# Arctic Sea Ice Concentration and Extent from Danish Meteorological Institute Sea Ice Charts, 1901-1956, Version 1.1

## 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 1.1. [Indicate subset used]. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center.

https://doi.org/10.7265/N5MP517M. [Date Accessed].

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National Snow and Ice Data Center

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# 1 DATA DESCRIPTION

## 1.1 Summary

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.

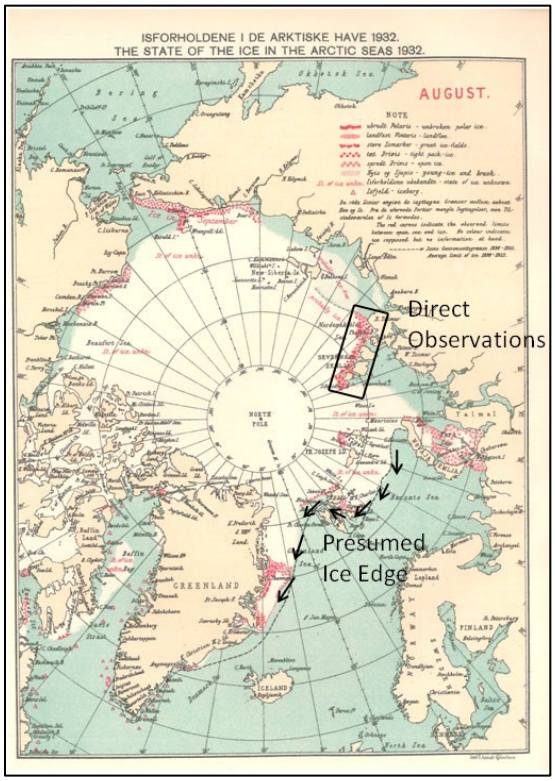



Figure 1. An August 1932 example from the DMI Arctic Sea Ice Charts data set. Ship and shore observations are marked in red. The presumed, but not observed ice extent, is the white field. Observed regions may often show the type of ice present using a legend in the top right corner.

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 more usable formats 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. This step preceded the processing that resulted in shapefiles and NetCDF files.

This sea ice concentration and extent data set is comprised of GIS shapefiles with associated browse images and NetCDF files with associated browse images. There are 252 processed charts, one for each of the original DMI charts from 1901 to 1956 with the exception of April 1904. 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.

## 1.2 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.

## 1.3 Parameters

This data set holds combined fields of sea ice extent and concentration. Inferred sea ice extent is indicated where sea ice concentration information is not given.

## 1.4 File Information

### 1.4.1 Format and File Contents

The data are provided in two formats: vector shapefiles (.shp) and gridded NetCDF files (.nc). Browse images in JPEG (.jpg) and PNG (.png) formats accompany the data files.

#### 1.4.1.1 Shapefiles and Shapefile Browse Images

The shapefiles are provided two ways: as individual files with one for each date and as one single merged file that contains all dates in one file. There are 252 individual shapefiles (.shp), one for each of the original DMI charts from 1901 to 1956 with the exception of April 1904. These are zipped up with their three associated ancillary files (.prj, .shx, and .dbf). See Figure 2 for an example of one of the individual shapefiles and Figure 3 for an example of the attribute table. Table 2 describes the attributes of the shapefiles.

The files are named according to the following convention and as describe in Table 1:

**Individual files**: `DMI_Charts_digitized_YYYY-MM.ext`
**Merged file**: `DMIshapefile.ext`

Where:

Table 1. Shapefile Naming Description

| Variable | Description |
|---|---|
| DMI_Charts_digitized and DMIshapefile | Indicates that this contains digitized DMI charts |
| YYYY | 4-digit year |
| MM | 2-digit month |
| .ext | File extension: .zip, prj, .shx, .sbn, .sbx, .shx, .xml, and .dbf |

