Ice Draft and Ice Velocity Data in the Beaufort Sea, 1990-2003, Version 1

USER GUIDE

How to Cite These Data

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

Melling, H. and D. A. Riedel. 2008. *Ice Draft and Ice Velocity Data in the Beaufort Sea, 1990-2003, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. https://doi.org/10.7265/N58913S6. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/G02177

National Snow and Ice Data Center

TABLE OF CONTENTS

1 BACKGROUND

Note: The majority of this document was created from Draft and Movement of Pack Ice in the Beaufort Sea: A Time-Series Presentation April 1990 - August 1999 (H. Melling and D.A. Riedel 2004). Download this document without graphics: draft_movement_beaufort_2004.pdf (PDF, 1.6 MB). Download this document in zip format with graphics: draft_movement_beaufort_2004.zip (zip file, 4.7 MB).

Sea ice grows in vast featureless sheets of uniform thickness if not disturbed by wind and current. An equilibrium thickness is attained when the heat conducted up through the ice from the ocean is adequate to balance the energy loss at the atmospheric interface. As this budget varies seasonally, so does the equilibrium thickness. Calculations show that the annually averaged thickness of Arctic sea ice, when subject only to thermodynamic forcing, is about 3 meters (Maykut and Untersteiner 1971).

The constant movement of sea ice in response to winds and currents generates stresses which cause ice sheets to break apart into floes separated by leads of open water. Under cold conditions, these leads develop a new cover of thinner ice. Where moving floes collide, ice is broken into fragments and piled into sinuous mounds called ridges. By these processes, the ice pack is quickly deformed into a rough and geometrically complex landscape both above and below the sea surface. In the southern Beaufort Sea in late winter, first-year sea ice typically ranges in thickness from zero to about two meters. However, ridges accumulate to a much greater total thickness. The deepest free-floating ridge keel recorded to date almost extended to a depth of 50 meters (Kovacs et al. 1973).

This study is focused in the Eastern Beaufort Sea. Its initial motivation was the acquisition of a statistical description of pack ice in the area, particularly in relation to features of extreme draft (ridge keels) and their rate of drift. From 1976 to 1987 there was very active exploration for oil within the zone of drifting pack ice. Since 2001 there has been a resurgence of interest in exploration, with emphasis this time on natural gas within the zone of land-fast ice.

Pressure ridges are the most severe commonplace ice hazard to offshore structures and shipping. Icebreaking ships and drilling platforms typically reach their design limits when transiting ice ridges. Grounded ridges gouge deeply into the seabed in the Beaufort Sea, thereby threatening sub-sea well completions and pipelines. Accurate data are needed for the cost-effective and safe design of the offshore infrastructure such as surface piercing platforms, seabed installations, sub-sea pipelines, icebreaking ships, environmental constraints on operations, etc.

Observations were made using two types of self-contained sonar moored near the seafloor. A four-beam Doppler sonar measures the velocity of ice drift and a narrow-beam ice-profiling sonar measures its draft. Ten sites on the Mackenzie and Banks Island shelves were instrumented to meet various objectives during this period. However, long time series were maintained at only three locations, namely the middle shelf and shelf edge north of the Mackenzie delta and the shelf edge to the north-west of Amundsen Gulf. In a typical year, pack ice covers the sites except in late summer. Approximately 2000 km of pack ice were surveyed annually by each installation.

2 DETAILED DATA DESCRIPTION

2.1 Parameters

The parameters of this data set include sea ice draft (m) and sea ice velocity/ice drift (cm/s). Ice draft is a measurement of the thickness of the sea ice below the waterline and often serves as a close proxy for total ice thickness. The ice velocity or ice drift is a measure of the speed of the drift of the ice.

2.2 Spatial and Temporal Coverage and Resolution

This data set covers the Eastern Beaufort Sea. Figure 1 is a graphical representation of the mooring sites; see Table 11 for a complete list of specific latitudes and longitudes by mooring site number.

