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Finnish Institute of Marine Research



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University of the Faroe Islands

Nordic Arctic Research Programme

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Authors (in alphabetic order):

Henrik Steen Andersen, Halla Björg Baldursdóttir, Robin Berglund, Jyrki Haajanen, Guðmundur Hafsteinsson, Torill Hamre, Thor Jakobsson, Ville Kotovirta, Morten Lind, Leif T. Pedersen, Roberto Saldo, Stein Sandven, Ari Seinä, Knud Simonsen and Renne Tergujeff

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Nansen Environmental and Remote Sensing Center (NERSC) Edvard Griegsvei 3A N-5059 Bergen, Norway Phone: + 47 55 29 72 88 Fax: + 47 55 20 00 50 E-mail: Stein.Sandven@nrsc.no	**Finnish Institute of Marine Research (FIMR)** Lyypekinkuja 3 FIN-00931 Helsinki, Finland Phone: +358 9 6139 4440 Fax: +358 9 6139 4494 E-Mail: Ari.Seina@fimr.fi	**Technical Research Centre of Finland (VTT)** Tekniikantie 4B, PO Box 1201, FIN-02044 Espoo, Finland Phone: + 358 9 456 6018 Fax: + 358 9 456 6027 E-Mail: robin.berglund@vtt.fi
Danish Meteorological Institute (DMI) Lyngbyvej 100 DK-2100 Copenhagen, Denmark Phone: + 45 39157350 Fax: + 45 39157390 E-Mail: hsa@dmi.dk	**Technical University of Denmark (DTU)** Danish Center for Remote Sensing, Department of Electromagnetic Systems (EMI), Building 348, Technical University of Denmark, DK-2800 Lyngby, Denmark Phone: + 45 45881444 Fax: + 45 45931634 E-Mail: ltp@emi.dtu.dk	**Icelandic Meteorological Office (IMO)** Bustadvegur 9 IS-150 Reykjavik, Iceland Phone: + 354 522 6000 Fax: + 354 522 6001 E-Mail: thor@vedur.is
University of the Faroe Islands Faculty of Science and Technology, Torshavn, Faroe Islands Phone: + 298 352562 Fax: + 298 352551 E-mail: knuds@setur.fo		

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Executive Summary

This report gives an overview of the atmospheric, sea ice and ocean conditions in the Nordic region, including the Baltic Sea, Greenland and Icelandic Waters, the Northern Sea Route and the Nordic Seas, with a focus on how ship traffic is affected and needs updated information to plan and conduct navigation more safely and efficiently.

The use of models and observing networks in monitoring and forecasting of sea ice in two regions, the Baltic Sea and Greenland Waters, is described. Main products available from each of these ice services are listed. The role of satellite data in sea ice monitoring is then discussed in general terms, outlining how new high-resolution image data can be used in an operational context.

A system for distribution of met-ice-ocean data and information via Internet and other communication networks (e.g. satellite or mobile phone) is described, and examples of how such products can be delivered in real time shown. This system has been developed during an EC-funded project IWICOS (Integrated Weather, Sea Ice and Ocean Service System).

The report also contains numerous links to organisations, institutes, international programmes, etc. working with issues related to atmospheric, sea ice and ocean conditions in the Nordic region and Arctic or Antarctic regions. Extensive contact information is provided for ice services around the world, and Internet links are given for these and other entities working with meteorological, sea ice and ocean data and information products.

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1 Introduction

1.1 Overview of atmosphere, sea ice and ocean in the Nordic region

The sea ice occurs on average higher than latitude 60º. The northern Atlantic Ocean is an exception, where the Golf Stream carries warm water northwards all the way to Svalbard in the north and past Murmansk in the east and keeps these areas ice-free. In lower latitudes, smaller sea areas are ice covered, like the Baltic Sea in Europe, Gulf of St. Lawrence in Canada and Sea of Ohotsk in the Pacific Russia. The Bohai Bay in China (between latitudes 36ºN and 40ºN) is the sea area nearest to the Equator, which annually is ice covered.

Sea ice is a part of the cryosphere, which interacts continuously with the underlying oceans and the overlaying atmosphere. The growth and decay of sea ice occur on a seasonal cycle at the surface of the ocean at high latitudes. The seasonal global and regional variability in ice extent and concentration can be observed by satellites such as the Special Sensor Microwave Imager (SSM/I) onboard the Defence Meteorological Satellite Program (DMSP). As much as 30 million km² of the earth's surface can be covered by sea ice (Table 1.1). In the Northern Hemisphere, sea ice extent (area enclosed by the ice boundary) fluctuates each year from a minimum in September, when most of the ice is confined to the central Arctic Ocean, Greenland Sea and Canadian Archipelago, to a maximum in March, when the ice covers almost the entire Arctic Ocean and many adjacent seas. In the Southern Hemisphere, the annual fluctuation is even greater, from a minimum in February to a maximum in September when the ice surrounds the Antarctic continent and extends equatorward to 55° - 65° S (Gloersen et al., 1992). Figure 1.1 shows example of maximum and minimum ice extent in both hemispheres observed by passive microwave satellite data. Figure 1.2 shows ice conditions over the northern Hemisphere on 12 February 2001.

The largest volume of sea ice is found in the northern hemisphere in March, 0.05 mill km³, which is nearly twice the maximum ice volume in the southern hemisphere. The reason for this is that the mean thickness of the Arctic sea ice is about 3 m, whereas the mean thickness of the Antarctic sea ice is 1 -1.5 m.

Sea ice research and monitoring is an important area for many countries at high latitudes including those who operate in the Antarctica. Sea ice imposes severe restrictions on ship traffic in Arctic countries, it is a sensitive climate indicator, and plays an important role in exploration and exploitation of marine resources.

Sea ice has many roles in the global climate system. For one, it serves as an effective insulator between the ocean and the atmosphere, restricting exchange of heat, mass, momentum and chemical constituents. During winter when there is large temperature difference between the cold atmosphere and the relatively warm ocean surface, ocean-to-atmosphere heat transfer is essentially limited to areas of open water and thin ice within the pack. The winter flux of oceanic heat to the atmosphere from open water can be two orders of magnitude larger than the heat flux through an adjacent thick ice cover. As a result, the distribution of open water and thin ice is particularly important to the regional heat balance.

Table 1.1 Sea ice cover, volume and ice thickness in the northern and southern hemisphere.

Maximum and minimum estimates	**Area (106 km²)**	**Volume (106 km³)**	**Ice thickness (m)**
Northern hemisphere winter	16.0	0.05	0-5
Northern hemisphere summer	9.0	0.03	0-5
Southern hemisphere winter	19.0	0.03	0-2
Southern hemisphere summer	3.5	<0.01	0-2
Baltic Sea winter	0.2	<0.002	0-1
Baltic Sea summer	0.0	0.0	0.0

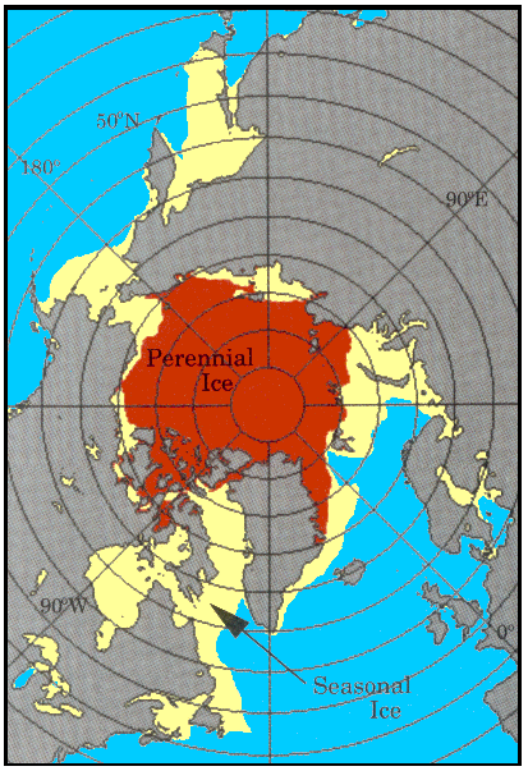


Figure 1.1 Sea ice distribution in the northern hemisphere.

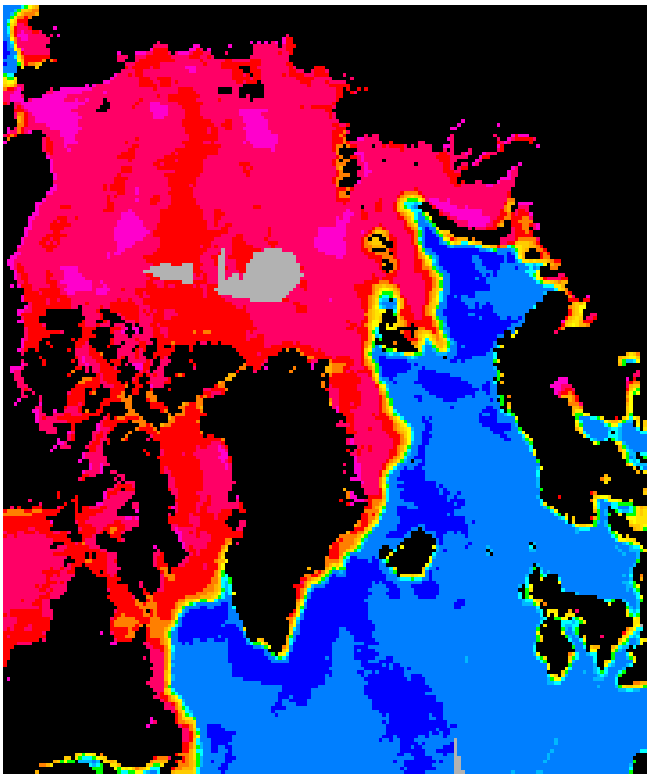


Figure 1.2 Ice conditions over the Northern hemisphere on 12 February 2001. Sea ice in red and open water in blue. © DTU, 2001.

Another important role of sea ice in the global climate system is that it affects surface albedo. Ice-free ocean generally has albedo below 10 - 15 %, whereas snow-covered sea ice albedo average about 80 %. A fresh snow cover on the ice can increase the surface albedo to values as high as 98 %, whereas melt ponds can decrease the ice albedo to as low as 20 %. Because the albedo of snow-covered sea ice is high, relative to that of open water, the presence of sea ice considerably reduces the amount of solar radiation absorbed at the earth's surface. This is most significant in summer, when the isolation, or solar heating is high.

Sea ice processes also affect oceanic circulation directly by the rejection of salt to the underlying ocean during ice growth. This increases the density of the water directly under the ice, thereby inducing convection that tends to deepen the mixed layer. This convection contributes to driving the thermohaline circulation of the ocean and, in regions with density structures that were initially weak or unstable, can lead to overturning and deep water formation. Much of the world oceans' deep and bottom water is believed to be formed in polar latitudes by these mechanisms. Conversely, the input of relatively fresh water to the ocean during ice melt periods tends to increase the stability of the upper layer of the ocean, inhibiting convection. Furthermore, the net equator-ward transport of ice in each hemisphere produces a positive freshwater transport and a negative heat transport.

On hemispheric scale, the seasonal variability of ice extent and ice edge location is controlled by atmospheric and oceanic forcing, which include ocean temperature and salinity and atmospheric temperature and winds. The location of the ice-edge will in turn feedback on several atmospheric and oceanic processes which has effect on the regional weather, such as generation of polar lows. On regional scale surface roughness of the ice and the drag coefficient depend upon ridging and rafting, both of which can be produced by wind or wave-induced ice convergence. Ice observation is therefore important for weather forecasts at high latitudes.

Data from polar orbiting satellites are used extensively in research as well as monitoring of sea ice. However, the most important sea ice parameter is ice thickness, which cannot be measured accurately by any space-borne instrument today (*Wadhams, 1994*). The key objective in sea ice science during the next decade is to achieve the capability of synoptically measuring sea ice thickness in both hemispheres. Data on ice thickness are very sparse, especially in the Antarctica. Our estimates of sea ice volume, which are mainly based on model results due to lack of data, can have errors of + 50 %. In the Arctic there are a few synoptic surveys of ice thickness obtained by submarine sonar and point measurements from expeditions and drifting ice stations. The data sets available provide some information about regional and seasonal variability, but they are too sparse to provide any information about temporal changes.

General circulation models predict enhanced climatic warming in polar areas, and this should be reflected in a decreased mean sea ice thickness as well as possible changes in the intensity of pressure ridging. Without a technique to map sea ice thickness routinely, however, such changes can not be detected. Only a satellite-borne method can achieve the required coverage in time and space without prohibitive cost, and this will have to be a technique, which measure topography directly, since imaging methods (active and passive microwave, visual, infrared) do not yield thickness but only an identification of ice type.

1.2 The Baltic Sea

The Baltic Sea affects the lives of 85 million people living at the draining area of the Baltic Sea in Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Russia and Sweden. The largest city in the area is St. Petersburg with over 5 million inhabitants.

The Baltic Sea is a semi-closed sea located in the northern Europe between approximately 53°50´ - 64°50´ N and 09°20´- 30°20´E and connected to the North Sea through the Kattegat and Skagerrak (Figure 1.3).

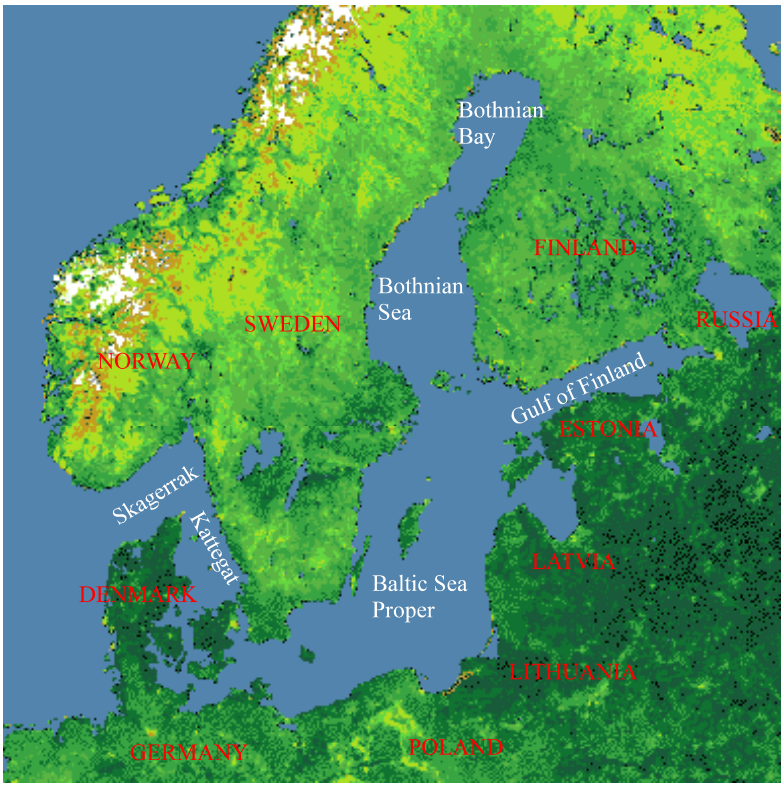


Figure 1.3 The Baltic Sea, divisions and surrounding countries.

The Baltic Sea including the Kattegat covers 420,000 km². The Baltic Sea is a basin with a mean depth of 56 m and a maximum depth of 459 m. In autumn the water column is well mixed, being homogenous to some 60 m between October and March. The water in the Baltic Sea is brackish, with surface water salinity ranging from 9‰ in the south-west to fresh water at the mouth of the River Tornio in the northernmost Bothnian Bay and River Neva in St. Petersburg. (Voipio, 1981).

The maximum annual ice cover of the Baltic Sea ranges from 52,000 km² to 420,000 km² (12-100 % respectively) being on average 218,000 km² (Seina et al., 1996) (Figure 1.4). In the Bothnian Bay and in the eastern Gulf of Finland the probability of ice occurrence is 100 %, the 50 % probability lying in the northern Baltic Sea at around latitude 59° N, while 10 % covers the southern Baltic Sea. The maximum annual ice extent occurs between January and March (Seina et al., 1991).

Ice formation begins in the northern Bothnian Bay in early November, and in the Gulf of Finland in early December. The Bothnian Bay is covered with ice on an average by mid-January and the Sea of Bothnia by mid-February. The Gulf of Finland freezes over completely on average in late January, not completely freezing over in mild winters. The normal ice cover break-up starts in April, by the beginning of May the only remaining ice is situated in the Bothnian Bay, and by the end of May – beginning of June the melting of ice is complete. The average ice season duration varies from < 20 days in the northern Baltic Sea Proper to 190 days in the northern Bothnian Bay, being 5-7 months in the northern archipelago of the Bothnian Bay (Seina et al., 1991).

The ice in the Baltic Sea occurs as fast ice and drifting ice. Fast ice occurs in coastal and archipelago areas where the depth is less than 15 metres. It develops during the early ice season, remaining stationary to the melting period. The maximum measured fast ice thickness is 122 cm.

The drifting ice has a dynamic nature being forced by winds and currents. The drift ice movements are large: in the stormy conditions, the ice field can move 20-30 km during a single day. The motion results in an uneven and broken ice field with distinct floes up to several kilometres in diameter, leads and cracks, slush and brash ice barriers, rafted ice and ridges. The ridges and brash ice barriers are the most significant obstructions to navigation in the Baltic Sea. The maximum measured depth of an

ice ridge keel is 28 m below sea level. Powerful, ice-strengthened vessels can break through ice up to 80 cm thick, but they are not capable of navigating through ridges and thick brash ice barriers without icebreaker assistance. The ice dynamics affects navigation considerably - high pressure in the ice field can be dangerous to the vessels and may at least cause the vessels time delays of from hours to days.

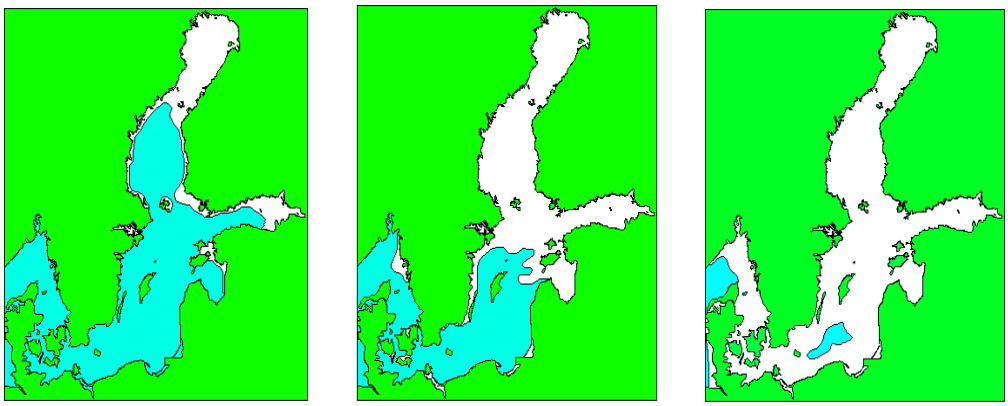


Figure 1.4 Classification of ice seasons in the Baltic Sea. Examples of the maximum ice cover for extremely mild (1994/95 with 68,000 km²), average (1993/94 with 206,000 km²) and extremely severe (1986/87 with 405,000 km²) ice seasons. Image Analysis © FIMR.

1.3 Sea ice and icebergs near Greenland

1.3.1 Introduction

Sea ice and icebergs are natural obstacles and hazards for most kinds of ship based operations in all parts of the Greenland Waters. However, the physical characteristics, drift and distribution show recurrent phenomena on annual basis and high degree of variability at longer or shorter timescales. The basic physics, characteristics and dimensions as well as the uneven distribution of sea ice and icebergs will be described in the following sections.

1.3.2 Sea ice

Basically, two ice regimes dominate the Greenland shores and waters (see Figure 1.5 and Figure 1.6):

- The East Greenland Ice, locally called “Great Ice” (in Danish: Storis) due to the thickness of the ice - thickness 3-4 meter.
- The Davis Strait Ice, locally known as the “West Ice” - thickness 0.5-1.5 meter.

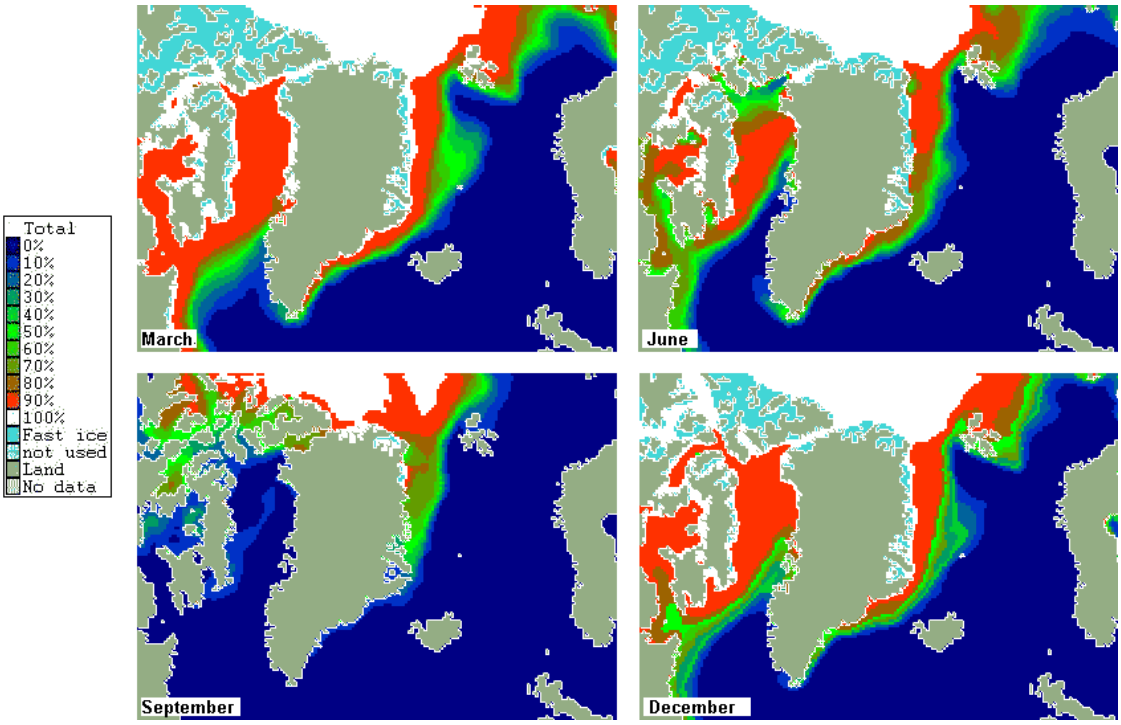


Figure 1.5 Normal and extreme distribution of sea ice (Mean sea ice concentration) around Greenland for March, June, September and December. 50% may be interpreted as a normal distribution. 0-10% and 90-100% as maximum and minimum distribution, respectively at this time of the year. [Source: WMO Global Digital Sea Ice Databank].

The East Greenland Ice is several years old and originates from the Arctic Ocean and drifts south to the Greenland shores in the Transpolar Drift Stream and the East Greenland Current. The normal thickness of these huge amounts of sea ice is about 3-4 meters but thinner ice types, first year ice, young ice is also present (see Figure 1.7).

The annual ice flux through the Fram Strait is 2400-2800 km^3 pr. year but varies from year to year as well as from season to season. The meridional southward sea ice flux through the Fram Strait is generally 3-4 times larger during the winter than in the summer months.

An important reason for this is that the seasonal change in the sea ice flux is the intensified sea level air pressure gradients (see Figure 1.8) due to frequent and deep lows near Southeast Greenland in the winter period. Also, the seasonal changes in freshwater input to the Arctic Ocean and the East Greenland Current contributes to the variability the meridional ice drift.

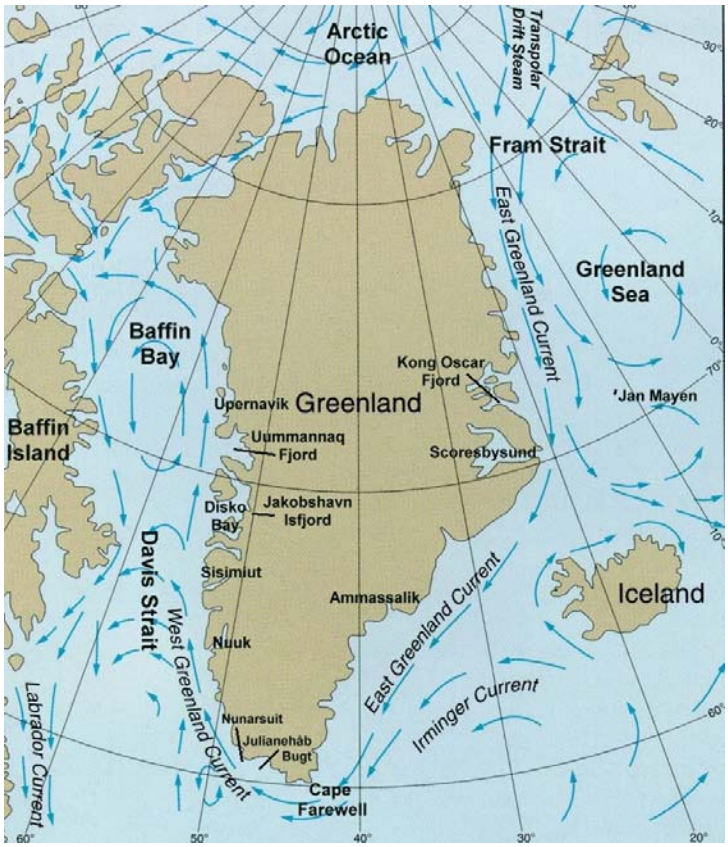


Figure 1.6 Major ocean surface currents near Greenland and the geographical place names used the present description.

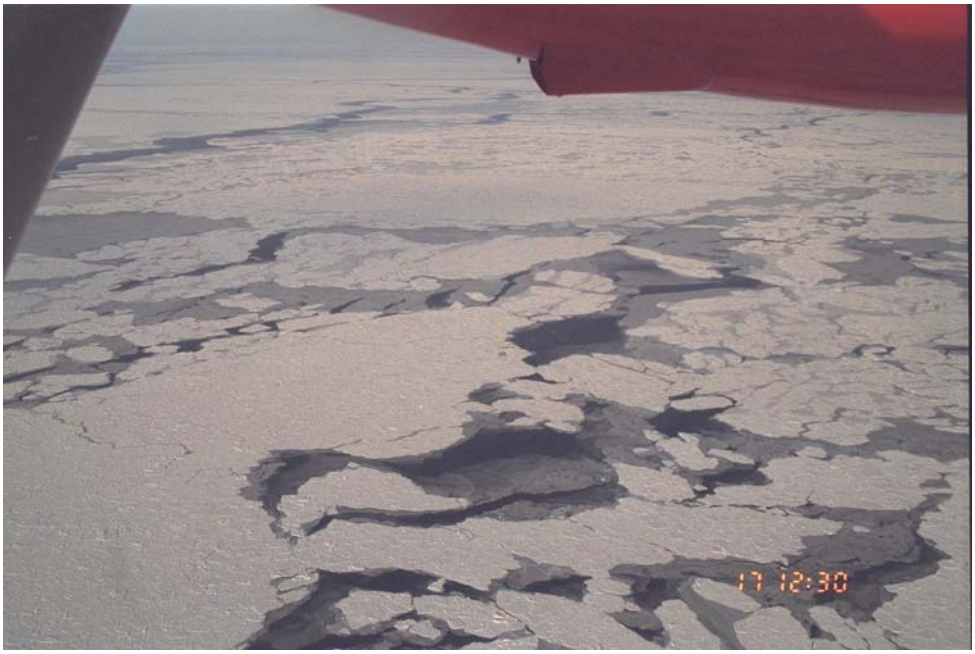


Figure 1.7 The Greenland Sea 17. March 2001 near (73ºN, 10ºW). Large floes composed refrozen small multi year ice floes. Between the larger floes of thick ice open water, nilas (<10 cm) and grey ice (10-15 cm). [Photo: Keld Q. Hansen]

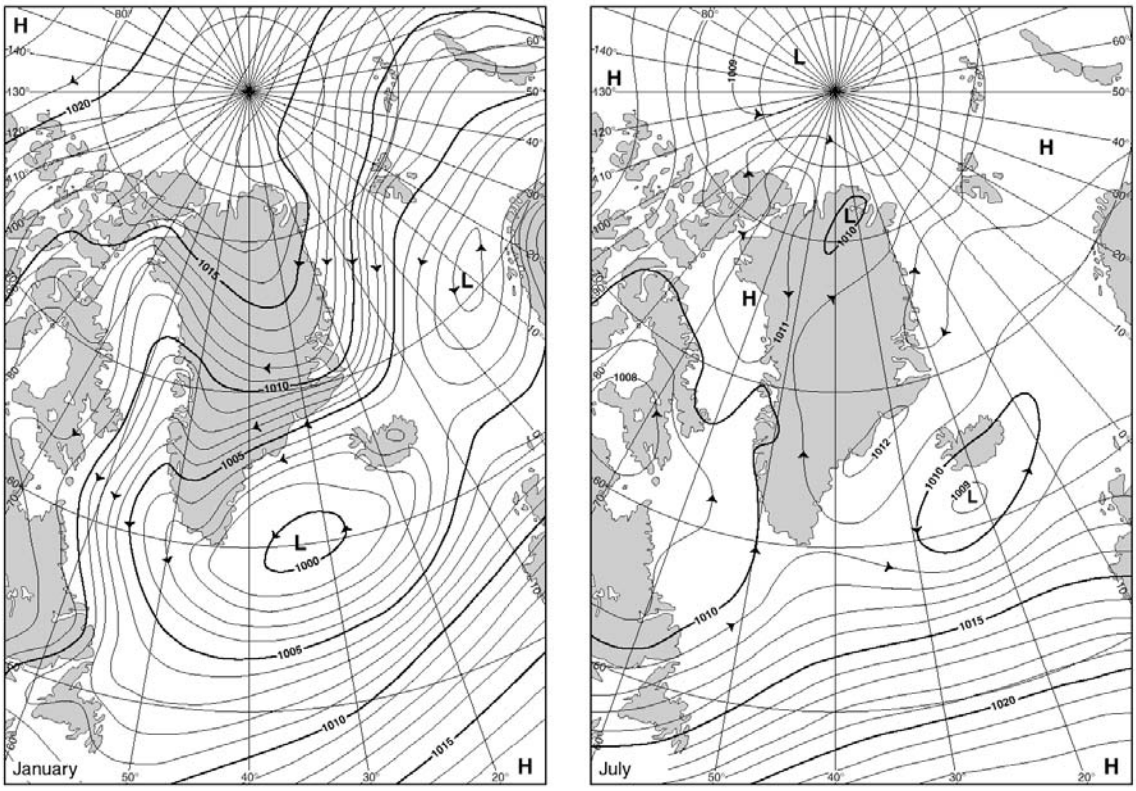


Figure 1.8 Mean sea level air pressure (hPa) winter and summer.