Table 2. Description of the attributes in the shapefile attribute tables

| Attribute | Description |
|---|---|
| SP_ID | Shapefile polygon ID. This attribute is only in the individual files and *not* the merged file. |
| 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 chart legend term for an ice category. Note: Chart notation changed in 1951. |
| Area | Area of that category of sea ice in sq km. |
| Notation | Text description of the legend symbol for an ice category on the original DMI charts. Values are Broken Solid; Closed Circle(s); Crosshatch; Dashed Line; Dots; Dots/Open Circle; Fish; Open Circles; Solid, Broken Solid; Stripes; and White. |

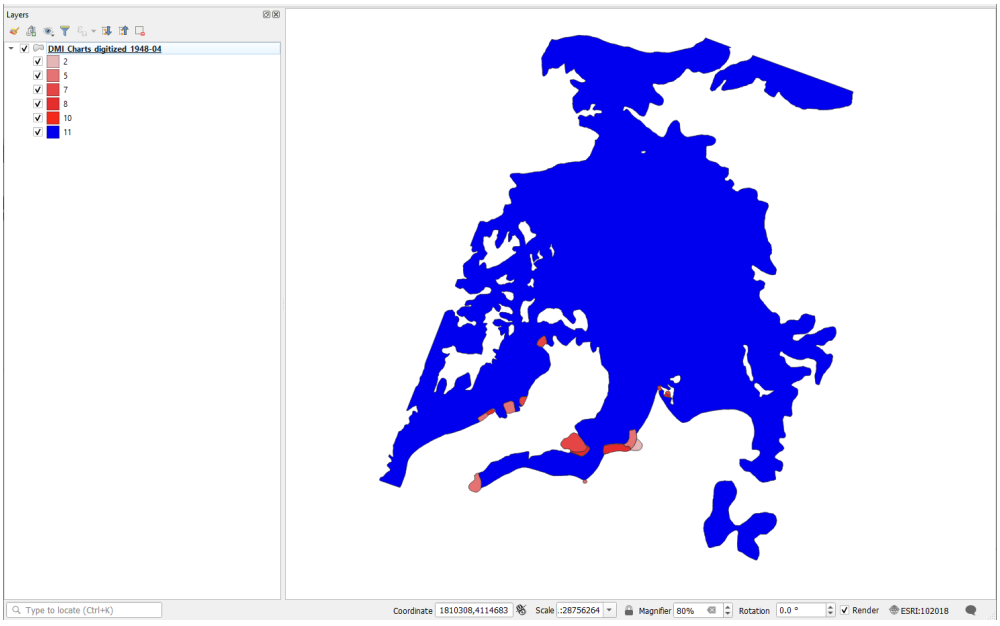
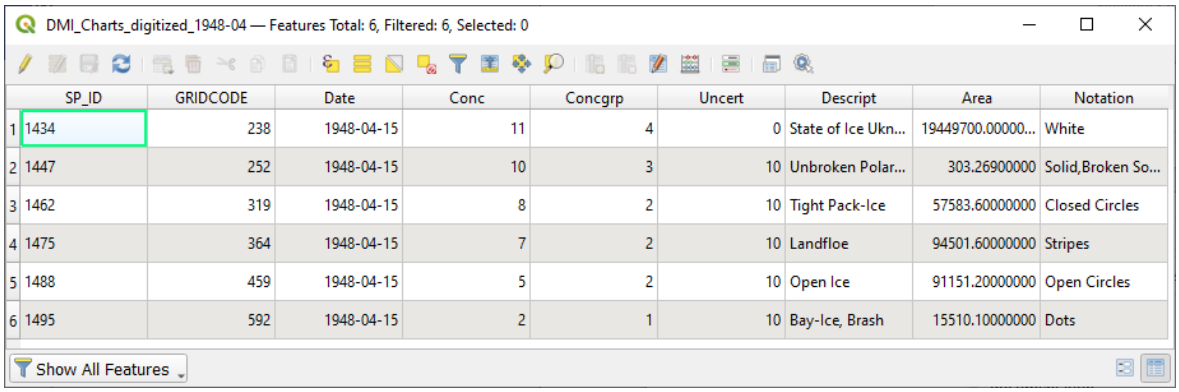



