Arctic Sea Ice Concentration and Extent from Danish Meteorological Institute Sea Ice Charts, 1901-1956, Version 1

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Underhill, V., F. Fetterer, and C. Petersen. 2014. *Arctic Sea Ice Concentration and Extent from Danish Meteorological Institute Sea Ice Charts, 1901-1956*, Version 1. [Indicate subset used]. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center.

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FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/G10007

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

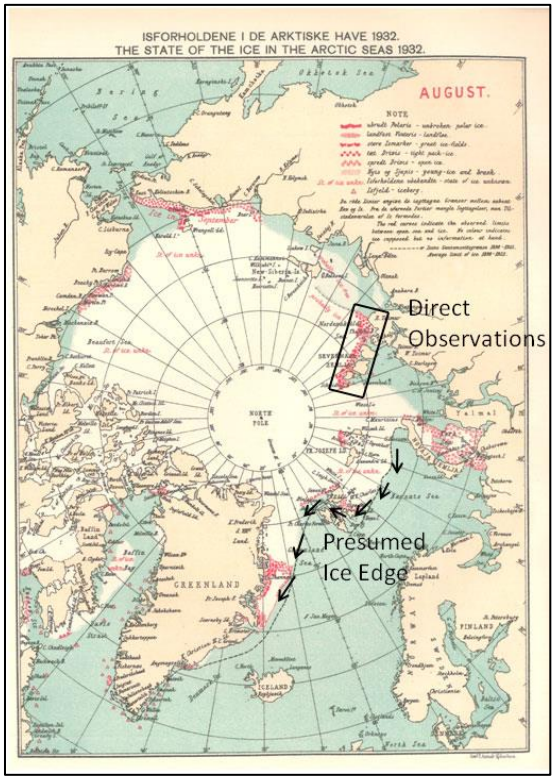

Figure 1. An August 1932 example from the DMI Arctic Sea Ice Charts data set. Ship and shore observations are marked in red. The presumed, but not observed ice extent, is the white field. Observed regions may often show the type of ice present using a legend in the top right corner.

From 1893 to 1956, map makers at the Danish Meteorological Institute (DMI) created hand-drawn charts of observed and inferred sea ice extent for each summer month, generally April to August but occasionally including March and September. Scanned versions of these charts were released as the Arctic Sea Ice Charts from Danish Meteorological Institute, 1893 - 1956 data set and are the input data for the sea ice concentration and extent estimates described in this document.

The original DMI charts are based on compiled observations of ice conditions reported by a variable network of national organizations, shore-based observers, scientific expeditions, and ships that are detailed by month in a report that accompanies each year of charts. In cases where no observations were available, the lead map makers may have drawn further ice cover using their knowledge of ice climatology and movement. They show observed or inferred ice extent as a light-colored field and ship observation locations as red symbols, with the symbol representing a type of ice cover that can be used to infer concentration (for example, tight pack-ice, for which we infer a concentration of 7/10 to 9/10, or 80% ± 10%). Figure 1 shows an example of these original charts. The original charts are particularly valuable for research about Arctic sea ice because of the length of the record and the early time period they cover.

The data set described in this document was created to convert the original DMI charts to a more usable format for research. To accomplish this, ice extent and areas of the same concentration were traced by hand on top of each digitized chart using a graphical image manipulation program. Areas of ice where observations had been made were color-coded red, with a saturation value that indicated percent concentration. Areas where the presence of ice was inferred by map makers rather than observed by ships were assigned a light-blue color. Each resulting image of concentration and extent was then projected into a common map framework using a Graphical Information System (GIS). Shapefiles were created and concentration and other information were included in attribute tables. Because the original hand-drawn DMI charts are in a polar stereographic projection, the derived sea ice concentration and extent estimates were kept in this projection as well.

This derived sea ice concentration and extent data set is comprised of both JPEG and GIS shapefile formats. There are 253 processed charts, one for each of the original DMI charts from 1901 to 1956. For most of the record, there is one chart per month covering April through August; however, for the years 1901 and 1907, there are charts for September; and 1902 has a chart for March. There is a gap in the record for the years between 1940 and 1945. Spatial coverage varies from year to year, but observations are much more highly concentrated in the North Atlantic region. Although the original hand-drawn DMI charts used to create these estimates begins in 1893, this data set begins in 1901 because charts earlier than 1901 do not cover the entire Arctic.

