

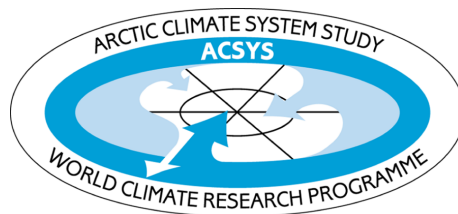
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**WORLD  
METEOROLOGICAL  
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## **World Climate Research Programme**

### **ARCTIC CLIMATE SYSTEM STUDY**



## **ACSYS HISTORICAL ICE CHART ARCHIVE (1553 – 2002)**

Tromsø, Norway  
January 2003

IACPO Informal Report No. 8

**ACSYS Historical Ice Chart Archive**

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**NB: Quality control efforts are described within the text of this report. Errors may still be present in the data set. Please report any errors found to the International ACSYS/CliC Project Office, in order that the data set may be corrected and updated.**

Copies of this report and CD ROMs can be obtained from:

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The International ACSYS/CliC Project Office (IACPO), the World Wide Fund for Nature (WWF), the Norwegian Polar Institute, and the Norwegian Meteorological Institute, supported production of this report and the accompanying CD-ROMs. It forms part of a project also supported by the Norwegian Research Council.

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## Summary

The ACSYS Historical Ice Chart Archive presents historical sea-ice observations in the Arctic region between 30°W and 70°E in the form of digitized maps, stored as shape files. The earliest chart dates from 1553, and the most recent from December 2002. More recent charts are available electronically from the Norwegian Meteorological Institute ([www.met.no](http://www.met.no)).

Vessels sailing to the Arctic to explore or to hunt whales and seals made early sea-ice observations. Over the centuries, technological advances and commercial opportunities in the Arctic led to more frequent and regular sea-ice observations, with associated increasing accuracy. As sailing ships gave way to steam powered vessels, and with the advent of aircraft and satellites, regular mapping of sea ice conditions became an organized activity. From 1967 onwards, hand drawn weekly charts were produced, showing not only an ice edge, but also concentrations of sea ice within the ice pack. Since July 1997, improved technology allowed daily production of digital sea ice maps on workdays.

In an effort spanning many years, early observations from ship logbooks and other records were collected, translated as necessary, and plotted as hand-drawn maps. For more recent years, sea ice charts from various organized sources were collected. The total of over six thousand charts were placed on two CD-ROMs, and these can be viewed and analysed using geographical information system (GIS) software. The data set is complemented by less detailed 'quick-look' versions of all maps.

This report provides background information regarding the data and its collection. Prospective users should consider the uncertainties related to the ice-edge definition, and to the difficulty of navigating in remote areas prior to the satellite era.

## **Introduction**

### ***The importance of sea ice in the environment***

The extent of sea ice is a critical parameter in the global climate system. Sea ice forms a layer of insulation between the warm ocean surface and the cold atmosphere, reducing heat transport from ocean to the atmosphere. Similarly it forms a barrier to moisture transport. The result is that the atmosphere may be several tens of degrees Celsius colder than the ocean beneath it, and much dryer than it might otherwise be in the absence of this layer. In addition, sea ice can support a covering of snow, the surface with the highest natural albedo of up to about 0.8. Seawater, with the lowest natural albedo of approximately 0.07, reflects far less solar radiation back into space. Hence, sea ice can have a major effect on how much solar radiation is absorbed at the Earth's surface, and so provides a positive feedback mechanism that may amplify any change in surface temperature.

Not only does sea ice extent influence climate, but it may also be an indicator of climate variability and change. Colder conditions are likely to lead to a greater extent of sea ice, although the relationship is not a simple one, with many other factors also having an effect. For example, local geography, synoptic wind conditions, and seawater salinity can all influence the growth of sea ice and its distribution. However, sea ice will only form where the surface temperature is below the freezing point of seawater, and hence the extent is a useful general indicator of the state of cold region climate.

Apart from its significance in the global climate system, sea ice is important to other aspects of the environment. It provides a habitat for wildlife, both above and below the sea surface. High marine biological productivity is often associated with the retreat of the ice edge during spring, and there may be concentrations of wildlife near the ice edge, covering the complete size range from algae to seals and whales. Many species rely on sea ice to provide a habitat for breeding and feeding, and changes to sea ice conditions can have a profound effect on population distribution and dynamics. The traditional way of life for many indigenous peoples of the Arctic and sub-Arctic regions may also depend on sea ice and its associated wildlife. Methods of travel and hunting rely on sea ice conditions, and changes in sea ice extent can affect the viability of entire communities.

### ***Climatic observations of sea ice***

One very significant advantage that sea ice extent has as a climate indicator is that it is relatively easily observed. If ice is present, then a simple note of its position provides a valid observation. At this basic level, no technical instruments are required, and this has led to such observations making up one of the longest records of any climate parameter in existence. From the northwestern tip of Iceland, it is possible to observe the sea ice by eye, and the inhabitants of Iceland have documented these observations almost from the time they arrived from Norway around the year 1000 A.D.

Although it may be relatively easily observed at any particular location, observations covering a large area are rather more difficult. Only in the past few decades have Arctic wide observations become possible with the advent of satellite techniques. Using the record of observations from passive microwave satellites for the period 1981 to 1999, a decrease in sea ice extent of 2.04% per decade has been reported (Comiso, 2002) for the Arctic as a whole, while a similar analysis by Parkinson and Cavalieri (2002) for 1979 to 1999 shows a decrease in extent of 2.7% per decade. There is concern that this retreat of sea ice may be an early result of human induced climate change, but also recognition that it may be the result of natural climate variability.

A major problem of distinguishing between human and natural causes of reduced sea ice extent is a lack of information about changes in the period prior to satellite observations. Although many observations of sea ice position have been made, these have often been in a form that is not generally accessible for scientific analysis. Ships logbooks, hand drawn maps, notebooks and diaries have all been used to record observations, but without a consistent format and electronic access to digitized information it is difficult for wide-spread scientific use to be made of all these data.

With this in mind, a major effort has been conducted over the past decade and a half to collect information on sea ice extent over a wide region of the Arctic. As part of the World Climate Research Programme's Arctic Climate System Study (ACSYS) project, observations have been collected, quality controlled, and converted into digitized sea ice charts for presentation along with this report. The aim has been to make these data widely accessible for scientific use, thereby allowing analyses that will improve our understanding of past variations in sea ice extent and their relationship to global and regional climate.

### **Report contents and metadata**

This report provides an introduction to the data set, describing how the information has been collected and processed, and how it is presented in the individual maps. A brief discussion of the definition of the sea ice 'edge' is also included: a non-trivial aspect of all sea ice extent observations, as discussed below. A 'user guide' is then provided to help the researcher with initial viewing of the information. In addition, a section on the historical background to early observations of sea ice is included, which attempts to provide a perspective on the reliability of sea ice observations as techniques of navigation and observation have improved over the years. In particular, it should be noted that changes in observation method have led to changes in the definition of the ice edge, and that it has not been possible to standardize all observations retrospectively. This, coupled to difficulties of precise navigation, particularly for the early charts, is an important source of uncertainty when interpreting data from individual maps or attempting to identify trends in sea ice cover.

*Prospective users of these charts are therefore strongly encouraged to read this data description and historical background and to consider the associated uncertainties when using the charts.*

Further reading has also been suggested for those who are particularly concerned with the early methods used to record sea ice information. As an appendix to this report (Appendix A), a list of data sources is provided. Unfortunately, most of the information contained in these sources is in Norwegian, and translation would be both costly and slow. This makes it difficult to access the detailed information, but it is hoped that this report is adequate to meet the needs of the majority of potential users. The historical material referred to in this appendix is archived under environmentally controlled conditions at the Norwegian Polar Institute, and researchers may be able to access this under supervision where this is vital to the outcome of their study.

## **Data set description**

### **Geographical and temporal coverage**

The observations in this set of historical sea ice charts cover the Greenland, Iceland, Norwegian, Barents and Kara Seas, extending from 30°W to 70°E (Figure 1). Most of the background material is from the Greenland Sea, East Greenland, Svalbard, and the western parts of the Barents Sea. The amount of information available diminishes towards the limits

of these geographical areas. This region is of critical importance to global climate, being the region where warm, salty water from the Atlantic flows into the Arctic Basin, and where fresher Arctic Ocean water is exported to the Atlantic Ocean in the East Greenland Current. Changes in the ocean-ice-atmosphere interactions in this region are recognized as being of critical importance to the ventilation of the deep oceans and to the global thermohaline circulation in general.

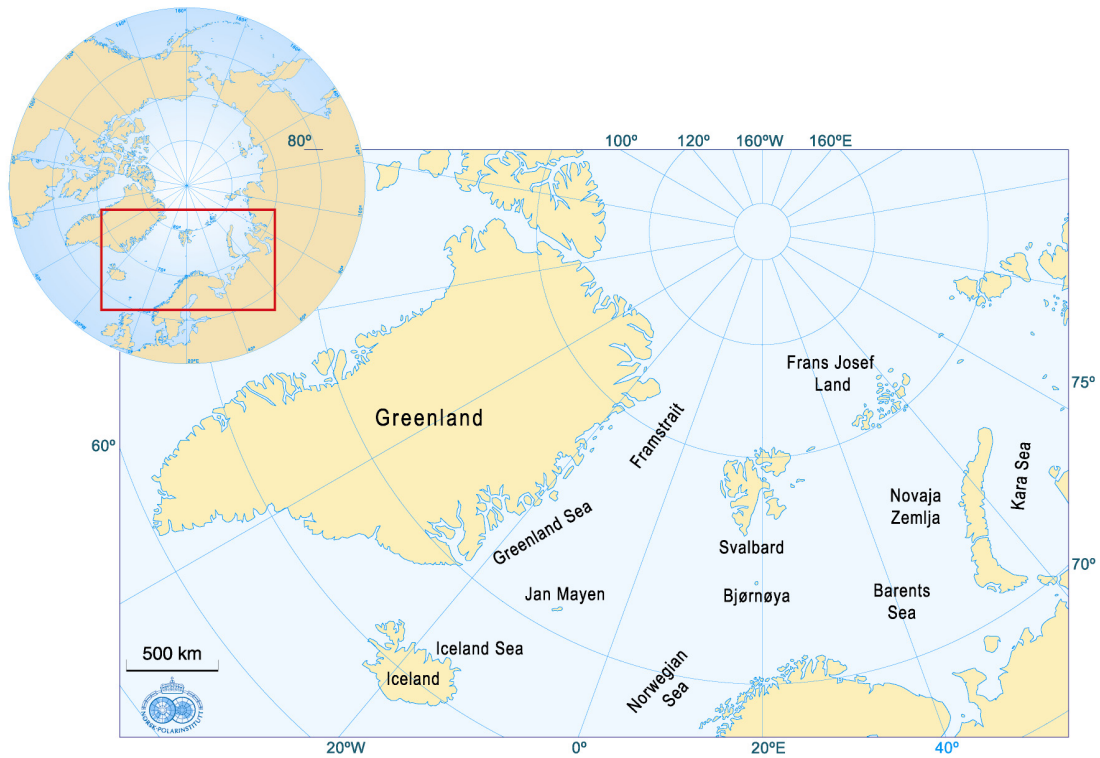


Figure 1. Approximate geographical coverage of the ACSYS historical ice chart archive

The earliest chart in the data set comes from 1553, when Sir Hugh Willoughby and Richard Chancellor, commanders of two expeditions sent out by the Company of Merchant Adventurers, recorded their observations of the ice edge. Early charts are irregular and infrequent, reflecting the remoteness and hostility of the region. The frequency of observations generally increases over time, as the economic and strategic importance of the Arctic grew, along with the ability to access, observe and record information on sea ice. The most recent charts are from 2002, by which time the Norwegian Meteorological Institute in Tromsø used a combination of satellite imagery and in situ observations to produce daily digital charts each working day. These show not only the ice edge, but also detailed information on the range of sea ice concentrations and ice types. The Norwegian Meteorological Institute is continuing this series, and more recent charts may be obtained from this source ([www.met.no](http://www.met.no)).