Figure 2. Example of an individual shapefile (DMI_Charts_digitized_1948-04.shp) in QGIS for April 1948 showing the concentrations mapped to the same colors as the JPEG browse images (Figure 4). Note: The coastline is not included in the shapefiles.




| | SP_ID | GRIDCODE | Date | Conc | Concgrp | Uncert | Descript | Area | Notation |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1434 | 238 | 1948-04-15 | 11 | 4 | 0 | State of Ice Ukn... | 19449700.00000... | White |
| 2 | 1447 | 252 | 1948-04-15 | 10 | 3 | 10 | Unbroken Polar... | 303.26900000 | Solid,Broken So... |
| 3 | 1462 | 319 | 1948-04-15 | 8 | 2 | 10 | Tight Pack-Ice | 57583.60000000 | Closed Circles |
| 4 | 1475 | 364 | 1948-04-15 | 7 | 2 | 10 | Landfloe | 94501.60000000 | Stripes |
| 5 | 1488 | 459 | 1948-04-15 | 5 | 2 | 10 | Open Ice | 91151.20000000 | Open Circles |
| 6 | 1495 | 592 | 1948-04-15 | 2 | 1 | 10 | Bay-Ice, Brash | 15510.10000000 | Dots |

Figure 3. Example of the attribute table for DMI_Charts_digitized_1948-04.shp

### Shapefile Browse Image

The shapefile browse images are provided in JPEG format and show ice extent in blue and, where observations were made, ice concentration in shades of red. See Figure 4 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 253 JPEG image files (.jpg), one for each of the original DMI charts from 1901 to 1956.

**Note**: There is one extra browse image than there are shapefiles. This is for April 1904. The shapefile was not completed for that date but we have kept the browse image so that the ice information can still be seen for that month.

The files are named according to the following convention and as described in Table 3:

`DMI_YYYY_MM.jpg`

Where:

Table 3. JPEG File Naming Description

| Variable | Description |
|---|---|
| DMI | Indicates that this file is from this DMI data set |
| YYYY | 4-digit year |
| MM | 2-digit month |
| .jpg | Indicates that this file is a JPEG image file |

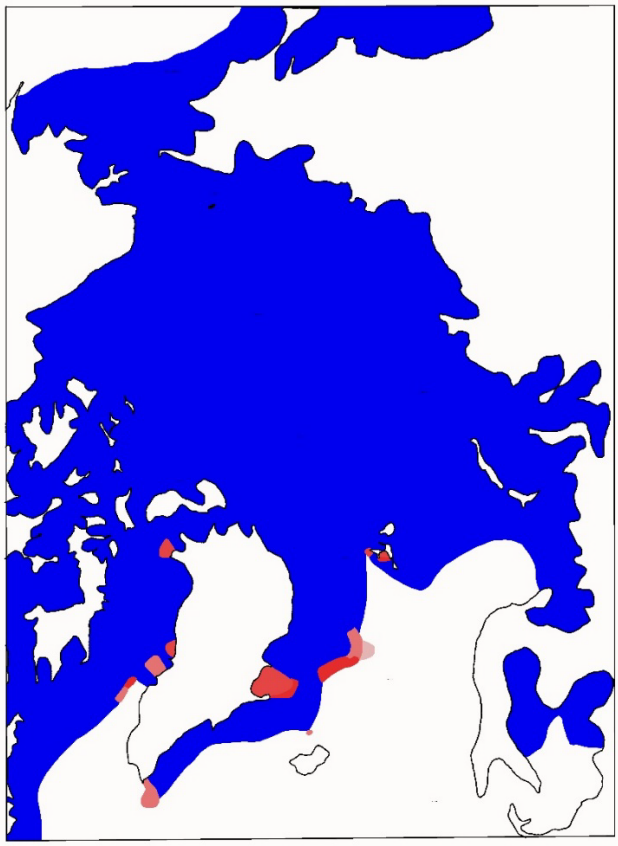


Figure 4. Example of the JPEG version (DMI_1948_04.jpg) of the processed chart for April 1948 with the concentration fields (in shades of red) and extent fields (in blue) mapped with the coast outline.