These data are contributing to larger data collections, including the Historical Sea Ice Atlas of Alaska sea ice, mid-1800s to the present, that are part of a joint project funded by the Alaska Ocean Observing System (AOOS), the Alaska Center for Climate Assessment and Policy (ACCAP), and the Scenarios Network for Alaska and Arctic Planning (SNAP)

1.1 Background

The early history of this collection is described in Thomsen (1947). In 1885, the DMI began systematically collecting information on sea ice in the Davis Strait. Ship captains sailing to settlements in west Greenland and residents of Greenland were asked to record all ice they observed. This sea ice observation program quickly grew to include observers on ships from other nations and to cover a wider geographic area. Beginning in 1900, these observations were collated and published annually in reports entitled "The State of the Ice in the Arctic Seas." In 1901, the charts' coverage expanded from a North Atlantic view to pan-Arctic coverage. Each chart shows observed ice (using standard phrases like unbroken polar ice or open ice) as well as the inferred ice edge in non-observed areas. The charts were published yearly along with a detailed written summary of pertinent ship logbook observations and ship traffic patterns.

Kelly (1978, 1979) recognized the value of these charts for research and digitized the ice edge shown in them as a graduate student at the University of East Anglia. He described the DMI charts as "the only major chart series containing circumpolar ice limits for the first half of this century" (Kelly 1978). Kelly digitized only the inferred ice edge and only to a spatial resolution of about 100 km, depending on the distance of the ice boundary to the pole (1978). He chose not to improve the resolution because of the low accuracy of the inferred ice edge itself. The eventual plan was for this digitized data to be incorporated on a one-degree grid into larger sea ice data products as an ice/no ice indicator.

Kelly also worked on assessing the reliability of DMI chart data. He notes that coverage differs spatially and temporally and planned to use both auxiliary historical sources and statistical methods to find and flag gross errors in ice extent data. He also suggested giving the data, as a whole, a series of reliability ratings. To the best of our knowledge, this work was never completed.

Kelly's work was cited by Sear (1988) as part of a larger group of Arctic sea ice data sets from which Sear created a simple index of sea ice extent. Kelly's digitized edge was also used with other historical data in a gridded sea ice data set first published in 1991 (Chapman and Walsh 1991). For complete details on the original charts, see the Arctic Sea Ice Charts from Danish Meteorological Institute, 1893 - 1956 documentation.

1.2 Format

1.2.1 JPEG Files

The JPEG image files show ice extent in blue and, where observations were made, ice concentration in shades of red. See Figure 2 for an example of the JPEG images. Percent-concentration values are given by red percent-saturation values. For instance, a 70% ice concentration area is colored red at a saturation of 70%. Areas of assumed open water are colored white.

There are a total of 253 JPEG image files (.jpg), one for each of the original DMI charts from 1901 to 1956. Each JPEG image is approximately 5000 by 7000 pixels and 945 KB in size.

The files are named according to the following convention:

DMI_YYYY_MM.jpg

Where

Table 1. JPEG File Naming Description

Variable	Description
YYYY	4-digit year
MM	2-digit month

1.2.2 Shapefiles

1.2.2.1 Individual

There are 252 individual shapefiles (.shp), one for each of the original DMI charts from 1901 to 1956, plus three other associated ancillary files for each of the .shp files (.prj, .shx, and .dbf) for a total of 1008 files. Note: The shapefile for April 1904 is missing. The shapefiles (.shp) range in size from 402 KB to 1.8 MB. Each ancillary file (.prj, .shx, and .dbf) ranges in size from 1 KB to 2 KB. See Figure 3 for an example of the shapefiles.

The files are named according to the following convention:

DMI_Charts_digitized_YYYY-MM.ext

Where

Table 2. Shapefile Naming Description

Variable	Description
YYYY	4-digit year
MM	2-digit month
.ext	File extension: .shp, .prj, .shx, or .dbf

1.2.2.2 Merged

The merged shapefile is a combined GIS file with all of the DMI charts included into one. Note: April 1904 is missing. The shapefile (.shp) itself is 177 MB in size and the ancillary files (.prj, .shx, .sbn, .sbx, .shx, .xml, and .dbf) range in size from 1 KB to 809 KB.