Normally, the East Greenland Ice retreats to the waters near Scoresbysund in early September but in the fall the ice rapidly drift south in the East Greenland Current and normally reaches the Cape Farewell area in late December.

Normally, the multi year ice distribution peaks in May/June in the South Greenland Waters and melts away in early August. Only a few percent of the ice that enters the Fram Strait will reach the Cape Farewell area due to melt and break-up, and the typical floe diameter decreases on it's way south from many kilometres to less than 100 m. However, the thickness of the ice is only reduced marginally and even in the Cape Farewell area the normal floe thickness is more than 2 meters.

In spring and summer the multi year ice of Arctic Ocean origin frequently drift into Julianehåb Bugt, pass Nunarsuit (see Figure 1.9 and Figure 1.10) and drift northwards along the west coast, from time to time north of latitude 62ºN The length of the South Greenland ice season and the northernmost distribution varies irregularly from year to year (see Figure 1.11). Normally, multi year sea ice is present near Cape Farewell until early August.

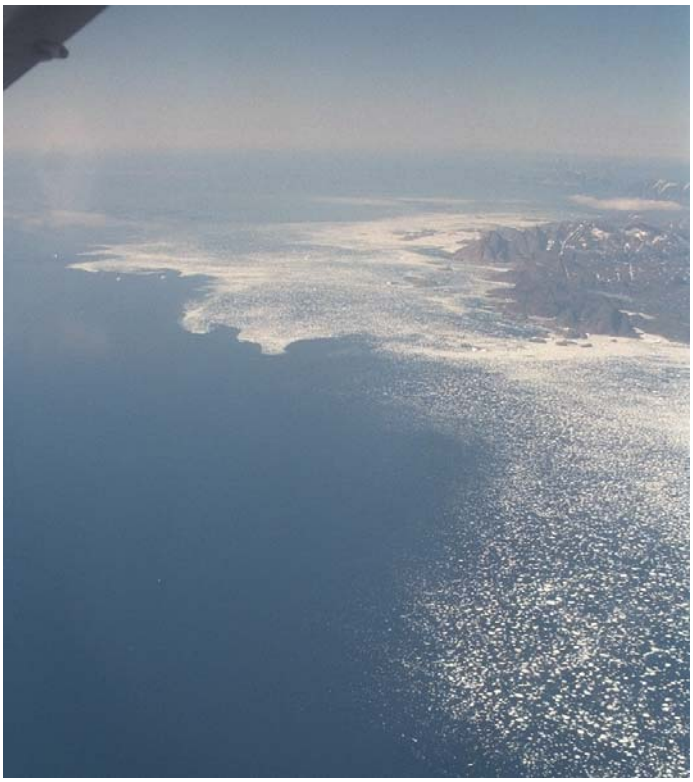


Figure 1.9 Medium to high concentrations of multi-year ice near southwestern Nunarsuit June 8th 1998. The dominant floe diameter is 10-20 meters in diameter. Photo taken from an altitude of about 8000 feet. [Photo: Keld Q. Hansen].

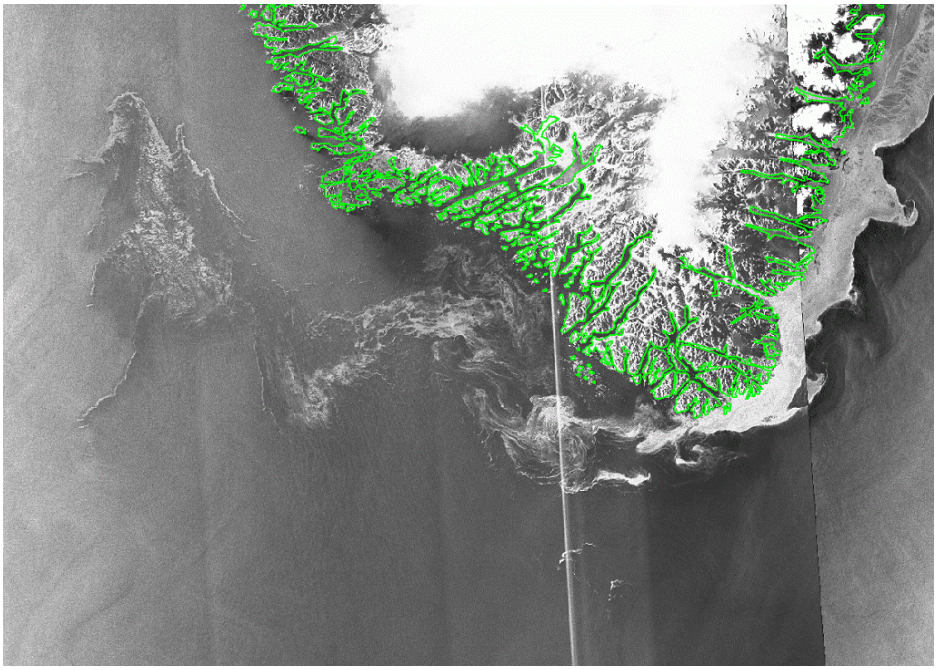


Figure 1.10 A RADARSAT ScanSAR Wide scene from May 12, 2000 20:48 UTC covering part of the Cape Farewell area. The pixel size is 100 meters. Huge amounts of multi year ice (small floes) is present west of Cape Farewell. The satellite orbit is ascending and consequently the left part of the image is in near range and the far range is to the right. The bright line parallel to the beam seams is a characteristic artifact of this particular ScanSAR mode (i.e., nadir ambiguity) © Canadian Space Agency, 2000.

Multi-year ice observed North of 62°N ('West Ice' not included)

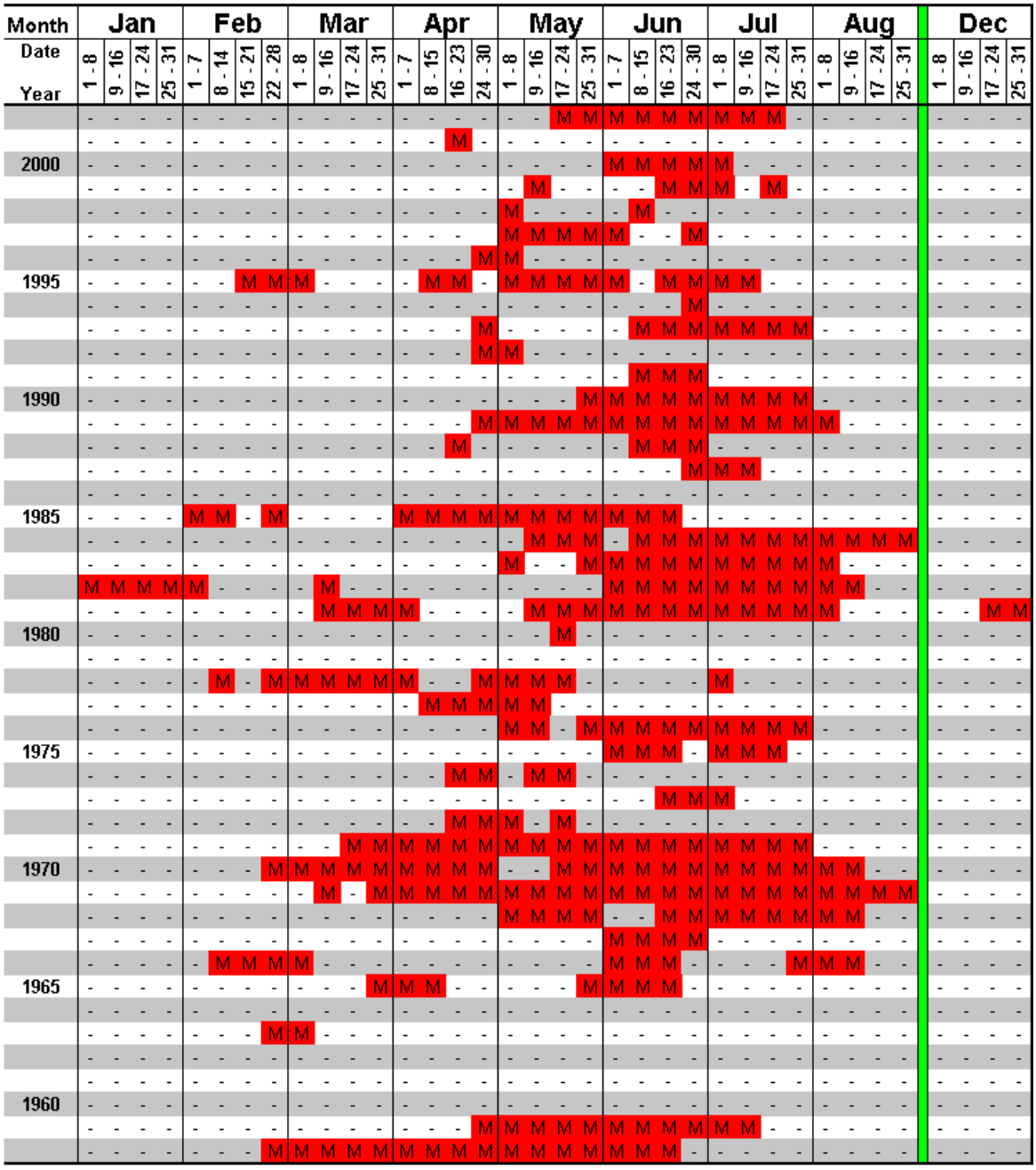


Figure 1.11 The occurrence of multi-year ice (from the East Greenland coast) at the Greenland West Greenland coast, north of 62°N for the period 1958-2002. Each month was split into four time periods of 7 or 8 days, and when multi-year ice was observed north of 62ºN, at least once in a period, it is indicated in the table.

The formation of the Davis Strait sea ice begins in Late October in north western Baffin Bay and through November the ice rapidly covers most of Baffin Bay and western Davis Strait. By early January young ice forms in Disko Bay and the waters north of Sisimiut are characterized by very large floes of first-year ice drifting south (see Figure 1.12).

The waters south of Sisimiut are normally free of sea ice due to the relatively warm West Greenland Current. Through short periods these near shore waters may freeze and be covered with young ice, however, the sea ice near the west coast of Greenland is sensitive to wind.

Frequently atmospheric lows move northward into the Davis Strait and generate easterly winds near the Greenland shore and these events often create open water as north as Sisimiut. Only during very cold winters first year ice will be present in the entire area and the “open water cities” Nuuk and Sisimiut will be unreachable by ship, except for icebreakers.



Figure 1.12 First year ice (thickness ~ 1 meter) in large floes, June 14th, 1997 in Eastern Baffin Bay near (74ºN,54ºW). [Photo: Keld Q. Hansen].

Through the Arctic winter fastice forms in bays and fjords. Further offshore the mobile high concentration drift ice is present. Nevertheless, some recurrent open water areas, known as polynyas, appear close the shore or fastice edge deep inside the ice pack. Near Greenland some polynyas exist (see Figure 1.13) and the largest are “The North Water” in northern Baffin Bay and “The Northeast Water”.

The formation of a polynya may be caused by local melting or divergence in the local sea ice drift and by definition a polynya be characterized as a “sensible heat polynya or a “sensible heat polynya”. Behind these features can be several local physical reasons, and some times combinations of reasons to explain the specific reason for the presence of a polynya.

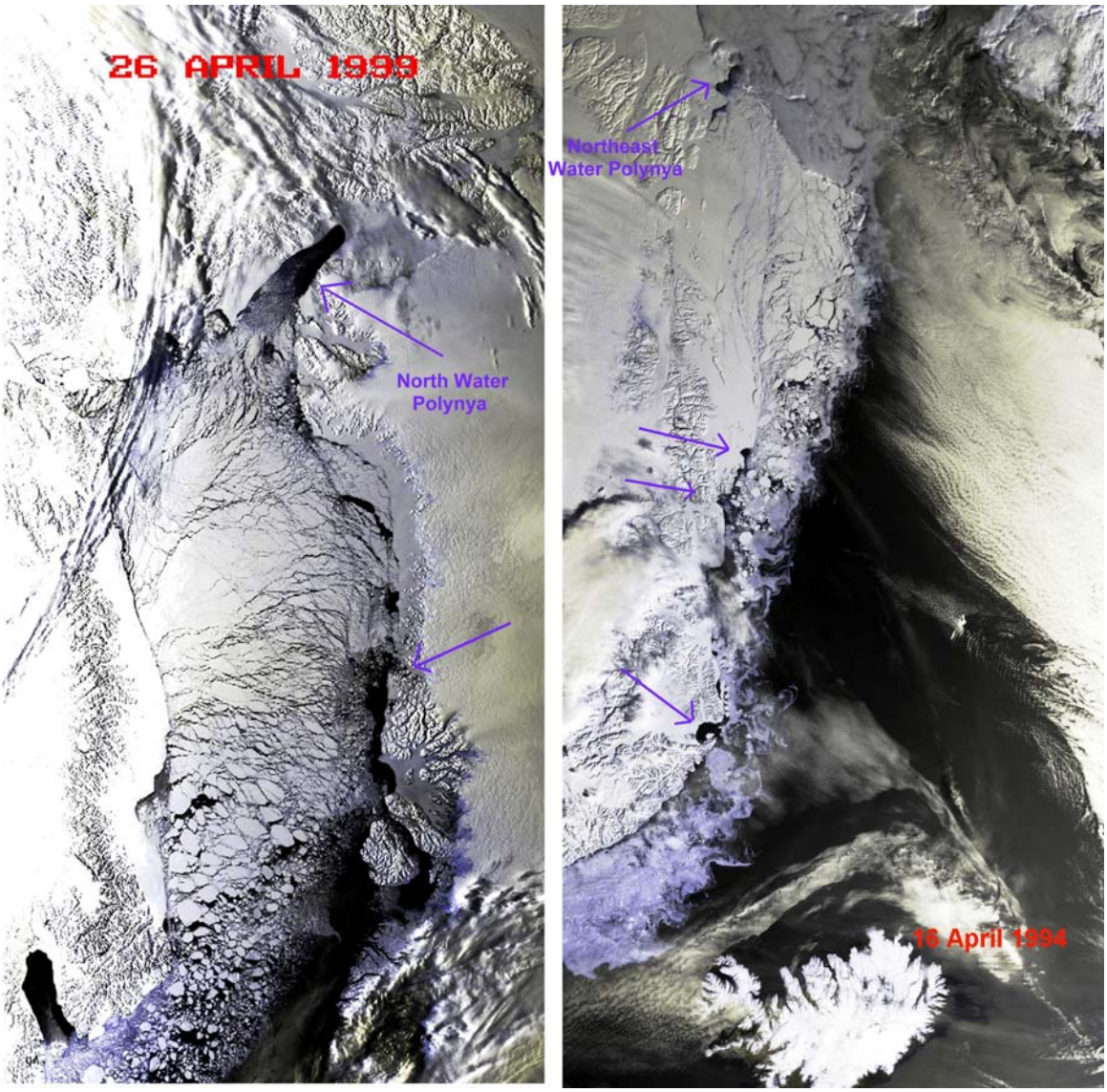


Figure 1.13 Nearly cloud free NOAA-AVHRR images showing the ice conditions at the Greenland west and east coast. Polynya areas area pointed out. [Source: DMI].

The waters off the multi year ice edge in the Greenland Sea, north of Jan Mayen, play an important role in the ocean circulation and the climatic variability. One effect of the ocean convection processes and the atmosphere-ocean interaction is the formation of “Odden” in the Greenland Sea (see Figure 1.14).

The strength and timing of the formation of “Odden” varies interannually and some winters it is weak or non-existing, other years it is present for several months. Odden characterized by relatively thin ice types, i.e. nilas and pancake ice (see Figure 1.14, A and B)

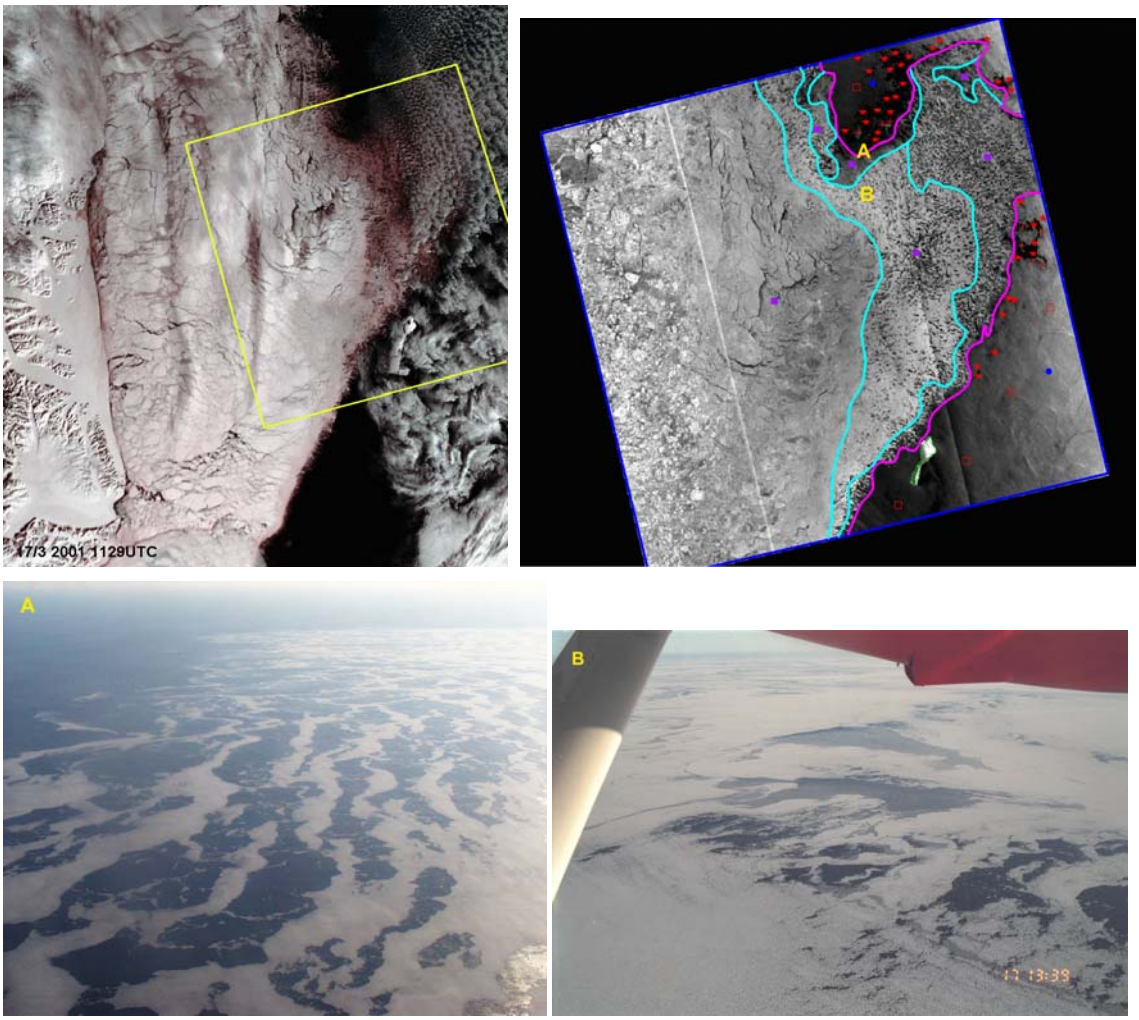


Figure 1.14 The "Odden area" in the Greenland observed in different ways at March 17th, 2001. NOAA-AVHRR 1128 UTC channel 1&2 combined. Yellow frame indicates coverage of a Radarsat SAR image from 0728 UTC. The Radarsat image is shown with a part of the operational ice analysis on top. The letters "A" and "B" indicates the position of two photos taken from aircraft in an altitude of 3000 feet showing the typical ice types in this particular area. Very thin ice, nilas and frazil ice near the ice edge. Within the ice edge pancake ice, thickness 20-30 cm and 1-2 meter in diameter. [Sources: NOAA-AVHRR: DMI. Radarsat: © Canadian Space Agency, 2001. Photos: Keld Q. Hansen]

1.3.3 Icebergs

The presence of icebergs is an integrated and well known element of the ocean environment near Greenland. However, the physical characteristics of the Greenland icebergs, e.g. drift, draft, distribution and variability are hardly investigated and therefore only roughly known.

The volume of the Greenland Ice Cap is about 2.5×10^6 km^3. The mass balance has been studied intensively by scientists but due to many uncertainties and unknown parameters it is hard to conclude whether the Ice Cap is in balance or not (see http://www.grida.no/climate/ipcc_tar/wg1/415.htm#tab115).

The iceberg calving from the glacial outlets is estimated to be in the order of 200-300 km^3/year and the freshwater runoff is approximately the same magnitude. The most productive glaciers is found in the central and north western parts of Greenland and the Jakobshavn Isbræ (in Disko Bay) alone produces about 25-30 km^3/year (see Figure 1.15). The production of icebergs on a volumetric basis varies only slightly from year to year.

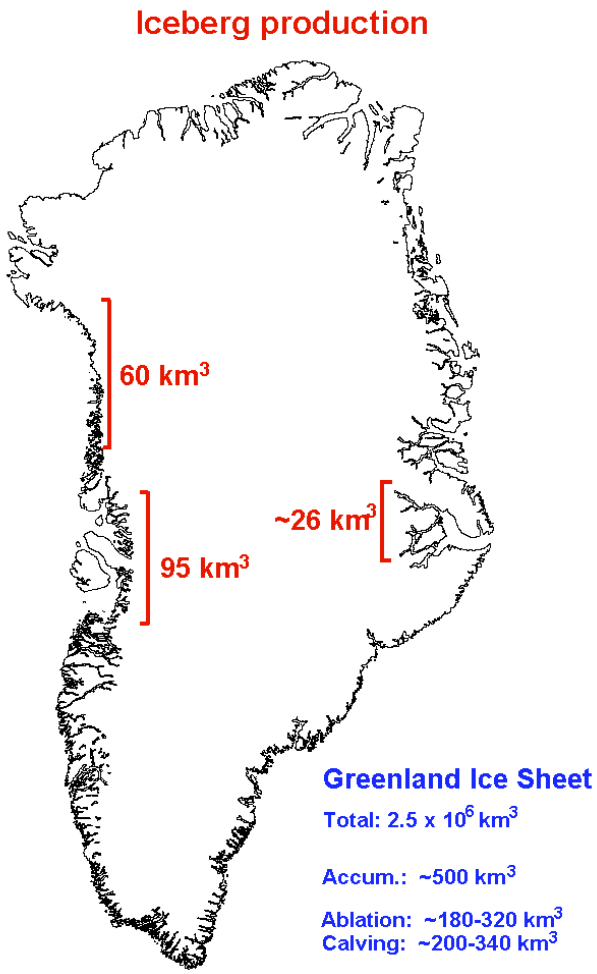


Figure 1.15 Estimated mass balance and iceberg production of the Greenland Ice Sheet.

It is notable that some important physical differences between sea ice and icebergs:

1) Sea ice is formed by freezing of saline water at the sea surface. Icebergs originate from the Ice Cap which is frozen freshwater containing small air bobbles.
2) Icebergs have a large vertical scale compared with the horizontal scale, opposite to sea ice (see Figure 1.16).

The glaciers produce a variety of icebergs, bergy bits and growlers. Icebergs are primarily described by their size and the following classification is used internationally

TYPE	HEIGHT (ABOVE SEA LEVEL)	LENGTH
growlers	under 1 m	under 5 m
bergy bit	1 to <5 m	5 to <15 m
small iceberg	5 to 15 m	15 to 60 m
medium iceberg	16 to 45 m	61 to 120 m
large iceberg	46 to 75 m	121 to 200 m
very large iceberg	over 75 m	over 200 m

Icebergs occur everywhere in the Greenland Waters but in some areas they only occur rarely, e.g. off Sisimiut. In other areas, e.g. in Disko Bay, hundreds of icebergs are always present due to the nearby large source, Jakobshavn Isbræ (see Figure 1.17). The number of bergs produced here is counted in several thousands every year. A similar number is produced from several glacial outlets in Uummannaq Fjord.



Figure 1.16 Tabular iceberg (length about 340 meter) surrounded by thin first year ice (thickness 50-70 cm) northwest of Upernavik near (73ºN, 54ºW) at June 12th, 1997. [Photo: Keld Q. Hansen]

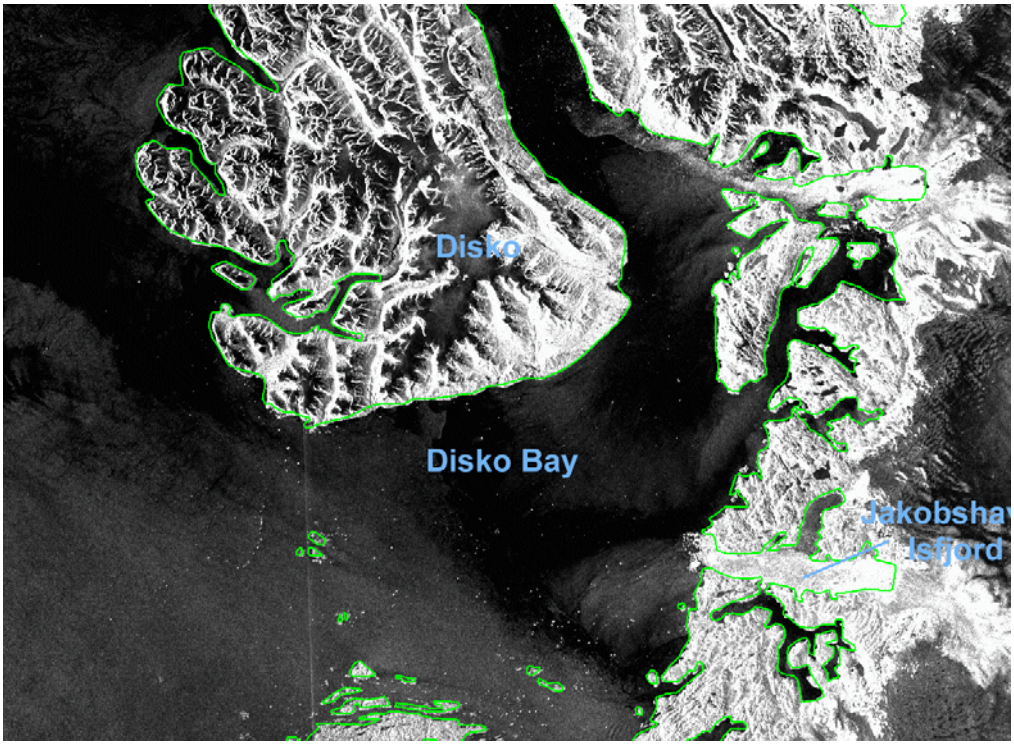


Figure 1.17 The Disko Bay observed by Radarsat ScanSAR Wide June 2nd 2002, 2050 UTC. The large icebergs in the Disko are shown as white dots and belts of glacial ice (small bergs) are also identified (bright signatures). No sea ice is present. © Canadian Space Agency, 2000.