### 1.4.1.2 NetCDF Files and NetCDF Browse Images

The NetCDF files are provided two ways: as individual files with one for each date and as one single merged file that contains all dates in one file. There are 252 individual NetCDF files (.nc). Table 4 describes the variables in the NetCDF files.

Table 4. NetCDF Variable Description

| Variable Name | Description |
|---|---|
| crs | Coordinate reference system: Quarter-degree latitude/longitude grid north of 30 degrees |
| latitude | Latitude in degrees north |
| longitude | Longitude in degrees east |
| seaice_conc | Sea ice concentration with values in percent from 0 to 100. Flag values:<br>105 – off grid<br>110 – unknown sea ice type or sea ice edge<br>115 – bergy bit<br>120 – land inside grid |
| time | Time in days since 1900-01-01 |
| x | Projection x coordinate |
| y | Projection y coordinate |

### NetCDF Browse Images

The NetCDF browse images are provided in PNG format. Figure 5 shows an example browse image and Table 5 describes the color bar.

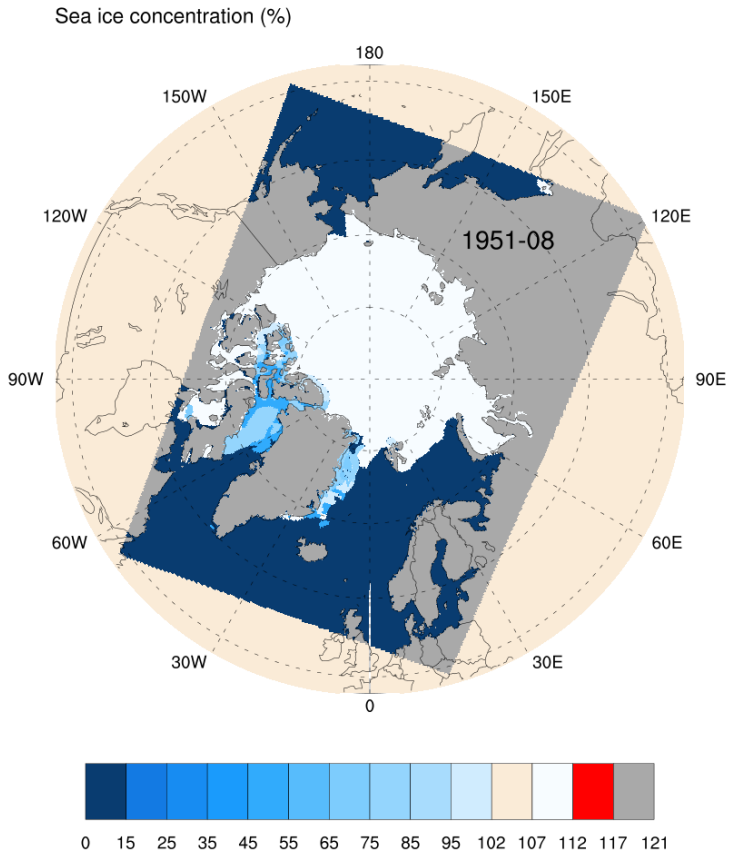



Figure 5. NetCDF browse image for August 1951

Table 5. NetCDF Browse Image Color Bar Description

| Color (R, G, B) | Value | Description |
|---|---|---|
| Shades of blue | 0-100 | Sea ice concentration |
| Beige (250, 235, 215) | 105 | Off grid |
| White (247, 252, 255) | 110 | Unknown sea ice or ice edge |
| Red (255, 0, 0) | 115 | Bergy bit |
| Grey (169, 169, 169) | 120 | Land inside grid |

### 1.4.2 File and Directory Structure

Data are available from this site: https://noaadata.apps.nsidc.org/NOAA/G10007/. Within the G10007 directory, there are two sub-directories: `netcdf` and `shapefiles`. Within each of those directories are three subdirectories: `browse-images`, `individual`, and `merged`. See Table 6 for a description of the directory contents. In addition, there is a projection description file for the shapefiles (NorthPoleStereographic.prj) in the `shapefile` directory.