The merged shapefile and its associated ancillary files are named the following:

DMIshapefile.ext

Where: .ext is the file extension (.shp, .prj, .shx, .sbn, .sbx, .shx, .xml, or .dbf).

1.3 File and Directory Structure

Data are available on the FTP site, click the link, select “Guest”, and choose which items to download; ftp://sidads.colorado.edu/DATASETS/NOAA/G10007. Within the G10007 directory, there is one file and three sub-directories (Figure 2). See Table 3 for a description of the directory contents. See the Format section for additional details.

Table 3. Description of Directory Contents

Directory	Description
browse-images	Contains the JPEG images
individual-shapefiles	Contains the individual shapefiles
merged-shapefiles	Contains the merged shapefile

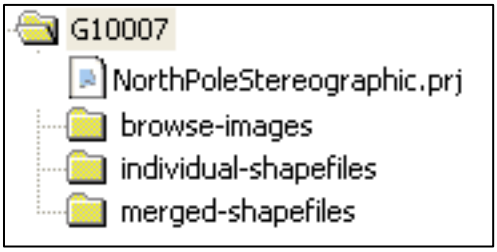

Figure 1. FTP Directory Structure

1.4 Volume

Table 4. Total File Volume by File Type

File Type	Size (MB)
Merged Shapefiles	178
Individual Shapefiles	204
JPEG	272
Total (All files)	654

1.5 Spatial and Temporal Coverage

These data provide a pan-Arctic estimate of sea ice extent from approximately 55° N to 90° N. The processed charts span 1901 to 1939 and 1946 to 1956. There is a gap in the record for the years between 1940 and 1945 because of World War II. The number of charts ranges from 1 to 6 per year depending on the year. For a complete list of charts, see the DMI Chart Inventory by Month and Year (1893-1956) (PDF 35 KB). Note: The September ice is often depicted for some regions on the same chart as August. In the processed charts, September ice conditions are shown in separate files.

While the original DMI charts begin in 1893, the processed charts begin in 1901. The first eight years may be processed at some point in the future, but have not been yet because of differences in spatial and temporal coverage. Refer to the original Arctic Sea Ice Charts from Danish Meteorological Institute, 1893 - 1956 data set for information regarding years 1893 to 1901.

1.5.1 Projection and Grid Description

The graticule on the original hand-drawn DMI charts made it possible to georeference each high resolution (4960 x 7015 pixel) scanned chart to a North Pole Stereographic projection, WGS84 coordinate system.

Projection details follow:

- North_Pole_Stereographic
- WKID: 102018 Authority: ESRI
- Projection: Stereographic
- False_Easting: 0.0
- False_Northing: 0.0
- Central_Meridian: 0.0
- Scale_Factor: 1.0
- Latitude_Of_Origin: 90.0
- Linear Unit: Meter (1.0)

The projection definition is available as a projection file. Select the link, select, “Guest” and choose which items to download; NorthPoleStereographic.prj