Eastern Baffin Bay north of Upernavik is also an important iceberg source and here over 10.000 icebergs are calved every year from 19 major glaciers. Some of these are capable to produce icebergs about 1 kilometer on the horizontal scale. The total annual production of icebergs calved in the Baffin Bay and the northern Davis Strait is estimated to be about 150 km^3 per year or 25-30.000 icebergs, but estimates vary to as high as 40.000. Surveys conducted by USCG International Ice Patrol decades ago indicate that the total number of icebergs in the Baffin Bay and the northern Davis Strait is of the same magnitude.

South of Disko Bay almost no icebergs are produced. The fjords are longer, narrower and shallower than in the northern areas of the Greenland west coast and the calving is in form of growlers and bergy bits rather than icebergs which nearly always melt before reaching the open sea. Thousands of large icebergs are calved every year from several glacier outlets at the Greenland east coast, i.e. in Scoresbysund or southwest of Ammassalik. Many icebergs are stuck in the near shore fastice awaiting the sea ice melt season.

As the icebergs reach open sea they drift southwards in the East Greenland Current conveying large amounts of sea ice from the Arctic Ocean most of the year. Even in the winter most of the sea ice from high latitudes melts when it drifts southward off the southeast Greenland coast. Many icebergs drift off the sea ice edge and melt quickly due to a high water temperature or the wave/swell action on the icebergs. Within the sea ice edge in the cold East Greenland Current, the deterioration of these icebergs is small due to the “protection effect” by the sea ice in the East Greenland Current.

There are no scientific historical investigations of the East Greenland iceberg environment, only a few local studies but these do not contribute to a general description of the offshore icebergs. Thus, most knowledge is based on experience and qualitative descriptions rather than quantitative numbers or scientific studies.

Large variations in the number and size of icebergs rounding Cape Farewell are to be expected because of the variability of the currents and the amounts of ‘protecting’ sea ice, and, of course, the extreme weather conditions. An important factor controlling the iceberg environment off Southwest Greenland is the input of icebergs to the East Greenland Current at high latitudes during summer. It is well known that sea ice is present off the east coast most of the year, but with large seasonal and inter annual variations, especially during summer. In many cases the occurrence and drift of sea ice controls the movements of icebergs. If the fast ice in fjords with major icebergs sources, e.g. Scoresbysund or Kong Oscar Fjord, doesn’t melt during summer or if the East Greenland sea ice doesn’t drift off the coast, this event will probably reduce the input of icebergs to the East Greenland Current and cause a decrease in the number of icebergs at lower latitudes.

Numerous icebergs deteriorate or ground close their sources but many icebergs manage to drift long distances. Grounded icebergs may work as small islands which influence the formation of sea ice (see Figure 1.18). Offshore the currents and drift of Baffin Bay and Davis Strait icebergs are fairly simple. There is a north-moving reasonably slow current along the Greenland coast and a south-flowing current along the Baffin Island shore, which continues to the Labrador Sea, giving a general anti-clockwise drift pattern. However, branching and eddies the general currents cause some variability which have a significant impact on the iceberg drift, population and their residence time. Most of the icebergs from Baffin Bay drift southward in western Davis Strait joining the Labrador Current further south and in the spring and early summer these cause hazards to the transatlantic shipping routes near New Foundland.

Occasionally many small icebergs and bergy bits calved in the Southwest Greenland fjords are observed close to the coast in this area, but normally these ice masses melt quickly and do only rarely affect ocean areas farther offshore (see Figure 1.19). Icebergs occur only occasionally in eastern Davis Strait between Nuuk and 67°N, which is explained by the dominant currents, the bathymetry and the distant sources.

Dimensions of the Greenland icebergs are exceedingly poorly investigated. However, icebergs larger than 1 km in diameter are very rare even close to the big glacial outlets in eastern Baffin Bay, e.g. the 25 km wide “Steenstrup Glacier” at 75ºN (see Figure 1.20).



Figure 1.18 Grounded icebergs in the shallow water areas in the northwestern Uummannaq Fjord helps the formation and resistance of fastice [Photo: Keld Q. Hansen]

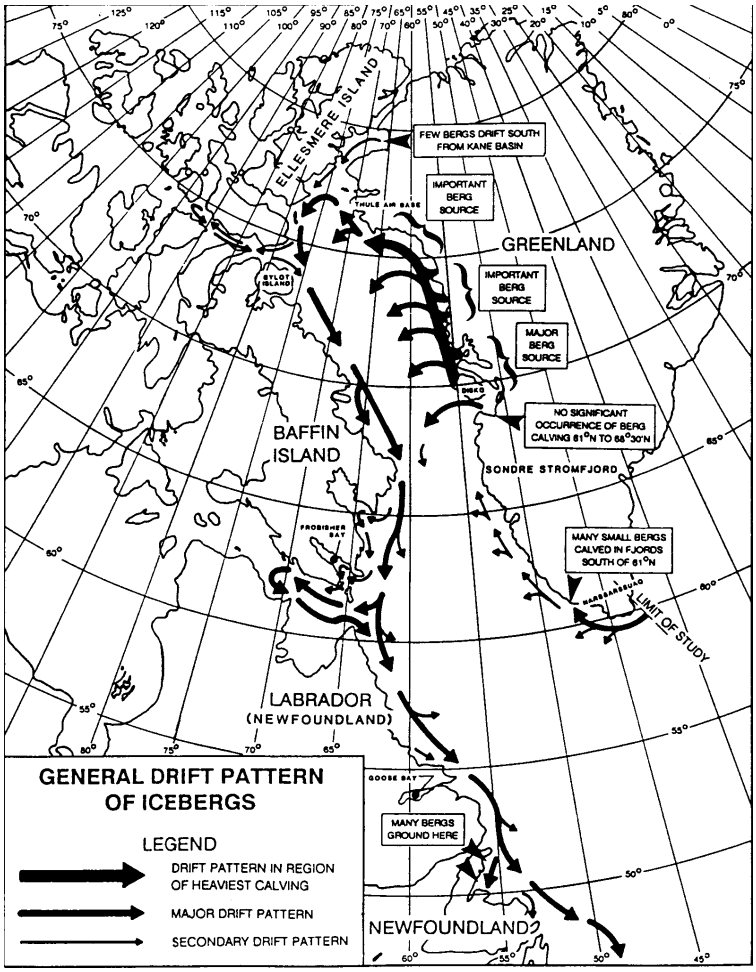


Figure 1.19 Major iceberg sources and general drift pattern for icebergs in the South and West Greenland Waters. (Source: US National Ice Center, Washington DC).

Many icebergs in/and north of Disko Bay are normally 2-300 meter in diameter, a mass of 5-20.000.000 tons and a draft at 100-150 meter. Observed extremes report iceberg about 100.000.000 tons and a draft at about 250 meter, yet these upper limits are not regarded as the absolute extremes due to the inadequate research on this subject. Similar characteristics are expected for East Greenland icebergs. Maximum draft can be evaluated by studying factors which limit the dimension: glacier thickness, topographic factors which cause icebergs to be calved in 'small' pieces and thresholds in the mouth of the fjords with glaciers. Icebergs near the southwestern shores originate from the East coast and are affected waves, water temperatures, sea ice, sea floor etc. which cause a significant deterioration of these bergs. Typically relatively small icebergs occur in this area. Normal dimensions are 50-100 meter in diameter and expected characteristic draft of 75-125 meter.

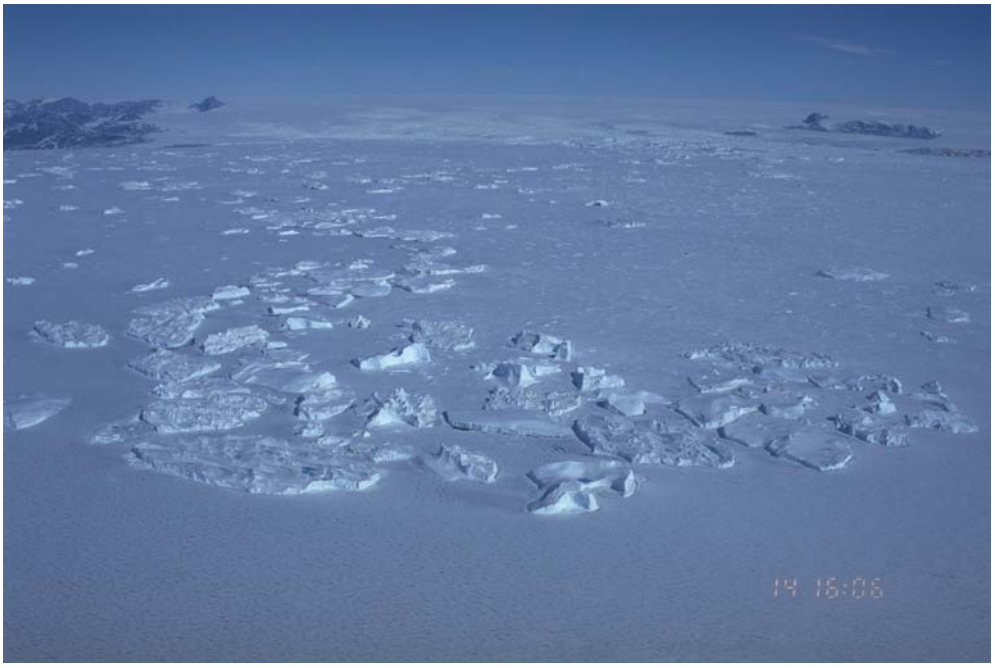


Figure 1.20 Steenstrup Glacier June 14th, 1997. The width of the glacier front is about 25 km. Several very large icebergs from this or the nearby Kjer Glacier are grounded at a water depth of about 200 meter but also stock in the fast ice until it melts away in July. [Photo: Keld Q. Hansen]

1.4 Weather and climate in Iceland

1.4.1 A general description of the climate in Iceland

Iceland enjoys a much milder climate than its name and location adjacent to the Arctic circle would imply. A branch of the Gulf Stream flows along the southern and the western coast greatly moderating the climate. However, this brings mild Atlantic air in contact with colder Arctic air resulting in a climate that is marked by frequent changes in weather and storminess. Furthermore this leads to more rainfall in the southern and western part than in the northern part of the island.

The summer tourist season is from late May to early September. During the first half of this period the sun stays above the horizon for almost 24 hours and the interplay of light and shadows on mountains, lava fields and glaciers yield an ever changing landscape. However, even during the middle of summer the sky is frequently cloudy or overcast and the sunshine does not warm the air much. Hence, during daytime, the air is usually cool ("refreshing" is the local euphemism) and cold during nighttime.

The winter season is the abode of long nights, and severe winter storms. However, the silence of the frozen expanse and the dance of the Aurora Borealis on a clear night sky draws an increasing number of tourists.

During summertime tourists should bring a windbreaker, rainwear, a thick pullover (wool or fleece) and sturdy walking shoes. Travelers who are camping or heading into the interior will need warm underwear and socks, rubber boots and a warm sleeping bag. During wintertime tourist should bring warm clothing, warm coat, mittens etc. Iceland has many swimming pools, usually with geothermally heated water. Hence, in either season a visitor should bring a swim suit.

1.4.2 Processing of meteorological data

The traditional (manned) Icelandic meteorological network produces about 130 thousand observations per year and the number of observations from automatic stations now approaches one million per year. The department of research and processing monitors the continuity and quality of all these observations for storage in a database and further climatological processing.

The department publishes the monthly climatic summary "Veðráttan", which includes tables of climatological information from the traditional network in Iceland. The summary has been published since 1924. Subscription fee is now about 30Usd per year.

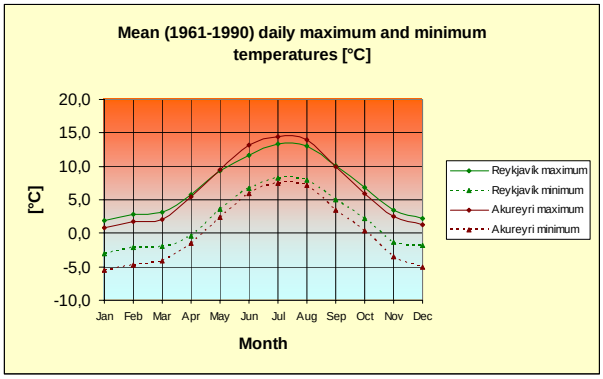
The department issues formal ratification/attestation of weather and climate in legal and insurance matters on request. The department is a provider of general climatological services for the official and private sectors as well as the general public.

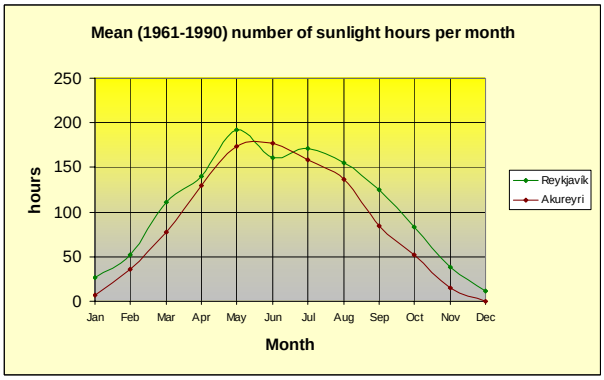
Links on "Climate Data":

- http://www.vedur.is/ur/yfirlit/vedurfarsgogn_en.html
- http://www.vedur.is/ur/yfirlit/hitatoflur/langtimatoflur.html

1.4.3 Climatic diagrams

Figure 1.21 shows selected climatic diagrams.





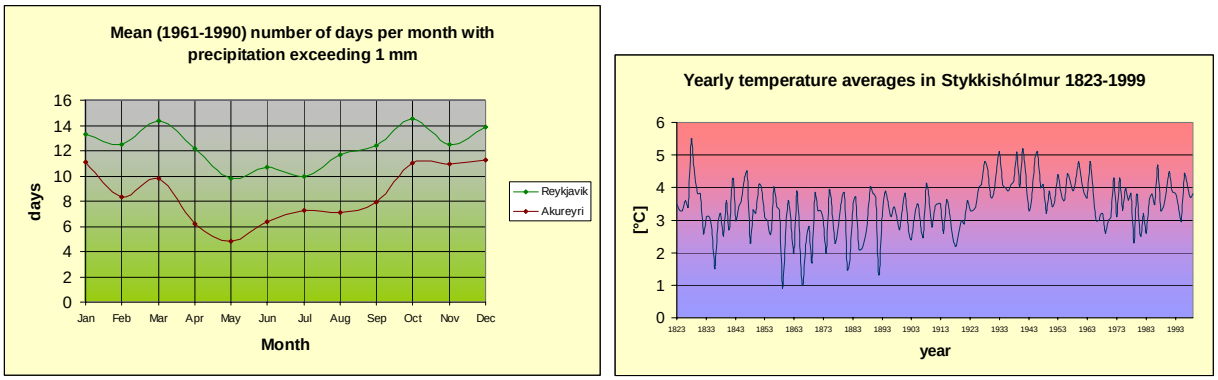


Figure 1.21 Selected climatic diagrams.

1.4.4 Useful links on weather and climate

Wealth of weather and climate data from Iceland is now available at the web page of the Icelandic Meteorological Office (IMO) http://www.vedur.is/ . An English version is available in most cases. The climate information is taken from "Veðráttan", a monthly publication of the institute. Data from selected stations are accessible at the web page.

There are tables of both monthly and yearly values of various weather data since 1961. A map displays the location of numerous meteorological stations for which data are reported. Further, climatic means at many stations for the period 1961 - 1990 are available as well as monthly mean temperature at selected stations.

A convenient key table for the columns of the climate data files directs the user in looking for a number of parameters as the IMO station number, year, month, mean temperature, mean maximum temperature, highest temperature recorded during the month/year, the day the highest value was recorded, mean minimum temperature, the lowest temperature recorded during the month/year, the day the lowest value was recorded, mean relative humidity, total accumulated precipitation for year/month, greatest 24 hr precipitation recorded during the month/year, day of maximum 24 hr precipitation, mean number of days with precipitation greater than zero, or 1 mm, mean surface air pressure, mean cloud cover, number of sunlight hours in the month/year and mean windspeed.

Information on sea ice in Icelandic waters is also available at http://www.vedur.is/ur/hafis, both on current conditions as well as all charts resulting from sea ice reconnaissance flights by the Icelandic Coast Guard since January 1998 and all ship reports since October 1998. Finally, it should be mentioned that the Icelandic Maritime Administration (IMA) provides various information on sea state around Iceland, easily accessible at its web page: http://www.sigling.is/vedur_sjolag.html.

1.4.5 Avalanches in Iceland

1.4.5.1 General information

The Icelandic Meteorological Office (IMO) is a governmental institute responsible for producing regular and specific weather forecasts. It's Avalanche Section is responsible for avalanche warnings, evacuations, hazard zoning and is the scientific advisor to the Icelandic government in the field of avalanche defense structures.

The Avalanche Section at the IMO was strengthened considerably after the avalanche disasters in the villages Súðavík and Flateyri in 1995. The staff increased from 2 to 8 and we have been able to broaden our range of expertise. Although the Office has since 1979 been responsible for issuing avalanche warnings, it has since December 1995 been given the added responsibility for ordering evacuations, both evaluating the extent of, and deciding upon their timing.

The IMO is responsible for avalanche hazard zoning in Iceland. New methods have being developed and tested in the hope that better and safer zoning will result. Research projects have been carried

out regarding risk and risk management. Hazard maps have been made and are being made for several villages.

The government of Iceland has undertaken the task of constructing avalanche protection measures for the communities at risk. The brunt of the scientific part of that work has been carried out by the IMO resulting in a rapid buildup of expertise in that field. Several research projects and field experiments have been undertaken as part of the avalanche defense project. They include a pilot projet installation of avalanche supporting structures, to investigate their effectiveness and decide upon design criteria for Iceland. The interaction between avalanches and deflecting walls and retarding mounds has been studied, and also snow accumulation around retaining walls and mounds. In addition, theoretical investigations and modelling are being performed regarding the flow of avalanches.

1.4.5.2 Abstract from an article: Accidents and economic damage due to snow avalanches and landslides in Iceland

Tómas Jóhannesson and Þorsteinn Arnalds
Icelandic Meteorological Office, Bústaðavegur 9, IS-150 Reykjavík, Iceland
Abstract — Snow avalanches have caused many catastrophic accidents and severe economical losses in Iceland since the country was settled in the ninth century. The first reported avalanche accident dates back to 1118 when a snow avalanche killed 5 people in western Iceland. Altogether about 680 deaths by avalanches have been reported in Iceland since then. Unaccounted deaths may be assumed to have been several hundreds, especially during two gaps a total of 250 years in the written records before 1600. Since 1901 altogether 193 persons have been killed in avalanche and landslide accidents in Iceland. Catastrophic avalanches in the villages Súðavík and Flateyri in 1995, which killed 34 people and caused extensive economic damage, have totally changed the view regarding avalanche safety in Iceland. These avalanches made it clear that a substantial number of people in several Icelandic towns and villages live in areas where avalanche risk is unacceptable.

Although extensive evacuations may be used to reduce the risk to some extent, this can only be viewed as a temporary measure. Avalanche protection measures or land use changes are necessary for a permanent solution to this problem. Direct economic loss due to avalanches and landslides in Iceland in the 26 year period between 1974 and 2000 is about 3.3 billion IKR (41 million USD). The total cost of defence structures, which have been constructed or are under construction in the towns Flateyri, Siglufjörður and Neskaupstaður since 1995, together with the cost of relocation in endangered areas is about 2.5 billion IKR (31 million USD). The loss includes insurance payments and the cost of rescue and relief operations due to avalanches in towns and villages, and insurance payments due to avalanches in rural areas (damages to farm buildings, power and telephone lines and ski lifts). Other economic losses, especially due to avalanches in rural areas, are substantial, but may be assumed to be much smaller than the loss estimated above. A total of 52 people have been killed by avalanches in buildings, at work sites or within towns during the period 1974 to 2000, while 17 people have been killed by avalanches and landslides outside populated areas during the same period. If the death of a person in an avalanche or landslide accident is included in the economic loss as 100 million IKR (1.2 million USD) per fatal accident, the total cost of avalanche and landslide accidents in Iceland in the last 26 years together with the cost of avalanche protection measures is more than 13 billion IKR (162 million USD). The Icelandic government has drawn up a plan to construct avalanche protection measures for hazard areas and/or to purchase endangered property in order to reduce the death toll and the economic losses caused by avalanches in the future.

Full paper is available at http://www.vedur.is/snjoflod/haettumat/jokull-2001.pdf.

1.4.6 Sea Ice in Icelandic waters

The Sea Ice Research Unit of the Icelandic Meteorological Office (IMO) is responsible for sea ice monitoring and sea ice service all year round in ocean waters around Iceland. The monitoring is performed in cooperation with the Icelandic Coast Guard, the Marine Research Institute in Iceland as well as ships in and close to ice covered areas in the Iceland Sea and the Denmark Strait.

1.4.6.1 Observations received

Ship report are received from Icelandic and foreign ships in Icelandic waters. Any ship, small or large, is obliged to send a report to IMO whenever sea ice is spotted in the area. The reports are received quite frequently every day from many ships in late winter during heavy ice years but during light ice years the frequency of reports tapers naturally down to a few or none for periods of time.

The Icelandic Coast Guard performs sea ice reconnaissance flights in the Iceland Sea north of Iceland and the Denmark Strait, resulting in sea ice charts of the sea ice edge area. Flights are made according to needs, depending on the extension of sea ice close to or covering fishing grounds and transport routes along the coasts of Iceland.

In addition to these main sources of sea ice observations data , any other reliable information obtained at IMO is recorded and taken into account by further processing, as, for example, reports from coastal meteorological observation stations or from smaller airplanes.

On al larger scale, though not satisfactory for warnings on sailing routes, satellite imagery received at the IMO forecast division sometimes gives a useful indication of the overall extension of sea ice in the Denmark Strait. Ice charts obtained from sea ice divisions abroad, in particular the East-Greenland ice charts made at the Danish Meteorological Institute, are very informative in relation to following the large scale sea ice development further north in the East-Greenland Current.

1.4.6.2 Processing and warnings

All the various observation data mentioned above are recorded at IMO and forwarded further to those who need them. First of all, the information is broadcasted in the next radio weather broadcast via the State Radio Broadcasting Service as well as put on the NAVTEX system where all ships in the area are able to receive latest reports on sea ice. Also, the information is immediately put on the IMO web site.

Besides the reports, warnings are issued if considered necessary and broadcasted. Judgement has then been made according to weather forecasts at IMO, which are prepared on the basis of various large-scale forecasts, as medium range weather forecasts received regularly from the European Medium Range Weather Forecast Center in Reading, England. In addition warnings are based on knowledge of normal ocean currents in the vicinity of Iceland.

All data obtained are then preserved and gathered in an electronic data bank. Preliminary monthly overviews on sea ice at the coasts of Iceland are placed on the IMO web site as soon as possible. Eventually, annual reports containing final monthly overviews as well as the Icelandic Coast Guard ice charts are published in annual reports.

1.4.7 IWICOS Products

1.4.7.1 Text forecasts

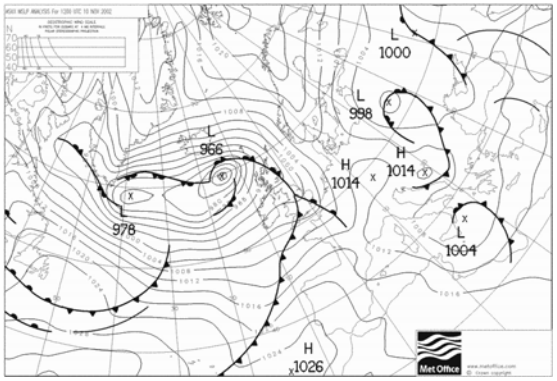
The traditional way of presenting weather information to seafarers is through the radio, either from public broadcast stations or from coastal radio stations specially designated to services for the marine community. The information distributed via radio must of course be in text format and it should be as clear and concise as possible. The content and format of official marine weather information is regulated by WMO (World Meteorological Organisation). Even if the theoretical and technical background for these forecasts has improved dramatically during the last few decades the format of these weather bulletins have been essentially unchanged for decades.

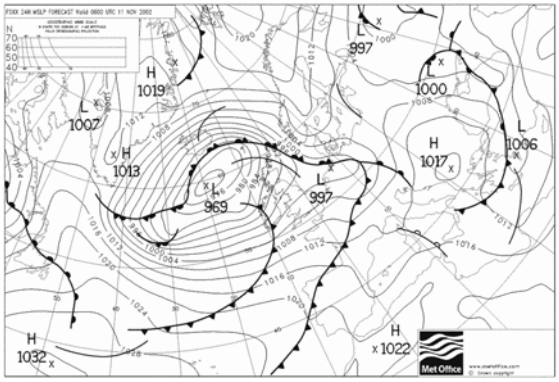
The text forecasts are written by a forecaster which should have access to all the data which might affect the weather on the forecasting areas he is expected to keep under watch. A very important part of this data is the output from numerical prediction models. Even if the regular forecasts are transmitted at scheduled times the forecaster might change the forecast and even issue a new warning at other times if he discovers some evidence in the latest data which makes him change his opinion.

The essential difference between a text forecast and a graphical presentation of a numerical weather forecast product is that the text forecast is under continuous watch by a professional forecaster which should ensure that the forecast is practically always up to date. He will compare the forecast with new data when they become available and issue an amendment or a warning when needed. The weather map based on a numerical product is an output result from a production cycle which is started at scheduled hours. Even if it becomes obvious that such a map shows a completely wrong picture of the development of the weather it will not be amended. It stays unchanged until the next cycle will hopefully give a better result.

An important difference which must be kept in mind is that the text forecast describes the changes of the weather during a period, usually the next 24 hours after the forecast is issued. The typical wether map is a snapshot at fixed time. A sequence of weather maps would be needed to cover the whole period of the text forecast.

A seafarer's best approach to the weather forecast will be a combination of these two types of products. Well designed graphical maps are suited to give an overview of the synoptic situation, describe the active weather systems, help the user to understand the background of the weather forecast and make it possible for him to make his own forecast. But he should also watch carefully the latest text forecast and compare it with his own ideas. Good agreement will make the user more confident in his operations but disagreement should make him better alert for that something unexpected might happen.





Warning:

A strong gale warning (more than 20 metres per second) is in effect for the Southwest and West banks Northwest banks the East banks (S-part) and the Southeast banks.

Synopsis:

Some 400km south of Iceland is an increasing 975mb low almost stationary moving north tonight. Just south of Cape Farewell is 980mb low moving east. Near Spitzbergen is 1025mb high.

Southeast Banks:

Easterly winds 18 to 23 metres per second and rainshowers, but northeast 20 to 25 and rain in the afternoon. Lighter winds tomorrow afternoon.

Figure 1.22 Weather maps and weather forecasts. To left: Synoptic analysis (upper) and 24 hours forecast map (lower). They are issued by the UK Meteorological Office and these maps have been heavily used by seafarers for decades. To right: The weather forecast for the area off the southeast coast of Iceland together with an inference of the weather maps and warning issued by the Icelandic Meteorological Office.