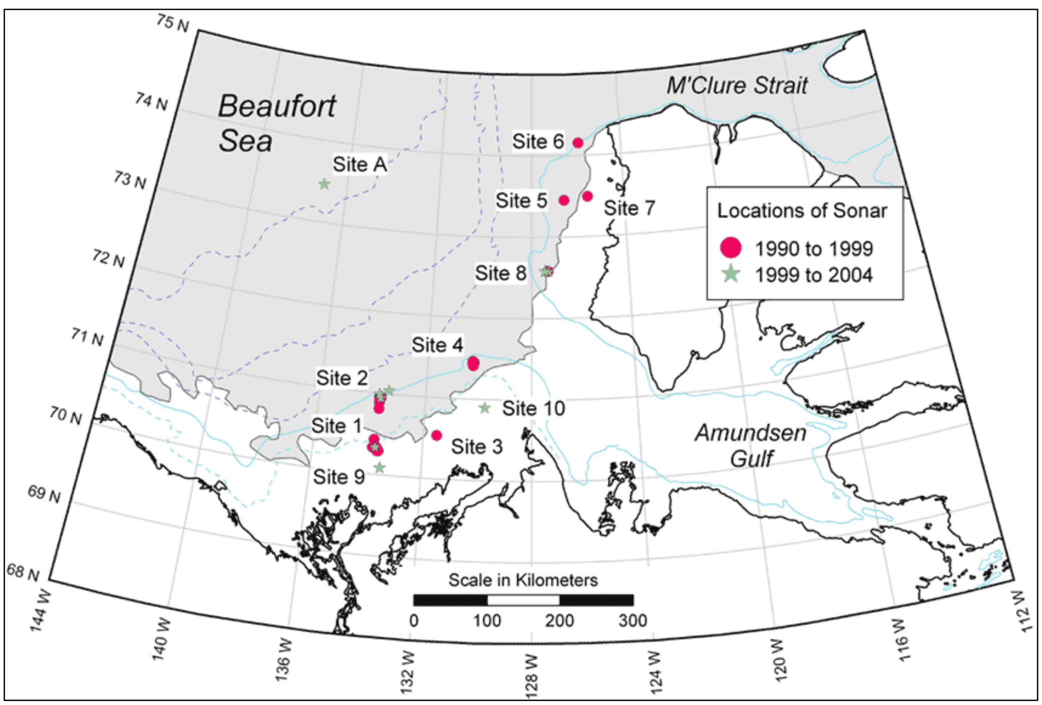

Figure 1. Sonar Mooring Sites

2.2.1 Temporal Coverage and Resolution

This data set begins in April 1990 and spans through September 2003. Nominal temporal resolutions are four minutes for ice draft data, 30 minutes for ice drift data. **Note**: Actual values vary somewhat from deployment to deployment. Statistics were calculated for nominal monthly intervals.

2.3 Format

All files are provided in ASCII text format. The top line of all data and header files is a time stamp of the date the file was created. The data files (both ice draft and ice velocity) contain flags as described in Table 1.

Table 1. Data Flag Descriptions

Value	Description
0	Inserted when the original full length sonar record revealed prolonged ice free conditions or rough seas in which ice at low concentration cannot be detected. Note: Shorter periods of open water were not removed during processing and are evident as ice draft near zero (±0.05 m)
-88.88	Inserted when no observations were made. For example, there was no instrument in the sea or the instrument was non-functional.
-99.99, -99	Inserted when temporary ambiguity in the validity of echo ranges merited a judgment of bad data.

2.3.1 Header Files

Each data file for both the ice draft and ice velocity data is paired with an ice draft header file in ASCII text format that provides specific information about its data file. Each header file contains information about the location of the moored sonar and other log information. The headers have a standardized set of sections, sub-sections, and fields within sub-sections. However, these components can be in any sequence and not all are included in every header file. In the files, the * symbol indicates the start of a section and the $ symbol delineates the start and end of a sub-section.

2.3.2 Ice Draft Files

2.3.2.1 Data Files

The ice draft data files are provided in ASCII text format and contain four columns of data as described in Table 2.

Table 2. Column Descriptions for Ice Draft Data Files

Column	Description
1	Decimal day of the measurement relative to 00:00 UTC on January 1, 1990 (which has a value of 1.000) Note: The header files incorrectly list this column as being Julian days.
2	Decimal day of the measurement relative to 00:00 UTC on January 1 of the year of instrument deployment Note: The header files incorrectly list this column as being Julian days.
3	Ice Draft (m)
4	4-digit year that the instrument was deployed

2.3.2.2 Statistics Files

The statistics files contain various statistical indicators of ice draft and are calculated over monthly intervals. The monthly intervals alternate between 31-day and 30-day durations based on the calendar year. In a leap year, the last "month" of the year has 30 days; otherwise it has 29 days.