Table 6. Description of Directory Contents

| Directory | Description |
|---|---|
| browse-images | Depending on whether this resides under the `netcdf` or `shapefiles` directory, contains browse images for the format indicated by the parent directory. |
| individual | Depending on whether this resides under the `netcdf` or `shapefiles` directory, contains the individual files, one for each date, for the format indicated by the parent directory. |
| merged | Depending on whether this resides under the `netcdf` or `shapefiles` directory, contains the merged file that contains all dates in one file for the format indicated by the parent directory. |

## 1.5 Spatial and Temporal Information

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. Note: The shapefile for April 1904 is missing but the browse image exists and was retained to show the data. 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).

Note: While the original DMI charts begin in 1893, these processed charts begin in 1901. The first eight years have not been processed because of differences in spatial and temporal coverage – they do not cover the entire Arctic. Refer to the original Arctic Sea Ice Charts from Danish Meteorological Institute, 1893 - 1956 data set for information regarding years 1893 to 1901. In addition, 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.

### 1.5.1 Projection and Grid Description

#### 1.5.1.1 Shapefiles

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.

The projection definition is available as a projection file: NorthPoleStereographic.prj

Projection details:

- 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)

#### 1.5.1.2 NetCDF Files

Data are on a quarter-degree latitude by quarter-degree longitude grid. The grid was chosen to be compatible with the Gridded Monthly Sea Ice Extent and Concentration, 1850 Onward data set (Walsh et al., 2019). Table 7 and Table 8 provide geolocation details for this data set.

Table 7. Geolocation Details

| | |
|---|---|
| **Geographic coordinate system** | WGS 84 |
| **Datum** | WGS 84 |
| **Units** | degrees |
| **EPSG code** | 4326 |
| **PROJ4 string** | +proj=longlat +datum=WGS84 +no_defs +type=crs |

Table 8. Grid Details

| | |
|---|---|
| **Grid cell size (x, y pixel dimensions)** | 1440 x 240 |
| **Number of rows** | 240 |
| **Number of columns** | 1440 |
| **Geolocated lower left point in grid** | 30.125° N, 359.875° E |
| **Nominal gridded resolution** | ¼ degree x ¼ degree |
| **ulxmap – x-axis map coordinate of the center of the upper-left pixel (XLLCORNER for ASCII data)** | -7346358.4 |
| **ulymap – y-axis map coordinate of the center of the upper-left pixel (YLLCORNER for ASCII data)** | 7346358.4 |

# 2 DATA ACQUISITION AND PROCESSING

## 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. See Figure 6 for examples of how the charts changed over time.

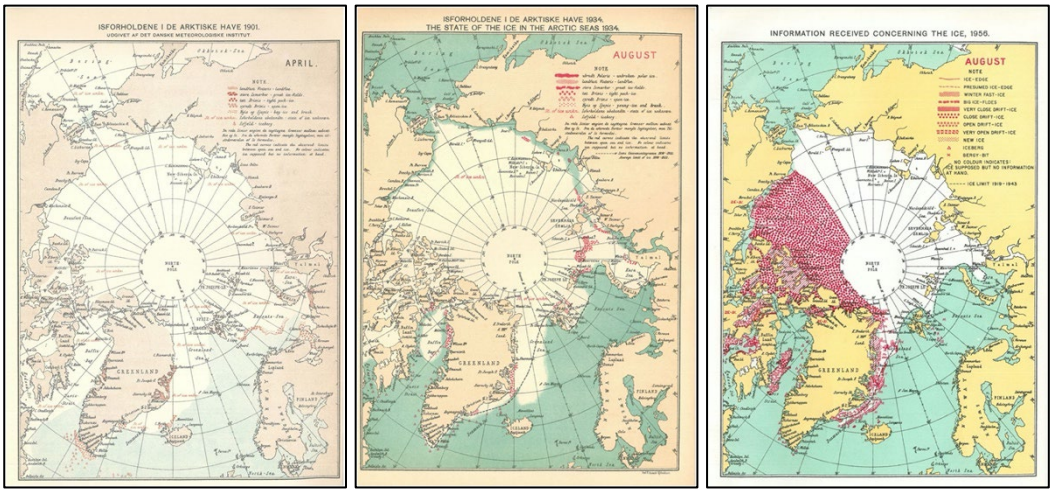



Figure 6. Example of an early chart from 1901 (left), a mid-program chart from 1934 (center), and a late chart from 1956 (right) showing the differences in the legends over the program's history.