1.5.2 Sample Data Record

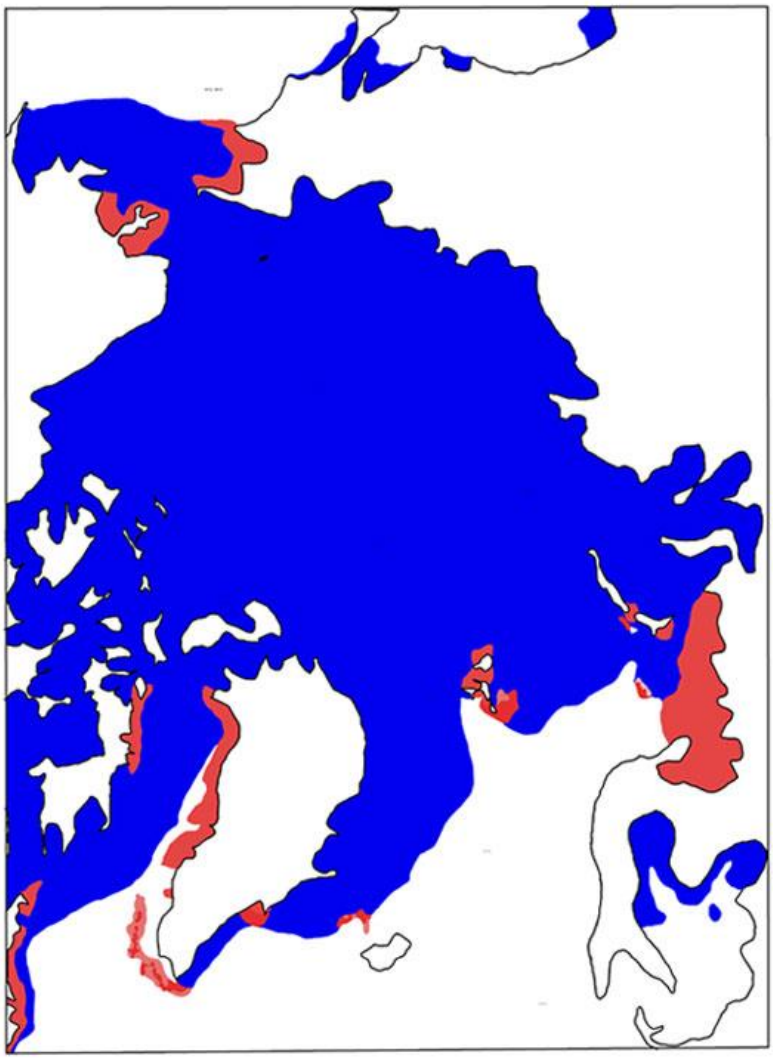

Figure 2. Example of the JPEG version of the processed chart for April 1903 with the concentration fields (in shades of red) and extent fields (in blue) mapped out with the coast outline.

Figure 3. Example of the shapefile version of the processed chart for April 1903 with the concentration and extent fields mapped out in arbitrary colors as shown in the legend on the right. Note: The coast outline was not included in the shapefiles.

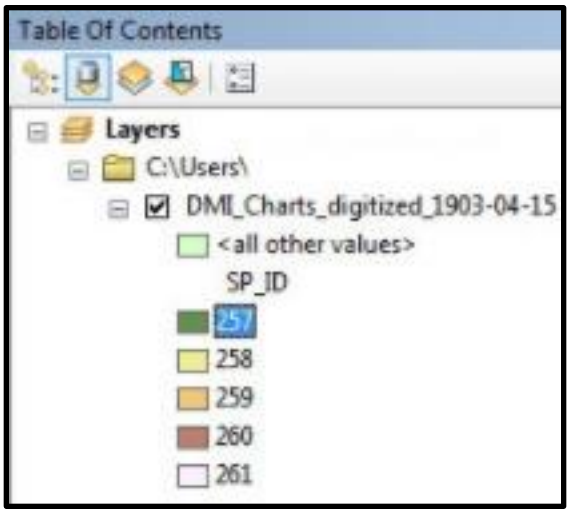

Figure 4. Example of the shapefile version of the processed chart for April 1903 with the concentration and extent fields mapped out in arbitrary colors as shown in the legend on the right. Note: The coast outline was not included in the shapefiles.

2 SOFTWARE AND TOOLS

2.1 Quality Assessment

Especially early in the century, these charts are based on relatively sparse data and rely to a large degree on the inference and extrapolation of the lead DMI mapmakers: V. Garde, C. Speerschneider, H. Thomsen, and M.V.L. Lorck (Thomsen, 1947). Direct observations are always clearly marked, but in many of the charts, inferred ice edge is the prevailing type of data shown. How reliable is the drawn ice edge location? The DMI mapmakers were experienced climatologists, so while their inferences are subjective, they also probably reflect the most reliable and accurate thinking of the time regarding sea ice extent.

The mapmakers may have used auxiliary data that are not included in the DMI publications themselves. According to Kelly (1979), inferred ice edge follows a 30-year climatological average for a period of years that shifts over the record. We do not have any information on this 30-year climatology. However, in some instances the inferred ice edge moves independently of the climatological average line. This suggests that the mapmakers were also working with other outside information not shown in the charts themselves.

The mapmakers probably created the inferred ice edge in a combination of three ways:

- Extrapolation over space, given nearby directly-observed data points and their understanding of ice growth, movement, and melt dynamics.

- Extrapolation over time, given directly-observed data points from previous months or the same month in previous years, and their understanding of ice growth, movement, and melt dynamics.
- Added input from auxiliary resources and information sources not plotted on the maps; these may have included annual climatic or atmospheric/oceanic circulation data present in the scientific community at the time.

