NATIONAL ICE SERVICE OPERATIONS AND PRODUCTS AROUND THE WORLD

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Summary

This chapter is about sea ice – what it is, how it is monitored, by whom and how the information about the dynamically changing sea ice cover is conveyed to those that need this information for efficient and safe navigation. The increase of international shipping activities generated by economic and social developments, transportation needs and utilization of natural resources, are prominent particularly in areas susceptible to sea ice. As sea ice affects marine transport and navigation significantly and directly, provision and development of services for monitoring and forecasting sea ice coverage has generated an increased interest globally.

Specialized meteorological services, originally developed to support local mariners, have developed their service portfolio to support users, providing a wide range of sea-ice information services.

To understand the nature of sea ice, some knowledge is needed about how sea ice is formed, as well as the most important characteristics of the frozen sea. Sea ice occurs in many forms and the ice cover is described by ice analysts in ice charts summarizing the most significant parameters of the sea ice.

Earth Observation technology (satellites) is playing an increasing role when monitoring the ice cover, especially in remote areas where it is difficult to obtain in situ

observations. The possibilities and use of different satellite sensors is described in the sections below.

Also advances in numerical forecasting methods that utilize improved weather forecasts, combined with satellite observations, will enable better and more reliable forecasts to be utilized in ship routing and guidance. This will result in safer and more economic transportation.

1. Background and Need for Ice Services

Marine transport and navigation is affected significantly and directly by sea ice which occurs in a wide range of types and forms. Shipping activities generated by economic and social developments, transportation needs and extraction of natural resources are susceptible to sea ice in the Polar seas and other areas like the Baltic Sea and Yellow Sea. To support the mariners, specialized meteorological services have expanded to include a wide range of sea-ice information services.

The presently-observed reduction of the Arctic sea ice extent, in particular during the summer months, and an increasing demand for natural resources are the key mechanisms that are driving increased human activities in the Arctic. Companies and governments are looking north for commercial opportunities and security of supply of important non-renewable raw materials. The Arctic region is estimated to contain potentially as much as 13% of the remaining undiscovered reserves of oil and gas, with the largest reserves expected to be found in the Russian Arctic. Minerals and metals are abundant in the region. Parts of the Arctic Ocean – especially the open areas close to the ice and the zone where warm and cold water meet – are extremely bountiful in terms of marine life. The ocean is a major fishing area. The timber potential near parts of the Arctic onshore areas is also huge. The Arctic also has considerable tourism appeal, as one of the few remaining areas on earth still dominated by pristine wilderness.

Most studies see any major increase in Arctic shipping based primarily on economic activity within the region, e.g., export of the different Arctic commodities such as oil and gas, minerals, timber and forest products, coupled with imports of equipment and supplies to support the extraction of such resources. Also navigation in the Northern Sea Route (NSR) (part of the Northeast Passage) has increased. There has been a significant increase in the number of vessels using the NSR in recent years, although the volumes are still small compared to shipping in other parts of the world and the numbers show a large variation from year to year (see Figure 1). Some prognoses estimate that shipping along the Northern Sea Route could account for as much as a quarter of the cargo traffic between Europe and Asia in 2030. Dependent on future ice condition changes, marine activity will shift if the marginal ice zone (MIZ) shifts.

The physical conditions for maritime operations in the Arctic are more challenging, by an order of magnitude, than operations in other isolated waters. These include extreme air temperatures and thick ice with large ridges. In the open water conditions, storms can be very rough and unpredictable, and icing on ships can be very heavy. Multi-year ice and icebergs are a constant threat to both ships and platforms. Arctic waterways along the shores are relatively shallow, which limits navigability with large ships.