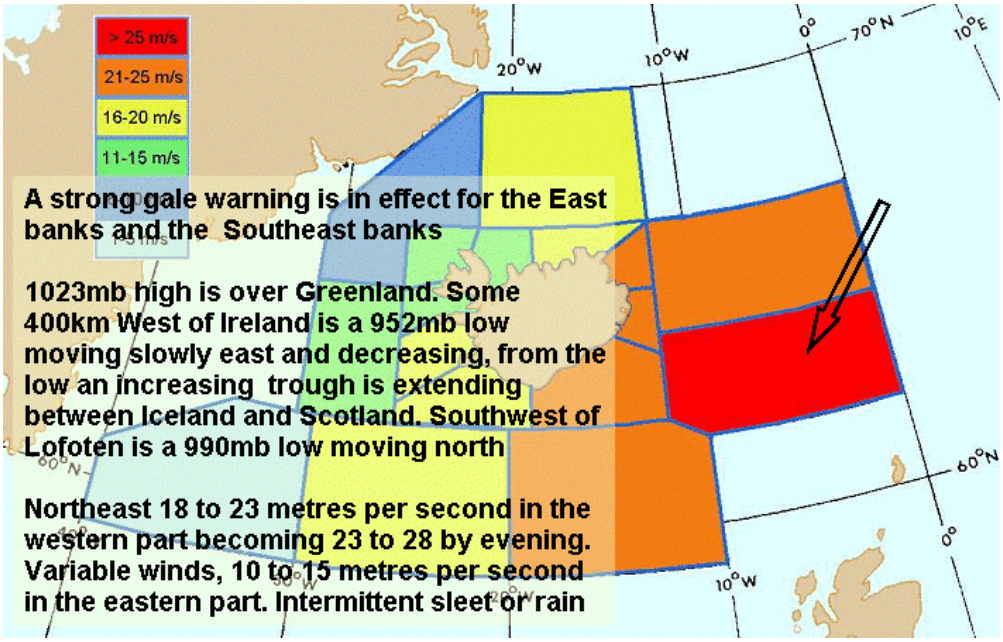


Figure 1.23 A map of the forecast areas coloured by the maximum wind speed to be expected during the forecast period. The colour scale is shown in the upper left corner. The text forecast for a selected area is also shown.

The IWICOS-approach to the text forecasts is intended to give the user a quick estimate of the expected wind speed which is definitely the most important factor in the marine weather forecast. On a map showing the forecast areas, each area is coloured according to the highest wind speed expected in the area during the whole forecasting period. When a new or amended forecast has been issued the colours will be updated. To read the forecast itself the user clicks on the area on the screen and the text forecast will pop up.

It can not be seen from the map if a strong wind indicated in an area is already blowing there or if it is expected by the end of the forecasting period. But if the area is coloured blue only light winds are expected during the whole period and sometimes this information might be sufficient for the user.

The colour scale is chosen in best possible agreement with ideas presented in the EUMETNET-project called EMMA which was started in October 2002. The aim of this project is to coordinate weather related warnings within Europe. Most national meteorological services in Western Europe are members of the EUMETNET cooperation.

1.4.7.2 Wave forecasts

Ocean wave forecasts, as presented here, are a pure numerical product. The significant wave height, mean wave direction and mean wave period are calculated by means of a numerical wave model coupled to an atmospheric model. The maps which have been used within the IWICOS project are based on the so called WAM model at ECMWF (European Centre for Medium range Weather Forecasting). The model is run once a day and new forecasts are normally available early in the morning. This forecast will not be updated or amended even if it appears not to fit with observations or other information.

The forecasting range could be stretched so far as to ten days but validation at ECMWF shows clearly that deterministic numerical forecasts for weather or waves should normally not exceed four or five

days. For medium range forecasts (up to a week or even longer) some kind of probabilistic presentation is preferable.

The significant wave height is given by a colour scale going from dark blue where the sea is calm to red where the highest waves are forecasted. The mean wave direction is indicated with an arrow and a number near the arrowhead gives the mean wave period in seconds. Validation of these forecasts against wave buoys off the coast of Iceland has shown them to be quite reliable.

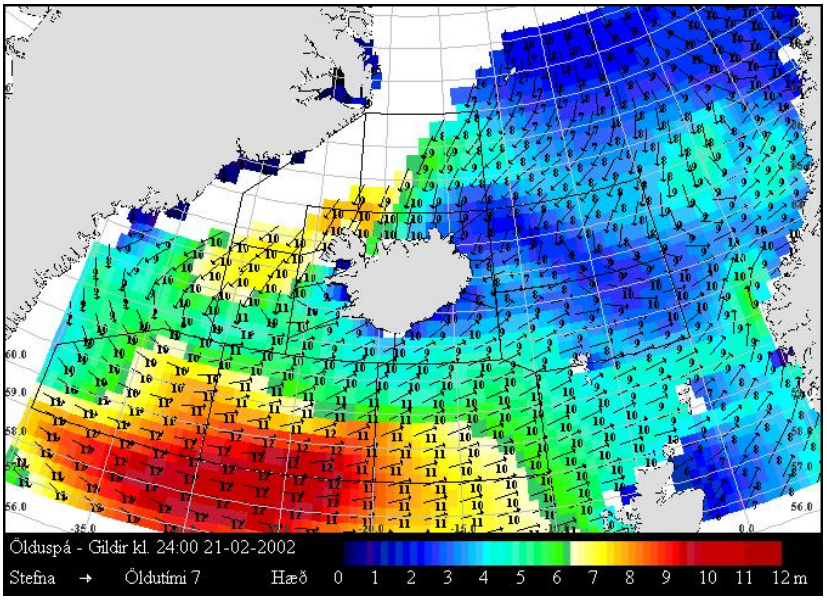


Figure 1.24 Numerical forecast of ocean waves. Significant wave height in meters is indicated by a colour scale, mean wave direction is shown with an arrow but mean wave period in seconds is given by a number. The forecast is based on the ECMWF wave model.

1.4.7.3 Ice accretion forecasts

Ice accretion on ships is a real hazard in polar and sub-polar waters and has lead to many accidents when ships collapse under the weight of the ice accumulated on the ships superstructure. Warnings for the risk of icing are therefore very important.

During the fifties at least four trawlers capsized because of icing in North-Atlantic waters and were lost with their entire crews. In the following years an empirical method was developed to forecast the risk of icing. This method, named after its developer, H.O.Mertins, has since then been widely used by many meteorological offices. It is based on graphical diagrams and is not immediately suited for numerical forecasts.

Another method, presented some twenty years later (Overland 1990), is based on an algorithm where the main factors governing the rate of ice accretion on ships, wind speed, air temperature and sea temperature, are used as an input. These factors can easily be taken from numerical forecasts and automatic icing forecasts, based on this method, are therefore technically very easy.

These algorithms were based primarily on reports from vessels that were 20 to 75 meters long and the output shows an expected icing class and rates of ice accretion for vessels that are steaming into the wind. The icing classes are defined in the following way:

Icing Class	None	Light	Moderate	Heavy	Extreme
Icing Rates (cm/hour)	**0**	**<0.7**	**0.7-2.0**	**2.0-4.0**	**>4.0**

In Figure 1.25 an icing forecast is shown. It is a 48 hours forecast based on a numerical weather forecast made by the ECMWF model.

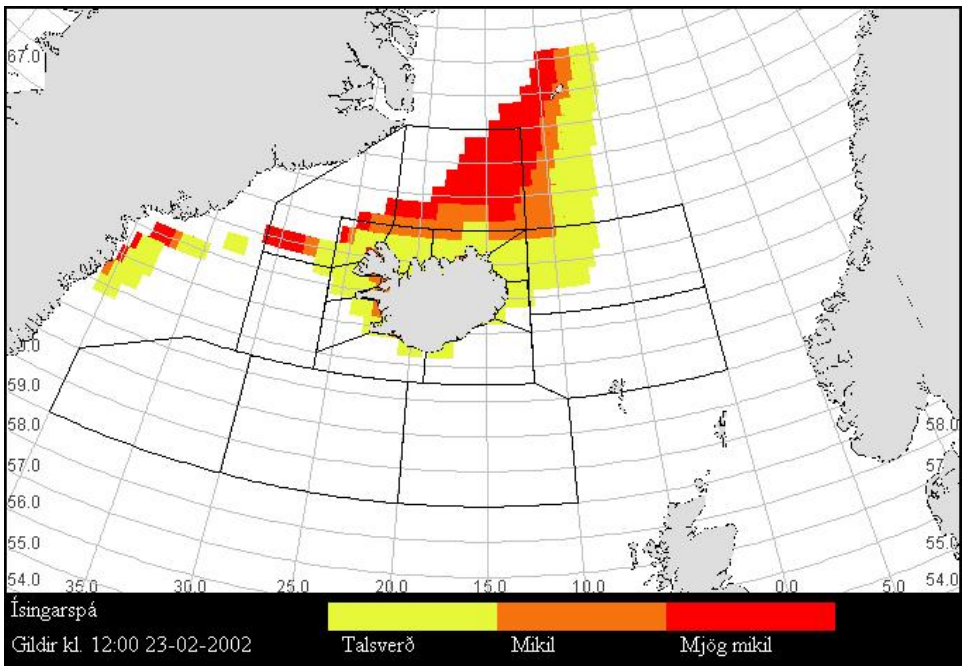


Figure 1.25 The map shows forecasted icing classes calculated by the algorithm of Overland described in the text and table above. The icing classes are Moderate (yellow), Heavy (orange) and Extreme (red).

Maps of forecast icing classes would probably be very useful for seafarers for planning of operation in polar and arctic areas. They should also be a good guidance for forecasters who have to issue warnings for icing risk.

Further reading on vessel icing and its prediction can be found on this very informative web page on Polar Meteorology: http://www.weather.nps.navy.mil/~psguest/polarmet/geninfo/index.html.

1.4.7.4 Forecasting Diagrams

Local forecasts presented as time series of weather parameters may be considered as an alternative to textual weather forecasts for defined forecasting areas and to weather maps showing the distribution of a limited number of weather parameters at a fixed time. A graphical presentation of the time series can give a very clear picture of the expected changes of weather at the selected place.

Forecasting diagrams (meteograms) are normally produced by interpolating the weather and/or ocean parameters for a point from nearby gridpoints from a series of numerical weather prediction charts. In a meteogram for a synoptic weather station the observations can be used to enhance the forecast by some kind of statistical post-processing. Kalman filtering is used here to remove bias from the forecasts of temperature and wind speed. Meteograms made from direct model output can also be produced for any point in the ocean but quality control for such products is difficult because of the lack of observations.

Figure 1.26 shows a meteogram for the synoptic station Stórhöfði in Vestmannaeyjar off the south coast of Iceland. The forecasting range is six days but this selection of weather parameters is aimed at the general public rather than seafarers. A meteogram specially designed for seafarers should include at least wind speed and direction, air pressure and temperature, and possibly also sea temperature and wave parameters such as wave height, direction and period. Such meteograms will be developed at the IMO in near future.

Meteograms for coastal stations would be useful for small boats operating near the coast.

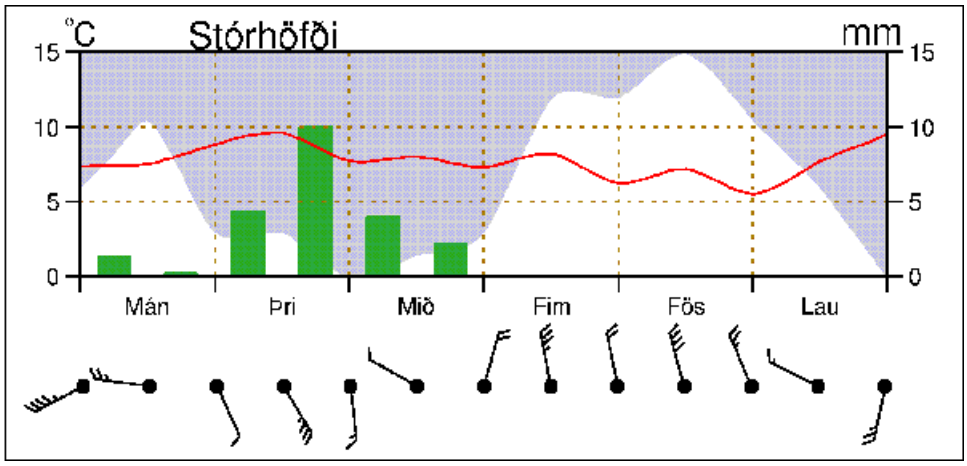


Figure 1.26 A meteogram showing a six days forecast for the synoptic station Stórhöfði off the south coast of Iceland. Wind speed is shown with flags where one whole barb denotes 5 m/s and a half barb 3 m/s. Air temperature is shown with a red line and accumulated precipitation with green columns. Cloud cover is shown with a blueish background.

1.4.7.5 Sea Ice maps

The sea ice maps shown in Figure 1.27 are based on satellite images, both high resolution images from NOAA polar orbiting satellites and Quikscat. The mapping method is developed at the University of Iceland, Science Institute using ArcGIS software. The images were retrieved from Kongsberg Satellite Services in Tromsö, Norway.

The main ice edge and the maximum known ice extent are shown on the charts. The ice concentration is indicated and every map does also contain a warning that ice might be present outside the known limit.

Such ice charts would be useful for ships operating near the ice edge. In principle it should be possible to issue the charts every day but in overcast conditions it may be impossible to distinguish the ice edge through the clouds.

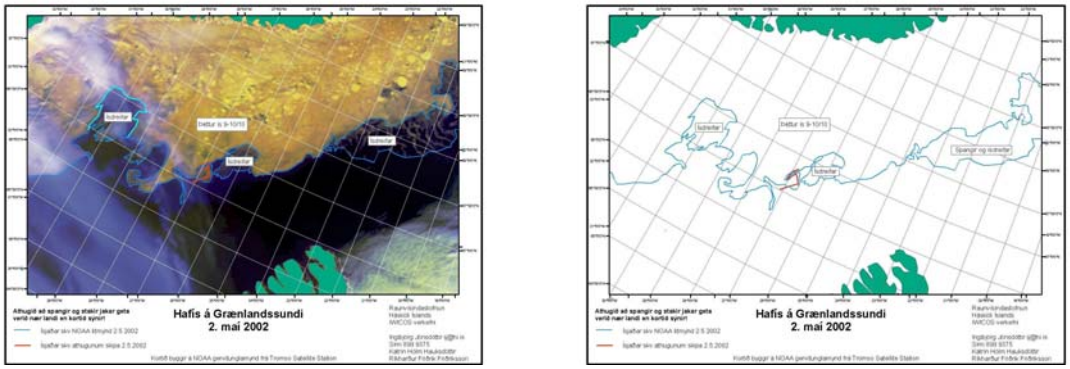


Figure 1.27 Ice charts based on satellite images. On the left chart the underlying satellite image is shown but on the right chart the image has been removed. The ice edge is drawn with a blue line but the red line shows the ice edge according to observations from ships.

1.5 Ice conditions in the Northern Sea Route

1.5.1 Introduction

The Northern Sea Route is the navigational route along the north coast of Russia from the Barents Sea in the west to the Bering Strait in the east (Figure 1.28). This sailing route is very important for Russian transport to and from many towns and cities in Siberia. The route can also be used for international ship traffic between Europe and the Pacific. This route is much shorter than sailing through the Suez Canal and the Indian Ocean.

The ice conditions along the Siberian coast in the Russian Arctic can be very difficult and sea ice transportation requires icebreaker support throughout the year. The icebreakers need good sea ice monitoring and forecasting systems to find optimal sailing routes. In addition, companies involved in offshore oil exploration and production activities in areas such as the eastern Barents Sea and Kara Sea require information on ice conditions. Monitoring of pollution and other environmental conditions is also possible with remote sensing data.

All the most critical straits of the Northern Sea Route can today be covered by SAR data that are downlinked to ground stations in Northern Europe (western part) and in Alaska (eastern sector). Operational SAR ice mapping has been demonstrated onboard Russian icebreakers during several expeditions in the Northern Sea Route.

The winter distribution of sea ice is characterised by growth of landfast ice in the areas where the water is less than 30 m deep. Seaward of the fast ice boundary, the ice cover is responding to ocean currents and wind forcing, creating flaw polynyas.

Sea ice remote sensing in the Northern Sea Route started in 1968 when Side-Looking Airborne Radar satellite Toros was launched especially for ice surveys. The wide swath width (approximately 60 km), independence on light and weather conditions and possibility to compose ice charts onboard the aircraft provided regular use of SLAR for ice reconnaissance and for scientific research. Use of special communication link for transmission of radar imagery to icebreakers was very useful for the purposes of tactical navigation support. From the late 60s to the late 90s, a number of Russian satellites were used in operational sea ice monitoring in the Northern Sea Route, including the Okean-series, which carried a Side-Looking Radar (SLR) with a swath width of 450 km.

In July 1991 ERS-1 satellite with high-resolution synthetic aperture radar was launched and in August 1991 SAR derived sea ice maps were sent for the first time by telefax to the French polar vessel “L’Astrolabe” during her voyage through the Northeast Passage from Norway to Japan (*Johannessen et al., 1992*). This demonstration was evaluated as very interesting by the captains and sea ice experts onboard the Russian icebreakers which escorted “L’Astrolabe” through the ice-covered parts of the route. Since autumn 1993 such demonstration campaigns were carried out several times by NERSC, NIERSC and Murmansk Shipping Company. These campaigns showed importance of high-resolution SAR images for navigation support in the Northern Sea Route (*Johannessen et al., 1994*, *1996*). In 1995 ICEWATCH, a joint project between European Space Agency and Russian Space, started with the objective to establish a satellite radar monitoring system for the western Arctic ice cover with the use of “Okean” and ERS-1 SAR images (*Johannessen et al., 1996*).

Both the ERS-1 and the subsequent ERS-2 satellite had a SAR sensor with a spatial resolution of 30 m and a swath width of 100 km. With the launch of the Canadian RADARSAT satellite in 1995, more radar satellite data became available for use in ice monitoring. The RADARSAT SAR provided a number of beam modes, and a swath width up to 500 km for the wide swath modes.

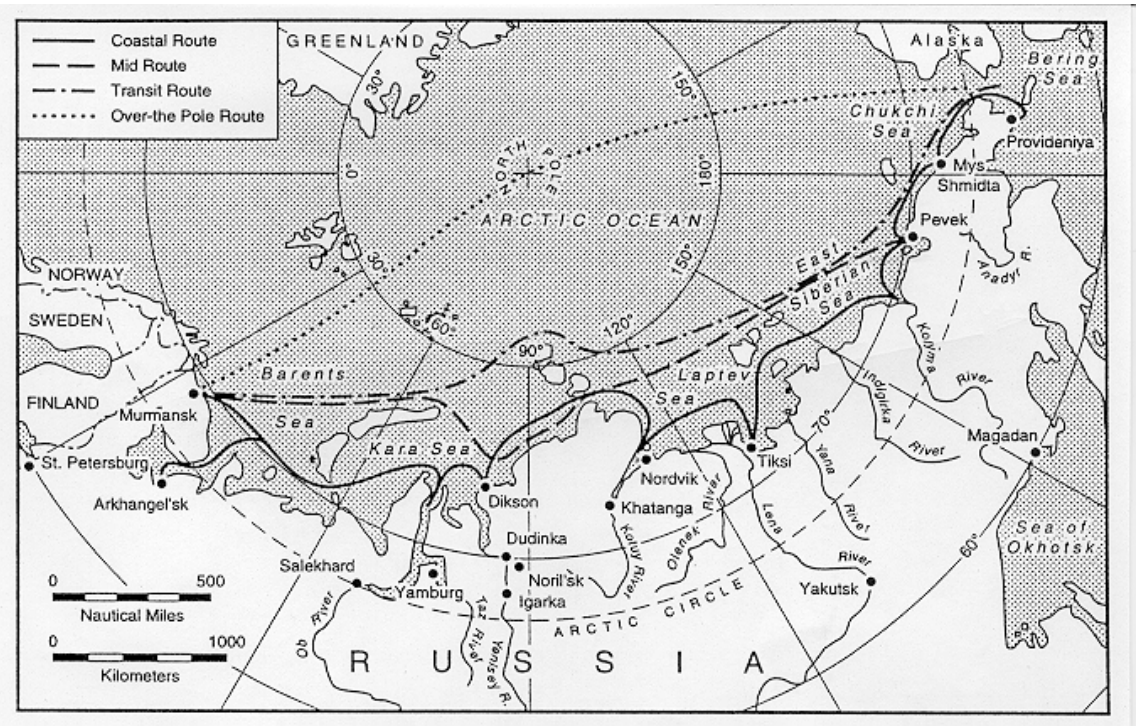


Figure 1.28 Map of the Northern Ship Route with different sailing alternatives.

1.5.2 Example of detailed RADARSAT ice observation

The Kara Gate is one of the critical straits where ice conditions can be difficult during winter conditions. The RADARSAT image shown how rougher ice (brighter signature) from Pechora Sea drifts through the Kara Gate into the Kara Sea where the ice cover is less deformed (darker signature). This increase in backscatter is explained by the action of both tidal and wind driven currents that break and raft the ice. Thus, the zone of rough ice can be identified for strategic applications.

Figure 1.30 shows a subset of a RADARSAT ScanSAR image from 25 April 1998, classified using a sea ice classification algorithm developed at ERIM (Wackerman and Miller, 1996). Texture and local statistics for the image were used in the classification procedure.

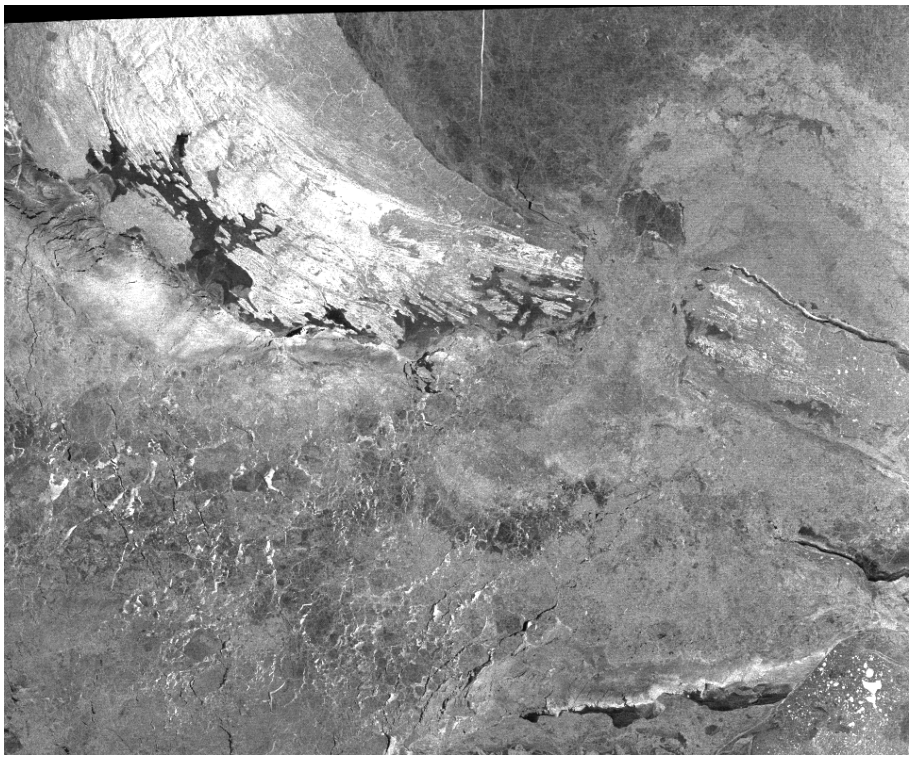


Figure 1.29 Subset of RADARSAT SAR 4 March 1998 03:07 UTC showing the Kara Gate between Novaya Zemlya and Vaygach Island. This area is highly dynamic and the ice is pressed trough the Kara Gate, and the area of rough ice east of the gate can be seen through the ice season. Image Data © RSI/NERSC 1998.

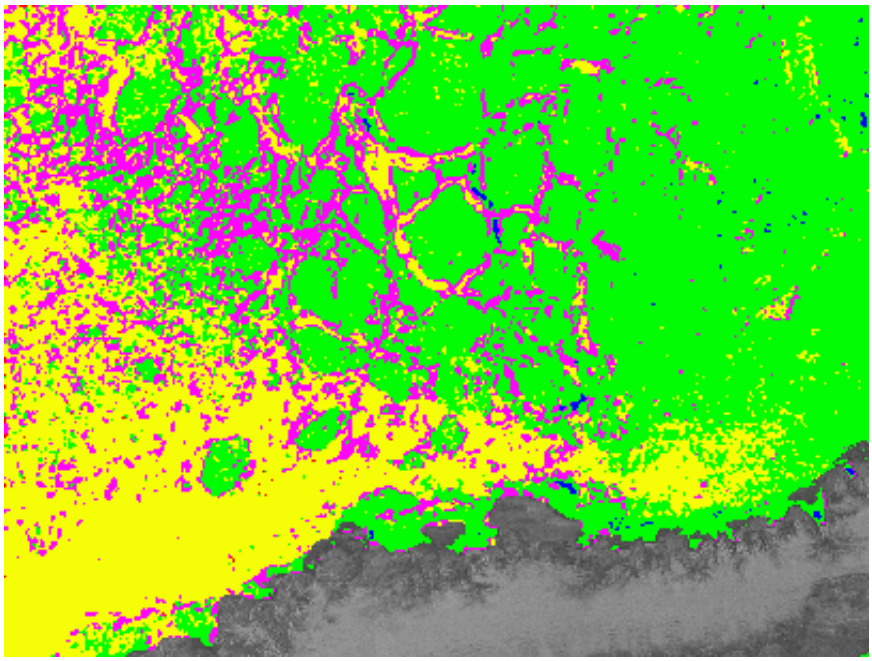


Figure 1.30 Subset of RADARSAT SAR along the north-western coast of Novaya Zemlya. Image Data © CSA 1998. Colour coding: Blue - open water and nilas. Green - first year ice. Yellow - young ice. Violet - small flows of first year ice and young ice.

1.5.3 Coastal polynya and fast ice in the Pechora Sea

The subset of the ERS-1 SAR scene from 8 March 1994 shows a typical coastal polynya located east of Kolguyev Island covered with new ice (grease ice or nilas) that appears as a dark area. With southerly winds the new ice accumulates along the northern border of the polynya, against a band of thicker young ice (grey and grey-white ice). The bright signature is due to new ice compressed by wind, which have a rough surface causing high backscatter of the SAR microwave signals. Wind blowing over the polynya generates a Langmuir circulation, which organises the frazil and pancake ice into streaks parallel to the surface wind. The observed wind in this case has direction 185° and speed 12.5 m/s, and we can see that the tiny bright signatures can be used to roughly estimate the wind direction.

Knowledge about coastal polynyas and fast ice is very important for oil companies and offshore industry planning to build new terminals for transportation of oil and gas from the fields in the Timan-Pechora area, (*Figure* 1.31). With SAR data it is possible to produce more detailed and accurate ice maps compared to the standard ice maps issued by the Russian ice services. An example is shown where a SAR image of 11 May 1996 from the coast of Varandey is analysed. The image was interpreted with help of meteorological data and presented as a standard ice map, using the Russian variant of the WMO ice code.

Another example of ridge observation is seen in an ERS-1 SAR image from the northern coast of Varandey 16 April 1994. This image shows a more well developed ridge area located between the fast ice and the drifting ice. The bright line indicates an area consisting of many ridges located within a belt that is of order 200-300 m wide. The wind during the day before the image was obtained had been from north-east and 5-7 m/s, pushing the drifting pack ice towards the fast ice. This is the main generating mechanism for ridge formation. Even without any in situ observations, it can be concluded from the SAR images combined with meteorological data that relatively heavy ridges are formed.