The data set contains 6007 maps in total (for the period 1550-2002). Figure 2 shows the distribution of maps in 50-year periods from 1550 to 2000.

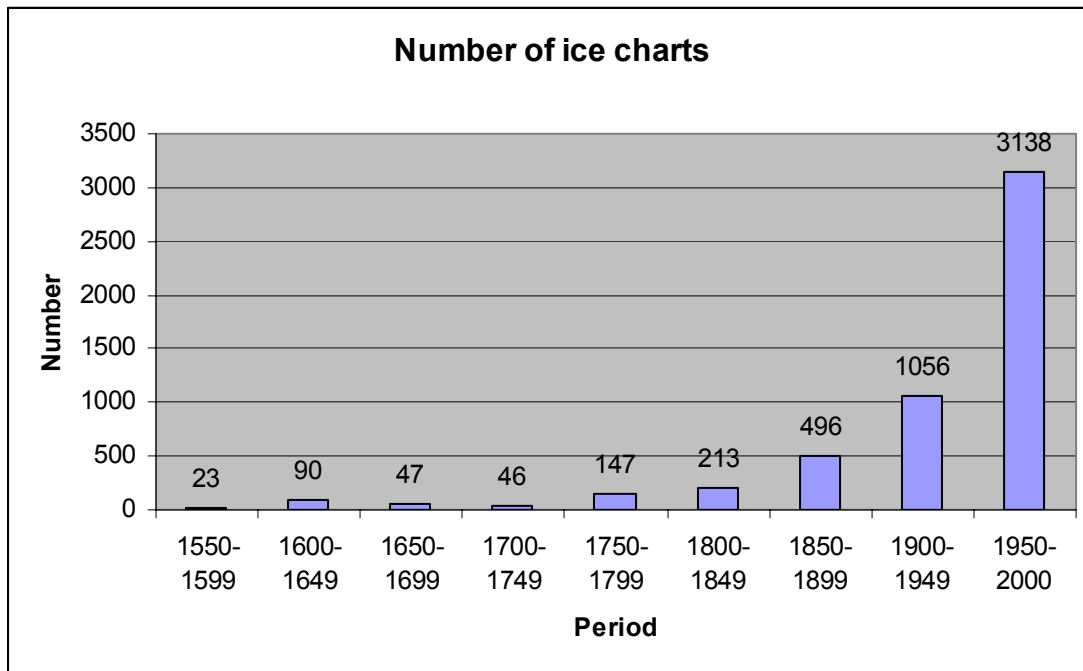


Figure 2. Distribution of maps 1550-2000. The number of maps in each 50-year period is noted on top of the bars.

### ***Data collection and processing***

Vinje (2001) and archive material at the Norwegian Polar Institute (letters and reports) tell that Otto Sverdrup and Capt. A. Hermansen collected the ordinary ships logs from previous Norwegian voyages to northern seas, on a round trip of Norway in 1922. This activity was funded by the Norwegian government, in connection with the planning of coal shipping from Longyearbyen on Spitsbergen. They collected around 285 ship logs covering the period 1850-1922. Since then, ice information has been collected at the Norwegian Polar Institute from sealers, ship-traffic, and retrospectively from trappers wintering on islands in the Svalbard archipelago since 1800. Some of the Norwegian observations from the 19th century have been published by Lindeman (1869), Chavanne (1875), and Pettersen (1884, 1885, 1886, 1889, 1926). The list of ships logs used in this investigation is given by Isaksen and Isaksen (1932).

Around 1900, the Danish Meteorological Institute (DMI) was appointed as the European centre for ice data, and most of the Norwegian observations were copied and sent to DMI for presentation in the DMI Yearbooks with the title 'The state of the ice in the Arctic Seas' (1899-1956). From 1957, DMI continued this series of yearbooks as 'Ice conditions in the Greenland Seas'.

Russian, Norwegian and American aircraft observations have been collected since 1950, and observations from the meteorological land stations on Bjørnøya and Jan Mayen have been gathered since 1963.

In 1966, the Norwegian Polar Institute started to produce ice charts on a regular weekly basis, handing over this responsibility to the Norwegian Meteorological Institute in 1970. The maps

were drawn by hand until June 1997, when a digital production and archiving process was implemented, allowing daily charts to be produced.

In 1986, an initiative was taken to compare the Norwegian ice charts with similar charts and observations from other nations (UK Meteorological Office, the US Navy-NOAA Joint Ice Center, air and satellite observations, library sources) for the period 1966 onwards. In the cases where differences were found, the original sources were investigated and the Norwegian maps corrected. These analog ice charts were then digitized through several stages, with the final result stored in shapefiles, an open standard GIS format.

Some years later, a new initiative was taken to investigate all available sea ice information from 1550 to 1966. Information available from logbooks, diaries, letters and maps was plotted on charts and marked according to the different sources. All charts were drawn by hand to ensure they were of an equal standard, and these charts were then also digitized.

As part of the digitization process, codes were ascribed to each line, giving information regarding sea ice characteristics (when available) and data source. The meanings of these codes are given in the 'User Guide' below.

Quality control of the digital data set produced by these efforts has involved inspection of a randomly selected sub-set of the charts, covering the entire period of the record. For the period 1553-1799 at least one map was picked out for every 10th year, displayed on the screen, and the properties of the digitized lines were checked. For the period 1800 to 1965 at least one map for each year was picked and checked in the same way. The same control was done for the period 1966-1997, but in this period at least 6 maps for every year were picked out. Where problems were found, either because of missing data or clear errors in ice edge position, these were corrected with reference to the original data. Charts before and after the one containing errors were also checked, in an attempt to ensure that the errors were not systematic. The table in Appendix B lists the maps that were controlled during this procedure.

*It should be noted that this procedure has only allowed a relatively small proportion of the total number of maps to be checked. Hence, maps in the data set may still contain errors. Users of the data set are encouraged to report any errors they might find to the International ACSYS/CliC Project Office (acsys@npolar.no or clic@npolar.no), so that these may be corrected and the database updated.*

### **Definition of the ice edge**

Vinje (2001) discusses the definition of the ice edge concerning the accuracy related to the different methods of observation. To obtain the presumably best homogeneity in the series, the outer ice edge has been used as the limit for ice extent estimates. This means that a degradation of recent observations has not been made to obtain a possible better match with the ship observations. Sealers and whalers, who provided much of the data prior to 1950, operated mainly along the outer boundary or in the marginal ice zone where they reported ice concentrations from 30 to 60% ( $3/10 < C < 6/10$ ). In particular, during the sailing era, it is likely that ships tried to avoid ice concentrations greater than about 30% ( $C = 3/10$ ). Since the advent of satellites the outer ice edge is generally defined as a concentration greater than 10% ( $C > 1/10$ ). This means that the actual area defined as encompassing sea ice during the time of ship observations is somewhat smaller than the area encompassing sea ice after the advent of satellites. A typical width of the area with ice concentrations  $1/10 < C < 3/10$ , or the error in the position for estimating the outer ice edge, is 30 km along the whole ice border in the Nordic Seas. Vinje (2001) concludes that the ice extent during the ship observations period should be somewhat increased to match the recent observation series.

# User Guide

## The data

All data are provided in Series ArcView shapefile format and are readily viewed using ArcView or ArcGIS software. (More information about this software and data format specification can be found at [www.esri.com](http://www.esri.com).) A shapefile consists of 3 files with extensions “.shp”, “.shx”, and “.dbf” and all must be present in the same directory in order to view them. Two additional files “.sbn” and “.sbx” may be present but are not required.

The data are organized by date in appropriate directories on the CD-ROMs. Between 1550 and 1800 directories contain data for the following 50 years. For example, data in the directory “1550” cover the period from 1550 until 1599. From 1800 until 1960 data are archived every decade, i.e., the directory “1800” contains data from 1800 until the end of 1809. From 1966 to the present each directory contains data from the corresponding year. This structure reflects the increasing frequency of ice observations and increasing regularity of ice chart production with time. A brief overview of the directory structure is given in Figure 3.