Table 3 describes the rows in the ice draft statistics files.

Table 3. Row Descriptions for Ice Draft Statistics Files

Row	Description
Section	3-character month and 2-digit year of the section being analyzed
Start rec	Start number of the record
End rec	End number of the record
Total rec	Total number of records available for statistical analysis
Flags	Number of flags present in the record
Total possible rec	Total number of possible records
Mean (from D_S)	This is the mean computed from all non-flagged data values including open water (zero-draft values are included).
StDev (from D_S)	This is the standard deviation computed from all non-flagged data values including open water (zero-draft values are included).
Mean from HIS	Mean from the histogram: The mean calculated as the sum of the products of the bin-center-value times the bin population. This calculation is included to allow direct comparison with the mean with out open water.
Mean w/o O/W	Mean excluding open water. The mean calculated as the sum of the products of the bin-center-value times the bin population excluding the first bin.
Ice Concentration	Percent ice concentration
Fraction of possible	Fraction of the total possible records available for statistical analysis

Row	Description
Min	Minimum value
20th %ile	20th percentile
50th %ile	50th percentile (median)
80th %ile	80th percentile
Max	Maximum value
BIN(m)	Binned draft data. There are 401 bins with the smallest spanning (-0.05, 0.05) and the largest (39.95, 40.05) m.

2.3.3 Ice Velocity Files

2.3.3.1 Data Files

The ice velocity data files are provided in ASCII text format and contain three columns of data as described in Table 4.

Table 4. Column Descriptions for Ice Velocity Data Files

Column	Description
1	Decimal days relative to the start time of the instrument Note: The header files incorrectly list this column as being Julian days.
2	Ice speed (cm/s)
3	Direction towards which ice is drifting in degrees in a geographic convention referenced to true North and increasing clockwise from North.

2.3.3.2 Statistics Files

The statistics files contain various statistical indicators of ice velocity for nominal monthly intervals. The intervals alternate between 31-day and 30-day durations based on the calendar year. In a leap year, the last "month" of the year has 30 days; otherwise it has 29 days.

Table 5 describes the rows in the ice speed statistics files.

Table 5. Row Descriptions for Ice Speed Statistics Files

Row	Description
Section	3-character month and 2-digit year of the section being analyzed
Start rec	Start number of the record
End rec	End number of the record
Total rec	Total number of records available for statistical analysis
Flags	Number of flags present in the record

Row	Description
Time increment	The velocity sampling interval in minutes. Each value is a vector average over the interval. Times are referenced to the start of the averaging interval.
Total possible rec	Total number of possible records
Mean (from D_S)	The mean computed from all non-flagged data values.
StDev (from D_S)	The standard deviation computed from all non-flagged data values.
Mean from HIS	Mean from the histogram: The mean calculated as the sum of the products of the bin-center-value times the bin population. This calculation is included to allow direct comparison with the mean when moving.
Mean when Moving	The mean of all non-zero ice speeds. This variable is included because during winter ice can can be stationary approximately 50 percent of the time.
Percentage no-motion	Percentage of the record with ice speed of 0 cm/s
Percentage of possible	Percentage of the total possible records available for statistical analysis
Min	Minimum value
20th %ile	20th percentile
50th %ile	50th percentile (median)
80th %ile	80th percentile
Max	Maximum value
BIN(cm/s)	Binned ice speed data. The bins of the histogram are 2 cm/s in width. There are 50 bins with the smallest spanning (0, 2) cm/s and the largest (98, 100) cm/s.

2.4 File and Directory Structure

The data are available via HTTPS: https://noaadata.apps.nsidc.org/NOAA/G02177/ and are divided into two directories: Statistics and TimeSeries. These two directories are further subdivided and are described in Table 6 and Figure 2.

Table 6. File and Directory Structure

Directory	Description
Statistics	Contains the statistics files for this data set. This directory is further subdivided into two other directories: IceDraft and IceSpeed. These two directories contain the `ice draft` and `ice speed` statistics files, respectively.
TimeSeries	Contains the data and header files for this data set. This directory is further subdivided into two other directories: IceDraft and IceVelocity. These two directories contain the `ice draft` and `ice velocity` data files, respectively.