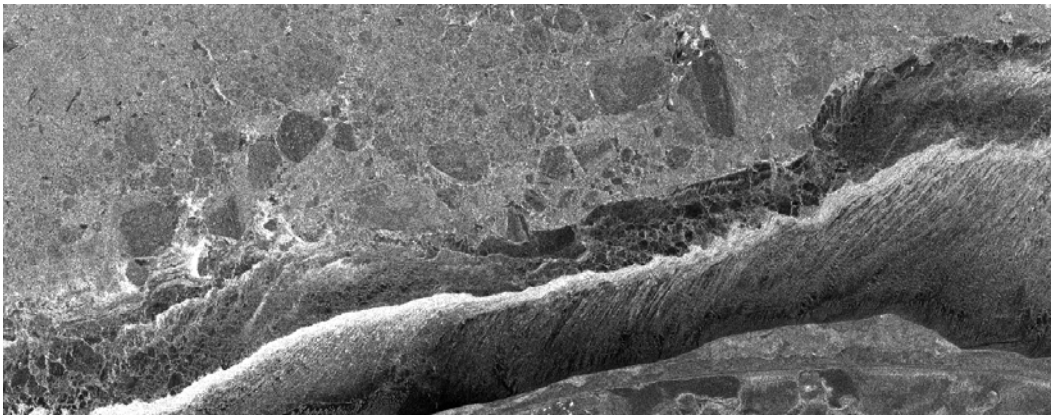


Figure 1.31 A sub-set of the image from 8 March 1994, the image size is about 28 by 72 km. The broad white feature is a band of newly formed pancake ice at the northern edge of the polynya generated during southerly winds. Image Data © ESA/TSS 1994. Image Processing NERSC.

1.6 Ocean fluxes in the Nordic Seas.

The convective processes in the Nordic Seas and in the Arctic Ocean are important driving forces of the Great Conveyor Belt (Broecker, 1991), which ventilates the world oceans, and of vital importance for the regional climate. Knowledge about the fluxes through the borders of the Nordic Seas and the causes to variations in these fluxes are important in understanding of the climate system.

Large efforts have been used to get reliable estimates of the ocean fluxes in the Nordic Seas, but due to the complexity in ocean currents through the passages and harsh climate conditions it is not a trivial task. However, in last decades the technological development and international cooperation have lead to major achievements. The measurements are partly funded through national programmes, and partly through international programmes like Nordic WOCE (1994-1997), EU MAST II ESOP (1996-1998), EU MAST III VEINS (1997-2000), EU MAST III MAIA (2000-2001) and now by the ASOF programme. A brief overview of the major efforts in recent years (Figure 1.32) and a few major results

are provided below. Further information is available from the programme and institute web sites listed in Chapter 7.

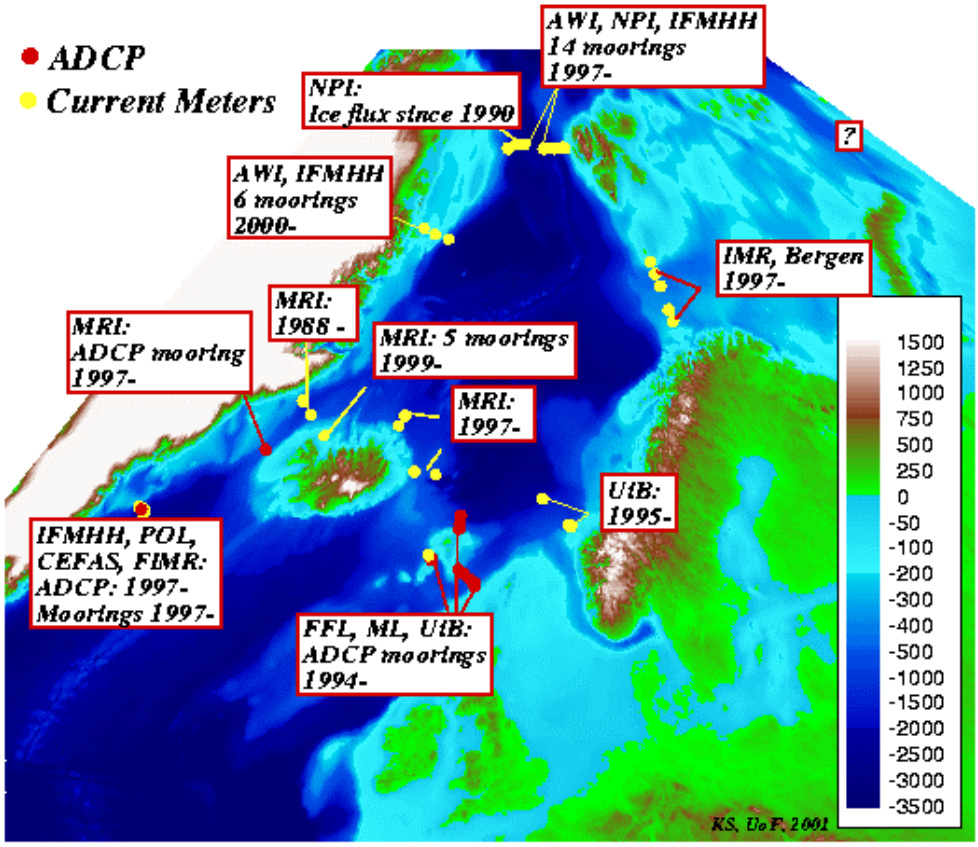


Figure 1.32 Overview of moored current meter and ADCP measurements in and at the borders of the Nordic Seas.

1.6.1 Fluxes through the borders of the Nordic Seas

1.6.1.1 Greenland Scotland Ridge.

The southern border of the Nordic Seas consists of the ridge system between Greenland and Scotland, which has three passages: the Denmark Strait, the Iceland-Faroe Ridge and the Faroe-Shetland Channel (FSC). The cold and deep water resulting from the deep water formation further north is overflowing through these passages into the Atlantic, and is replaced by a northward flow of warm and saline water.

Standard hydrographic sections crossing the Denmark Strait has been obtained one to four times per year at least since 1987 by MRI in Iceland. Since 1994 flux estimates using semi-permanent ADCP moorings combined with traditional moorings has been added to the hydrographic monitoring on the sill in the Denmark Strait, and since then the measuring programme has been extended into the shelf area. Non-continuous measurements are also performed on the Greenland slope south of the Greenland Strait since 1986, and since 1997 a mooring array designed for measuring the freshwater and sea ice transport with the East Greenland Current has been deployed on the East Greenland Shelf. The activities have been a joint effort by CEFAS and POL, both UK, IFMH and IFMK, both Germany, and IMR, Finland in cooperation with IMR Iceland.

Research vessels from various countries have frequently visited the Iceland Faroe Ridge and Faroe Shetland Channel in the last century. Standard sections north of the Faroe Islands, and across the Faroe Shetland Channel has been taken two to four times every year since the mid 1980'ies by the

fishery laboratories in the Faroe Islands and Scotland. Regular observations along one of the sections across the Faroe Shetland Channel extend over the last 100 years (Turell, 1999). Since 1994 the hydrographic sections north of the Faroes, across the Faroe Shetland Channel and across the Faroe Bank Channel west of the Faroe Islands has been supplemented by semi-permanent arrays of ADCP's.

Recent results indicate the about 50% of the deep overflow and 12 % of the Atlantic inflow across the Greenland Scotland Ridge is passing through the Denmark Strait in addition to the freshwater export with the East Greenland Current (Østerhus et al, 1999). The arrays around the Faroe Islands capture 88 % of the Atlantic inflow, 92 % of the heat flux, and 33 % of the deep outflow across the Greenland Scotland Ridge (Hansen and Østerhus, 2000). Of Atlantic inflow an approximately equal amount is passing on each side of the Faroe Islands. The inflow of the Atlantic water is about 8 Sv, which is balanced by about 6 Sv as overflow and transports with the East Greenland Current. However, these numbers may be subject for adjustments for at least two reasons: The first is continuing measurements and the other is that the volume fluxes may due to changes in climate. The current measurements (Hansen et. al, 2000) in the Faroe Bank Channel shows a decline in the deep overflow since 1994. Combination of the current measurements in Faroe Bank Channel with hydrographic measurements at the weather ship M in the Norwegian Sea indicates that the decrease has lasted in the entire measuring period, which starts in 1948.

1.6.1.2 Barents Opening.

The section along the entrance to the Barents Sea crosses the northward flow of Atlantic water and the southward flow of Artic water. Hydrographic observations has been taken regularly since 1967, and since 1977 the section has been taken at least 6 times every year mainly by the Norwegian institutes IMR and NPI, but also by IOPAS, Poland. Since 1997 the monitoring has been extended by an array of conventional current meter moorings, and since early 1990'ies current data are also obtained from ship born ADCP (Haugan, 1999).

The recent results by Ingvaldsen et al (2002) shows a net northward transport of 2 Sv, which is in accordance with previous estimates indicating a northward transport of 3.1 Sv and a transport of 1.2 Sv out of the Barents Sea (Blindheim, 1989). However, this transport is highly variable and may vary over a range of order 10 Sv on a monthly basis (Ingvaldsen et al., 2002).

1.6.1.3 Fram Strait.

The magnitude and variability of the sea ice, freshwater and heat fluxes through Fram Strait is an important element in understanding and monitoring climate variability in the Arctic as well in the Nordic Seas. In the 1980'ties GFI, UoW, and IFMH made some measurements with moored instruments, and in 1990 NPI started to monitor sea ice thickness and transport. Since 1997 AWI, IFMH and NPI have operated several moorings across the Fram Strait equipped with current meters and upward looking sonars, and in some years also with ADCP's. Hydrographic observations are taken on annual basis by AWI, NPI, UNIS, UEA and IOPAS.

Based on data from the mooring program volume transports of 9.5 Sv to the north and 11.1 Sv to the south are obtained, resulting in a net transport to south of 1.6 Sv. An intense annual variation is superimposed on the mean currents, suggesting that short-term estimates based on single CTD survey can be misleading (E. Fahrbach, pers. comm. 2001).

1.6.2 Circulation in the Nordic Seas.

The hydrographical state of the Nordic Seas is monitored by numerous measurements made mainly by the Fishery Laboratories and other research institutions in the surrounding countries. Programmes using drifting floats in order to map circulation patterns are also ongoing. Activities on flux estimates of the interior circulation in the Nordic Seas are however focused to three key locations.

1.6.2.1 Measurements of poleward heat flux west of Norway

The Atlantic inflow passing the Faroes continues northward along the Norwegian coast. The hydrographic conditions of the poleward flow are monitored along the Svinoy section since 1995 and along the Gimsoy section since 1978. These measurements have mainly been undertaken by IMR, Norway. Since 1995 these two sections have been undertaken more than 5 times every year. In 1997

the monitoring on the Svinoy section was extended with conventional moorings, and the hydrography by regular cruises running undulating CTD (SeaSoar) and ship-borne ADCP measurements in a programme at the GFI (Orvik, et al, 1999). The objective of these efforts is to quantify the mean and seasonally varying poleward volume and heat transport, and to get insight in the distinct two-branch structure of the northward flow of Atlantic water.

1.6.2.2 The transports of the East Greenland Current at 75°N

The hydrography of the section along the 75°N latitude from the Bear Islands onto the Greenland Shelf has been undertaken by a large number of institutions from various countries. In the Greenland Sea Projects in the late 80ties and early 90ties current meter measurements were done in the East Greenland Current. Presently AWI and IFMH maintain 6 moorings in the East Greenland Current on an experimental basis to investigate the effect of cross-current bottom roughness on the down-slope transport. Another mooring is deployed on shelf, to estimate freshwater fluxes in the uppermost layers. Objectives of these measurements are to measure variations in the East Greenland Current down stream from its entrance to the Nordic Seas through the Fram Strait.

1.6.2.3 Flux Measurements of the East Icelandic Current.

The hydrography around Iceland has been monitoored on a regular basis by MRI at least since 1987, including the flow of Arctic water into the Nordic Seas with the East Iceland Current. In 1997 the monitoring of East Icelandic Current was extended by arrays with 2 moorings on two sections.

1.6.3 Conclusion

A brief overview of the flux measuring activities of fluxes through the borders of the Nordic Seas and ongoing activities to measure parts of the interior circulation at three specific locations is mentioned. Estimates of the fluxes across the southern border of the Nordic Seas has become considerably more reliable in the last decades, while estimates of the fluxes across the northern border still remains uncertain due to extreme variability in the circulation. Additional information may be found at the research programme web sites listed below or at the web-sites of the institutes involved in the activities.

1.7 Sea traffic

There are two economically important areas in the world where the seasonal sea ice plays an important role in the navigation: the Gulf of St. Lawrence in Canada and the Baltic Sea in Europe.

The ships must navigate through the ice in order to sail to the harbours. They cannot avoid the ice areas as could be done in parts of the Arctic areas. The ice in the Baltic Sea makes navigation difficult at least in Finland, Sweden, Russia, and Estonia. During average and severe ice season sea traffic difficulties occur in all Baltic Sea countries and in Norway and the Netherlands.

The sea transportation consists of normally 70-90% of the total transportation which of some 40% occur during winter. At the most difficult ice areas of the Baltic Sea, large amount of goods are transported: e.g. in Finland during the winter months about 30 million tons is transported with 25,000 port-calls. In Sweden about 12 million tons of cargo is shipped annually to and from north of Stockholm, which of 5 million tons is shipped during the period when icebreaker assistance is necessary. Total amount of cargo turnover in the Baltic Sea in 1995 was 450 mil. tons (Breitzmann, 1996).

The value of sea transportation in winter time is very high, e. g. in Finland about 20 billion €. These conditions are forcing the Baltic Sea countries to keep on icebreaker fleets and merchant vessels suitable to ice-navigation. In order to make the winter navigation as optimal as possible, there is a great need of accurate up-to-date data information of the ice conditions changing all the time. The traffic has increased 30% in last ten years, and it is expected to rise another 30 % in next ten years. During this time the number of icebreakers has not increased. The ships are navigating as independently as possible under the guidance of an icebreaker. In the future this traffic will increase, and it would only be possible because of the extensive use of high resolution EO data and ice products onboard the ships.

2 Use of models and observing networks in monitoring and forecasting

2.1 Baltic Sea ice monitoring services

In the Baltic Sea there are national ice services in Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, and Sweden. The sea ice data are collected, analysed and distributed by these national ice services.

The ice service collects sea ice data from various sources. These sources are:

- the ground truth, such as data of observation stations, observations of vessels and icebreakers etc.,
- visual and/or digital air-borne data collected by aeroplanes and icebreaker based helicopter, and
- space-borne data of various satellites.

The scale of data varies, space-borne is normally with a resolution of 100-1000 m, air-borne data in resolution of 10-100 m, and ground truth in centimetres to hundreds of metres. The observation coverage is at the observation stations <20 km, helicopter could cover <300 by 300 km in a day, aeroplane >500 by 500 km in a day, ERS SAR swath is 100 km, RADARSAT swath is 500 km and NOAA AVHRR swath is 2600 km.

All these data are collected by the ice services using various communication means like networks, faxes, telexes, mail, radio etc. In the service the data is analysed, compared with other updated data and interpretation is made. Using the latest updated ice chart or other ice information product and the conditions are updated, and the products are sent to the users, again using various communication means (Figure 2.1).

Main products of the all ice services are

- ice charts,
- ice reports in plain language, and
- ice reports in the Baltic Sea Ice Code.

Some services also provide

- forecasts and
- satellite images (“raw” and classified).

2.2 Greenland Waters ice monitoring services

The Danish Meteorological Institute (DMI) is responsible for sea ice monitoring and information for the Greenland Waters. The purpose of the sea ice mapping is to aid navigation and to provide strategic and tactical support in the Greenland waters. The main areas of concern are the waters around Cape Farewell. Furthermore, the sea ice outside the Cape Farewell area is mapped in selected periods and regions, depending on navigational needs and the actual ice distribution.

DMI operates a two branch ice service. At Narsarsuaq Airfield in South Greenland, the DMI Ice Observation and Warning Service, ‘Ice Central Narsarsuaq’ was established in 1959. Ship piloting and ice reconnaissance of the South Greenland inshore routes and the inner parts of the Julianehåb Bay is carried out year round by a dedicated helicopter and is coordinated by Ice Central Narsarsuaq.

The second branch, ‘Ice Charting and Remote Sensing Division’, is located at the Danish Meteorological Institute in Copenhagen. The launch of RADARSAT with its ScanSAR Wide capabilities marked the beginning of a new era and active and passive satellite data are now the main data source for the production of ice charts for all Greenland Waters, except in the melt season (Cape Farewell). The mapping on satellite data takes place at DMI in close coordination with the office in Narsarsuaq. NOAA-AVHRR and DMSP-SSM/I are also important data sources in the Ice Service. Satellite data are always analyzed by experienced and special trained ice analysts.

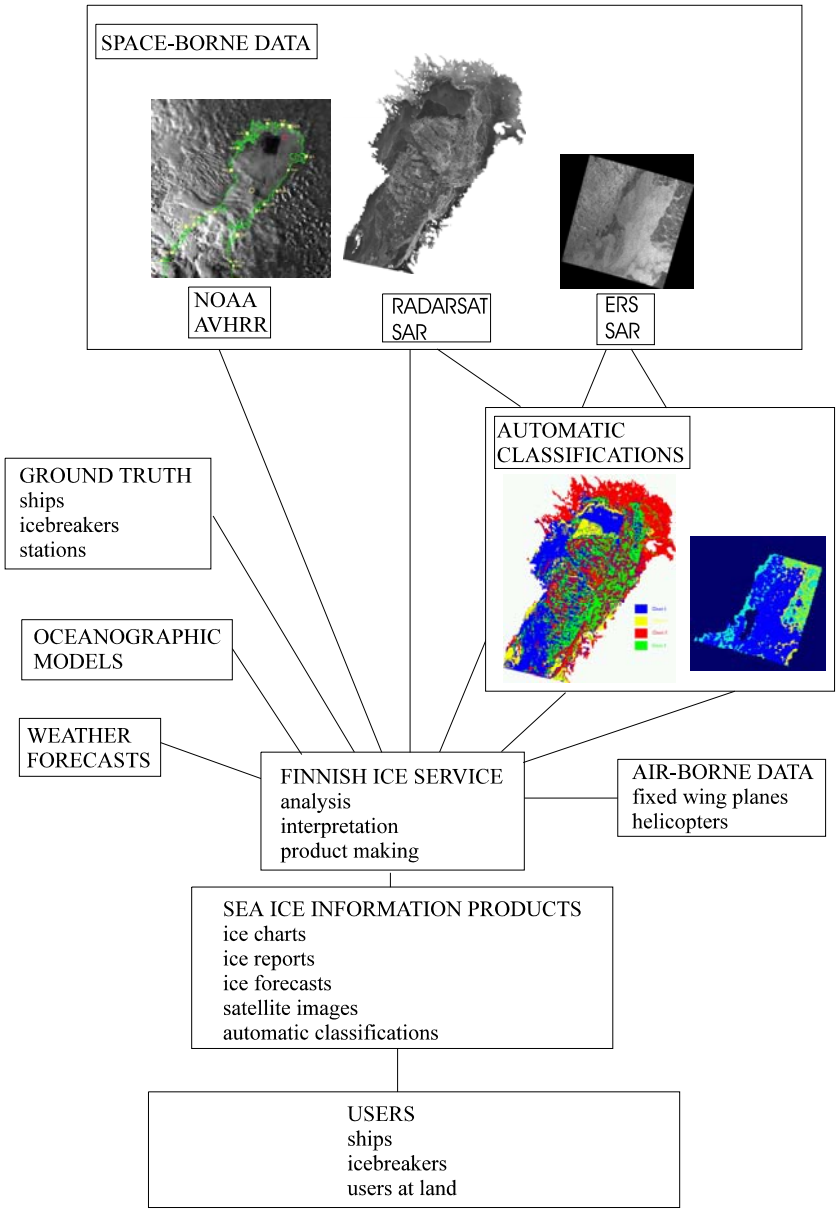


Figure 2.1 The operational scheme of the Finnish Ice Service.

Output products from DMI's service:

- Ice charts for the **Cape Farewell area** are updated and issued 3-4 times a week when sea ice occur. Outside the melt season a new ice chart is published once a week
- Ice charts, primarily based on NOAA-AVHRR and RADARSAT, for **other areas in Greenland** are produced 1-6 times weekly depending on the actual ice situation and navigational needs.
- Ice conditions near or in shore ship routes in **South Greenland** are mapped on a weekly basis or on request.
- A weekly summary ice chart for all **Greenland waters** is published once per week.
- Ice charts follow international standards (Egg code) and are published by use of telefax, INMARSAT, facsimile and Internet. Further, ice information is broadcasted by radio, radiolinks, telex, telephone and e-mail.

3 The role of satellite data in sea ice monitoring

Sea ice observation from coastal stations and ships has a history of more than 100 years. Regular sea ice charting, however, using aircrafts and satellites has developed mostly after the Second World War. Aircraft surveys have been the main observation method, but use of satellite data has developed gradually over the last three decades as a consequence of the instruments and observation techniques available from satellites.

The first satellite sensors providing views of the large-scale structure and motion of sea ice utilized visible and infrared channels such as those onboard the early Nimbus, Tiros, and earth Resources and Technology Satellite (ERTS, later renamed Landsat). By the late 1960s, it was apparent that the sequential synoptic observations needed for sea ice and climate studies could not be acquired by satellite-borne visible sensors, which are limited to cloud-free and well-illuminated conditions. Sea ice exists in regions that are dark for several months and are frequently cloudy in the remaining months (Gloersen et al., 1992).

Therefore, it has been necessary to develop observation methods using microwaves that are able to penetrate clouds and are not dependent on light conditions. The first passive microwave remote sensing systems for satellites were launched on the Russian Cosmos 243 and Cosmos 384. In 1968 and 1970, respectively. In the US, passive microwave technology was first used in remote sensing of sea ice during the late 1960s and early 1970s, when a prototype of the Electrically Scanning Microwave Radiometer (ESMR) was flown on Nimbus-5 over the Arctic (Campbell, 1973).

The period since 1970 has been one of great advancement in remote sensing of sea ice. After the ESMR period 1973-1976, a more advanced satellite instrument, the Scanning Multichannel Microwave Radiometer (SMMR) was operated on Nimbus-7 for nine years, from 1978 to 1987. This instrument provided the longest and first regular time series of global sea ice data. Passive microwave observations have fairly coarse resolution (typically 30 km) and are more suitable for large scale or global monitoring than for regional and local observations. Active microwave systems, such as Side-Looking Radars (SLR) and Synthetic Aperture Radar (SAR) were developed for aircraft surveillance and used in ice monitoring to provide detailed maps of the ice conditions, especially in areas of heavy ship traffic.

In 1978 Seasat was the first satellite that provided high-resolution SAR images of sea ice, but the satellite only operated for about three months. With spaceborne SAR data, which combines high spatial resolution with independence of cloud cover and light conditions, it is possible to observe sea ice with much better accuracy than visible and passive microwave methods. ERS-1 represented a major milestone in satellite SAR remote sensing of sea ice, because the satellite delivered tens of thousands of SAR images of sea ice from most ice covered regions in the world. The satellite SAR technology is being improved and SAR systems offered by RADARSAT and ENVISAT have wide swath, multimode, dual polarization. Also other microwave systems such as scatterometer and side-looking radar (SLR) data have shown promising results in sea ice observations.

In order for SAR and other microwave data from satellites to become central elements in ice observation, products useful for a wide range of users, interpretation techniques and algorithms must be improved and streamlined. The data products must be developed based on requirements from established users.

The status of sea ice monitoring can be summarized as follows: It is

- of national importance in countries whose coasts are ice-infested during the winter,
- of considerable economic importance in sea transportation,
- one of the most important and appropriate applications of satellite data with potential to increased use as new satellite data becomes available,
- an established and organized activity in many countries where sea ice has impact on sea transportation,
- important for weather forecasting,
- important for climate change detection.

Use of satellite data in sea ice monitoring is developing steadily. The main aspects of this development are:

- satellite methods such as visual/infrared data (AVHRR) and passive microwave data (SSM/I) are used operationally in many countries,
- introduction of spaceborne SAR data represents a major milestone and improvement of ice monitoring quality,
- synergy with other data (aircraft, in situ, etc.) is essential for optimal extraction of ice information from satellite data,
- in many regions only satellites can provide data because aircraft and ships cannot cover the whole Arctic or Antarctic ice area,
- the market for sea ice data and related services is expected to grow because of increased activities and more focus on environmental issues in polar regions,
- considerable improvements of ice monitoring products and services are needed, which require more use of SAR data from satellites.

Sea ice monitoring takes place on three different scales - each of which has characteristic users and role for satellite data, as shown in Table 3.1.

Table 3.1 Summary of sea ice monitoring scales, user groups and role of satellite data.

Scale	**Geographical regions**	**Applications - user groups**	**Role of satellite data**
Global	Northern and Southern Hemisphere	Climate monitoring Weather forecasting Polar ocean and atmospheric research	Satellite data is the most important source of information (SSM/I and AVHRR are established data, Scatterometer data are new)
Regional	Baltic Sea, Barents Sea, Kara Sea, Greenland coast, etc.	Ship traffic planning Offshore planning Weather/ice forecasting Strategic navigation Safety at sea Ice research	Satellite data essential (AVHRR and SAR) Wide swath SAR data will become the most important data source. Aircraft, ship data and coastal observations are also necessary
Local	Straits, Sailing routes, Entrance to harbours, Near offshore operations	Tactical navigation Ship traffic control Support to offshore operations Input data to construction, ship-building, etc.	Ship, aircraft, helicopters and coast stations data are the most important sources of data. Satellite data will play a more important role as SAR data become fully operational

4 A system for distribution of met-ice-ocean data and information

The needs for distributing meteorological, sea ice and oceanographic data and information from multiple producers to users at sea and on land, have been addressed in the EC-funded project IWICOS (Integrated Weather, Sea Ice and Ocean Service System). The overall objective of IWICOS has been to develop a prototype marine information system that will provide a single-entry access to integrated meteorological, sea ice and oceanographic (met-ice-ocean) products in electronic form, and to demonstrate this prototype for a group of users working in fisheries, sea transport, exploitation of marine resources in Northern European waters, or whose work is related to sea ice monitoring on a scientific or pre-operational basis. This chapter describes some aspects of the architecture, design and implementation of the information system developed in the IWICOS project.

4.1 The IWICOS reference architecture

The IWICOS system can be characterised as a dynamic multiproducer GIS system. This kind of system can be divided into three subsystems as shown in Figure 4.1.

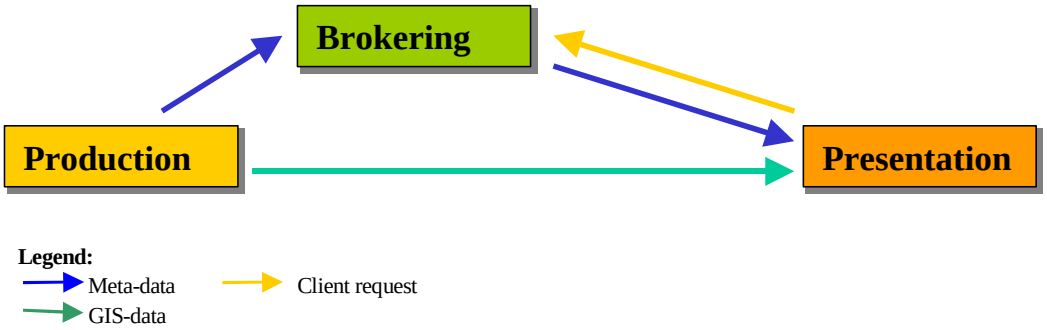


Figure 4.1 The reference architecture for IWICOS.

The main subsystems include the ***production***, ***brokering***, and ***presentation*** of GIS-products. The actual tasks in these subsystems are determined by decisions related to issues such as distribution, delivery mechanisms (push/pull) and client model (thin/thick). In the production subsystem the GIS-data is produced and packed for delivery with a meta-data description of the product. The brokering subsystem receives this information (or plain meta-data and GIS-data address) and the user needs (either a profile or a request). The presentation or End-User subsystem takes care of presenting the data to the user. The Client software can be characterised as thin- or thick according to the functionality and requirements of software installation.