For modern use, we have continued in the tradition of the DMI mapmakers and clearly differentiate where we have a good idea of ice concentration from observed ice conditions and where we are inferring that ice was present (concentration unknown) based on ice extent inferred by the mapmakers. Each user can decide how to use that information.

3 DATA ACQUISITION AND PROCESSING

3.1 Creating Shapefiles from Processed Files

This work was done at the University of Alaska at Fairbanks (UAF); only a general description is included here.

3.1.1 Producing Georeferenced Raster Files

The graticule on the original hand-drawn DMI charts made it possible to georeference each high resolution (4960 x 7015 pixel) scanned chart. Eight geographic tie points (control points) were selected when ice edges were traced as each chart was analyzed at NSIDC. An additional eight tie points were added at UAF to improve georeferencing. The images were imported into ArcGIS after setting the spatial reference of all digital images to "North Pole Stereographic". The imported charts images were georeferenced by applying a first-order polynomial, or spline, transformation.

3.1.2 Generating Shapefiles

The objective of this step was to create shapefiles with polygons and attributes that reflected the ice type, concentration, and uncertainty information from the analysis done at NSIDC. The polygon attributes also include several additional derived fields. In addition to individual shapefiles, a single merged shapefile containing all of the dates is provided.

In the processed image files, color and saturation indicate ice concentration. Each area with the same color and saturation was made into a polygon. To do this more easily in ArcGIS, the red-green-blue (RGB) band values that give concentration were first summed to create a single value; and a polygon formed around groups of cells with the same value. This value may vary slightly from image to image. The value is the GRIDCODE in the attribute table. See Table 5 for a description of all of the shapefile attributes.

Table 5. Description of the attributes in the shapefile attribute tables

Attribute	Description
SP_ID	Shapefile polygon ID.
GRIDCODE	Value of a given region determined by summing the red-green-blue (RGB) band values that give concentration.
Date	The month and year of the chart, with an arbitrary "15" used for the day of month.
Conc	Percent concentration divided by 10. Note: In this field, the descriptions *State of Ice Unknown* and *Ice - Edge* have the value of 11 and a *Bergy-bit* has a value of 2.
Concgrp	This is a grouping that was made for use in other studies where Bin 1 = 0-30% sea ice concentration, Bin 2= 30-90% concentration, Bin 3 = 90-100% concentration, Bin 4 = unknown concentration, but ice present.
Uncert	Assumed uncertainty in percent
Descript	Contains the ice chart legend term for an ice category. Note that the chart notation changed in 1951.
Area	Area of that category of sea ice in sq km
Notation	Contains the legend symbol for an ice category

3.2 Derivation Techniques and Algorithms

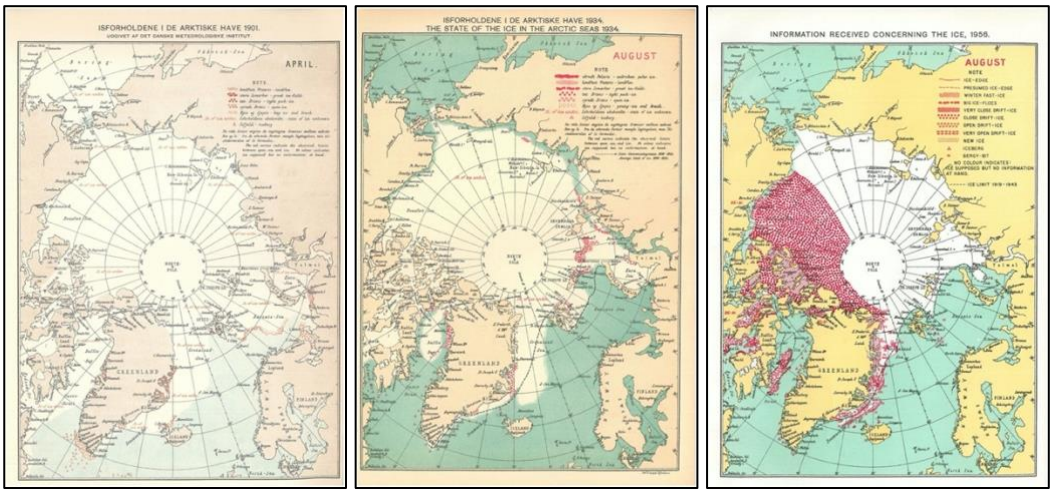

Figure 5. Example of an early chart from 1901 (left), a mid-program chart from 1934 (center), and a late chart from 1956 (right) showing the differences in the legends over the program's history.

