the water. The study will investigate the Romanian Black Sea shore, and the values expressed for Constanta meteorological station.

For the surface of the water, freezing investigated the temperature of air and sea surface and the speed of wind for the period of 01 – 10.02.2012.

![Figure 2. Ta - air temperature, Ws -wind speed and SST-Sea Surface Temperature during the period of 01 – 10.02.2012][13], [14]

All data used in the table above were measured respectively modeled daily at 12.00 UTC.

Further, in order to analyze the possibility of producing sea spray icing for ships with lengths between 20 and 75 m, the following formula is satisfactory:

\[
IP = \frac{W_s(T_f-T_a)}{1+0.3(SST-T_f)}
\]

where:
- IP \([\text{m}^0\text{C}\cdot\text{s}^{-1}]\) = icing predictor;
- \(W_s \text{ [m}^0\text{s}^{-1}]\) = wind speed;
- \(T_f [^0\text{C}]\) = seawater freezing temperature;
- \(T_a [^0\text{C}]\) = air temperature;
- \(SST [^0\text{C}]\) = sea surface temperature [11].
Taking into consideration the low salinity of the Black Sea, we assess that $T_f = -10^\circ C$.

Further, the values obtained using formula (1) will be used along with Table 1 to assess the icing rate for ships with lengths between 20 and 75 m.

### Table 1. Icing classes and rates [11]

| IP | < 0 | 0 – 22.4 | 22.4 – 53.3 | 53.3 – 83.0 | >83.0 |
|----|-----|---------|------------|-------------|------|
| Icing class | Light | Moderate | Heavy | Extreme |
| Icing rates [cm/h] | 0 | <0.7 | 0.7-2.0 | 2.0 – 4.0 | >4 |

3. Results and discussion

#### 3.1. The occurrence of sea ice

As can be observed from Figure 2 at the beginning of February 2012, the conditions for sea surface freezing met, and starting with 03.02.2012 fast to the shore ice sheet was reported. Though starting with 04.02.2012, the $T_a$ and SST started to increase can be observed in Figure 3 that the ice sheet was present even on 22.02.2012. The said figure can be observed, as a ridge shape, the delimitation between salt waters of the Black Sea and the freshwater of the Danube river, the caption made in the vicinity of the mouth of the Danube River (Chituc area).

![Figure 3. 22.02.2012 – Sea ice in the NW part of the Black Sea [15]](image)

Measurements on sea ice in February revealed a thickness of around 1 m and even 2 m in the vicinity of piers or other marine structures [16].

#### 3.2. Probability of sea spray ice accretion

The result of the calculus of probability of sea spray icing occurrence for the period of 01 – 10.02.2012 presented in Table 2.

### Table 2. Sea spray icing probability 01-10.02.2012 [11], [13], [14]

| Day | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 |
|-----|----|----|----|----|----|----|----|----|----|----|
| IP  | 53.37 | 6.70 | -20.74 | -24.90 | -33.94 | -12.59 | -10.83 | 13.45 | 18.42 | 23.50 |
| Icing class | Heavy | Light | - | - | - | - | - | Light | Light | Moderate |

Analyzing values from Table 2 and the chart from Figure 2, we can easily observe that sea spray icing for ships with a length between 20 and 75 m can occur when the air temperature is negative, and sea surface temperature is also negative or close to zero. We mention that though from calculus exists...
a noticeable probability to occur icing of sea spray, in practice, if anti-icing measures are correctly applied, most probably ships will not accrue ice.

3.3. Impact of ice on naval operations
This section analyzes the impact of ice on different systems onboard ships, ship hull, and different naval operations and activities conducted during cold and icy weather.

Majority of systems are affected by icing conditions, but just most relevant are analyzed below:

- **Hull, propellers, shaft, rudder, and appendages** – vulnerable to damage, plastic deformations are likely to occur when ships navigate in ice infested waters posing a significant risk of accidents with impact on property, personnel life and environment [3], [17], [18], [19];

![Figure 4. Deformation of the hull – ship climb the ice [17]](image)

- **Personnel** – slippery decks and surfaces, cold sea spray and low air temperatures increase risk of accidents for personnel or negatively impact work and life conditions onboard or even can abort or postpone operations which imply personnel exposition to cold weather or water [6], [7], [20];

- **Aircrafts** – slippery decks, iced flight deck machinery, obstruction of path indicators, foreign object debris (FOD) concealed in snow or ice are elements which hinder the safety of flight deck and aircraft operations [6], [21];

- **Weapon systems** – generally torpedoes and missiles are kept in climatized storages, some malfunctions can occur when on the launchers due to icing and low temperatures. Guns are the most reliable but still due hydraulics and mechanical parts can encounter some difficulties in operations [6], [8], [21];

- **Batteries** – a significant reduction in the output for normal rate discharge and critical for high rate discharge like cranking [7], [21];

![Figure 5. Impact of sea ice on military operations [22]](image)

- **Hydraulic systems** – increased viscosity of fluids, clogging of intakes, small chunks of ice entering in the chest or fire main systems, failure of seals, o-rings, moisture in fuel diminishing combustion performances are just some of the issues encountered by these systems.
3.4. De-icing

Any workable strategy of countering harmful icing effect starts before the icing occurrence. Issuance and posting of all materials prescribed by classification societies to exist for de-icing are of paramount importance.

Training of personnel, seamanship, maneuver, and handling of a ship constitutes the factor of success in an ice infested environment.

An accurate ice forecast to be maintained at all times along with a proper look-out carried both visually and with radar means.

Not at last the use of models and satellite data offered by different services (NOAA - National Oceanographic and Atmospheric Administration, NCEP - National Centers for Environmental Prediction) in order to predict ice accretion and to take timely and effective mitigation actions [11].

4. Conclusions

Despite its geographic location, the Black Sea experience almost every winter fast ice fields with thickness reaching 2 m in the piers or shore structure areas posing a significant risk of damage of ship’s hull or systems and equipment onboard.

Compared with the ships meant to navigate in arctic waters, which are ice-strengthened, the ships navigating in temperate areas have to compensate these hull improvements through adequate training of crews, proper handling, and maneuver of the ship, discipline onboard and commitment to success.

Planners have to anticipate sea icing periods and schedule operations to produce a maximum effect for friendly forces.

Salvage and towing ships must be well prepared and equipped to provide assistance to ships in distress or open safe routes to leading ports in icing.

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