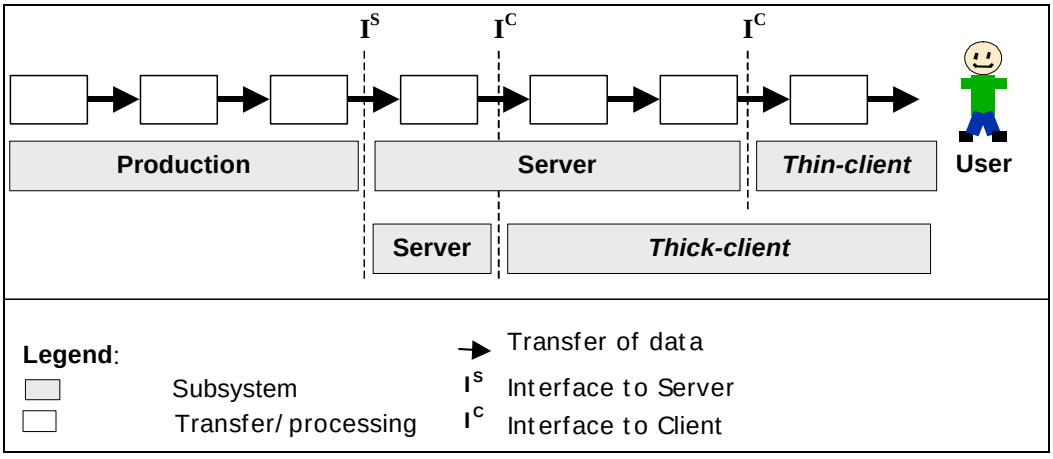


Figure 4.2 The role of Thin and thick clients in Client-Server GIS systems.

4.2 Interoperability in the IWICOS system

The IWICOS interoperability is based on a common description of available products and their features presented in XML. These metadata descriptions are submitted to the Broker. The customers can base their product selection on the metadata description, and then retrieve the actual products from the Producer Servers with the help of a Facade subsystem. Finally, Client Software is used to acquire a presentation of the product data (Figure 4.3).

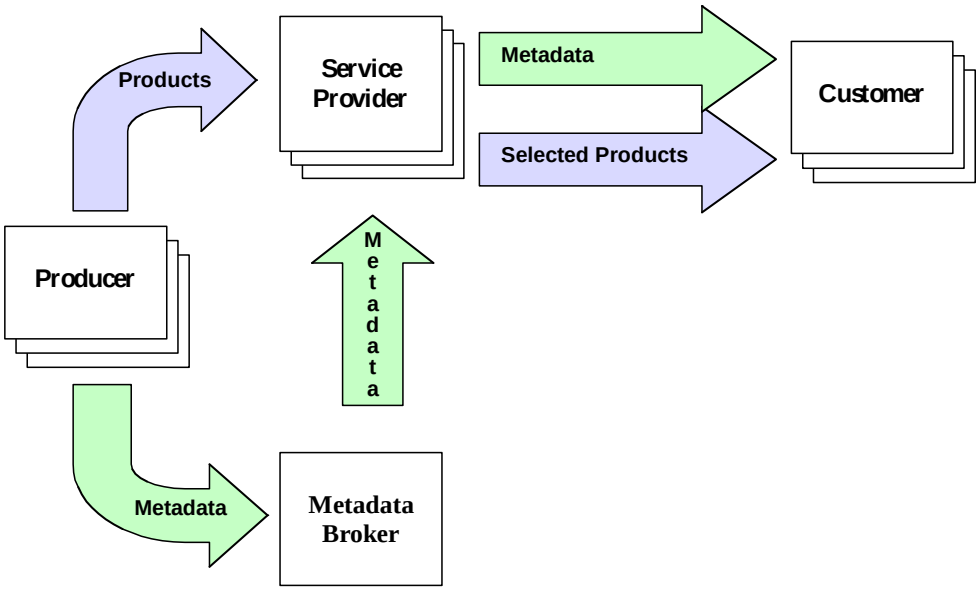


Figure 4.3 The IWICOS Service Chain.

4.3 Detailed Architecture

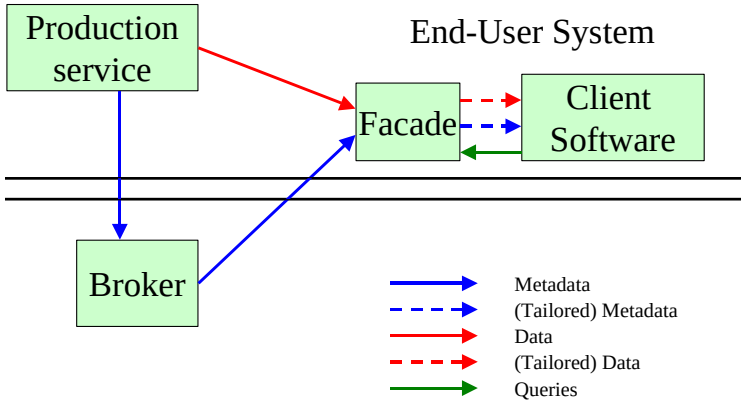


Figure 4.4 The structure and data flows between the subsystems.

4.3.1 Interfaces

The IWICOS Architecture is illustrated by the four following interfaces between the various subsystems: **Producer Server - Broker, Facade - Broker, Facade - Producer Server, and Facade - Client Software**. These are explained in more detail below.

Producer Server - Broker
Using this interface the Producer Server manages the Broker metadata content with the operations: *newProduct*, *outdatedProduct*, and *productList*. The operations are used for informing the Broker of new and outdated products, and acquiring of a list of the producer's products that have metadata stored to Broker.

Facade - Broker
The Facades execute queries on metadata using this interface at the Broker to gain a list of products that might be applicable for user needs. This interface contains a single operation called *query*. However, it is more complicated than the previous interface, hence the parameter and reply content is more dynamic.

Facade - Producer Server
This interface is used by the Facades to acquire the actual product data based on the metadata. The product data at the passive (web-server) part of the Producer Server is accessed using the HTTP-protocol.

Facade - Client Software
This interface is actually a black-box one - the decision of what protocols and other means of communications to use here is left for the designer of the Client Software - Facade pair. In the scope of the IWICOS System it is enough for us to know that such implementation is present.

4.3.2 Producer Server

The Producer Server integrates the IWICOS system to the producer's existing production process. It communicates with the Broker using specific small stub programs designed for the messaging between these components.

The Producer Server consists of two parts (Figure 4.5):

a. An active part, that informs the Broker of the events, such as a new product becoming available or an old product getting outdated, that occur in the production process.
b. A passive part, that is basically a web server where the active part places it's output for the Broker (the metadata) and the Facades (the product data) to retrieve.

The set of data formats for the communication between the Producer Servers and the Facades was limited to Binary Sequential Files (BSQ), GRIB (GRIdded Binary), Shapefile, and XML for reducing the complexity of the implementation. Within the End-User Systems (Facade and Client Software pair) there are no such limitations. The Facades can use the base types listed above to generate products in any format. Basically the End-User System is a black box - the subsystems outside should and shall not be interested in what happens there.

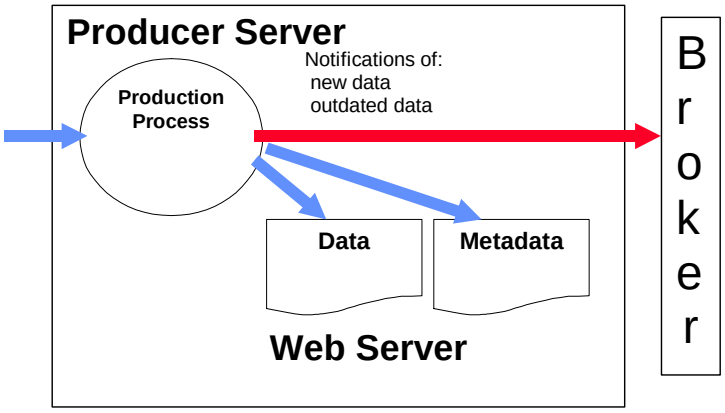


Figure 4.5 The IWICOS Producer Server Components and Internal Data Flow.

4.3.3 The Broker

The Broker provides two interfaces for metadata operations. One is intended for the Producer Servers for managing the Broker's metadata content. The other one is the query interface for the End-User Systems through which they can access the Broker's metadata content. The Broker is based on freely

available components: Apache web server, Apache Tomcat servlet container, Apache SOAP implementation and MySQL database. The Broker runs on Linux OS and the service programs are written in Java. The communication is secured using SSL encrypted HTTP protocol (HTTPS).

The Broker is divided into three main components: the Database, a storage for metadata; the Metadata Parser, that will process the metadata descriptions of the new products and store them to DB for later access by queries; and the Query Engine that will interpret the queries posed in an XML format to SQL and execute them on the DB and return the results for the caller.

The Broker communication is implemented with the Remote Procedure Calls (RPC) implemented over the Simple Object Access Protocol (SOAP). The RPC uses a small program called a *stub* in both ends of the communication, which will marshal the required parameters and return values of the call. Example of stubs is shown in Figure 4.6.

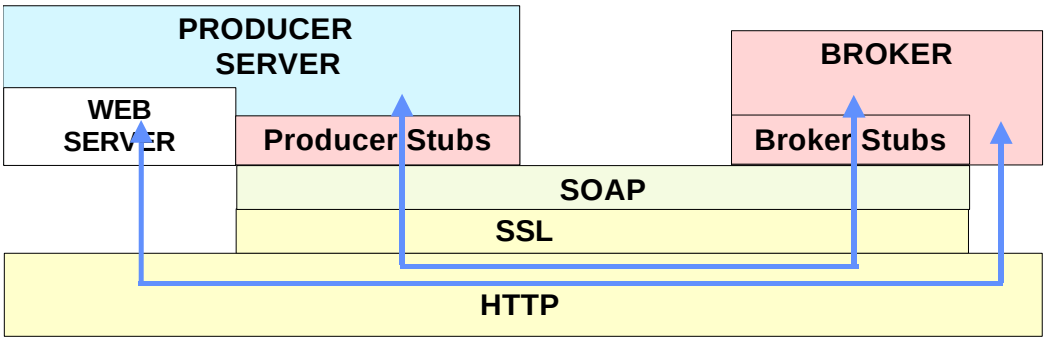


Figure 4.6 Stub Example - The IWICOS Producer Server and Broker communication.

4.3.4 The End-User subsystem - Facade part

The End-User system consists of the Facade and the Client Software. The Facade implementations can vary. For a simple web-browser based client it will be closely integrated to the Client Software. On the other hand it may be very complicated element containing reasoning of user needs based on a profile, product generation based on the products provided by the Producer Servers, and filtering of unnecessary components of products (e.g. layers with unnecessary data content).

The End-user subsystem consists of the Facade and the Client software. The Façade can be understood as a server for the Client Software. The Façade and Client Software might not be located in the same physical location, and the communication link between Client and Façade varies from high-speed Internet connection to low bandwidth cellular phone link.

4.3.5 Example of a Façade implementation

An example architecture of the Façade consists of two logical subsystems, the Metadata & Product Manager, and the Profile Manager. The former is responsible for getting the metadata, selecting and downloading the products, and delivering them to the users. The latter provides the Client Software with methods for inputting and editing the profile data.

The Façade creates a web page from where the user downloads the files. By this way part of the selection logic is given to the user, and this simplifies the task of choosing appropriate files on the Façade's side. The user actively retrieves a list of available files, which the Façade created based on user's preferences, and selects the most suitable ones for downloading. The Façade attaches some metadata in the web page, which describe the contents of the files, categorizes the file list by the data type, and sorts the files by their relevance to the user. Figure 4.7 shows an example web page created by the Façade.

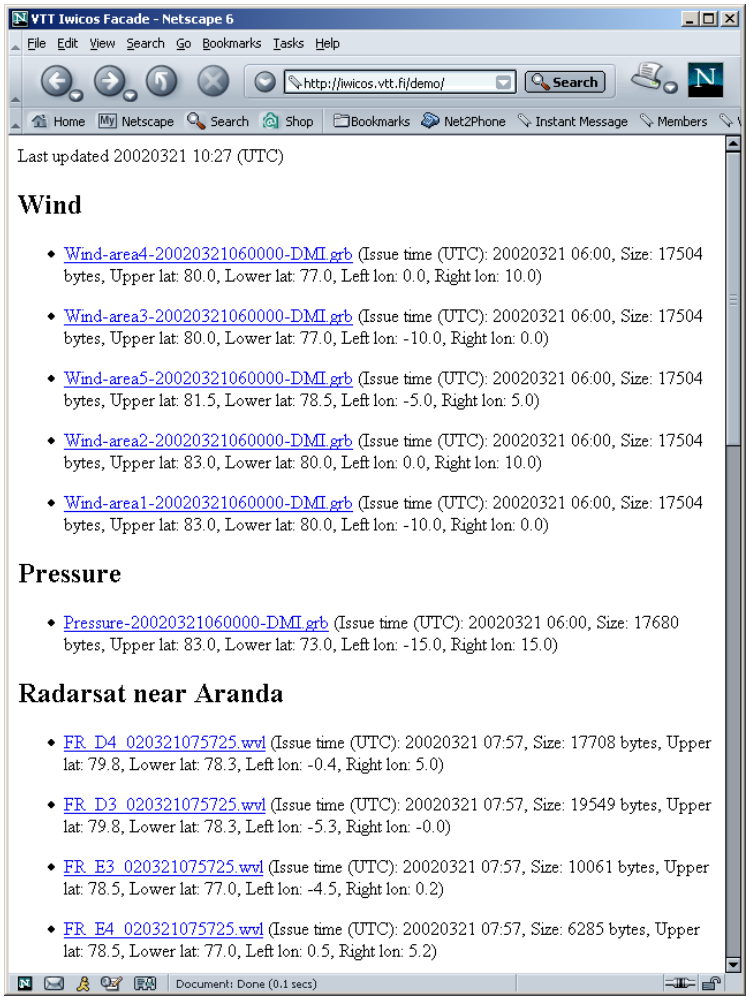


Figure 4.7 An example web page created by the Façade.

4.3.6 The End-User subsystem - Client Software part

The Client Software is intended for presenting the acquired data and the implementations have a range from thin to thick clients. In the IWICOS project all types of clients (thin, balanced and thick) have been tested in the demonstrations during the project.

The Client Software visualizes the weather and ocean information to the user. It retrieves the data from Façade, which has already tailored the data into a proper form.

An example of the user interface of a Client Software is shown in Figure 4.8.

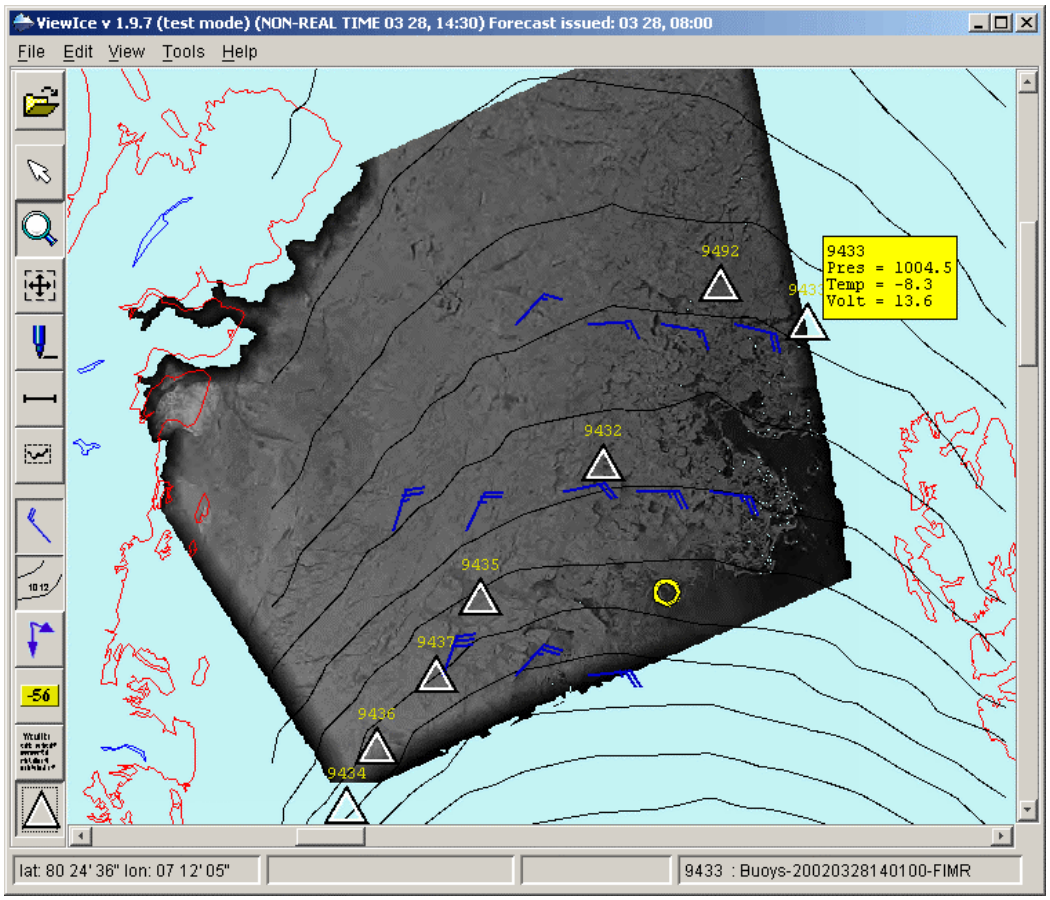


Figure 4.8 ViewIce presenting Radarsat image, buoy observations (triangles), wind and pressure forecast, and ship's location (yellow ring).

The Client Software includes the following functions:

A Receive/Retrieve data from Facade
The Client Software has to be able to communicate with Façade. User queries are delivered to Façade, and meta data and weather-ocean data are received in return.

B. Display meta data
Client Software is responsible for presenting the meta data to the user and providing means for product selection. Predefined profiles may also be used to retrieve the purposeful data. In that case, some means for profile input are provided.

C Generate presentation (thick-clients)
As thin clients mainly present the image data received from the server as such, thick clients are able to generate a visualization from raw data received.

D Allow customisation of the presentation (thick-clients)
Users typically want to combine some data and filter out some aspects of data. (E.g. User may want to see weather forecast and an ice-image combined on the screen, or want to view only the wind field instead of whole weather forecast).

4.4 Communication issues

Basically the requirements for IWICOS communication capabilities fall into two categories. First category is the communication between the Producer Server, Broker and Facade components that will occur in a stable high-band Internet environment. The second category is the communication within the End-User System (Client Software and Facade). This category is more complicated since the means and capability of the communication may vary a lot. The parties may communicate with a high-band Internet connection (a web-client), a costly high-band satellite connection, or narrow-band radio or cellular phone connection.

The first scenario is under a rapid change, although the communication capability is likely to remain at approximately the same level, but the way of using this capability is changing. New Internet technologies are developed with an aim to solve the problem of describing, discovering, selecting, and using the various services automatically. This trend known as the Semantic Web or Web Services is evolving rapidly.

In the second scenario there will not likely be any dramatic changes in the near future. The Satellite connections are likely to remain expensive and thus scarce. The cellular phone network coverage will be limited and out of scope for the sailors at high seas, although the GPRS and other new technologies may improve the bandwidth near the coast. Advances in Mobile Packet Data Services (MPDS) may change the cost scenarios in the near future, however.

The communication with the Broker is performed using SOAP, SOAP RPC and XML-related technologies where applicable (Figure 4.9)

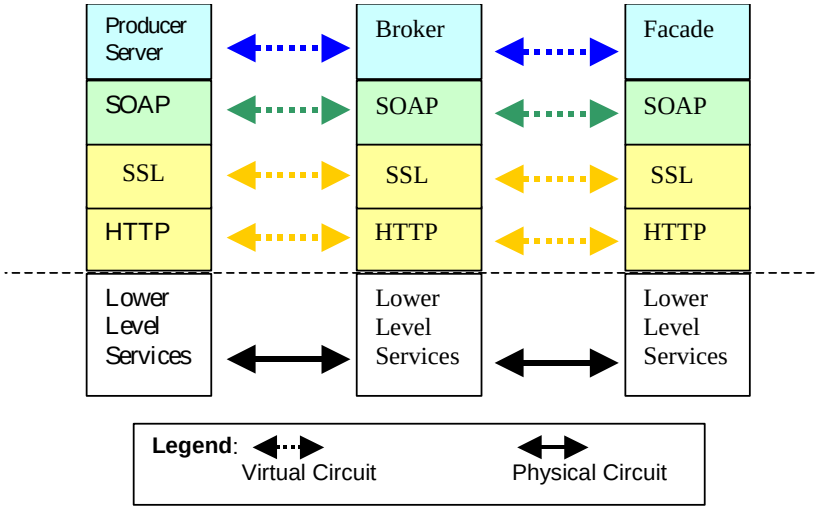


Figure 4.9 The SOAP Based Communication in the Broker Interfaces

The Simple Object Access Protocol (SOAP) is an open standard that supports the interoperability of autonomous systems. Since it can be run over the Hypertext Transfer Protocol (HTTP), it helps to resolve the communication problems that occur when the applications have to operate through the firewalls of different organizations. The security issues are controlled by applying Secure Socket Layer (SSL) on the HTTP communications, the SSL encrypts all the traffic among end-points based on two-key technology. Furthermore, SOAP supports RPC for invoking services on the service. SOAP messages can contain data packed in XML format, so they provide an ideal platform for implementing a tailored messaging service. Due to the XML approach the SOAP messages are easy to understand when compared to their binary correspondents such as CORBA, DCOM and RMI. The character-based nature of the messages introduces the requirement for encoding and decoding at the ends of communication, however this is relatively easy task when compared to the cost of the transmission itself. The SOAP is also a fundamental building block in the yet to come Semantic Web technologies, that will probably utterly change the way we look at implementation of interoperability.

4.4.1 *Shore - Ship Communication limitations*

In the IWICOS project a Questionnaire was sent to selected potential users in the Baltic Sea and for users in the Greenland Sea. The purpose was to recheck the capabilities that the potential users at sea have at the moment and also to have a forecast of the situation two years from now on. In the Baltic sea the target group are shipping companies that have cargo or passenger ships navigating in the Baltic Sea all year around.

The answers to the questionnaire showed that in the Baltic sea, which is relatively small, many ships find it sufficient only to use terrestrial communication means such as GSM. Still, satellite communications is increasing. The questionnaire was brief on purpose and aimed at providing basic information on what telecommunication equipment ship has on-board and what kind of communication program is used. The reason for this is that potential IWICOS customers hardly want to purchase any special equipment just to get the services provided by IWICOS, or this kind of requirement would severely restrict the number of potential IWICOS users.

The questionnaire indicates that E-mail is used on almost all ships at the moment, and is estimated to be used 100% within two years. All ships in the shipping companies interrogated, have GSM-data, but GSM data is limited to use when the ship is within reach of the base station (maximum of 30 km approximately from the nearest base station because of signal delay restrictions). Although this may seem to be a severe restriction, for ships whose route is mainly in the Baltic sea, the time when out of reach will be about 10 hours, and for the passenger ferries regularly navigating in this area even less than this. When looking at the answers from the Greenland Sea the situation is quite different. In this area the ships are out of reach of the cellular phone system 95% of the time, thus the need for satellite communications is much higher here.

The Icelandic survey shows that satellite traffic is expected to triple within the next two years. In the Baltic area NMT-450 service will phase out (support for NMT-450 will cease in Finland by the end of 2002).

High speed satellite links at sea are still not common, but in the Baltic Sea within 2 years of time a third of the ships in the shipping companies that replied to the questionnaire, will have a high speed link, either on permanent or on-demand basis. This will enable use of more detailed images and maps for a larger user group at sea.

5 DCRS interactive sea ice visualisation system

5.1 Background

Danish Center for Remote Sensing, Technical University of Denmark (DCRS/DTU) has demonstrated near real time distribution of free weather, ice and ocean data over the Internet:

http://www.dcrs.dtu.dk/DCRS/latest-ice.html

The demonstration has taken place throughout the duration of the IWICOS project (2000-2002) and the system has recently been secured to continue through 2005.

The main objectives of the demonstration were:

- Use of standard software and hardware platforms
- Platform independency (JAVA software, standard web browser)
- Provide interactivity (user can tailor view of data)
- Demonstrate a near real time service running for an extended period of time
- Use freely available satellite data
- Supplement by freely available weather and wave forecast data
- Take into account the limited bandwidth of many users

Figure 5.1 and Figure 5.2 show examples of screenshots from the DCRS interactive sea ice visualisation system.

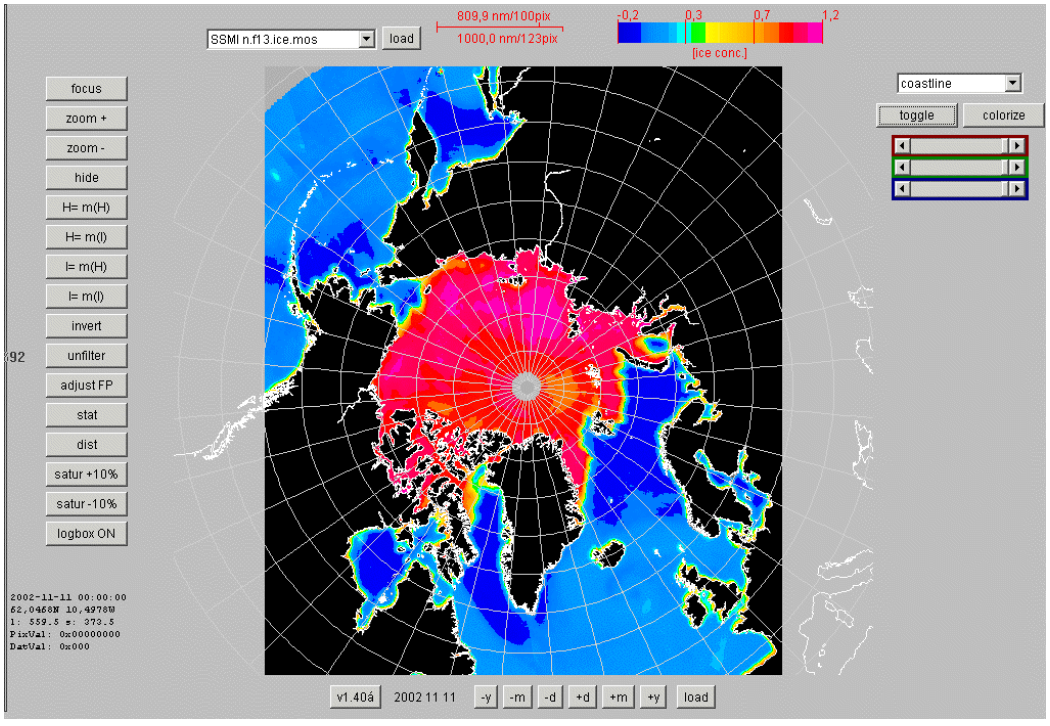


Figure 5.1 Example of an SSM/I ice concentration image in the Interactive Java viewer.

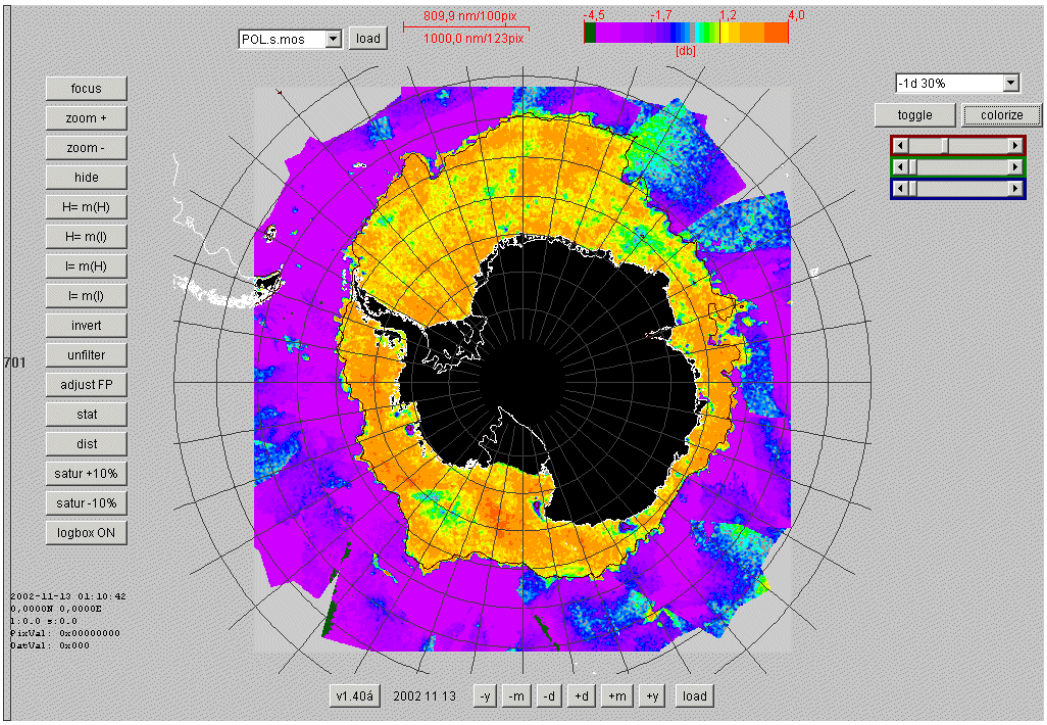


Figure 5.2 Example of a Quikscat polarization ratio image in the Interactive Java viewer.