Table 9 and Table 10 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 the 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 9 and the English Term column in Table 10 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.

The term *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 Icelandic Meteorological Office (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 10 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 9. 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. |

| Danish Term | English Translation | DMI Tenths | Ice Concentration | Uncertainty | Color Saturation | Concentration Range Determination |
|---|---|---|---|---|---|---|
| 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 10. 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 | |

## 2.2 Processing Steps

The general steps to create the data in this data set are as follows:

1. Create a coastline template
2. Create georeferenced raster files
3. Generate shapefiles
4. Produce NetCDF files from shapefiles

### 2.2.1 Create a 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 7). Users incorporating these data in other studies can then apply the land mask or coastline that works best for their study without fear of erroneously missing ice because of coastline differences. The shapefiles do not use this coastline template.

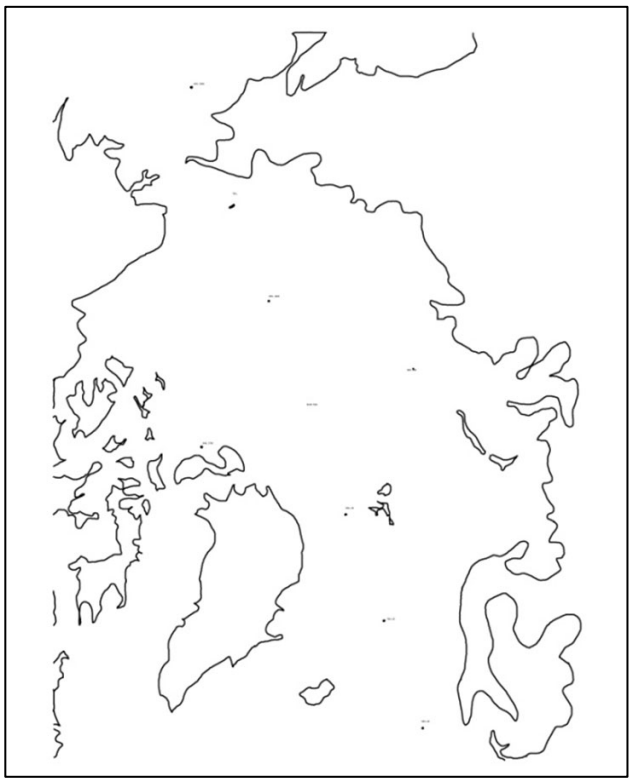


Figure 7. Arctic Coastline Template Overlay

### 2.2.2 Create georeferenced raster files

This processing step was carried out at NSIDC in 2013.

The original paper charts, archived by the library at the DMI, were scanned by hand at the 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 7), 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 8 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.

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 University of Alaska, Fairbanks (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.