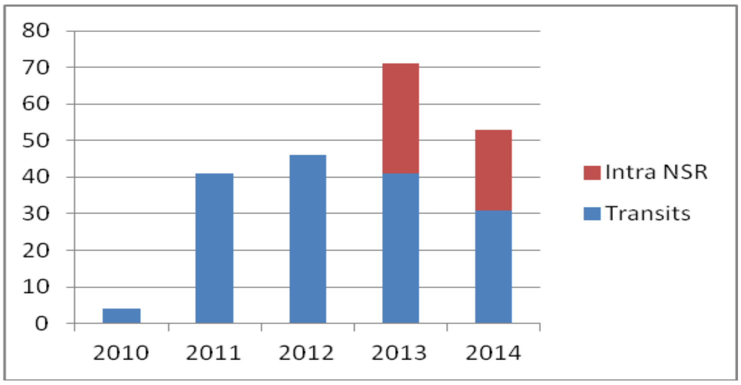

Figure 1. Number of ship transits through the Northern Sea Route (NCRIO, 2015)

2. Sea Ice

Sea ice is the result of freezing of the sea surface. Both sea ice and ice originating from land (icebergs), can be dangerous to shipping and thus have an effect on navigation. As sea ice may cover large areas of the sea (about 7% of the total area of the world oceans) it has a significant impact on the interaction between atmosphere and ocean. An ice cover on the ocean's surface acts as an insulating layer that effectively reduces energy exchange between water and air. The ice surface also reflects the greater part of the sun's radiation back to space, thus preventing some energy absorption by the ocean. This in turn slows down new ice formation (referred to as the *sea ice-albedo feedback mechanism*). Thus the sea ice extent is also of great interest to meteorologists, oceanographers and climatologists.

2.1. Formation and Development of Sea Ice

Definitions of different types of sea ice are primarily based on how thick or old the ice is and is categorized by specific so-called stages of development. Using these categories, the magnitude of the obstacle or hazard presented by sea ice to vessels or structures can be estimated.

The freezing of the sea surface is made possible through loss of heat from the water bulk into the atmosphere. As a result the water is cooled below the freezing point and tiny ice crystals start to form. On a calm water surface, such as in leads or in sheltered areas close to shore, the new ice forms directly as a continuous thin layer called *ice rind* or *nilas*. When growing thicker, this ice builds up a well-organized structure of ice crystals giving it very transparent appearance. At its thinnest it is called *dark nilas*, showing the dark color of the water as it is easily penetrated by light. This effect decreases with increasing thickness, leading to the terms *grey ice* and *light nilas*.

In typical ocean conditions, however, there is usually some kind of a wind-induced wave field at the sea surface. Therefore the turbulent sea surface causes the sea ice freezing process to start by forming small ice platelets or flakes, called *frazil ice*. The layer of frazil ice typically extends a few centimeters from the surface. In this layer the ice flakes first create a slush-like suspension which simultaneously dampens the smallest surface waves, making the surface look oily. This effect, together with the matt appearance, has caused this ice type to be called *grease ice*.

When the grease ice gradually grows thicker the frazil finally solidifies, forming small plates of consolidated slush. These ice plates collide into rounded ice floes with higher edges, aptly named *pancake ice*. These pancakes gradually grow larger in both size and thickness (up to 3-5 m and 50-70 cm, respectively) and finally consolidate to a uniform ice sheet.

Collectively ice rind, nilas or pancake ice that has thickened into grey ice and grey-white ice, is called *young ice* as long as the thickness is below 30 cm.

When young ice is developing further, it is called *first-year (FY) ice* and is subdivided into thin, medium and thick ice depending on the ice thickness. *Thin FY* has a thickness between 30 and 70 cm, *medium FY* a thickness between 70 and 120 cm while *thick FY ice* may attain a thickness up to 2 m.

One particular characteristic of ice formed by sea water is that the growth of the ice crystals tries to reject the salt. This partly fails, leading to salt brine being captured inside the ice, creating a network of brine channels or pockets. During the thickening of FY ice, the brine remains more or less in the structure in which it was captured. This results in a relatively porous composition compared to ice that has formed from freshwater. The porous characteristics of FY sea ice make it a little more sensitive to breaking or crushing forces, and consequently easier to penetrate by a vessel.