5.2 Target user groups

The system was originally developed for internal use at DCRS. The purpose was to enable distance working, and to allow our data collection system to be supervised from remote places. Project partners and colleagues became very interested in the service, and we decided to open the system up for external use. We now see our main users as universities and other scientific institutions doing arctic research, operational ice centres, shipping companies, fisheries companies, etc. - people with a need for varied and timely information about the arctic marine environment.

Our target user group is expected to perform some interpretation of the images themselves, so we see our objectives as providing the tools to make decisions, rather than making the decisions.

5.3 Data sources

All data are automatically gathered from the Internet. We are continuously looking for new data sources, to expand our coverage, to become independent of single sources, and to be able to include new facilities, higher resolution and/or more timely data.

The main sources are:

5.3.1 SSM/I data

The Global Hydrology Resource Center (GHRC) provides both historical and current Earth science data, information, and products from satellite, airborne, and surface-based instruments. The GHRC acquires basic data streams and produces derived products from many instruments spread across a variety of instrument platforms. The GHRC is supported by NASA and is the data management and user services arm of the Global Hydrology & Climate Center (GHCC) in Huntsville, Alabama.

5.3.2 QuikSCAT data

Quikscat scatterometer data are provided by IWICOS partner DMI. The data are provided as ascii files containing latitude and longitude coordinates, HH and VV backscatter as well as wind speed and direction.

5.3.3 AMSU data

The Cooperative Institute for Research in the Atmosphere, CIRA was established at Colorado State University in 1980 to increase the effectiveness of atmospheric research in areas of mutual interest between the National Oceanic and Atmospheric Administration (NOAA), Colorado State University and other groups.

CIRA operates an extensive satellite earthstation. CIRA's earthstation first collected GOES weather data in 1980. Since then, CIRA's earthstation has collected from each succeeding GOES satellite. Currently, CIRA collects GOES-8, and GOES-10. In addition to GOES, CIRA also collects conventional surface and upper air data, Meteosat, AMSU and AVHRR data. These data products are collected in their high resolution form for CIRA researchers.

5.3.4 NOAA AVHRR data

Tromsø Satellite Station AS. TSS operates two ground stations for downloading, processing, disseminating and storing of data from polar orbiting satellites. Based on data from satellites, TSS offers earth observation products and monitoring services to customers within our coverage area, in near real-time.

5.3.5 Sea Surface Temperature data

Top Karten. Zusammenstellung von für Europäer interessanten Wetterkarten (Analysen und Prognosen, Beobachtungen, Satbilder usw.). Die meisten selbst erzeugt. Original data from NOAA. http://www.wetterzentrale.de.

5.3.6 Wind and Wave forecasts

The Marine Modeling and Analysis Branch is part of the Environmental Modeling Center, which is responsible for the development of improved numerical weather, marine, and climate prediction modeling systems within NCEP/NWS.

Provide analysis and real-time forecast guidance (1-16 days) on marine meteorological, oceanographic, and cryospheric parameters over the global oceans and coastal areas of the US.

5.3.7 Digital Ice Charts

The National Ice Center (NIC) is a multi-agency operational center representing the Department of Defense (Navy), the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), and the Department of Transportation (Coast Guard). The NIC includes personnel from the National Environmental Satellite Data Information Service (NESDIS) within NOAA. The Navy component within NIC is called the Naval Ice Center (NAVICECEN) and is a fourth echelon command reporting directly to the Naval Oceanographic Office (NAVOCEANO) at the Stennis Space Center, Mississippi. Both NAVICECEN and NAVOCEANO are part of the Naval Meteorology and Oceanography Command, headquartered at the Stennis Space Center. The Commanding Officer of NAVICECEN also serves as the Director of the National Ice Center.

5.4 Production chain

Figure 5.3 shows the DCRS production chain for the interactive sea ice visualisation system. The production chain produces images for our thin client solution (plain simple gif og jpg images to be viewed in Netscape or MSIE) as well as data for the balanced JAVA applet client and for the IWICOS broker system for other IWICOS partners.

The number of individual data products per day exceeds 500 of which ca. 20 are for the thin client, and the remaining for various versions of the balanced client that allows the user to produce her own views (Table 5.1).

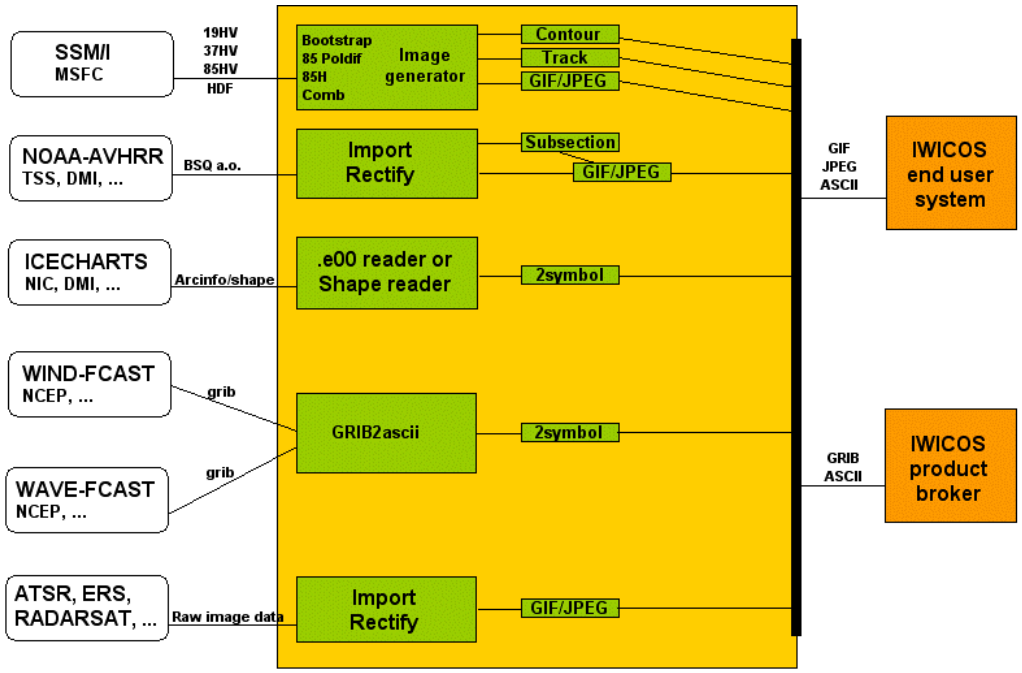


Figure 5.3 The DTU/DCRS data production chain.

Table 5.1 Typical daily data throughput.

Data source	Daily throughput
SSM/I	225 MB
AMSU	80 MB
QuikSCAT	20 MB
Wave & wind forecasts	9 MB
AVHRR quiklooks	15 MB

5.5 User interface

There are two main user interfaces, one for the thin client data (images), and one for the balanced client. The main web page in Figure 5.4 gives access to both clients.

The thin client images are primarily from the SSM/I instrument. Figure 5.5 shows an example of the thin client interface and a typical image product. Another example of a thin client product is seen in Figure 5.6. The characteristics of the thin client products are that they are simple images with a land mask, a lat/lon grid, and a coastline and a minimum of annotation (date and time).

The main balanced client interface is seen in Figure 5.7, and an example of the interactive screen is seen in figure 8. The total size of the JAVA applet is ca. 60 Kbytes, so it does not necessarily require a lot of data transfer to obtain considerable interactivity.

The balanced client allows the user to select date and pick data from the selected date. Subsequently a list of vector overlays such as coastlines, lat/lon grids, ice concentration contours, wind and wave forecasts, ice charts etc can be selected and toggled on/of. Colours of the selected overlays can be controlled individually to suit individual needs. The user can zoom in and out, and pan around in the image.

The screen view contains information areas such as colour legend, image info (date, time) and a vector legend. The user can click inside the satellite image, and lat/lon coordinates and parameter value (e.g. ice concentration) will be displayed in the image info panel.

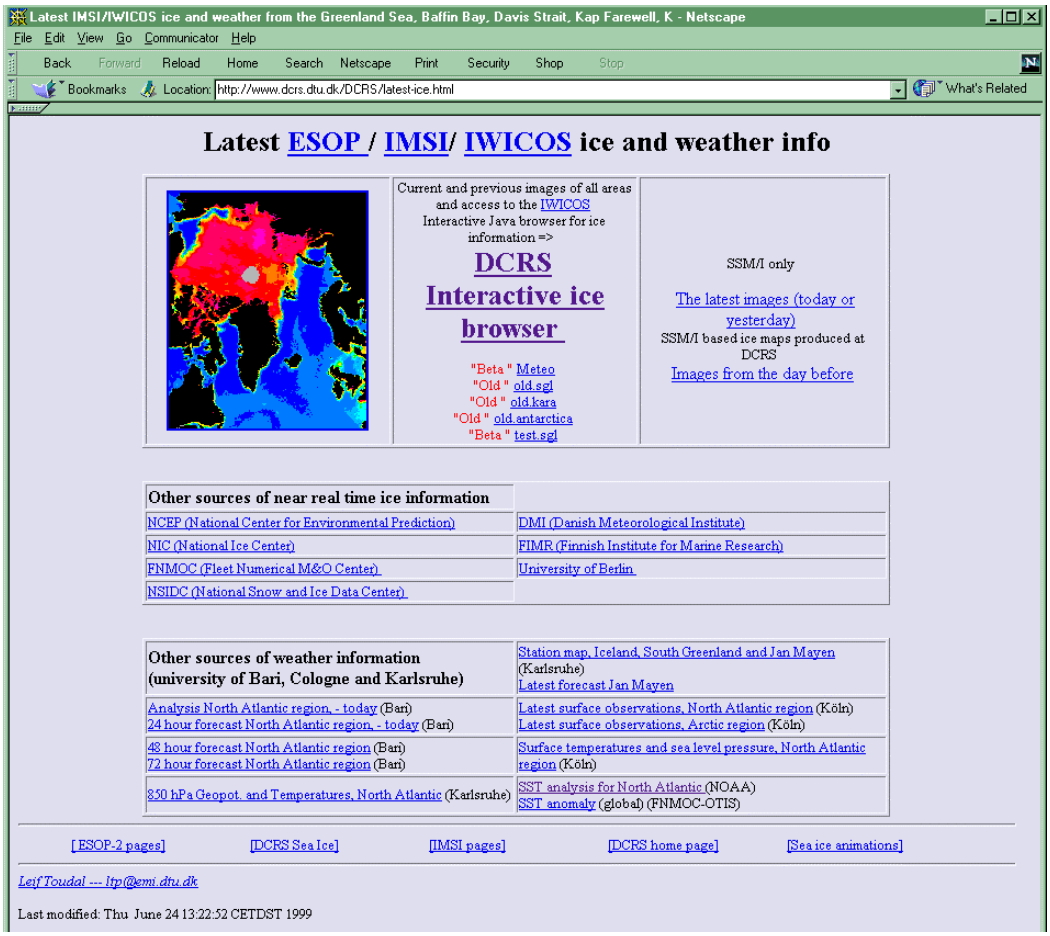
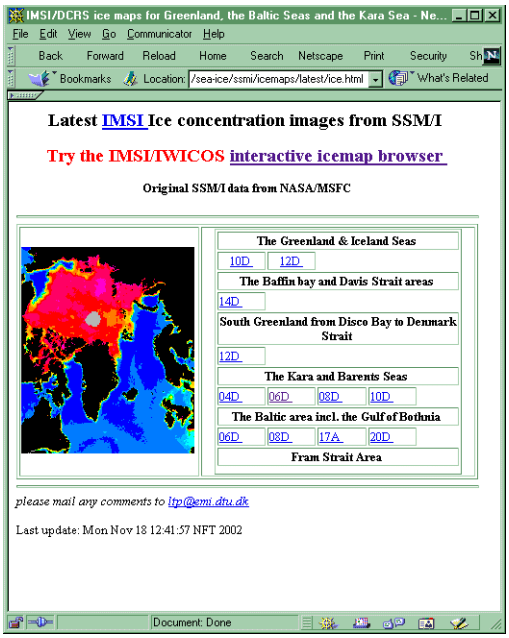


Figure 5.4 Screenshot of main web page directing the user to the "interactive ice browser" or the "latest" thin client images.



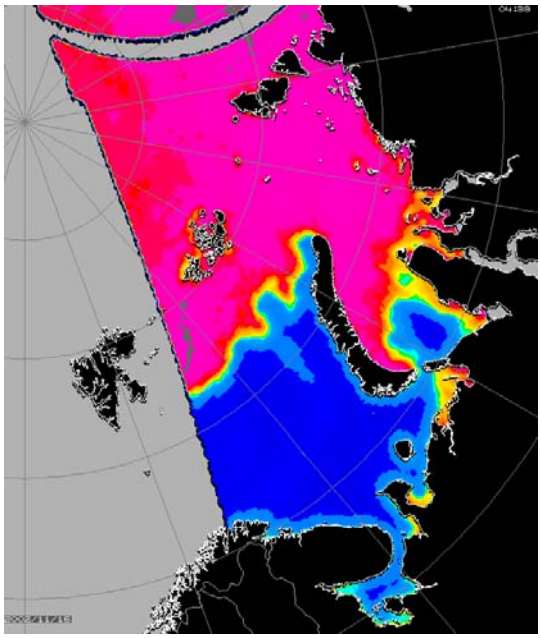


Figure 5.5 User interface and example of thin client product.

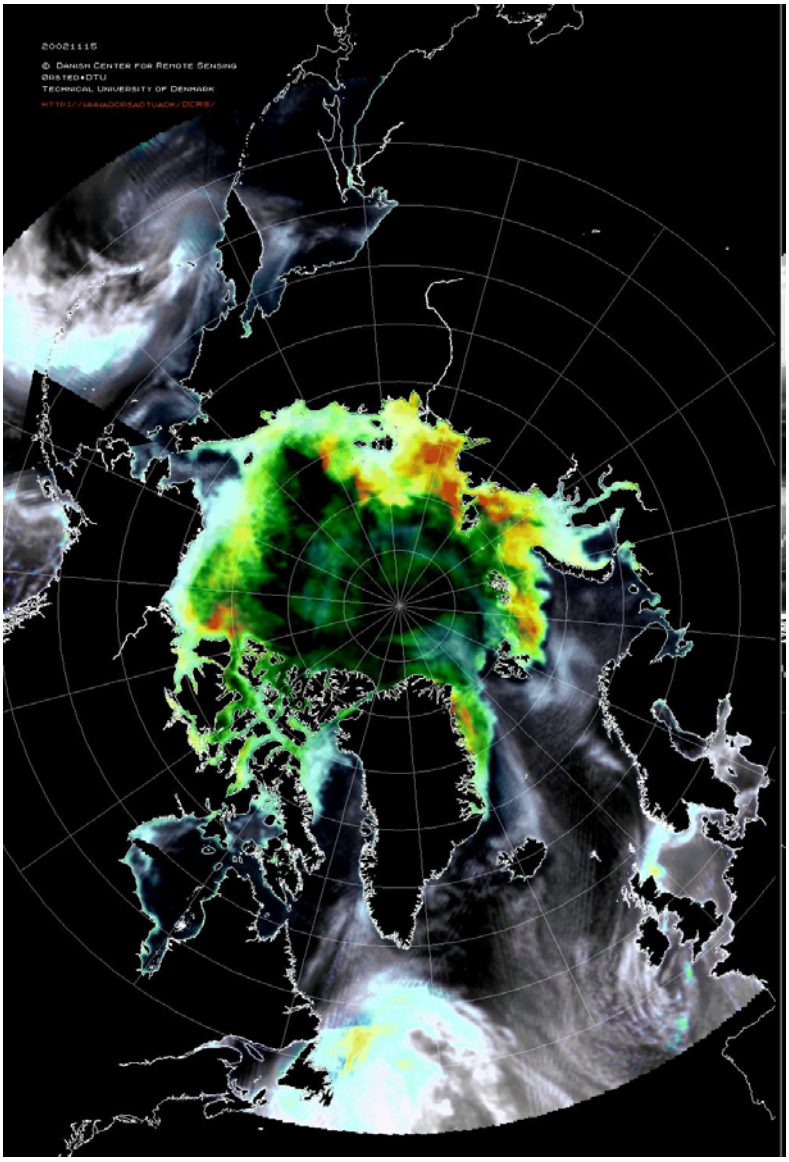


Figure 5.6 Example of AMSU mosaic as presented to the thin client.

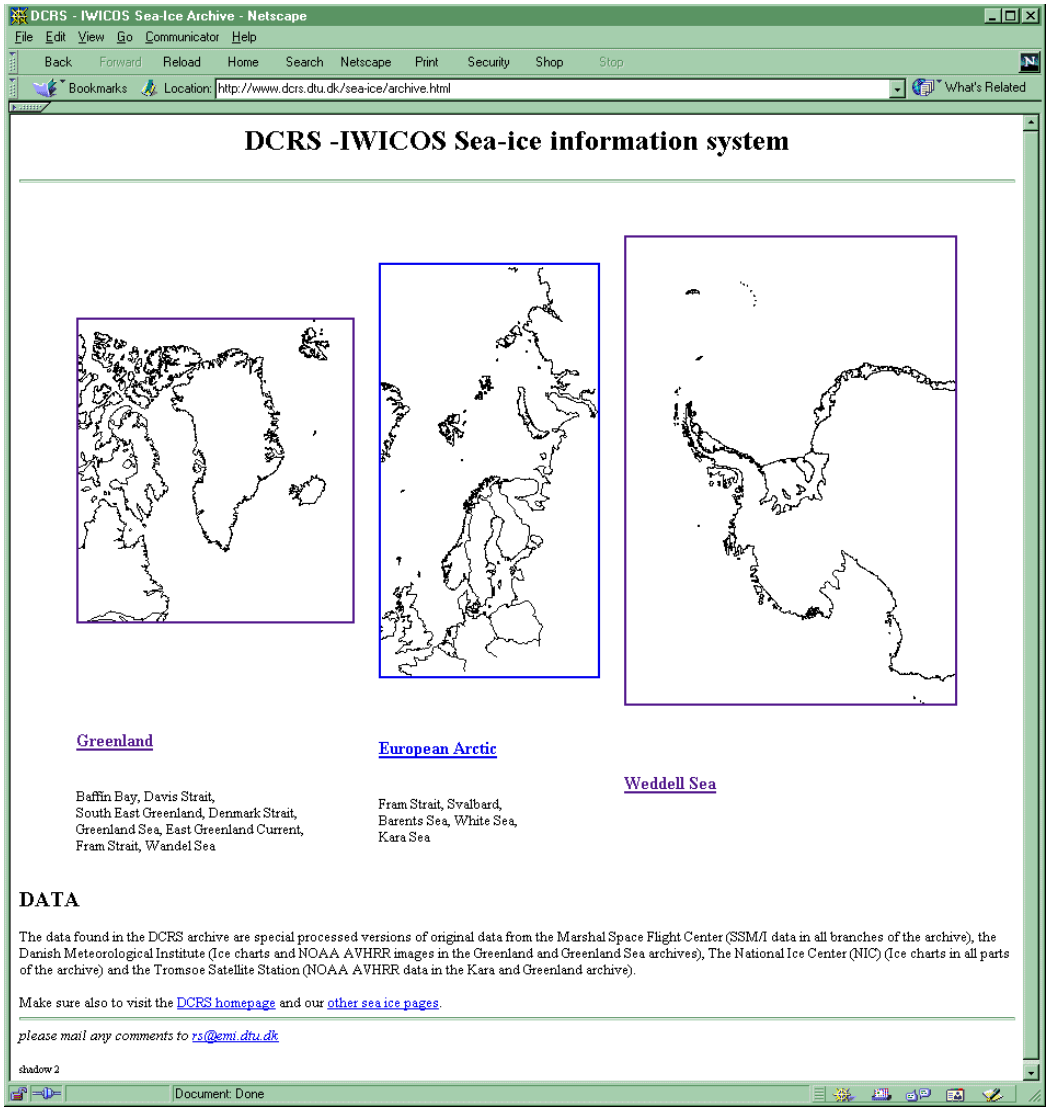


Figure 5.7 The interface to the interactive system.

5.6 User's Guide to the balanced client

The balanced client can be started from http://www.dcrs.dtu.dk/DCRS/latest-ice.html. The browser in action with a QuikSCAT image and a number of vector graphics overlays is shown in Figure 5.8, with marking of the different user interface elements overlaid.

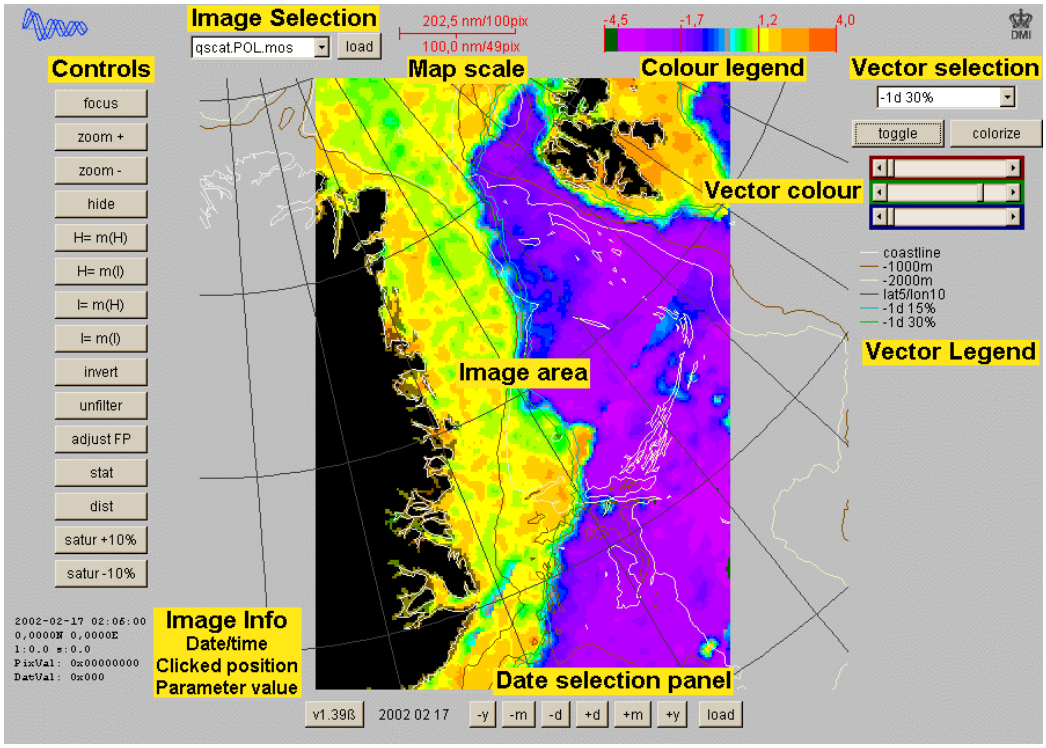


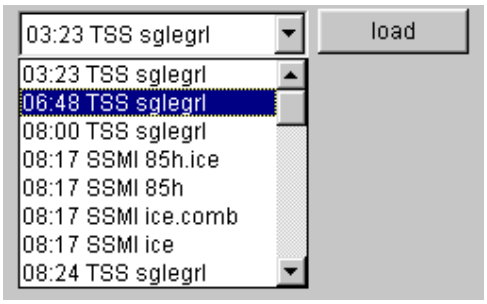
Figure 5.8 User interface of DCRS balanced client.

5.6.1 Getting started

Having started the applet, you will need to load an image. This is carried out by selecting a date from the control panel at the bottom of the screen and clicking the load (date) button. The browser will as default have selected the present date. The control buttons changes the date by one year, one month or one day each time you click. Remember to click "load" when you have reached the desired date.



Having selected a date, you need to select an image from the image list at the top, and subsequently press the load (image) button.



The image will be loaded and displayed, centered at the center of the view area of the screen. Even though the image datafiles are typically some 10s of kilobytes in size, loading an image may take quite some time over a slow connection, or on a slow computer (486 or lower).

The status indicator at the bottom of the screen should show status information for the load process. All images has a standard colour map associated, which will be used for displaying the first instance of the image.

Note: When switching between dates, the system will search for the corresponding image from the new date being loaded, and if an image is found, it will be automatically loaded with the selected zoom, and keeping the selected overlays. If no image is found, the image from the previously selected date will remain in the display, and only the list of available images from the new date will be loaded.

5.6.2 Image datasets explained

SSM/I	**Data from a NASA passive microwave instrument very usefull for regular ice information since the microwave instrument will look through clouds and work during the polar night**
SSM/I .ice	Standard ice concentration product. (very little atmospheric disturbance)
SSM/I .ice.comb	Enhanced resolution ice product
SSM/I .85h	Original high resolution data (some atmospheric disturbance is present)
SSM/I .85h.ice	Original high resolution polarization difference (less atmospheric disturbance is present)
	.mos images are mosaics of all available orbits (satellite passes) from the actual day, use time information with caution!

qscat (QuikSCAT)	**NASA scatterometer (radar) for measuring wind and ice over the ocean**
qscat HH	Data from the US QUIKSCAT scatterometer. The colours indicate either ice or wind patterns. (Horisontal polarisation of electromagnetic radiation)
qscat VV	Data from the US QUIKSCAT scatterometer. The colours indicate either ice or wind patterns. (Vertical polarisation of electromagnetic radiation)
qscat POL	Data from the US QUIKSCAT scatterometer. The colours are primarilly related to ice, but some ocean surface effects may be present. (Polarisation ratio (VV/HH))
	.mos images are mosaics of all available orbits (satellite passes) from the actual day, use time information with caution!

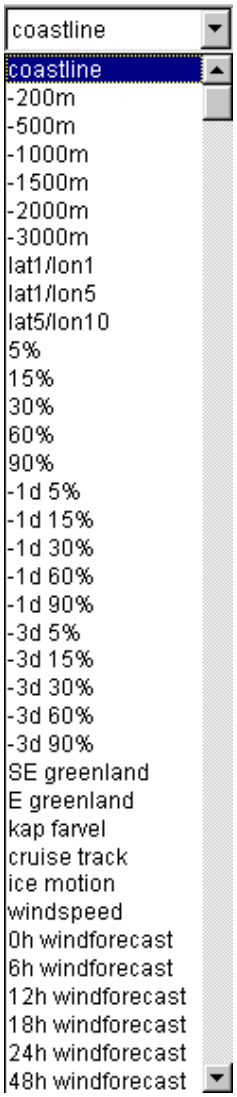
NOAA AVHRR	**Visible and infrared images from US weather satellites**
TSS greenland	NOAA AVHRR visible or infrared image from the Tromsø satellite station. This image is an overview image at 7500 meter resolution. (Images show mostly cloud patterns, the surface (ice/ocean) is only visible in clear sky conditions).
TSS sglegrl	NOAA AVHRR visible or infrared image from the Tromsø satellite station. This image covers East Greenland at approx. 3000 meter resolution. (Imaghes show mostly cloud patterns, the surface (ice/ocean) is only visible in clear sky conditions).
TSS sglwgrl	NOAA AVHRR visible or infrared image from the Tromsø satellite station. This image covers West Greenland at approx. 3000 meter resolution. (Imaghes show mostly cloud patterns, the surface (ice/ocean) is only visible in clear sky conditions).

NOAA AMSU **Passive microwave images from US weather satellites**

amsu .comb.mos	DCRS combination of 89 GHz and 150 GHz microwave radiometer data Experimental!!
amsu diff	difference between 89 GHz and 150 GHz images Experimental!!

- Additional files may be available as well. Only downloaded files are available off-line.

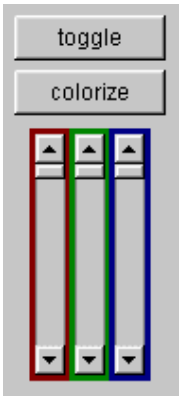
5.6.3 Vector graphics

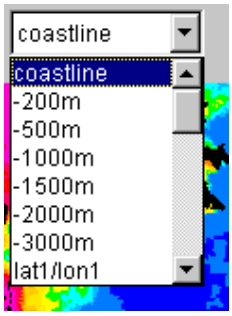


A number of vector graphics overlays may be available, and can be selected from the vector graphics selection box that appears when you hit the 'coastline' button.