3.2.1 Ice Terms and Definitions

The original DMI charts used phrases like large ice fields or new ice to describe ice conditions in regions of observation. NSIDC converted these descriptors into approximate percent-concentration values based on a combination of historical references. Among these are the World Meteorological Organization's (WMO) Sea Ice Nomenclature (WMO, 1989) and a document titled "International Ice Symbols: The Egg Code" (DMI, 1982). In the DMI publication, the terms very close pack ice, close pack ice, open pack ice, and very open pack ice are associated with concentrations in tenths of 9-10, 7-9, 4-6, and 1-3, respectively. NSIDC uses these DMI Tenths for this analysis.

The corresponding WMO terms are very similar: ice, close ice, open ice, and very open ice, with concentrations in tenths of 9-10, 7-8, 4-6, and 1-3, respectively. Note the different concentration range for close ice. The DMI changed their terminology in 1951, using the term pack ice where they had formerly used drift ice; but the terms seem to be interchangeable. Also, in 1951, the DMI charts began using a new legend of standard terms as set forth by the WMO.

Tables 6 and 7 show the phrases and subsequent conversions to tenths, concentrations, and color-coded digitization legend for the years 1901-1950 and 1951-1956, respectively. The DMI Tenths column contains the fraction of sea ice cover as defined by the DMI or assigned as described in Concentration Range Determination column of each table. Each area with the same concentration range was assigned a concentration in the middle of that range (Ice Concentration column), and that concentration was assigned a color saturation value (Color Saturation column).

The Uncertainty column contains the assumed uncertainty for these concentrations. The Danish Terms and English Translation columns in Table 6 and the English Term column in Table 7 show exactly how the ice conditions were described by the original map makers. Note the following:

For the years 1951 through 1953, there is an additional legend item named polar fast-ice. We believe that this is the same as winter fast-ice, but there is no documentation proving this.

The charts after 1935 do not contain the Danish language column of the legend.

Pack ice changes to Drift Ice in chart legends in 1951. DMI documentation (in "The Egg Code" 1982) uses the term pack ice, but DMI charts consistently use the same hatching system, so we assume these two terms to be equivalent.

Percent concentration ranges for the terms great ice fields and brash ice were suggested by Trausti Jonsson at the IMO (personal communication, 2011), referencing Koch (1945). Following Koch's reasoning, we assume ranges for landfloe, big ice floe, and new ice although there is substantially more uncertainty in these values. Matthew Ayre, with the University of Sunderland's ARCdoc project, gives the value for winter fast ice as a presumed 10/10 (personal communication, 2011). See Table 7 for these values. Many of these terms are not necessarily concentration descriptions, but an informal survey of International Ice Chart Working Group (IICWG) members at the 2011 IICWG meeting reinforced our postulated concentration equivalencies and uncertainties for each term.

Table 6. Chart Legend (columns 1 and 2) and corresponding concentration for charts 1901 to 1950.

Danish Term	English Translation	DMI Tenths	Ice Concentration	Uncertainty	Color Saturation	Concentration Range Determination
ubrudt Polaris	unbroken polar ice	1	100%	10%	100% Red	Inferred 100%.
store Ismarker	great ice fields	8/10 to 10/10	90%	10%	90% Red	Pers. comm. with T. Jonsson referencing Koch 1945 p 21
taet Drivis	tight pack-ice	7/10 to 9/10	80%	10%	80% Red	Shown in legends with the same hatching and in the same place as “close pack-ice” after 1951; assumed to be similar terms. From DMI (1982), “close pack ice” is 7/10 to 9/10.
landfast vinteris	landfloe	6/10 to 8/10	70%	10%	70% Red	Tenths from Koch 1945 p 21,
spredt Drivis	open ice	4/10 to 6/10	50%	10%	50% Red	Shown in the charts with the same hatching and in the same place as “open pack-ice” after 1951; assumed to be similar terms. From DMI (1982), “open pack ice” is 4/10 to 6/10.
Nyis og Sjapis	bay-ice (young-ice after 1930) and brash	1/10 to 3/10	20%	10%	20% Red	Pers. comm. with T. Jonsson referencing Koch 1945 p 21
n/a	n/a	n/a	0% (open water)	n/a	Green	
n/a	n/a	n/a	Inferred ice, conc. unknown	n/a	Blue	
Isforholdene ubekendte	state of ice unknown	n/a	No Information	n/a	White	

Table 7. Chart Legend (column 1) and corresponding concentration for charts 1951 to 1956.