If the first-year ice survives the summer, it is then classified as *old ice*. Old ice can be further subdivided into *second year* and *multi-year* ice (MYI). It still experiences melting during the summer season, but continues to grow during the next freezing season. This cycle of melting and refreezing has a big impact on the shaping of the typical characteristics of MYI. During the melt period the snow cover on top of the ice sheet melts to create pools of water or slush. The so-called melt ponds may grow so large in width and depth that they melt their way all the way through the ice. In this way a large portion of the melt water may be flushed off the ice through these thaw holes. The melting water also penetrates the ice fabric through pores and channels in the ice. As most of these channels are remnants of salt brine from the first freezing process, most of that brine gets flushed out from the ice. Now fresh melt water replaces the brine and when this freezes it creates an ice sheet of much greater strength than before. By this strengthening, but also by its greater thickness, old ice poses a much greater obstacle to maritime operations and makes it more of a hazard to navigation than first-year ice. Old ice can also be distinguished from the more greenish shade of first-year ice by its bluish color which it obtains from the optical properties of pure fresh water.

2.2. Ice Drift

Sea ice may also be classified according to whether it is moving or is stationary. If the ice cover is attached to islands or the coastline, it does not move and is called *land-fast ice*, or just *fast ice*. Alternatively *drift ice* is in continuous motion, driven by wind and sea current forces. When the drift ice covers most, or all, of the water surface and has undergone deformation processes, it often is called *pack ice*. The portion of the sea surface that is ice-covered is expressed by a *concentration* value. It is usually given in tenths as a fraction of the whole area. The ice concentration is divided in different classes where 1/10 to 3/10 of coverage corresponds to the class *very open ice*, 4/10 to 6/10 *open ice*, 7/10 to 8/10 *close ice*, 9/10 to 10/10 *very close*, *compact* or *consolidated ice*.

The strength of the wind-induced force depends on the speed of the wind and the characteristics of the sea ice surface. A rough ice surface is affected more by the wind than a smooth surface. Because of the strong correlation between wind and sea ice drift, freely drifting sea ice can be assumed to move at approximately 2 percent of the wind speed. The directionality of free drift depends on the size of the moving sea ice; larger pieces of sea ice move at the higher range of 20 to 40 degrees to the right (Northern Hemisphere) or left (Southern Hemisphere) of the wind direction due to the Coriolis force. Other factors do also contribute to the free drift of sea ice, but the simple relationship between ice drift and wind explains up to 70 percent of sea ice motion on a daily to weekly basis.

Currents are an important factor in longer-term (monthly to yearly) ice motion. In some instances and regions (e.g. in shallow waters or where tidal effects are significant), currents may have a large impact on the drift pattern, even over short periods of time.

2.3. Ice deformation

As long as an ice cover has not undergone any deformation and forms a smooth homogeneous sheet, it is called *level ice*. As soon as it is subject to large enough horizontal driving forces (induced by winds and currents) it gets squeezed together, the ice blocks piling up on top of each other and forced upwards and downwards: that is, the ice becomes *deformed*.

In new and young ice this often results in *rafting* as the ice floes are pushed to override each other. In thicker ice fields the ice breaks under the compressive forces and forms *ridges* or *pressure ridges*, linear piles of broken ice blocks. In the ridging process, large quantities of ice are pushed downwards because of the weight of the ice in the ridge. The draft (depth of the part under the sea level) of a ridge may be 3 to 5 times the height of the ridge, thus causing ridges to be major obstacles to navigation. The thickness of pressure ridges can be from a few meters to more than 30 meters, depending on ice formation type and circumstances.

Sometimes an ice field experiences very heavy and lengthy compressive forces where virtually all of the level ice is deformed and the whole area consists of ridged ice. These *rubble fields* are very challenging for any shipping operation.