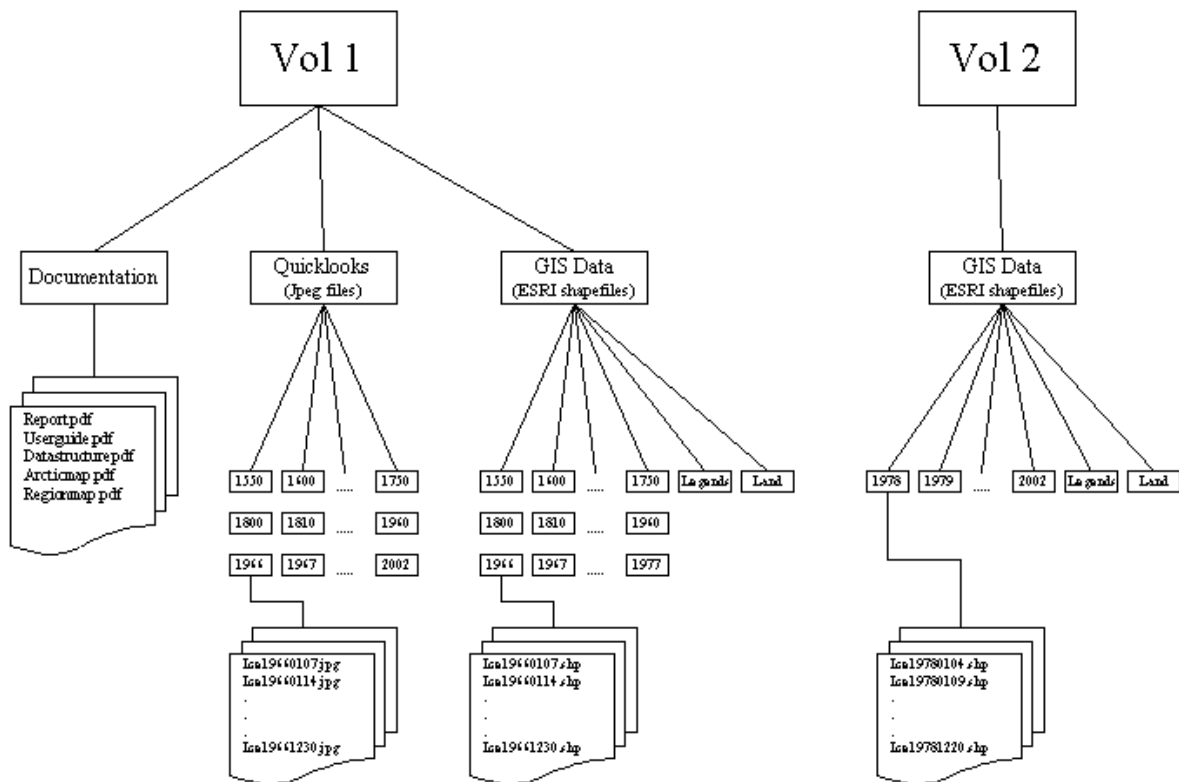


Figure 3. Overview of the directory structure of the archive. Prior to 1966, Quicklook and GIS data filenames are not prefixed by 'Ice'. GIS data also contain files with the extensions “.shx” and “.dbf”, and these must be present to view the files with ESRI software. 'Legend' and 'land' files are also for use with ESRI software, to allow information on ice types to be displayed more clearly, and to allow land to be viewed on shapefiles from July 1997 onwards. (See 'User Guide' text for details.)

Users may wish to copy all data from the two CD-ROMs to a computer hard disk to ease data access and retrieval.

### Filenames

Filenames contain the date for which the ice chart is valid. From 1550 until 1965 the filename only contains the date, and from 1966 onwards the date is preceded by the prefix “ice”. The date format is “yyyymmdd”. For example, the file “18660422.shp” contains the ice chart for the 22<sup>nd</sup> of April 1866, while “ice20020103.shp” contains the ice chart for the 3<sup>rd</sup> of January 2002 (Figure 4).

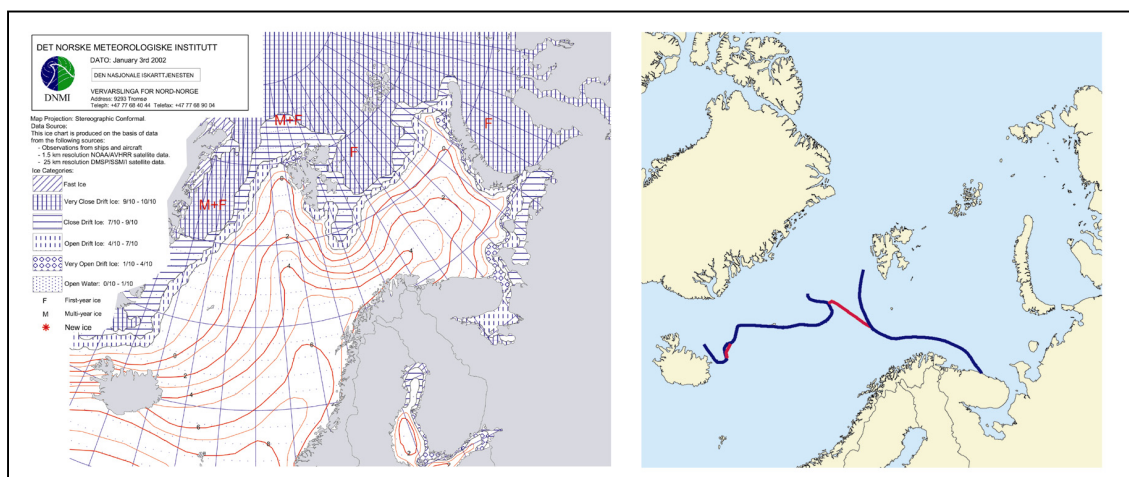


Figure 4. Examples of ice charts from 2002 and 1866. Colour of the ice edge on the 1866 chart (right) indicates different codes (see text ‘Information on the maps – Codes’).

### Quicklooks

“Quicklooks” for all ice charts are provided under the “Quicklook” directory and sorted by date as described above. The quicklooks are in “jpeg” format and should be readily viewable in any standard graphics software. File names contain the date in “yyyymmdd” format in the same manner as for the full chart, but with the extension “.jpg”.

### Viewing shapefiles

The data set has been compiled using ArcView and it is therefore recommended that the ice charts are viewed using one of the ESRI products: ArcView, ArcInfo or ArcGIS. Many other GIS software products exist and most have import utilities for handling shapefiles. The ability to import and handle shapefiles is obviously a minimum requirement of the GIS software for it to be used with this database.

Ice charts since 1997 do not include land. It is therefore necessary to add a land file to your view to create a mask over land areas. The shapefile “country.shp” supplied with the free data from ESRI is included on the CDrom for this purpose.

*A basic understanding of their own software package on the part of the users is assumed and details are not given here. For detailed descriptions of tools and functions in ArcView or other GIS software, the user should refer to the software documentation.*

For ArcView users a number of legend files are included on the CD-ROM in the “Legend” directory. These files have the extension “.avl”. For ice charts from before 1967 “leg\_1550\_1966.avl” should be used as these charts are simply lines displaying the position of the ice edge, as described in ships logbooks. From 1967 until July 1997 the charts use a format digitized at the Norwegian Polar Institute, and “leg\_1967\_1997.avl” should be used. From July 1997 to present, use “leg\_1997\_2002.avl” since these files adopted a new format when the Norwegian Meteorological Institute began producing daily, digital ice charts. For these more recent charts (1967 onwards) sea ice is denoted by closed polygons and attributed an ice concentration.

**To make use of the legend files on the CD-ROM:**

- 1) Open a view in ArcView and add the ice chart shapefiles you wish to display.
- 2) In the table of contents on the left hand side of the view, double click on an ice chart to open the legend editor.
- 3) Click on the button “Load” and then navigate to the directory containing the legend files and select the appropriate file corresponding to the chart’s date, as described above.

For users of other software packages it will be necessary to create a legend within their own package to obtain the best view of the data.

***Information on the maps - Codes***

For all charts, codes are associated with each digitized line characterizing the ice conditions inward from this line. It is important to note that this coded attribute data associated with the ice charts varies for different periods.

**From 1553-1965** two attributes are associated with each chart. The first attribute, “ice\_cond”, assigns a code to the ice concentration, which can be found in Table 1 below. The second attribute, “source”, assigns a code to the ice line describing the origin of the data, as shown in Table 2 below.

**Data from 1966** contains the single attribute, “ice\_cond”, as described above.

**Data from 1967 to June 1997** contains the two attributes, “ice\_cond” and “source”, as described above, and a third attribute called “Ice\_type”. This third attribute is an attempt to assign the equivalent attribute used in current Norwegian Meteorological Institute ice charts to the corresponding “ice\_cond”.

**From July 1997** a single attribute, “Ice\_type”, is used to describe the ice concentration. These values are described in Table 3 below.

**To retrieve attribute information about either ice lines or areas:**

- 1) Click on the ice chart in the table of contents in the view to select it.
- 2) Select the “identify” tool (the leftmost tool in the ArcView View menu).
- 3) Click on the line or area for which you wish to see information.

**Table 1:** Ice concentration codes for ice charts from 1550-1997, given by the first two numbers attached to each line

Number	Concentration	Description
01	10/10	Fast ice
02	9/10-10/10	
03	7/10-8/10	
04	4/10-6/10	
05	1/10-3/10	
06	> 6/10	Young ice
07	> 6/10	Grease ice
08	< 6/10	Young ice
09	< 6/10	Grease ice
10	< 1/10	Open water

**Table 2:** Data source used for compilation of ice charts

0 or 1	Satellite pictures (after 1966).
2	US ice maps (Birds Eye aircraft 1960-1971 and Joint Ice Center from 1972).
3	Other second hand sources, e.g. notes/collections from earlier reviews, such as 'Detailed information on ice conditions in the seas near Spitsbergen and Bjørnøya, 1899-1923' probably by Adolf Hoel.
4	Probable line based on a general description or observations before and after the date.
5	Assumed line, not digitized (Appears only on the maps used for digitization).
6	Radar aircraft observations. Russian 1950-1970. American 1960-1970. Norwegian 1963 onwards
7	Visual aircraft observation.
8	Ship observation, original or documented. 274 ice maps were drawn by Adolf Hoel on the basis of observations from sealers 1853-1922 (originals in the collection of hand written material at the Norwegian University Library in Oslo, copies at the Norwegian Polar Institute). 170 meteorological observation books from sealers and merchant ships in the European Arctic 1864-1922 (originals at the Norwegian Meteorological Institute, copies at Norwegian Polar Institute).
9	Observations from land stations (Bjørnøya, Hopen, Isfjord Radio, and Jan Mayen since 1963, or from earlier wintering stations in the Svalbard Archipelago).

**Table 3:** Ice concentration codes for ice charts from 1997-2002

Ice Type	Concentration
Fast ice	100% land fast ice
Very Close Drift Ice	90% - 100%
Close Drift Ice	70% - 90%
Open Drift Ice	40% - 70%
Very Open Drift Ice	10% - 40%
Open Water	0% - 10%

## Historical Background

### **General**

Observations of sea ice have been reported and documented over a period of more than 2000 years. At the time of Aristotle (320 B.C.), Pytheas, a Greek astronomer, mathematician and explorer, set out on one or several northward voyages from the port of Masillia (Marseille). His written reports are lost, and we only know of his achievements through other sources, written 100 to 200 years later. Pytheas described grease ice, in addition to the midnight sun and long summer nights. The authors some 100 years later thought he had used too much imagination. Nansen (1911) gives a thorough description of, and contributes to the discussion around, the achievements of Pytheas.