English Term	DMI Tenths	Ice Concentration	Uncertainty	Color Saturation	Concentration Range Determination
Winter fast-ice (Polar fast-ice)		100%	5	100% Red	Tenths from M. Ayre;
Very Close Drift-Ice	9/10 to 10/10	95%	5	95% Red	Directly from DMI (1982)
Close Drift-Ice	7/10 to 9/10	80%	10	80% Red	Directly from DMI (1982)
Big Ice Floes		70%	10	70% Red	Tenths after Koch 1945
Open Drift-Ice	4/10 to 6/10	50%	10	50% Red	Directly from DMI (1982)
New Ice		50%	25	50% Red	Tenths after Koch 1945
Very Open Drift-Ice	1/10 to 3/10	20%	10	20% Red	Directly from DMI (1982)
n/a		Observed Ice Edge, no conc.	n/a	Green	
n/a		Inferred Ice	n/a	Blue	
State of Ice Unknown		No Information	n/a	White	

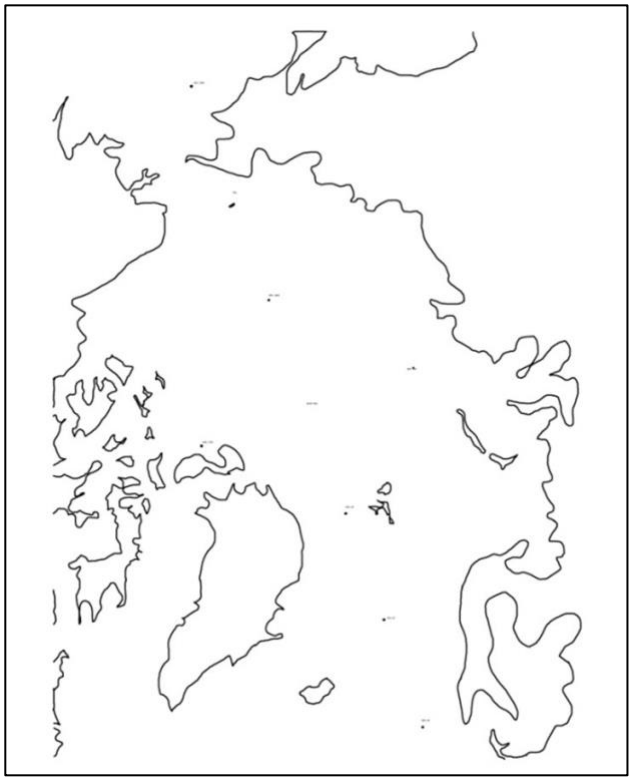

Figure 6. Arctic Coastline Template Overlay.

3.2.2 Coastline Template

These data will contribute to reanalyses and other work where it is important to capture all the ice up to the coast. Rather than use the drawn position of the coastline in the DMI charts, the NSIDC analyst used a rough outline that is well landward of the true coastline (Figure 8). Users incorporating these data in other studies can then apply the land mask or coastline that works best for their study, without fear of missing ice erroneously because of coastline differences. The shapefiles do not use this coastline template.

3.2.3 Processing Steps

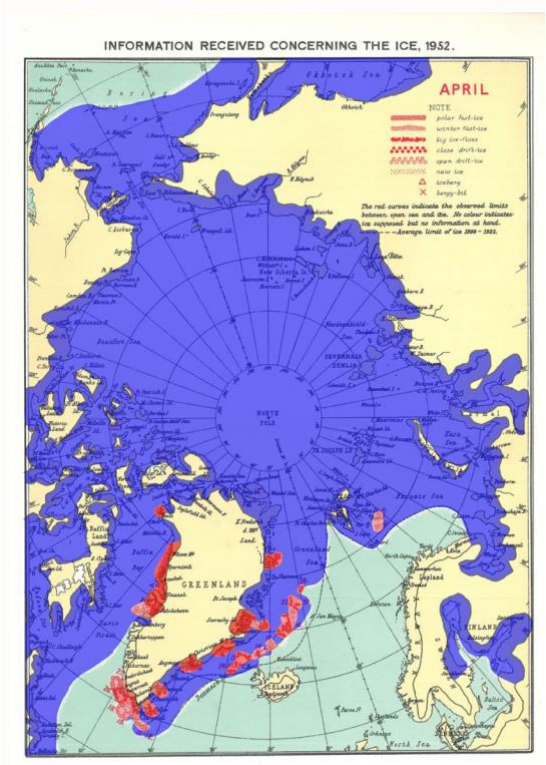

Figure 7. A processed chart, overlaid transparently, on an original chart to illustrate how the information in the original charts was used. The numbers to the south of Greenland correspond to dates of observation