When ice deformation happens in shallow waters the ridge draft (or keel depth) may exceed the water depth. In these cases the deformed ice becomes grounded, sometimes piling up high above the water surface. This kind of a pile is called a *grounded ridge* or *grounded hummock*. Also the name *stamukha* (from Russian) is becoming common for this ice feature. As these stamukhi are fixed formations, they often determine the fast ice edge by fastening the ice between themselves and a shoreline. At ice breakup, on the other hand, they go afloat forming large, freely-drifting chunks of ridged ice, so called *floe bits* or *floe bergs*, which easily endanger shipping.

When drift ice is deforming in certain areas, a natural consequence is the formation of openings in other areas. In these open zones the drift ice may break up and become evenly distributed, simply decreasing the ice concentration. The more common behavior, however, is the formation of wide openings along a fast ice edge or along the edge of thicker pack ice. These openings are called *leads*. In locations where the weather patterns typically keep pushing the ice away from a shoreline, the open water areas are called *polynyas*.

From the perspective of navigation or off-shore activities, ice deformation is a critical phenomenon, since ships and structures are exposed to the same forces that cause deformation in the ice itself. This stress experienced by ships is called *ice pressure* and may cause serious damage to a ship's hull, steering and propulsion system. The most dramatic consequence of ice pressure is that a ship may be pushed aground by the ice masses, or such serious damage is inflicted on a vessel that it sinks.

2.4. Icebergs

Icebergs originate from glaciers on land. Some icebergs, typically in the Arctic region, break off as soon as the glacier stream meets the ocean. In the Antarctic it is more common that glaciers flow out over the sea, extending as floating ice shelves or glacier tongues. Tides and swell then systematically break pieces off the edges. The outcome of this *calving* can be icebergs more than 100 km long. Large icebergs eventually break into smaller pieces and most bergs are typically a few hundred meters in diameter, in the Antarctic waters a little bit larger than in the Arctic.

As in the case with all floating ice, having a slightly lower density than liquid water, icebergs show only a small part of their volume above the water surface. The visible part represents a little more than 10% of the iceberg's volume. Due to differences in formation mechanisms, Antarctic icebergs typically have a more tabular form where the uppermost 10 – 20 m is composed of an intermediate form of snow and ice called *firn*. The lower density of firn (compared to solid ice) is why a tabular iceberg presents a greater part of its volume above the water than icebergs with other shapes. In particular, icebergs of irregular shape may have surprising extensions beneath the water line. They are also often very unstable. The unevenly distributed mass, in combination with various melting and break-up processes, can result in sudden overturning.

While icebergs melt reasonably slowly, they also tend to drift long distances in the sea currents. The drift speed and direction is mainly dictated by the ocean currents as they have a relatively greater effect on the iceberg than the wind. However the shape of the iceberg also influences the drift behavior, the sidewalls acting as sails set in random sense and causing irregular drift paths. The average drift speed of an iceberg is considered to be less than half a knot, but speeds of up to two knots have been recorded.

Because of their significant draft, icebergs easily *ground* or get stuck on the bottom. They either drag their keels along the seabed causing deep *scours* on the bottom or they just get jammed until they disintegrate into smaller pieces or melt before drifting further.

Icebergs decay by calving, melting and erosion caused by waves and swell. When a floating iceberg calves, its equilibrium can be disturbed whereby the iceberg may change its orientation or even capsize.

Disintegrating icebergs form a particular hazard to navigation as there are likely to be many *growlers* and *bergy bits* around the iceberg. These fragments are large enough to cause damage to the ship hull when the ship cruises at normal speed. Unfortunately these growlers and bergy bits are usually very difficult to detect with the ship's radar as sea clutter and swell obscure the backscatter radar signal from the ice object itself.

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Biographical Sketches

Robin Berglund (M.Sc).graduated from Helsinki University of Technology, Computer Science, Department of Technical Physics in 1981. Since 1996 Mr. Berglund has worked at VTT Technical Research Centre of Finland and now holds a position as a Senior Scientist in the department of *Environmental Data Solutions.* He has been Project Manager on several projects related to developing telematics applications for maritime users, with a focus on winter navigation.

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