Irish monks described sea ice as 'mare concretum' in 825 A.D., and must have observed sea ice on the voyages to and from Iceland 50 years earlier. In 1070, Adam of Bremen wrote detailed reports about societies and nature in Scandinavia, Iceland, Greenland, and Vinland (the name given to Nova Scotia by the Vikings). He also described sea ice. An anonymous author wrote a book named *Kongsspeilet* around 1240. According to Weeks (1994), this book is notable because of the detailed, reliable and non-fantastic description of both sea ice and the Greenland ice sheet.

The key concept for the exploration of the Arctic from 1550 was 'The Northern Sea Route' to the markets of the Orient. Although the existence of the North East Passage was known after the expeditions of Vitus Bering in 1733, it was not considered as a possible sea route, mainly because of heavy ice conditions at several choke points.

Another activity that produced much information about sea ice conditions was the hunt for whales and seals. In Europe, national trading companies were established in the late 16<sup>th</sup> and early 17<sup>th</sup> century. With fierce competition between these companies, expeditions were equipped and sent northwards in search of blubber and fur. Land stations were established on the islands such as the Svalbard archipelago and shores of the Arctic Ocean, where the blubber was melted and put in barrels for transport at sea. Consequently, this activity led to an increasing number of sea ice observations as ships recorded information on their position and activities, and the prevailing conditions of weather, sea and ice. Further details about whaling in the 16<sup>th</sup>, 17<sup>th</sup> and 18<sup>th</sup> century, as well as a description of the climate and sea ice conditions, can be found in Scoresby jr. (1820) and Conway (1906). A brief overview related to the history of Svalbard, with suggestions for further reading, can be found in Arlov (1994).

After the Napoleonic Wars (1798-1815) there was an excess of naval vessels and officers from both sides of the conflict. Establishment of a Northern Sea Route was still a prized goal, and many attempts were made to explore the Arctic and find the North West Passage. Some expeditions disappeared, like the Franklin Expedition in 1845 when 134 men and two ships were lost in the Canadian Archipelago, and rescue expeditions were sent out to look for them. Robert McClure finally was the first to get through the North West Passage in 1854, from West to East. He lost his ship in the ice, but was rescued and saved. Roald Amundsen was later (1903-1906) the first to sail through the entire passage with the vessel 'Gjøa'.

The Norwegians took up annual sealing and whaling in the ice margins of the Nordic Seas around 1850. Around 1870 the Norwegian Sven Foyn invented the harpoon cannon, making seal and whale hunting more effective and profitable. In 1854 Foyn observed drift ice "closer to Norway than any other country". In that year, he observed a rare extension of the ice edge to around 71°N and 10°E. Scoresby jr. (1820) reported sea ice even further south at 65°N, 10°W, just north of the Faroe Islands. These severe ice conditions had a major impact on agriculture in Iceland with poor harvests noted in numerous records, following the long Icelandic tradition of writing. Ogilvie and Jónsson (2001) give an overview of the historic

climatology of Iceland over the last 1000 years. Towards the end of the 19th century, two further years of extreme ice conditions were observed, in 1867 and in 1881. In 1881, the drift ice and icebergs could be observed from the coast of Finnmark in northern Norway, and the ice edge was located just north of the Tromsøflaket (71°N, 19°E) in May 1881.

Around this time, the first scientific publications on sea ice started to emerge. At the end of the 19th century Fridtjof Nansen set out on his famous expedition to prove the existence of the transpolar drift. His ship, the Fram, was the first major vessel constructed to penetrate into the ice, rather than having to avoid it, and Nansen was able to allow it to become frozen into the ice and to drift across much of the Arctic Basin. The scientific recordings and observations of Nansen and his crew were presented in eight large volumes, covering almost all the natural sciences. One of the most famous results was the observation of Fram's drift (and that of the sea ice) to the right of the surface wind. These findings led to collaboration with the Swedish mathematician V. Ekman (Ekman, 1905), who formulated this problem in mathematical terms. His solution indicated a veering of the current vector with depth, known as the Ekman Current Spiral.

At the beginning of the 20th century, coal was found on Spitsbergen, and the need for information about sea ice and the ice conditions, to secure transport to Spitsbergen with supplies and back with coal, was emerging. With this in mind, systematic collection of sea ice information in these areas was initiated.

The technology of ship construction was also developing along with the engines used to power the vessels. Improvements facilitated manoeuvring in and close to the sea ice. At about the same time, aeroplanes made it possible to explore and observe large areas from above the surface in a very short time. With this new technology, information could be collected much more quickly than could be done by surface vessels. The number of sea ice observations was expanding exponentially.

In 1966, the Norwegian Polar Institute started regular production of sea ice maps. This task was taken over by the Norwegian Meteorological Institute in April 1970. At that stage, the time taken to gather the information about the ice field from various sources, produce the map, and send it back to the users, was long compared to the changes of sea ice characteristics due to shifts in the wind and weather. This meant that these maps were probably of more scientific interest, rather than for practical navigation purposes. However, at the same time, the first satellites provided optical pictures of the sea ice field and concentration, improving both the accuracy and amount of information available. Whilst this type of visual observation was still hampered by the cloud cover and the polar night, it was a huge improvement over earlier methods, mainly because it could cover such large areas so comprehensively.

Since these first visual satellite observations, technologies for observing sea ice have improved markedly, from the infrared satellite pictures that made it possible to indicate the ice edge even during the polar night, to passive microwave pictures that could be used to distinguish first-year from multi-year ice. More recently, development of Synthetic Aperture Radar (SAR) techniques for satellites during the 1990s has provided an all-weather capability meaning that sea ice observations can be available throughout the year, and in all weather conditions. Together with developments in computing, this has allowed the routine production of digital sea ice charts, initially for operational use, but with subsequent value for the research community, as they seek to understand the interactions of sea ice with the rest of the climate system.

### ***Navigation accuracy and the longitude problem***

Ancient astronomers in the Greek and Roman cultures were able to determine fairly accurate distances by astronomical observations and methods. They were able to determine the latitude by measuring the height of celestial bodies at the time of culmination, but in order to calculate the longitude at sea, navigators needed to know the time at a specific reference point. In times of no 'instantaneous' long distance communication devices this was a very significant problem, and one that took many years to solve satisfactorily.

The Dutch scientist Christian Huygens made the first pendulum clock in 1656, regulated by a mechanism with a 'natural' period of oscillation, based on the ideas and principles of Galileo Galilei. This clock had an error of less than a minute a day. However, the motion on board a ship and changes in humidity and temperature prevented these clocks from keeping accurate time at sea. In the United Kingdom, King Charles II founded the Royal Observatory in 1675 to solve the problem of finding longitude at sea. At this observatory, 'the Lunar Distance method' was soon established through which navigators used the measured position of the Moon relative to the bright stars, and tables of the moons position compiled at the Royal Observatory, to estimate the Greenwich Time. Not satisfied with this complex solution, the British Government, by Act of Parliament in 1714, offered, £20,000 for a method that could provide longitude to within half-a-degree (2 minutes of time). The method would be tested on a ship, sailing *"... over the ocean, from Great Britain to any such Port in the West Indies as those Commissioners Choose...without losing their Longitude beyond the limits before mentioned"* and should be *"...tried and found Practicable and Useful at Sea"*.

John Harrison, a carpenter from Lincolnshire who had very little formal education, eventually solved the problem with his invention of the 'chronometer'. This new type of clock functioned irrespective of its angle relative to the pull of gravity, and was little affected by changes in temperature and humidity. After a lifelong struggle with the 'Board of Longitude', an Act of Parliament finally awarded him the prize in June 1773. John Harrison was then in his 81st year. Before this recognition Captain James Cook had set out on his second voyage of discovery around the world, carrying a copy of Harrison's watch. He returned in July 1775, after a voyage of three years, which ranged from the tropics to the Antarctic. The daily rate of error for this clock never exceeded 8 seconds (corresponding to a distance of 2 nautical miles at the equator) during the entire voyage and Cook referred to the watch as *"...our faithful guide through all the vicissitudes of climates"*. Sobel (1996) gives a full account of Harrison's work and how he solved the problem. The Royal Observatory Greenwich provides an introduction to the problem on their website (<http://www.rog.nmm.ac.uk/>).

It seems likely that the chronometer became part of the standard equipment for a navigator onboard any kind of ship, military or civilian, sailing in the Polar Regions at some point during the years between the end of the Napoleonic wars (1815) and 1850. This estimate is based on a consideration of the time and cost to produce these pieces of fine and accurate mechanics, and that most of the production probably went to naval vessels during the Napoleonic wars. Further evidence for this estimate comes from Thierslund (1988), and from Else Marie Torstvedt (Norwegian Maritime Museum, personal communication, 2002). Eriksen (1999) uses 1825 as the year when ship chronometers were customary on board any vessel.

With the longitude problem solved, the location and time of observations of sea ice reported in the logbooks became more accurate. However, the problem remained that Arctic regions are often subject to persistent foggy conditions or low cloud cover making it difficult to find a celestial body to measure the height of culmination. It could still take several days or even weeks before an accurate observation of position could be made.

Technological developments after the 2nd World War such as Decca, Loran C, and GPS have made navigation at sea more or less independent of the weather conditions. Nowadays, in addition to several GPS systems on the bridge, many passengers may also carry a portable GPS receiver. Accuracy of the position of any observations is therefore not a problem in more recent times. However, information about how the position was determined is an important factor when sea ice extent and position of the ice edge are compared for recent and historical time periods. On this basis, users of the data set are encouraged to take the historical background into consideration when working scientifically with the ice maps.

## **Acknowledgment of Project Personnel and Support**

This project involved a major effort over a number of years, with the completion of this report being only a small part of the total work. The initial impetus for the study came from Torgny Vinje of the Norwegian Polar Institute, who acted as a project coordinator for more than 10 years, and who contributed throughout the entire endeavour. Roger Colony, the first ACSYS Project Office director, took the lead together with Vinje in making this an international project. Geir Kjærnli from the Norwegian Meteorological Institute made a huge contribution by creating all the ice maps by hand in a uniform format for later digitization. This digitization was carried out at the Norwegian Polar Institute, mainly by Geir Kjærnli, Terje Brinck Løyning, Gro Eriksrød, Nina Nordlund and Marit Nyborg. Consultants were Øyvind Finnekåsa, Geir Anker, Jostein Amlie and Reidar Mandt. Later, Harvey Goodwin, Stephane Hautier, Marzena Kaczmarek, Olga Pavlova, Sonja Reder, and the extensive voluntary efforts of Matthew Stokes, completed the data up to June 1997, when the Norwegian Meteorological Institute began producing digitized ice maps. Harvey Goodwin, Olga Pavlova and Terje Brinck Løyning carried out quality control of the completed data set.