The original paper charts, archived by the library at the DMI, were scanned by hand at the Icelandic Meteorological Office (IMO). NSIDC received these digitized charts and published them as the Arctic Sea Ice Charts from Danish Meteorological Institute, 1893 - 1956 data set in 2012.

Processing the original charts into concentration and extent fields consisted of overlaying a coastline template (Figure 8), encircling areas where ships reported ice with the same descriptive term, assigning a color value to these areas based on equivalent concentration in shades of red, and finally tracing the ice edge where there were no ship observations but the map makers had

assumed that there was ice. These areas were assigned a single-color value (blue) for ice. See Figure 9 for an example of the processing procedure.

The NSIDC analyst used the GNU Image Manipulation Program (GIMP) to overlay the coastline template on the original digitized charts and then traced the outlines of the areas where ships reported the same category of ice cover. Ice concentration was then assigned to these areas as described in the Ice Terms and Definitions section of this document. The processed chart images give ice extent in blue, and, where observations were made, ice concentration in red. Percent-concentration values are represented by red percent-saturation values. For instance, a 70% ice concentration area is colored red at a saturation of 70%. Areas of assumed open water are colored white.

These processed charts are being used in a larger project to create a long-term gridded sea ice product for use in reanalysis. To prepare files for use in this larger project, the image file versions of the processed charts were converted to shapefiles at the University of Alaska, Fairbanks. This involved additional processing steps. See the Creating Shapefiles from Processed Files section for more information.

4 REFERENCES AND RELATED PUBLICATIONS

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4.1 Related Data Collections

- Arctic Sea Ice Charts from Danish Meteorological Institute, 1893 - 1956
- Arctic and Southern Ocean Sea Ice Concentrations
- The Dehn Collection of Arctic Sea Ice Charts, 1953-1986
- National Ice Center Arctic Sea Ice Charts and Climatologies in Gridded Format
- Sea Ice Charts of the Russian Arctic in Gridded Format, 1933-2006
- Sea Ice Edge Location and Extent in the Russian Arctic, 1933-2006
- Morphometric Characteristics of Ice and Snow in the Arctic Basin: Aircraft Landing Observations from the Former Soviet Union, 1928-1989

4.2 Related Websites

- Historical Sea Ice Atlas
- Danish Meteorological Institute
- International Ice Charting Working Group
- Global Digital Sea Ice Data Bank
- ARCdoc project

5 CONTACTS AND ACKNOWLEDGMENTS

Acknowledgments:

Vivian Underhill did the work of researching and assembling these data while an undergraduate at the University of Colorado at Boulder. Her student position was supported by NOAA NESDIS NGDC. This data product is a contribution to the project titled A Long-Term Gridded Sea Ice Product for Use in Reanalysis and Diagnostic Studies funded by the NOAA Climate Program Office, John Walsh, PI.

Lena Krutikov, Corey Peterson, and associates at the University of Alaska Fairbanks converted the JPEG image files to shapefiles.

Kevin Wood, Joint Institute for the Study of the Atmosphere and Ocean (JISAO) at University of Washington, and John Walsh, University of Alaska Fairbanks, were instrumental in bringing the collection to our attention, providing links to references and advising on its use. Trausti Jonsson, IMO, encouraged us to use the collection he had scanned and provided advice concerning assigning concentrations.

We consulted with members of the International Ice Charting Working Group (IICWG) when building the table of inferences concerning ice concentration nomenclature.

Finally, we acknowledge the Danish Meteorological Institute and its library for recognizing the importance of systematic collection of sea ice information very early on, organizing the effort internationally, and freely sharing the published reports that resulted.

6 DOCUMENT INFORMATION

6.1 Publication Date

January 2014

6.2 Date Last Updated

26 November 2020