Figure 2 displays the HTTPS directory structure.

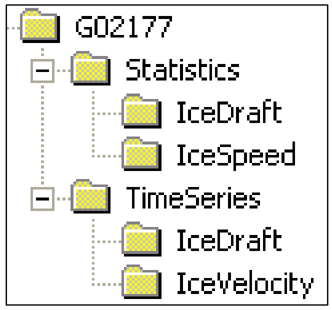

Figure 2. HTTPS Directory Structure

2.5 Sample Data Record

2.5.1 Ice Draft Data Files

The following is a sample data record of the ice draft data files. This sample shows the first six lines of Beaufort_site01_1992-04_draft.data. See Table 2 for a description of the columns.

```
846.87500 116.87480   1.62 1992
846.87781 116.87760   1.62 1992
846.88055 116.88040   1.61 1992
846.88330 116.88320   1.59 1992
846.88611 116.88600   1.61 1992
846.88892 116.88870   1.61 1992
```

2.5.2 Ice Velocity Data Files

The following is a sample data record of the ice velocity data files. This sample shows the first six lines of Beaufort_1990-03_drift.data from Site 01. See Table 4 for a description of the columns.

```
90.37150    0.2   314.1
90.39342    0.5   287.3
90.41534    0.8   280.1
90.43725    1.7   347.3
90.45917    1.7   305.3
90.48109    3.1   308.9
```

2.6 File Naming Convention

2.6.1 Ice Draft Data and Header Files

The ice draft data and header files are named according to the following convention and as described in Table 7:

```
Beaufort_siteXX_YYYY-MM_draft.FFFFF
```

Table 7. File Naming Convention for Ice Draft Data and Header Files

Variable	Description
Beaufort	Identifies this as data from the Beaufort Sea
XX	2-digit site number (01, 02, 03, 04, 05, 06, 07, 08, or 09) See Figure 1 for a map of the sites and Table 11 for specific latitude and longitude of the sites
YYYY	4-digit year that the record starts at the site
MM	2-digit starting month in the starting year
draft	Identifies this as containing ice draft data
FFFFF	File type (data: data file, header: header file)

2.6.2 Ice Velocity Data and Header files

The ice velocity data and header files are named according to the following convention and as described in Table 8:

```
Beaufort_siteXX_YYYY-MM_drift.FFFFF
```

Table 8. File Naming Convention for Ice Velocity Data and Header Files

Variable	Description
Beaufort	Identifies this as data from the Beaufort Sea
XX	2-digit site number (01, 02, 03, 04, 05, 06, 07, 08, or 09) See Figure 1 for a map of the sites and Table 11 for specific latitude and longitude of the sites
YYYY	4-digit year that the record starts at the site
MM	2-digit starting month in the starting year
drift	Identifies this as containing ice velocity/ice drift data
FFFFF	File type (data: data file, header: header file)

2.6.3 Statistics Files

The statistics files are named according to the following convention and as described in Table 9:

```
Beaufort_SiteXX_PTYPE_Stats.csv
```

Table 9. File Naming Convention for Statistics Files

Variable	Description
Beaufort	Identifies this as data from the Beaufort Sea

Variable	Description
XX	2-digit site number (01, 02, 03, 04, 05, 06, 07, 08, or 09)
PTYPE	Data parameter (drift or draft)
.csv	Identifies this as a comma delimited ASCII text file

2.7 File Size

Table 10 lists the size range of all files.

Table 10. File Size Range

File	Size Range
Ice draft data files	2.3 MB to 50 MB per file
Ice draft header files	3.0 KB to 8.1 KB per file
Ice velocity data files	69 KB to 1.6 MB per file
Ice velocity header files	9.1 KB - 16 KB per file
Statistics files (ice draft and ice velocity)	4.1 KB to 239 KB per file

3 SOFTWARE AND TOOLS

Users are advised to use any software that can read ASCII text.

4 DATA ACQUISITION AND PROCESSING

4.1 Sensor or Instrument Description

The Upward Looking Sonars (ULS) used to acquire this data were moored to the ocean floor. At each site, an Ice Profiling Sonar (IPS) was used to obtain ice draft data; and an Acoustic Doppler Current Profiler (ADCP) was used to obtain the ice velocity data. Exceptions are the use of a Water Structure Profiler (WASP) sonar instead of IPS for ice draft observation at Site 2 in 1991 and 1992, and the deployment of IPS without ADCP at Site 9 during 2001, where the primary emphasis was on the measurement of wind waves.