Financial support to construct the database (collect and transcribe records and digitize charts) came from various sources. The Norwegian Polar Institute and the Norwegian Meteorological Institute supported the work throughout, and the Norwegian Research Council provided funding for much of the work. Other major financial contributors during the earlier stages of the project included a consortium of oil companies operating north of 62°N.

Completion of the charts, quality control of the data set, and production of this report and dataset CDs were supported by the World Wide Fund for Nature (WWF), the Norwegian Research Council, the Norwegian Polar Institute, and the International ACSYS/CliC Project Office.

This project is a contribution to the Arctic Climate System Study (ACSYS), a core project of the World Climate Research Programme. As such, it has benefited from the input of many scientists associated with that project over the years.

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## **Suggestions for further reading**

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## **APPENDIX A: Ice observation meta-database**

This is a directory containing historical material about sea ice, which can be found in the Norwegian Polar Institute's Library. The material consists of text documents, logbooks and ice charts stored in the library's archive under environmentally controlled conditions. This list describes the material contained in each folder. The names of the folders are listed in bold face. Most of the text material is in Norwegian.

### **Miscellaneous 1700-1900**

#### **Miscellaneous 1800s I**

1. Karl Pettersen, Ice conditions in the Nordic Seas 1881 and 1882, in Norwegian with an introduction by Adolf Hoel, Print from Norsk Geografisk Tidsskrift, B. I., h.4, 1926
2. Diary. Written on board the yacht Cecilie Malene of Tromsø, Capt. H.E. Arnesen, 1896
3. An extract from a report about the ice conditions during Willem Barentz fourth voyage in 1881 under the command of Lt. H. Van Broekheuijzen.
4. An extract from a report about the ice conditions during a voyage with Willem Barentz in 1880 under the command of Lt. H. Van Broekheuijzen.
5. An extract from a report by Capt. Leigh Smith on Eira i 1889.
6. An extract from a report about the ice conditions during a voyage with Willem Barentz in 1878 under the command of A. De Bruijne.
7. An extract from a report about the ice conditions during a voyage with Willem Barentz in 1879 under the command of A. De Bruijne.
8. An extract about the ice conditions from an account of the Arctic Region, Vol I. by W. Scoresby jr. F.R.S.E., 1820
9. Seasons with the Sea-Horses, Lammont.
10. The ice conditions in 1898-99. A map drawn by Captein A.G. Nathorst, on board the Antarctic.
11. Transcript of weather observations on board D/S Fortuna from Sandefjord during dolphin hunting expedition in 1887.
12. The ice covered Sea in 1882. From Norwegian trappers reports to Karl Pettersen. Rewritten from the newspaper Tromsøposten 6<sup>th</sup> January 1883, Vol. 12, No. 2. Also in the paper Morgenbladet, 21. Dec. 1882, Vol. 64, No. 352A.
13. Transcript of Lloyds Register "When ice was observed during the period 1786-1823". Written by T. Vinje.
14. Hand written letter from H.C. Johannesen to Adolf Hoel, dated Tromsø 31<sup>st</sup> March 1916.
15. Report about the ice conditions around Spitsbergen in 1892 from skipper H. Andresen on the Galeas Rivalen from Tromsø.

## **Misc. II about ice conditions, temperatures and expeditions in the 1800s**

1. List and description of 220 copies of Finnmarksposten 1866-1894, and Finnmarkens Amtstidende 1832-1833, 1870-1894, written by Synnøve Ørnen.
2. Analysis and estimations of ice extent and area.
3. Meteorological Diary written on board the Steamship Albert of Tønsberg, Chief Capt. Lieutenant G. Otto, on a voyage to Spitsbergen in November and December 1872.

## **Misc. Maps 1800s + 1700s**

1. Map of the ice conditions, 1773, vessel Racehorse, Const. John Phipps.
2. Map of the ice conditions, 1806, Revolution of Whitby, Capt. W. Scoresby.
3. Map of the ice conditions, 1856, Sailing vessel Foam, Capt. Lord Dufferin
4. Map of the ice conditions, 1817, by W. Scoresby jr.
5. Map of the ice conditions, 1818, by W. Scoresby jr.
6. Map of the ice conditions, 1818, vessels Dorothea and Trent, Capt. D. Buchan, R.N.
7. Extract about the ice conditions from "A voyage of Discovery towards the North Pole" performed by his Majesty's ships Dorothea and Trent under the command of Capt. David Buchan, R.N, 1818, by Captain T. W. Beechey, R.N., F.R.S., 1843.
8. Map of the ice conditions in 1827, on the vessel Hecla, Capt. Parry
9. Extract about the ice conditions by Parry: Narrative of an attempt to reach the North Pole 1827 on the vessel Hecla.
10. Map of the ice conditions, 1869, vessel Diana, Capt. James Lamont
11. Map of the ice conditions, 1870, vessel Diana, Capt. James Lamont
12. Map of the ice conditions, 1870, vessel D.S. Eira, Capt. Leigh Smith
13. Map of the ice conditions, 1883, (See Ymer 1884, part 2), vessel Cecilie Malene, Capt. Magnus Arnesen
14. Map of the ice conditions, 1884, (See Ymer 1884, part 6), vessel Cecilie Malene, Capt. Magnus Arnesen
15. Map of the ice conditions, 1884, Galeas William, Capt. G. A. Sørensen
16. Map of the ice conditions, 1884, (See Ymer 1884), H.C. Johannessen
17. Map of the ice conditions, 1884, (See Ymer 1884, part 6), Yacht Tvende Brødre, Capt. Johan Kjeldsen
18. Map of the ice conditions, 1885, (See Ymer 1885, part 6)
19. Map of the ice conditions, 1885, (See Ymer 1885, part 6), Yacht Thora den Blide, Capt. O. Sevaldsen
20. Map of the ice conditions, 1885, (See Ymer 1885, part 6), Slup Eliezer of Tromsø, Capt. Heming Andreasen
21. Map of the ice conditions, 1885, (See Ymer 1885, part 6), Galeas William by Høvik, Capt. G. A. Sørensen
22. Map of the ice conditions, 1886, (See Ymer 1886, part 8), Galeas William, Capt. G. A. Sørensen
23. Map of the ice conditions, 1886, (See Ymer 1886, part 8), Skøite Elizer, Capt. Henning Andreasen.
24. Map of the ice conditions, 1886, (Se Ymer 1886, part 8), Yacht Diana, Capt. A. Jensen
25. Map of the ice conditions, 1886, (Se Ymer 1886, part 8)

## **Incorrectly dated maps**

Contain maps, reports and a diary that are incorrectly dated.

***Newspaper cuttings I, Finnmarksposten 1832-1892***

***Newspaper cuttings II, 1867-1879***

***Newspaper cuttings III, 1880-1884***

***Newspaper cuttings IV, Finnmarksposten 1885-1894***

***Newspaper cuttings V, 1878-1894***

***Newspaper cuttings VI, Finnmark Amtstidende 1871-1883***

***Newspaper cuttings VII, 1895-1940***

***Newspaper cuttings VIII, 1899-1941***

***Correspondence on collecting logbooks from ice covered seas, 1923***

- O. Sverdrup
- A. Hermannsen
- A. Hoel
- Wollebæk

***Letters***

Contains letters to and from A. Hoel about sea ice observations.

***Ice observations from the years 1897-1936***

- Ice descriptions and terms
  - Codes
  - Ice reporting services
1. Copy of the directory containing logbooks collected in Tromsø and Balsfjord.
  2. Copy of a list of logbooks borrowed by the curator, Wollebæk.
  3. Letter to T.E. Vinje from Rijksuniversiteit i Groeningen, from Louwrens Hacquebord. Contains a list of sea ice information published in the thesis 'Smeerenburg, the sojourn of Dutch whalers on the west coast of Spitsbergen in the 17th century', 1984, Groeningen/Amsterdam, pp. 261-263.
  4. Overview of the ice conditions around Bjørnøya and Spitsbergen, 1925-1937.
  5. Notes about coal boat traffic to Spitsbergen from 1905-1938.
  6. Notes about the ice conditions around Bjørnøya in a 14-year period from 1922-1937
  7. The ice conditions around Hopen 1923-1937.
  8. Draft report (in Norwegian): 'Overview 1923-1932 ice and weather conditions around West-Spitsbergen', sent from Torger Øritsland, The Institute of Marine Research, Bergen. Received 6<sup>th</sup> November 1969 by Torgny Vinje.
  9. Information about the ice conditions around Spitsbergen during the winters 1908/09 and 1914/15. Letter from The Norwegian Meteorological Institute.
  10. Diary from Karl Bay, summer 1916.
  11. Hand written report about the ice conditions around Bjørnøya and West-Spitsbergen 1893-1936. 114 pp.

***Misc. Overview of the sailing conditions to harbours in Svalbard 1893-1940***

- Newspapers and photos of icebergs along the coast of Finnmark in 1929.
1. Russian Iceberg observations in the Barents Sea, 1933-1990, by Valentin A. Abramov, Arctic and Antarctic Research Institute (AARI). Unfinished manuscript.
  2. Ice drift from the Kara Sea into the Greenland Sea, by V. Ju. Vize, In Russian, English summary.
  3. Photo of the ferry Dronning Maud close to an iceberg off the coast of Finnmark in 1929.

4. Draft of a report with the title 'Icebergs in the Norwegian Continental Shelf in 1880-1881' by Arne Kvitrud and Ingrid Hønsi, Norwegian Petroleum Directorate, Stavanger, Norway.
5. Ice map including observations of icebergs along the coast of Finnmark in 1881 and 1929.
6. Folder with original newspaper clippings from among others. Tidens Tegn Aftenutgaven, Wednesday 15<sup>th</sup> May 1929 about icebergs off the coast of Finnmark.
7. Letter from Adolf Hoel to Mr. Alf Wollebæk, curator, Zoological Museum, Tøien, including a draft concerning the ice conditions, 2 copies.
8. Overview of the sailing conditions to the coal harbours in Spitsbergen 1893-1940
9. Type written letter from Geophysical Institute, Tromsø, to Mr. Roalkvam, Tromsø, about the difficult ice conditions around Bjørnøya and Spitsbergen.
10. The ice conditions at Bjørnøya and west Spitsbergen 1893-1937. Report with a written comment (in pencil): Not complete. Missing a paragraph giving an overview of the ice conditions around Greenland and Svalbard.
11. The ice conditions at Bjørnøya and west Spitsbergen 1893-1937. Report with a written comment (with pencil): The complete and only copy.