When you have selected a vector dataset (one item) you must click the 'toggle' button on the right side of the screen to draw the graphics. Graphics are initially drawn using a predefined colour, but you can change the colour of any graphics layer by selecting the graphics from the vector graphics selection box, mixing the desired amount of red, green and blue using the scroll bars and pressing the 'colorize' button.

For a further description of the individual vector data files select the button below.





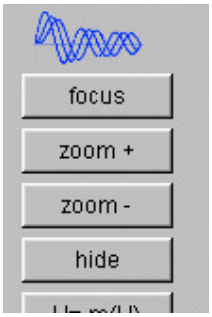
5.6.4 Vector graphics datasets explained

coastline	Coastline for the entire area of coverage
-200m	bathymetry 200 meter depth contour
-500m	bathymetry 500 meter depth contour
-1000m	bathymetry 1000 meter depth contour
-1500m	bathymetry 1500 meter depth contour

-2000m	bathymetry 2000 meter depth contour
-3000m	bathymetry 3000 meter depth contour
	More levels may be available
lat1/lon1	latitude-longitude grid with grid spacing 1 degree latitude, 1 degree longitude
lat1/lon5	latitude-longitude grid with grid spacing 1 degree latitude, 5 degree longitude
lat5/lon10	latitude-longitude grid with grid spacing 5 degree latitude, 10 degree longitude
5%, 15%, 30%, 60%, 90%	Ice concentration contours from today. Contours derived from low resolution SSM/I data (19 & 37 GHz only)
-1 d 5%, 15%, 30%, 60%, 90%	Ice concentration contours from yesterday. Contours derived from low resolution SSM/I data (19 & 37 GHz only)
-3 d 5%, 15%, 30%, 60%, 90%	Ice concentration contours from 3 days ago. Contours derived from low resolution SSM/I data (19 & 37 GHz only)
SE Greenland	High resolution coastline of South East Greenland
E Greenland	High resolution coastline of North East Greenland
kap farvel	High resolution coastline of Kap Farewell area
cruise track	Cruise track from file
ice motion	ice motion derived from SSM/I data of yesterday and today
wind speed	Wind observations from Ground station
0h, 6h, 12h, ... windforecast	Weather prediction model output from NCEP (model run at 00 UTC)
0h, 6h, 12h, ... waveforecast	Weather prediction model output from NCEP (model run at 00 UTC)

- Additional files may be available as well. Some files may not be available since they have to be updated every day.
- windforecast data only available off-line if the file yyyymmdd.ncep.zip has been downloaded
- ice concentration contours are only available off-line if the file yyymmdd-linier.iskort.zip has been downloaded for the relevant day(s).

5.6.5 Pan - Zoom

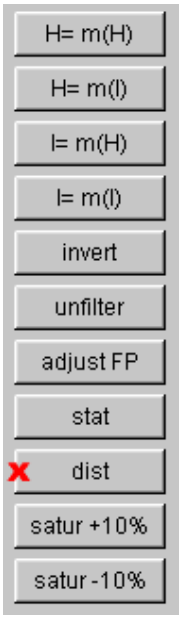


Pan
An image displayed on the screen will always be centered on it's focus point. When the image is initially loaded (or reloaded) the focus point is set to the center of the image.
Panning is obtained by clicking on the 'focus' button at the upper left corner of the screen and subsequently clicking on the desired new focus point. This will define a new focus point.

Zoom
Pressing the 'zoom +' button will magnify the image by a factor of two (by simple pixel duplication). The magnified image will be centered at the current focus point
Pressing the 'zoom -' button will shrink the image by a factor of two (using every other pixel only). The shrinked image will be centered at the current focus point. This feature is useful if you want an overview of the area covered by a small image. Vector graphics will be drawn to the full screen

image area is available.

5.6.6 *Distance tool*

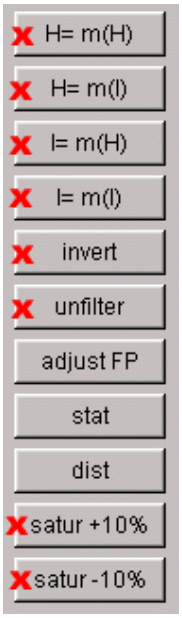


You may use the visualisation system to do simple distance calculations.

Press the dist button, followed by a number of points along the desired track. Finally press the end dist button (the same as the dist button) to finalize the distance calculations. The result is displayed in the status area at the bottom of your browser window.

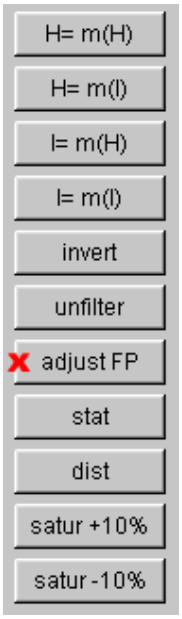


5.6.7 *Colour/greylevel manipulation*



A number of functions are available. The H= and I= functions works by clicking the butten and subsequently two points in the image, typically a dark point and a bright point. The functions are:
H=m(H): The hue of the image is generated as a rainbow scale from blue to red from the hue of the two points clicket.
H=m(I): The hue of the image is generated as a rainbow scale from blue to red from the intensity of the two points clicket.
I=m(H): The intensity of the image is generated as a grey-scale from black to white from the hue of the two points clicket.
I=m(I): The intensity of the image is generated as a grey-scale from black to white from the intensity of the two points clicket. This is the easiest way to enhance the contrast of a black&white image. Click the button, and then the area you want remapped to black, followed by the area you want remapped as white.All pixels darker than the first point becomes black and all points brighter than the second becomes white.
invert: Negates the image
Unfilter: Revert to original colour/graylevel map.
Satur +10% and **satur -10%** increases or decreases the colour saturation by 10% each time you press the button.

5.6.8 Geometry



Only simple geometry manipulation is possible. The adjust FP button allows you to shift the image relative to the coastline. Only simple translation is possible, no rotation.

You click on the adjust FP button and then on a point on the coastline and finally the corresponding point in the image. This function is useful if the automatic geometric correction carried out at DCRS of some of our data suppliers is inadequate.

5.7 User feedback

We appreciate user feedback, and we use user suggestions to improve the service. Please send email to Leif Toudal Pedersen (ltp@oersted.dtu.dk).

5.8 Conclusions

It has been demonstrated that a free Internet service with ice/sea/weather information can be established and it has attracted a large number of users in many fields.

The system has proven valuable for internal use as well as for many external users. Running the system, we have gained considerable goodwill amongst science partners and collaborators all over the world.

6 Organisations involved in monitoring and forecasting

6.1 Why ice services of the world are important

The ice-covered sea areas in the word are characterised by different ice conditions, sea traffic density and user requirements, which reflects the ice information service requirements and available information products.

Arctic and Antarctic:
- Hazard ice conditions
- Low traffic density
- Icebreakers and convoys

North Atlantic Ocean:
- Risk of icebergs
- Heavy traffic density
- Ships avoid ice-edge

The Baltic Sea:
- Annual marine transport >700 million tons of goods, of which 40% during winter months
- Largest marine traffic of ice covered sea areas in the word (number two is the Gulf of St. Lawrence with 180 million tons)
- Ice navigation obligatory
- No convoys

6.2 Ice services of the world

List and contact information of the ice services in the World could be found at WMO publication: SEA-ICE INFORMATION SERVICES IN THE WORLD, WMO-No. 574, available from WMO Secretariat in Geneva and http://www.aari.nw.ru/gdsidb/pub/WMO-574.pdf.

6.2.1 Ice services: Southern hemisphere

Argentina
Servicio Meteorológico de la Armada Argentina. Glaciología. Edificio Libertad
Address: Comodoro Py 2055, 15-37, 1104 Buenos Aires, ARGENTINA
Telefax: +54 11 43172309
E-mail: cnhsmara@rina.ara.mil.ar
Central Meterológica Naval Río Grande. Base Aeronaval
Address: 9420 RIO GRANDE. Tierra de Fuego, ARGENTINA.
Telefax: +54 2 0964 433092
E-mail: meteogra@infovia.com.ar

Australia
Bureau of Meteorology Tasmania/Antarctica Region GPO
Address: Box 727G, Hobart, AUSTRALIA, 7001
Telephone: +61 3 6221 2021
Telefax: +61 3 6221 2080

6.2.2 Ice services: Northern hemisphere

Canada
Canadian Ice Service – Environment Canada
Address: 373 Sussex Drive, Block E - 3rd floor Ottawa, Ontario, CANADA K1A 0H3
Telephone: (613) 996-1550 or toll-free in North America (800) 767-2885

Telefax: (613) 947-9160
E-mail: cis.client@ec.gc.ca
Internet: http://www.cis.ec.gc.ca

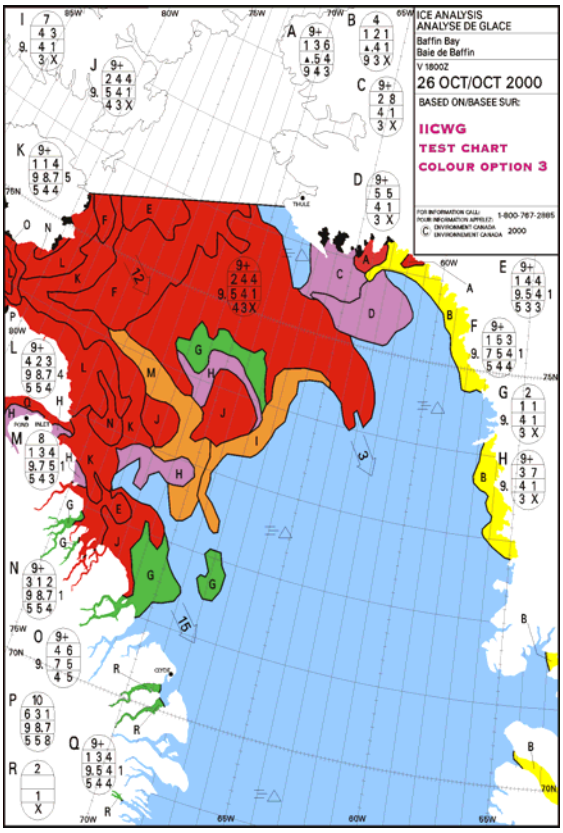


Figure 6.1 An example of the Canadian colour coded ice chart.

China

National Marine Environment Forecast Center,
Address: 8, Dahuisi Rd., Haidian District, Beijing, 100081, CHINA
Qingdao Marine Forecasting Observatory of SOA
Address: 22 Fushun Road, Qingdao, 266033, CHINA
Group of Sea Ice Management
Address: C/o General Dispatch Office China Offshore Oil Bohai Corporation, P.O. Box 501 Tanggu Tianjin 300452, CHINA

Denmark

Søværnets Operative Kommando, Istjenesten
Address: Postboks 483, DK-8100 Århus C, DENMARK
Telephone: +45 89 43 30 99, +45 89 43 32 53 (Ice-Breaking Service and Ice-reporting Service)
Telefax: +45 89 43 32 30
Telephone answering unit: + 45 89 32 44.
Telex: 64527 SHIPPOS DK
E-mail: bk4@sok.dk (Attention.: Danish Ice Service)
Danmarks Meteorologiske Institut
Address: Lyngbyvej 100, DK-2100 Copenhagen, DENMARK
Iscentralen Narsarsuaq
Address: 3923 Narsarsuaq, GREENLAND
Internet: http://www.dmi.dk (DMI main page)
Internet: http://www.dmi.dk/vejr/gron/iskort.html

Internet: http://iserit.greennet.gl/isc/ice/
E-mail: isc@greennet.gl

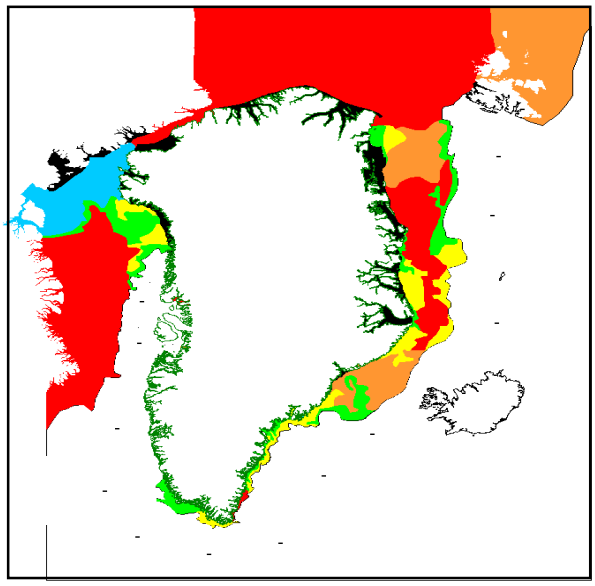


Figure 6.2 An example of the Danish ice service (DMI) Greenland colour coded ice chart.

Estonia

Estonian Meteorological and Hydrological Institute EMHI
Address: Rävala 8, EE - 0001 Tallin, ESTONIA
Telephone +372 6461561
Telefax +372 6461577
E-mail: emhi@online.ee

Finland

Finnish Institute of Marine Research, Finnish Ice Service
Address: P.O. Box 304, FIN-00181 Helsinki, FINLAND
Telephone: +358 9 6857659
Telefax: +358 9 6857638 or 6857639
Call-fax: +358 60018668
E-mail: info@ice.fmi.fi
Internet: http://ice.fmi.fi

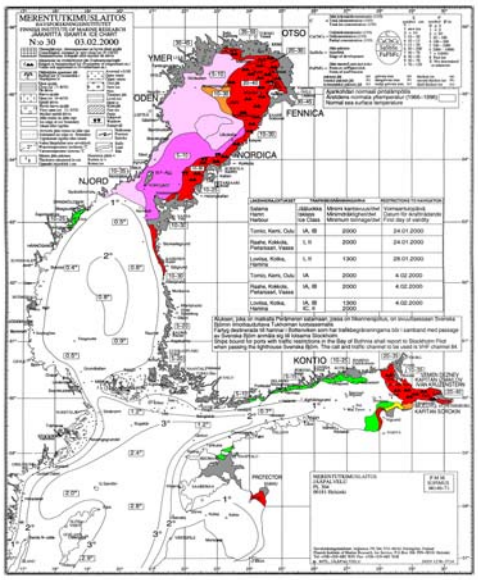


Figure 6.3 An example of the Finnish ice service colour coded ice chart.

Germany
BSH – Eisdienst
Address: Postfach 301220, 20305 Hamburg, GERMANY
Telephone: +49 40 3190 3290
Telefax: +49 40 3190 5032
E-mail: ice@bsh.d400.de
Internet: http://www.bsh.de (in German/English)

Iceland
Icelandic Meteorological Office
Address: Bustadavegur 9, IS-150 Reykjavik, ICELAND
Telephone: +354 560 0600
Telefax: +354 552 8121
Internet: http://www.vedur.is

Japan
Maritime Meteorological Division Climate and Marine Department, Japan Meteorological Agency
Address: 1-3-4 Ote-machi, Chiyoda-ku,Tokyo 100-8122, JAPAN
Internet: http://www.kishou.go.jp/
http://www.jodc.jhd.go.jp/inf/institute/jma/jma.html (In English)

Latvia
Latvian Hydrometeorological Agency
Address: 165, Maskavas Str., LV- 1019 Riga, LATVIA

Lithuania
CMR Address: Taikos str. 26, 5802 Klaipeda, LITHUANIA
Telephone: (+ 3706) 250324
Fax: (+ 3706) 250930
E-mail: CMR@klaipeda.omnitel.net.
LHMS Klaipeda Department
Address: Taikos str.26, 5802 Klaipeda, LITHUANIA
Telephone: (+ 3706) 252247;

Telefax: (+ 3706)2 52247;
E-mail: khmo@klaipeda.aiva.lt

Netherlands
Rijkswaterstaat / Riza, Information and Warning Centre
Address: Postbox 17, 8200 AA Lelystad, NETHERLANDS
Telephone: +31 320 298550, +31 320 298888
Telefax: +31 320 298580
E-mail: bc@riza.rws.minvenw.nl

Norway
Vervarslinga for Nord-Norge
Address: Postboks 2501, 9002 Tromsoe, NORWAY
Telephone: +47 77 68 40 44
Telefax: +47 77 68 90 04
Internet: http://www.dnmi.no

Poland
Instytut Meteorologii i Gospodarki Wodnej, Oddzial Morski
Address: Waszyngtona 42, PL 81-342 Gdydia, POLAND
Telephone: +48 58 6205221 (operator), +48 58 6201641 (ice team 06-14Z)
Telefax: +48 58 6205493
E-mail: pga@stratus.imgw.gdynia.pl
Internet: http://www.imgw.gdynia.pl/

Russia
Arctic and Antarctic Research Institute
Address: 38 Bering Street, St.Petersburg, RUSSIA, 199397
Telephone: +7(812)352-1520
Telefax: +7(812)352-2688
E-mail: service@aari.nw.ru
Internet: http://www.aari.nw.ru
Internet: ftp://aari.nw.ru

North-West Administration for Hydrometeorology and Enviromental Monitoring
Address: 23 Line, 2-a Basil Island, R-199026 St. Petersburg, RUSSIA
Telephone: +812 2181 467
Fax: +812 2180 962

Sweden
Swedish Meteorological and Hydrological Institute, SMHI. Marine Service
Address: S - 601 76 Norrkoping, SWEDEN
Telephone: +46 (0)11 495 8400
Telefax: +46 (0)11 495 8403
E-mail: ice@smhi.se
Internet: http://www.smhi.se (main web-page)
Internet: ftp://ftp.smhi.se (ftp-server)

United States
Director, National Ice Center
Address: 4251 Suitland Road, FB4, Washington, DC 20395, USA
Telephone: (301) 457-5303/-5300 (Fax)
E-mail: liaison@natice.noaa.gov
Internet: http://natice.noaa.gov
Commander, International Ice Patrol
Address: 1082 Shennecossett Road, Groton, CT 06340-6095, USA
Telephone: (860) 441-2626/-2773 (Fax)
Internet: http://www.rdc.uscg.mil/iippages/home.html

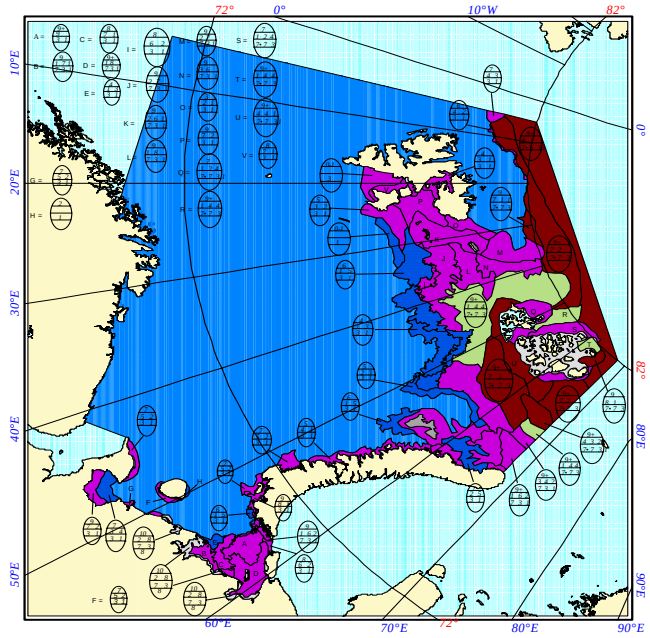


Figure 6.4 An example of the Russian ice service (AARI) colour coded ice chart.

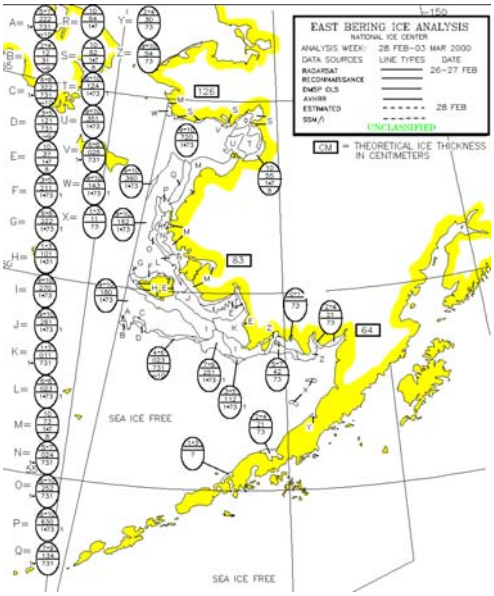


Figure 6.5 An example of the USA ice service (NIC) colour coded ice chart.

7 Links to useful Internet resources

7.1 Earth Observation organisations, satellites satellite data receiving stations

http://earth.esa.int (ESA's Earthnet)
http://www.esa.int (European Space Agency)
http://envisat.esa.int (ESA's ENVISAT satellite)
http://www.eumetsat.de (European Meteorological Satellite)
http://www.tss.no (Kongsberg satellite stations)

7.2 Meteorological Institutes

http://www.fmi.fi (Finnish Meteorological Institute)
http://www.smhi.se (Swedish Meteorological and Hydrological Institute)
http://www.dmi.dk (Danish Meteorological Institute)
http://www.dnmi.no (Norwegian Meteorological Institute)
http://www.vedur.is (Icelandic Meteorological Office)

7.3 Marine research institutes

http://www.fimr.fi (Finnish Institute of Marine Research)
http://www.dmi.dk (Danish Meteorological Institute)
http://www.imr.no (IMR, Institute of Marine Research, Norway)
http://www.gfi.uib.no (GFI, Geophysical Institute, University of Bergen, Norway)
http://www.npolar.no (NPI, Norwegian Polar Institute, Norway)
http://www.unis.no (UNIS, University Courses on Svalbard, Norway)
http://www.hafro.is (MRI, Marine Research Institute, Iceland)
http://www.smhi.se (Swedish Meteorological and Hydrological Institute)
http://www.awi-bremerhaven.de (AWI, Alfred Wegner Institute, Germany)
http://www.ifm.uni-hamburg.de (IFMH, Institute for Marine Research, University in Hamburg, Germany)
http://www.ifm.uni-kiel.de (IFMK, Institute for Marine Research, University in Kiel, Germany)
http://www.frs.fo (FFL, Faroese Fishery Laboratory, Faroes)
http://www.cefas.co.uk (CEFAS, Center for Environment, Fisheries and Aquaculture, UK)
http://www.marlab.ac.uk/FRS.htm (FRS, Fishery Research Services, Aberdeen, UK)
http://www.pol.ac.uk (POL, Proudman Oceanographic Laboratory, UK)
http://www.uea.ac.uk (UEA, University of East Anglia, UK)
http://www.iopan.gda.pl (IOPAS, Institute of Oceanology, Polish Academy of Science, Poland)
http://www.washington.edu (UoW, University of Washington, USA)

7.4 Ice services

http://www.cis.ec.gc.ca (Canada)
http://www.dmi.dk (Denmark)
http://ice.fmi.fi (Finland)
http://www.bsh.de/Oceanography/Ice/Ice.htm (Germany)
http://www.vedur.is (Iceland)
http://www.kishou.go.jp (Japan)
http://www.dnmi.no (Norway)
http://www.imgw.gdynia.pl (Poland)
http://www.aari.nw.ru (Russia)
http://www.smhi.se (Sweden)
http://natice.noaa.gov (USA)
http://www.rdc.uscg.mil/iippages/home.html (International Ice Patrol)
http://nsdc.org/noaa/iicwg (International Ice Charting Working Group)

7.5 Maritime administrations

http://www.fma.fi (Finnish Maritime Administration)
http://www2.statkart.no/IPS/statkart.no/IPS?module=Articles;action=ArticleFolder.publicOpenFolder;ID=438 (Sjøkartverket, Norway)
http://www.sigling.is (Icelandic Maritime Administration)
http://www.sjofartsverket.se (Swedish Maritime Administration)
http://www.bsh.de (Germany)

7.6 Information products

Weather:
http://www.fmi.fi (Finland)
http://www.dmi.dk (Denmark)
http://www.smhi.se (Sweden)
http://www.dnmi.no (Norway)
http://www.vedur.is (Iceland)

Sea ice:
http://ice.fmi.fi/tilanne.html (Simplified weekly ice and SST over the Northern Baltic Sea)
http://www.dcrs.dtu.dk/sea-ice/DCRS/seaice/ (Danish Center for Remote Sensing Sea Ice Pages)
http://www.geus.dk/ghexis/pdf/Iceberg.pdf (Distribution and Variability of Icebergs in the eastern Davis Strait 63°N to 68°N, Greenland Survey)
http://saf.dnmi.no/p/ice.shtml (Ocean and Sea Ice SAF)
http://www.bsh.de/aktdat/mk/ICE/M54ICE_monthly_e.html (Polar sea ice concentration and extent 1978-2002)
http://nsidc.org/ (National Snow & Ice Data Center)

Marine:
http://www.bsh.de/Meereskunde/Eisdienst/Tempost.htm (Weekly SST over the Baltic Sea)
http://ice.fmi.fi/tilanne.html (Simplified weekly ice and SST over the Northern Baltic Sea)
http://www2.fimr.fi/en/palvelut/aallokko-ja-vedenkorkeus.html (FIMR: wave and sea level)

7.7 International programmes and research projects

http://www.gfi.uib.no/forskning/nwoce (NWOCE)
http://www.ices.dk/ocean/project/veins (VEINS)
http://www.sintef.no/units/civil/coastal/Maia (MAIA)
http://arcss.colorado.edu/arcss/projects/asof.html (ASOF)
http://www.smr.uib.no (ESOP)
http://acsys.npolar.no/ (Arctic Climate System Study Mission)
http://iabp.apl.washington.edu/ (International Arctic Buoy Programme, IABP)
http://www.bmp.gl/E/EB3_petroleum/EB3_50ba_environ-report-contents.html

Data from the NWOCE, VEINS, MAIA, ASOF and ESOP programmes may be obtained from ICES, http://www.ices.dk.

7.8 Links in Iceland

Ice Tec, http://www.iti.is
Ice Tec is an Icelandic technological R&D and educational institution, serving a growing range of international clients with specialised needs. Acting in close cooperation with industry our primary aims are to strengthen the Icelandic economy through development, innovation and increased productivity.

Icelandic Fisheries Laboratories, http://www.rfisk.is
IFL ensures that Icelandic food products are associated with images of quality, safety and wholesomeness.

Icelandic Institute of Natural History, http://www.ni.is

The institute conducts basic and applied research on the nature of Iceland in the fields of botany, geology and zoology with emphasis in biology on taxonomy and ecology.

Institute of Freshwater Fisheries, http://www.veidimal.is
The Institute of Freshwater Fisheries is a research and developmental institute. Its role is to conduct research on the freshwater biota and to register Icelandic freshwaters, their physical and biological characters.

Marine Research Institute, http://www.hafro.is
The MRI conducts research on the marine environment and the living resources of Icelandic waters. It monitors the exploited stocks and provides advice to the government on sustainable utilization of the marine resources. The Institute also disseminates information about the sea and marine ecosystems to the industry and the public.

National Energy Authority, http://www.os.is
NEA consists of two main units, one responsible for energy administration and the other for research in geosciences and hydrology

The Agricultural Research Institute, http://www.rala.is
The ARI institute has a mission to provide access to agricultural information and develop new knowledge and technology needed to solve urgent agricultural problems of broad scope and high national priority.

The Icelandic Building Research Institute, http://www.rabygg.is
Activities can be categorized as applied research, material testing consultation and quality control.

The Icelandic Coast Guard, http://www.lhg.is
Main responsibilities are police control and supervision on the ocean around Iceland, inclusive sea ice registration, commanding search and rescue on land and on sea.

The Icelandic Maritime Administration, http://www.sigling.is
IMA is responsible for centrally administrating maritime, harbour and lighthouse issues. IMA is also responsible for research in waves and sea currents and they operate an information system on weather and sea state.

The Icelandic Meteorological Office, http://www.vedur.is
IMO supplies weather services mainly in Iceland and for the ocean surrounding the island. IMO is responsible for research in climate, avalanches, sea ice and earthquakes and provides alerting service of imminent natural hazards.

The Icelandic Research Council, http://www.rannis.is
The IRC mandate is to reinforce and underpin the cultural and economic foundation of Icelandic society by promoting vigorous and well co-ordinated scientific endeavour, technical development and innovation.

The University of Iceland, http://www.hi.is

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