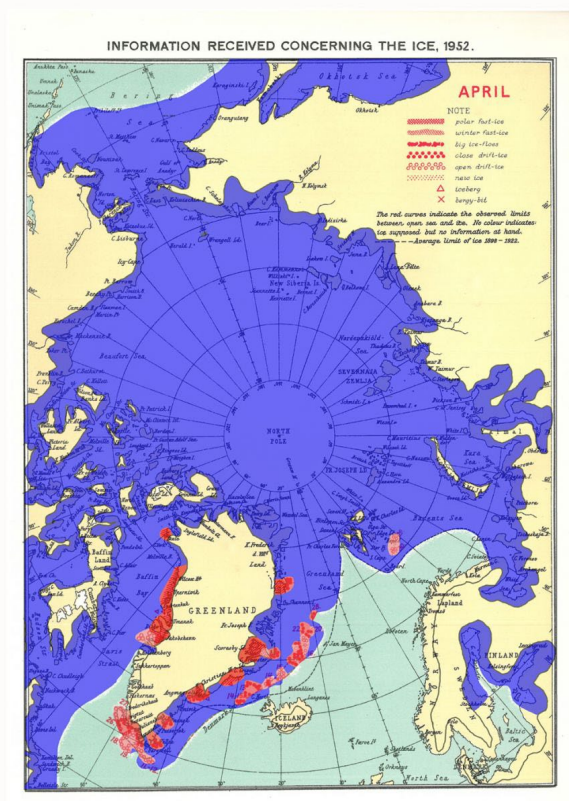



Figure 8. A processed chart, overlaid transparently, on an original chart to illustrate how the information in the original charts was used. The numbers to the south of Greenland correspond to dates of observation

### 2.2.3 Generate Shapefiles

The DMI charts were 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 UAF. This involved additional processing steps.

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 2 for a description of all of the shapefile attributes.

### 2.2.4 Produce NetCDF Files

This processing step was carried out at NSIDC in 2023. We aimed to make the NetCDF files compatible with those in Gridded Monthly Sea Ice Extent and Concentration, 1850 Onward data set (G10010) (Walsh et al., 2019) so that the DMI chart files might be used to assess and correct errors in that data set.

Each shapefile was converted to a NetCDF file using the following steps:

1. Project the quarter-degree latitude/longitude grid into the same map projection as the original shape files.
2. Overlay the quarter-degree latitude by quarter-degree longitude grid on the shapefile. This grid is that used in G10010. It covers the northern hemisphere north of 30 deg. The DMI charts cover a rectangular subsection of the G10010 grid.
3. Find all grid cell center points within each polygon of ice concentration. Set the grid cell concentration value to be that of the underlying polygon at the center point of the grid cell.
4. Where grid cell center points overlay polygon values of 11, indicating *State of Ice Unknown* or *Ice - Edge ice*, the corresponding grid cell is given a flag value of 110.
5. Where grid cell center points overlay polygon values of 2, indicating *Bergy-bit* ice, the corresponding grid cell is given a flag value of 115.
6. Use the land mask from the G10010 data set to find all grid points that are over land. Give the corresponding grid cells a flag value of 120.
7. Use a mask of points outside of the original shapefiles to designate points outside of the grid area. Assign these a flag value of 105.
8. Write out to a NetCDF file.

## 2.3 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 VERSION HISTORY

Table 11. Version History Summary

| Version | Release Date | Description of Changes | Citation |
|---|---|---|---|
| 1.1 | August 2023 | Added NetCDF gridded data as a new format to the data set. | Underhill, V., F. Fetterer, and C. Petersen. 2014. *Arctic Sea Ice Concentration and Extent from Danish Meteorological Institute Sea Ice Charts, 1901-1956*, Version 1.1. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. |
| 1.0 | January 2014 | Initial release of data set | 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. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. |

# 4 RELATED DATA SETS

- 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

# 5 RELATED WEBSITES

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

# 6 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 at NSIDC 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.

In 2023, Elizabeth Cassano converted shapefiles to NetCDF files at NSIDC.

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 at IMO encouraged us to use the collection he had scanned and provided advice concerning assigning concentrations.

We consulted with members of the 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.

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# 8 DOCUMENT INFORMATION

## 8.1 Author

This document was written by V. Underhill with editing by A. Windnagel and F. Fetterer.

## 8.2 Publication Date

January 2014

## 8.3 Revision History

**August 2023:** A. Windnagel and F. Fetterer updated the document to reflect the addition of the NetCDF format and the update to Version 1.1 and reorganized the Data Acquisition and Processing section.

**April 2023**: A. Windnagel rearranged the document to be more consistent with the new user guide layout. Updated Figure 2 showing the shapefiles so that the colors matched those in the browse images and added a figure showing the attribute table.