### ***Ice observations 1915 - 1966***

#### **Ice observations 1915**

1. Mail correspondence about ice and ice conditions in 1915. Among other things, a hand-written letter from Hilmar Nøis to the university scholar Adolf Hoel.
2. A list of dates for ships arriving in Spitsbergen.
3. Hand drawn maps.

#### **Ice observations 1916**

1. Copy of the Ice journal from the Radio Telegraph Station Spitsbergen 1915-1916
2. Diary notes about ice conditions in Bellsund 1916-1917.
3. Handwritten and typewritten notes about the ice conditions around Spitsbergen, summer 1916.

#### **Ice observations 1917**

1. Handwritten and typewritten notes about the ice conditions around Spitsbergen, summer 1917.

#### **Ice observations 1918**

1. Map of the ice conditions on the inshore sailing route to Advent Bay.
2. Handwritten and typewritten notes about the ice conditions around Spitsbergen, summer 1918.

#### **Ice observations 1919**

1. Map of the ice conditions around Spitsbergen.
2. Typewritten notes about the ice conditions around Spitsbergen, summer 1919.

#### **Ice observations 1920**

1. Hand drawn graphical presentation of meteorological observations made from Biørnøyen, November and December 1920. (temperature, wind speed and direction, barometric pressure).
2. Typewritten reports of ice conditions on several expeditions.

### **Ice observations 1921**

1. Map of the ice conditions in the Western Barents Sea, observed on board Fanny by Capt. Mogutchy.
2. Map of the ice conditions west of Sørkapp, observed on board T/S Farm by Capt. Hermansen.
3. Diagrams of ice thickness at Svea.
4. Sea Ice observations summer 1921 with copy (text).
5. Report of the ice conditions between Green Harbour and Van Mijen Bay.
6. Report from Kings Bay Kullkompani A/S about boat arrivals.
7. Meteorological observations from Bjørnøya: Synoptic obs. from August to December (tab. 0800h, 1400h, 1900h). Diagrams of weather parameters from January to April.

### **Ice observations 1922**

1. Reports and maps about the ice conditions from Capt. Abel Olsen on board D/S Torstein in a separate envelope.
2. List of rewritten material from 1922 to 1932 with copy.
3. Meteorological observations from Bjørnøya: Synoptic obs. from Jan-Mar, Nov-Dec (tab. 0800h 1400h 1900h).
4. Reports about the ice conditions summer 1922.

### **Ice observations 1923**

1. Meteorological observations from Bjørnøya: Synoptic obs. from Jan-Dec (tab. 0800 1400 1900h).
2. Map of the ice conditions west and north of Spitsbergen, observed on board M/K Blomstersel by Capt. R. von Krogh.
3. Map of the ice conditions north and east of Spitsbergen, observed on board M/K Staalis by Capt. Victor Arnesen.
4. Correspondence about a collection of logbooks from the polar seas, by Capt. Otto Sverdrup and Capt. A. Hermansen. 12000 kroner of funding was provided by the Norwegian Government on a Royal resolution dated 26<sup>th</sup> January 1923.
5. Map of ice conditions north of Spitsbergen observed from aircraft F16 by Capt. Ditrichson.
6. Map of the ice conditions east of Svalbard observed on board M/K Staalis.

### **Ice observations 1924**

1. Map of the ice conditions in the Greenland Sea, observed on board M/K Ringsel by Capt. Victor Arnesen, Tromsø.
2. Map of the ice conditions north-east of Svalbard, observed on board M/K Noris by Waldemar Kræmer, Tromsø.
3. Handwritten report/diary about the ice conditions observed on board M/K Noris.
4. Extract of a diary including weather observations by Hilmar Nøis in 1923-1924 in North-West Spitsbergen in the areas around Magdalenafjorden and Virgohavna.
5. Handwritten letter from Hilmar Nøis to Adolf Hoel about the observations mentioned in no. 4.
6. Meteorological observations from Bjørnøya (SYNOP: 0800h, 1400h, 1900h) with Ice Reports for the whole year 1924 (January-December).

### **Ice observations 1925**

1. Meteorological observations from Bjørnøya (SYNOP: 0800, 1400, 1900h) including Ice Reports. The period covers January-August, and the month of November. One report scheme is undated. The months September, October and December are missing.

2. Five maps of the ice conditions around Svalbard, observed on board Farm by several observers.
3. Type written report (copy) about the ice conditions on several voyages to the east coast of Svalbard.
4. Letter with enclosures from Adolf Hoel to The Danish Meteorological Institute about the ice conditions around Svalbard. Contents include an extract from Hilmar Nøis' diary including weather observations.

#### **Ice observations 1926**

1. Diary of ice observations written by Waldemar Kræmer on board D/K Frithjof
2. Map of the ice conditions on the north coast of Spitsbergen, observed by Waldemar Kræmer on board D/K Frithjof.
3. Map of the ice conditions observed on board Fanny on an expedition from Aberdeen to East-Greenland.
4. Letter with enclosures from Adolf Hoel to the Danish Meteorological Institute. The enclosures are extracts of diaries from Expeditions and trappers including Arthur Oxås who over-wintered at Flatehuken, winter 1925-1926.
5. Letter with reports from Adolf Hoel to the Danish Meteorological Institute about the ice conditions at Ny-Ålesund and on the west coast of Spitsbergen.
6. Meteorological observations from Bjørnøya (SYNOP: 0800, 1400, 1900h) with Ice Reports. Covering the period January-March.

#### **Ice observations 1927**

1. 11 maps and reports from Kings Bay Kullkompani A/S about ice conditions observed along the transport routes between the Norwegian Mainland and Ny-Ålesund.
2. Ice reporting from the ice covered seas and Ny-Ålesund edited by Arne Brøgger.
3. Mail correspondence between Adolf Hoel and Kings Bay Kullkompani and to several captains on board the coal freighters.

#### **Ice observations 1928 I**

1. Journal of observations of meteorological data from P/S Tordenskjold June -July 1928. Copy from the Meteorological Office in Bergen.
2. Several letters about Ice Reports and ice reporting from Adolf Hoel.
3. The ice conditions along the west coast of Spitsbergen, summer 1928 taken from observations on board the Norwegian Expedition vessel to Spitsbergen, The Royal Norwegian Navy 'Michael Sars', Capt. (Navy) O.I. Willoch, Capt. (Navy) A. Hermansen.
4. Diary of ice observations by Capt. (Navy) Willoch on board RNN Michael Sars.
5. 5 maps of the ice conditions around Svalbard and in the Greenland Sea, observed on board RNN Michael Sars, Heimland, Isbjørn, Ingertre, and Rensmo.
6. Diary of ice observations and map of the ice conditions by L. Ditmarsen on board Inger I.
7. Diary of ice observations and map of the ice conditions by R.B. Johannesen on board Inger II.
8. Diary of ice observations and map of the ice conditions from L. Feldt on board S/S Dagny I.

#### **Ice observations 1928 II**

1. Several ice reports sent to the Danish Meteorological Institute by Adolf Hoel
2. Several Ice Reports from Bjørnøya sent to Adolf Hoel from the Norwegian Meteorological Institute.
3. Ice Reports and Meteorological observations on board M/S Hobby of Tromsø to Svalbard.

4. Ice Reports and Meteorological observations on board M/K Heimland I from the east side of Spitsbergen.
5. Ice Reports and Meteorological observations on board M/K Heimland I from the ice fields to the north and west.
6. Ice Reports and Meteorological observations on board M/K Heimland I from the White Sea.
7. Ice Reports and Meteorological observations on board D/S Quest of Bodø
8. Ice Reports and Meteorological observations on board D/S Braganza from Spitsbergen.
9. Ice Reports and Meteorological observations on board D/S Braganza from the western ice fields.
10. Ice Reports and Meteorological observations on board M/K Isbjørn of Tromsø from the ice fields in the north and west.
11. Ice Reports and Meteorological observations on board M/K Helghorn from the White Sea.

### **Ice observations 1929**

1. Code for ice groups.
2. Several letters, requests, and reports about the ice conditions in the ice covered seas.
3. Synoptic observations and observations of sea ice. M/S Isbjørn I to the ice field in the west and in the Denmark Strait. March-April, May, July-August.
4. Synoptic observations and sea ice observations. D/S Heimland I of Tromsø to the White Sea.
5. Synoptic observations and sea ice observations. S/S Quest of Bodø in the White Sea.
6. Synoptic observations and observations of sea ice. M/K Heimen to Svalbard.
7. Handwritten copy of the ice journal from Svalbard Radio Station from August 1927 to 12<sup>th</sup> September 1929.
8. Ice map drawn on board M/S Hobby by Capt. A. Holm, 17<sup>th</sup> - 22<sup>nd</sup> June 1929.
9. Description and observations on board M/S Hobby on a voyage from Tromsø to Svalbard 17<sup>th</sup> June – 22<sup>nd</sup> June 1929.
10. Ice observations from D/S Heimland. Hunting expedition in the White Sea from 5<sup>th</sup> March - 29<sup>th</sup> April 1929.
11. Synoptic and sea ice observations from M/K Bjørnøy of Tromsø, June-August 1929.
12. Observations from M/S Hobby on a voyage to Svalbard - Tromsø 26<sup>th</sup> June – 6<sup>th</sup> July 1929.
13. Ice map drawn on board M/S Hobby by Capt. A. Holm 2<sup>nd</sup> – 11<sup>th</sup> June 1929.
14. Ice map drawn on board M/S Isbjørn I, by Capt. Peder Skogvik.
15. Ice observations 11<sup>th</sup> June - 10<sup>th</sup> July on the Naval Vessel and survey ship Michael Sars, on an expedition to Bjørnøya with the Norwegian Svalbard and Arctic seas survey.
16. Ice observations on board the Heimen with the Albertini expedition, 24<sup>th</sup> May – 5<sup>th</sup> Sep. 1929.
17. Map of the ice conditions observed on board M/S Heimen with the Albertini-expedition, 24<sup>th</sup> May - 5<sup>th</sup> Sep. 1929.
18. Ice observations on board M/S Bjørnøy's 2. Voyage with the Swedish Gulf Stream expedition from the 22<sup>nd</sup> July – 23<sup>rd</sup> Aug. 1929.
19. Map of the ice conditions observed from M/S Bjørnøy's 2nd voyage with the Swedish Gulf Stream expedition from 22<sup>nd</sup> July - 23<sup>rd</sup> Aug. 1929.
20. Ice observations from S/S Quest's hunting expedition to the White Sea, February to May 1929.
21. Map of ice observations from S/S Quest's hunting expedition to the White Sea, February to May 1929. Capt. L. Schjeldrup.
22. Map of ice observations from S/S Listø of Kristiansand S, on a voyage from Ny-Ålesund to Harstad, 4<sup>th</sup> July – 8<sup>th</sup> July 1929, Capt. Arne Andersen.

23. Ice Reports from Bjørnøya and Jan Mayen, May 1929. From the Norwegian Meteorological Institute, dated 3<sup>rd</sup> September 1929.
24. Ice Reports from Bjørnøya and Jan Mayen, March-April 1929. From the Norwegian Meteorological Institute, dated 7<sup>th</sup> May 1929.
25. Ice Reports from Bjørnøya for February 1929. From the Norwegian Meteorological Institute, dated 8<sup>th</sup> March 1929.
26. Ice Reports from Bjørnøya and Jan Mayen, December 1928 - January 1929. From the Norwegian Meteorological Institute, dated 7<sup>th</sup> May 1929.
27. A description of the ice conditions in 1929 from Store Norske Spitsbergen Kullkompani, 1st version.
28. A description of the ice conditions in 1929 from Store Norske Spitsbergen Kullkompani, 2nd version.
29. A description of the ice conditions in 1929 from Store Norske Spitsbergen Kullkompani.
30. Ice observations from M/K Bjørnøy's 1st voyage with the Swedish Gulf Stream Expedition 1929.
31. Map of ice conditions in the western ice fields observed on board Bjørnøy by Capt. V. Corneliussen. 1929.
32. Map of ice conditions in the western ice field observed on board M/S Isbjørn I by Capt. Peder Skogvin. May - August 1929.

#### **Ice observations 1930**

1. Ice observations from the Norwegian expedition to Frans Josef Land 1930 with the seal hunter Bratvaag.
2. Several Norwegian official and international letters concerning Ice Reports in the Arctic.
3. Ice and weather reports from M/K Bjørnøy 11<sup>th</sup> June – 30<sup>th</sup> June 1930. From The Norwegian Meteorological Institute.
4. Several Ice Reports from Svalbard, sent to Adolf Hoel from the Oslo harbour authorities.
5. Several Ice Reports from the Store Norske Spitsbergen Kullkompani.
6. Ice and weather reports from M/K Vaaland of Tromsø from the western ice field
7. Ice and weather reports from S/S Quest of Bodø in the White Sea.
8. Ice and weather reports from M/S Isbjørn I of Tromsø in the western ice field.
9. Ice and weather reports from M/S Isbjørn I of Tromsø in the western ice field, north and east coasts of Spitsbergen, and to Franz Josef Land.
10. Ice and weather reports from M/S Isbjørn I of Tromsø in the Spitsbergen western ice field.
11. Map of the ice conditions in the western ice field observed on board M/S Isbjørn I by Capt. P. Skogvin.
12. Two maps of the ice conditions in the White Sea observed on board S/S Quest of Bodø, Capt. L. Schjeldrup.
13. Map of the ice conditions in the western ice field observed on board D/S Skansen by Capt. Emil Brandal.
14. Map of the ice conditions in the western ice field observed on board M/S Vaaland of Tromsø by Capt. J. Johannessen.
15. Map of the ice conditions on the east coast of Svalbard to Frans Josef Land, observed on board Bratvaag, on the Norwegian expedition to Franz Josef Land 1930.
16. Map of the ice conditions between Jan Mayen and Greenland, observed on board D/K Veslekari, by Capt. Paul Lillenes.

### **Ice observations 1931**

1. Ice and weather reports from M/S Isbjørn I of Tromsø to the western ice field and the Denmark Strait.
2. Diary of ice observations from D/S Vesta of Ålesund, observations by Valdemar Kræmer.
3. Five maps of the ice conditions on the west, north, and east coasts of Spitsbergen, observed on board S/S Quest by Telegraphist Leif Rabben.
4. Two maps of the ice conditions in the White Sea and Eastern Barents Sea, observed on board M/S Heimen by Telegraphist Leif Rabben.
5. Map of the ice conditions in the Western ice field observed on board M/S Isbjørn I by Capt. P. Skogvin.
6. Map of ice conditions in the White Sea and Eastern Barents Sea, observed on board M/S Terningen by Nils Skog.
7. Ice report from M/K Heimen of Tromsø from the White Sea in 1931.
8. Ice Reports from M/K Isbjørn to the western ice field in 1931.
9. Ice report from Quest of Bodø from Svalbard and the northern ice border.
10. Several Ice Reports about the ice conditions in the fjords and around Spitsbergen.
11. Description of the ice conditions along the coast of East Greenland, summer 1931 after the observations by the Norwegian Svalbard and polar sea expedition to East Greenland on the M/S Polarbjørn.

### **Ice observations 1932**

1. Diary of ice observations from S/S Skansen of Ålesund, Capt. P. Andersen.
2. Map of the ice conditions in the Greenland Sea, observed on board S/S Skansen, by Capt. P. Andersen.
3. Diary of ice observations in the Greenland Sea observed on board Signalhorn, by Johs. Aksnes.
4. Diary of ice observations in the Greenland Sea observed on board Polaric, by Johan J. Vartdal.
5. Map of the ice conditions in the Greenland Sea observed on board D/S Polaric, Capt. J. Vartdal.
6. Several letters about the ice conditions, Ice Reports.
7. Map of the ice conditions in the Greenland Sea, Mar-Apr 1932, observed on board M/S Isbjørn I, Capt. Alb. Bergersen.
8. Map of the ice conditions in Western Barents Sea 1932, observed on board M/S Isbjørn I, Capt. Alb. Bergersen.
9. Map of the ice conditions in the Barents Sea 1932, observed on board M/K Terningen, Capt. Gustav Jensen.
10. Map of the ice conditions in the Greenland Sea (1932?), observed on board D/S Polaric, by Capt. Johan Vartdal.
11. Map of the ice conditions in the Greenland Sea 1932, observed on board D/S Signalhorn, by Capt. Johs. Aksnes.
12. Map of the ice conditions in the Barents Sea 1932, observed on board M/K Storis, Capt. Hagb. Kræmer.
13. Ice observations (text) from the Greenland Sea and Fram Strait, Mar-Jul 1932 M/K Isbjørn I.
14. Ice observations (text) from the White Sea, Feb-Apr 1932, M/K Quest of Bodø
15. Ice observations (text) from the northern ice field, Feb-Jun 1932, M/K Terningen of Bodø.
16. Ice observations (text) from the White Sea and northern ice field, Apr-Jun 1932, M/K Storis.
17. Ice observations (text) from the White Sea and western ice field, May-Jun 1932 M/K Grønbæk of Tromsø.
18. Ice observations (text) from the White Sea, Feb-Apr 1932 M/K Heimland of Tromsø

19. Map of the ice conditions in the Greenland Sea, May-June 1932, observed on board M/K Grønbakk, Capt. Victor Corneliusen.
20. Map of the ice conditions in the White Sea, observed on board D/S Heimland I, Capt. Karl Jacobsen, v/Ewald Øien.

#### **Ice observations 1933**

1. Letter from the ships radio telegraphist E. Andreassen on board M/S Isbjørn I to the Svalbard Office, Oslo, dated 14<sup>th</sup> August 1933 about the ice conditions observed on board the M/S Isbjørn - expedition to Svalbard and Kong Karls Land, 2<sup>nd</sup> July – 14<sup>th</sup> August.
2. Ice observations (text) from western ice field and northern ice boundary, Apr-Jul 1933, M/S Isbjørn I.
3. Two maps of the ice conditions in the Greenland Sea, Apr-July 1933 M/S Isbjørn I
4. Map of the ice conditions in the Barents Sea, 1933, M/S Isbjørn I.
5. Ice observations (text) from western ice field and Fram Strait, Feb-May 1933, S/S Heimland I of Tromsø.
6. Ice observations (text) from the White Sea, Jun-Aug 1933, S/S Heimland I of Tromsø
7. Map of the ice conditions in the Barents Sea, Jun-Aug 1933, S/S Heimland I of Tromsø.
8. Ice observations (text) from the northern ice boundary and the White Sea, 1933, M/K Terningen of Tromsø.
9. Two maps of the ice conditions in the Barents Sea 1933 M/K Terningen of Tromsø
10. Five logbooks containing ice observations.

#### **Ice observations 1934**

1. Letters and Ice Reports from the director of the State Harbour Authorities to Adolf Hoel about the ice conditions in the Arctic.
2. Diary of ice observations from M/K Isbjørn of Tromsø.
3. Ice observations (text) from a voyage to Spitsbergen, the Barents Sea and the White Sea, 1933, M/K Terningen of Tromsø.
4. Orvin, A.K., The Norwegian Svalbard and arctic seas expeditions 1934 and 1935, The Norwegian Svalbard and arctic seas survey Report no. 32. Reprint by the Norwegian Geographical Journal, Bind V, Part 8, 1935.
5. Diary of ice observations from M/S Algot on a voyage from Tromsø to the western ice field, Valdemar Kræmer, Tromsø.
6. Map of the ice conditions in the western ice field observed from M/S Algot by Valdemar Kræmer, Tromsø.
7. Map of the ice conditions in the western ice field observed from M/S Isbjørn Lolji by Telegrapher Egil Andreassen.

#### **Ice observations 1935**

1. Several letters and Ice Reports to and from Adolf Hoel.
2. Ice report from M/S Terningen of Tromsø, Feb-Jun 1935.
3. Map of the ice conditions in the Pechora Sea observed on board M/S Terningen of Tromsø by radio telegrapher Nils Hæg.
4. Diary of ice observations on board M/S Isbjørn I, by Reidar Richardsen.
5. Map of the ice conditions in the Greenland Sea observed on board M/S Isbjørn I, by radio telegrapher Richard Richardsen.
6. Map of the ice conditions on the east coast of Svalbard observed on board M/S Isbjørn I, by radio telegrapher Richard Richardsen.
7. Diary of ice observations on board M/K Bremsund, Capt. Valdemar Kræmer.

**Ice observations 1936**

1. Diary of ice observations on board M/K Isbjørn I, Reidar Richardsen.
2. Several letters about ice, and Ice Reports to and from Adolf Hoel.
3. Two maps of ice conditions in the Greenland Sea, observed on board M/S Isbjørn I, by telegrapher Reidar Richardsen.

**Ice observations 1937**

1. Ice observations and reports from Store Norske Spitsbergen Kullkompani A/S and from the captains on board the coal freighters.
2. Diary of ice observations from Torgilsbu, observed by S. Aaseth.
3. Several letters about ice and Ice Reports to and from Adolf Hoel
4. Map of the ice conditions in the Greenland Sea observed on board M/S Isbjørn by radio telegrapher Reidar Richardsen.
5. Map of the ice conditions in Baffin Bay, observed on board M/S Isbjørn by radio telegrapher Reidar Richardsen.

**Ice observations 1938**

1. Ice Reports.

**Ice observations 1939**

1. Ice Reports from Isfjord Radio and from the Norwegian Harbour authorities, and the Danish Meteorological Institute.

**Ice observations 1940-1945**

1. Ice observations and reports from Store Norske Spitsbergen Kullkompani A/S and from the captains on board the coal freighters.
2. Several letters about ice and Ice Reports around Svalbard and Bjørnøya to and from Adolf Hoel.
4. Report from Commander H.F. Meyer about the ice conditions around Iceland and Jan Mayen 1940-45.
5. Russian Map of ice borders in the Barents Sea Apr-May 1942.

**Ice observations + Misc. 1946-1958 I**

1. Several letters and Ice Reports to and from the Norwegian Polar Institute, including some maps and photos.

**Ice observations + Misc. 1946-1958 II**

1. Several military reports about the ice conditions in the Arctic, addressed to the Norwegian Polar Institute.

**Ice observations 1957 + special obs 46-57 by Lønø + Hornbæk 1957+**

1. Observations from Odd Lønø's winter camps, 1946-47, on Halvmåneøya, and in 1950-51 in the cabin on Zieglerøyane.
2. Several ice observations by Hornbæk in the fjord areas in Svalbard, 1948-1962
3. Ice Reports from Svalbard, Hopen and Bjørnøya in 1957.
4. Reports from flights in the vicinity of Svalbard, 'Scandinavian Airlines System Ice Photo-Reconnaissance Report'.
5. Two charts with ice observations noted.

**Ice observations 1958**

1. Several letters and Ice Reports from Hopen and Bjørnøya.
2. Reports from flights in the vicinity of Svalbard, 'Scandinavian Airlines System Ice Photo-Reconnaissance Report'.
3. Map of the ice conditions in the Greenland Sea and Barents Sea.

**Ice observations 1959**

1. Map of the position of the ice border during the seal hunting season in the western ice field, 1959.
2. Reports from flights in the vicinity of Svalbard, 'Scandinavian Airlines System Ice Photo-Reconnaissance Report'.
3. Ice reports from the Meteorological Office in Northern Norway.

**Ice observations 1961**

1. Map of the position of the ice border during the seal-hunting season in the western ice field, 1961.
2. Reports from air flights in the vicinity of Svalbard, Post card 'Scandinavian Airlines System Ice Reconnaissance Report'.
3. Ice Reports from the Met. Office in Northern Norway.
4. Several letters and reports about ice observed from airplanes and boats.

**Ice observations 1962**

1. Map of the ice border position during the seal hunting season in the western ice field 1962.
2. Reports from air flights in the vicinity of Svalbard, Post card 'Scandinavian Airlines System IceRecco Report'.
3. Ice Reports from the Met. Office in Northern Norway.
4. Several letters, reports and hand written notes and sketches about ice observed from airplanes and boats.

**Ice observations 1963 I**

1. Ice observations organized by month from January to May. Contains ice reports, map and photos.

**Ice observations 1963 II**

1. Ice observations organized by month from June to December. Contains ice reports, map and photos.

**Ice observations 1964**

1. Ice observations organized by month from January to September.
2. Ice Reports from Bjørnøya and Isfjord radio stations.

**Ice observations 1965**

1. Ice observations organized by month from January to December.
2. Ice Reports from Bjørnøya and Isfjord radio stations.

**Ice observations from the Odden, 1950-1965**

1. Contains only reports on special made sheets for Ice Reports for the whole period.

**Institute of Marine Research. 1951-1972 (-1952) NP 1946-1959**

1. A figure of the ice border in 1915 after a lecture by Adolf Hoel.
2. Report (hand written) about the ice conditions on the transport route to Svalbard and Hopen, 1946-1948, 1952, 1954, 1956-1959.
3. Sketches of the breeding grounds in the western ice field, 1951.
4. Map of the hunting areas in the western ice field, 1951-1972, with the exclusion of 1952.

**Protocols**

Protocol: Printout (copy) of the journals from the ice covered seas I.  
Collected by Otto Sverdrup and A. Hermansen in 1923.  
Original.

Protocol: Printout (copy) of the journals from the ice covered seas II.  
Collected by Otto Sverdrup and A. Hermansen in 1923.  
Copy. The original can be found in the collection of hand written material at the Norwegian University Library.

Protocol: Printout (copy) of the journals from the ice covered seas III.  
Collected by Otto Sverdrup and A. Hermansen in 1923.  
Copy. The original can be found in the collection of hand written material at the Norwegian University Library.

Protocol: Copy of sea ice journal 4.  
Collected by Otto Sverdrup and A. Hermansen in 1923.  
Copy. The original can be found in the collection of hand written material at the Norwegian University Library.

Protocol: Copy of sea ice journal 5.  
Collected by Otto Sverdrup and A. Hermansen in 1923.  
Original.

Protocol: Copy of sea ice journal  
Collected by Otto Sverdrup and A. Hermansen in 1923  
Original.

## Appendix B: Quality control

The table indicates those charts that were picked out for examination. Charts were displayed on the screen, and the properties of the digitized lines were checked. Problems of missing data or clear errors in ice edge position were corrected with reference to the original data.

Ice Chart control	Period	File names (YYYYMMDD.shp)
<b>Period 1550-1799: At least one map every 10<sup>th</sup> year</b>	1550-1599	15530812, 15560715, 15800812, 15810715, 15830715, 15940715, 15950812, 15960520, 15970617
	1600-1699	16040715, 16060715, 16070715, 16100617, 16110617, 16190812, 16250715, 16340715, 16390520, 16480812, 16570715, 16640715, 16710812, 16760812, 16830520, 16900812, 16950617
	1700-1799	17070617, 17220812, 17260715, 17340715, 17370617, 17410715, 17490812, 17520520, 17560617, 17650520, 17720617, 17800617, 17870520, 17920520, 17980617
<b>Period 1800-1965: At least one map every year</b>	1800-1809	18010325, 18020520, 18030715, 18040422, 18050520, 18060520, 18070422, 18080617, 18090603
	1810-1819	18100506, 18110701, 18120520, 18130520, 18140715, 18150603, 18160520, 18170715, 18180909, 18190812
	1820-1829	18200715, 18210812, 18220506, 18230729, 18240812, 18250715, 18260617, 18270701
	1830-1839	18310826, 18320812, 18330812, 18340520, 18350520, 18360909, 18370715, 18380715
	1840-1849	18400520, 18440422, 18450617, 18460520, 18470812, 18480520, 18490715
	1850-1859	18500520, 18510617, 18520812, 18540506, 18550520, 18560325, 18570617, 18580325, 18590422
	1860-1869	18600422, 18610729, 18620325, 18630715, 18640422, 18650520, 18660715, 18670812, 18680325, 18690909
	1870-1879	18700408, 18710422, 18720909, 18730812, 18740715, 18750520, 18760909, 18770617, 18780325, 18790812
	1880-1889	18800826, 18810422, 18821007, 18830701, 18840506, 18850826, 18860715, 18870826, 18890729
	1890-1899	18900701, 18910603, 18920422, 18930812, 18940826, 18950909, 18960422, 18970617, 18980408, 18990325
	1900-1909	19000729, 19010325, 19020506, 19030701, 19040225, 19050520, 19060617, 19070506, 19080812, 19090603
	1910-1919	19100408, 19110701, 19120715, 19130520, 19140909, 19150311, 19160715, 19170923, 19180520, 19190729
	1920-1929	19200520, 19210603, 19220812, 19230909, 19240422, 19250603, 19260617, 19270715, 19280617, 19290603
	1930-1939	19300408, 19310617, 19320715, 19330826, 19340506, 19350729, 19360506, 19370909, 19380701, 19390506
	1940-1949	19400812, 19410617, 19420617, 19430520, 19440520, 19451104, 19460826, 19470520, 19480729, 19490520
	1950-1949	19500617, 19510603, 19520325, 19530422, 19540715, 19550325, 19560617, 19570923, 19580311, 19590729
	1960-1965	19600325, 19610415, 19620729, 19630805, 19640513, 19650729

Ice Chart control	Period	File names (iceYYYYMMDD.shp)
<b>Period 1966-1997: At least 6 maps every year</b>	1966-1969	19660204, 19660304, 19660415, 19660506, 19660722, 19660923, 19661111, 19661230, 19670217, 19670401, 19670610, 19670819, 19671007, 19671209, 19680128, 19680325, 19680527, 19680729, 19680923, 19681125, 19690121, 19690314, 19690509, 19690725, 19690926, 19691128
	1970-1979	19700107, 19700311, 19700525, 19700730, 19700924, 19701126, 19710211, 19710405, 19710622, 19710831, 19711004, 19711227, 19720124, 19720323, 19720519, 19720725, 19720921, 19721127, 19730216, 19730426, 19730627, 19730823, 19731018, 19731220, 19740107, 19740311, 19740506, 19740711, 19740909, 19741105, 19750217, 19750421, 19750612, 19750814, 19751016, 19751204, 19760128, 19760331, 19760528, 19760729, 19760920, 19761129, 19770203, 19770404, 19770602, 19770802, 19771017, 19771212, 19780112, 19780302, 19780518, 19780704, 19780913, 19781103, 19790211, 19790409, 19790614, 19790814, 19791008, 19791206
	1980-1989	19800107, 19800306, 19800502, 19800718, 19800915, 19801113, 19810205, 19810421, 19810617, 19810812, 19811013, 19811216, 19820119, 19820301, 19820503, 19820713, 19820912, 19821109, 19830213, 19830409, 19830627, 19830820, 19831010, 19831219, 19840122, 19840312, 19840513, 19840715, 19840916, 19841126, 19850218, 19850416, 19850617, 19850827, 19851014, 19851209, 19860113, 19860316, 19860520, 19860715, 19860915, 19861125, 19870202, 19870406, 19870609, 19870817, 19871019, 19871214, 19880118, 19880314, 19880516, 19880718, 19880912, 19881114, 19890206, 19890410, 19890612, 19890814, 19891016, 19891211
	1990-1997	19900122, 19900312, 19900521, 19900723, 19900917, 19901126, 19910204, 19910402, 19910624, 19910826, 19911014, 19911209, 19920127, 19920323, 19920518, 19920713, 19920915, 19921123, 19930201, 19930419, 19930614, 19930830, 19931011, 19931213, 19940117, 19940321, 19940516, 19940711, 19940926, 19941128, 19950206, 19950403, 19950502, 19950807, 19951002, 19951204, 19960129, 19960325, 19960528, 19960729, 19960930, 19961125, 19970203, 19970401, 19970702, 19970805, 19971014, 19971114, 19971202