The newest model of the ice profiling sonar used for data acquisition was model 4 (IPS4), developed in 1995 and first used in 1996. Model 1 (IPS1) never delivered useful data. Models 2 (IPS2) and 3 (IPS3) differed only in terms of data storage and fail-safe features in firmware. IPS4 is a version completely re-engineered to reduce energy demand, sensitivity to other targets, and cost; and to increase reliability, operating flexibility, operating endurance, and data storage. The pendulums used to measure pitch and roll by IPS2 and IPS3 were replaced with solid-state sensors in IPS4; the operating frequency was increased from 200 kHz to 420 kHz and the data storage from 16 megabytes to 66 megabytes and ultimately to 132 megabytes. IPS4 can operate sequentially in up to eight unique configurations, activated on preset dates. This feature permits optimal use of the battery and data capacity as ice conditions change throughout the year. IPS4 also has a burst mode suited for brief high-resolution surveys or wave measurement. The WASP sonar, used at Site 2, is a self-contained echo sounder developed at Institute of Ocean Sciences (IOS) to record the amplitude of back-scatter from the water column.

Table 11 lists the mooring site history and Tables 12, 13, and 14 describe the instrument type, mooring type, and location type, respectively, used in Table 11. The gray type denotes failed deployments and underlining denotes a qualified success. Entries that are neither gray nor underlined indicate recovery of good data from that deployment.

Table 11. Mooring Site History

Site	Year	Deployment Name	Location	Latitude (deg min N)		Longitude (deg min W)		Instrument	Sonar (kHz)	Sample Interval (mm ss)		Mooring Type	Sonar Depth (m)	Water Depth (m)
1	1990	A179	ISC90-1A	70	18.300	133	36.620	NB-ADCP	614	31	34	2	50	56
1	1990	90IPS1-1	ISC90-1A	70	20.660	133	44.160	IPS1	200		15	0	54	56
1	1990	B179	ISC90-1B	70	20.830	133	43.960	NB-ADCP	614	30		2	50	56
1	1992	92IPS3-2A	ISC92-1	70	19.892	133	49.664	IPS3	200		10	1	49	54
1	1992	92IPS3-2B	ISC92-1	70	19.938	133	49.433	IPS3	200		10	1	48	53
1	1992	D318	ISC92-1	70	19.819	133	49.666	NB-ADCP	307	40		2	49	54
1	1993	93IPS3-2	ISC93-1	70	17.535	133	36.643	IPS3	200		10	1	50	55
1	1993	E318	ISC93-1	70	17.532	133	36.755	NB-ADCP	307	40		2	50	55
1	1994	94IPS3-1	ISC94-1	70	17.342	133	39.336	IPS3	200		10	1	49	54
1	1994	F464	ISC94-1	70	17.377	133	39.396	NB-ADCP	307	30		2	49	54
1	1995	95IPS3-1	ISC95-1	70	25.718	133	47.728	IPS3	200		10	1	55	60
1	1995	G506	ISC95-1	70	25.731	133	47.681	NB-ADCP	307	30		2	55	60
1	1996	96IPS3-1	ITT96-1	70	20.158	133	42.328	IPS3	200		6	1	52	57
1	1996	H318	ITT96-1	70	20.172	133	42.344	NB-ADCP	307	15		2	52	57
1	1997	97IPS3-2	ITT97-1	70	19.968	133	41.474	IPS3	200		5	1	49	54
1	1997	I318	ITT97-1	70	20.025	133	41.819	NB-ADCP	307	15		2	48	53
1	1998	98IPS4-0	ITT98-1	70	20.093	133	45.260	IPS4	420		2,5	1	50	55
1	1998	J586	ITT98-1	70	20.051	133	45.078	NB-ADCP	307	30		2	50	55
1	1999	99IPS3-3	ITT99-1	70	20.080	133	44.830	IPS3	200		4	1	50	55
1	1999	K318	ITT99-1	70	20.067	133	44.896	NB-ADCP	307	15		2	51	56
1	2000	00IPS3-1	ITC00-1	70	20.076	133	44.841	IPS3	200		4	1	50	55
1	2000	L464	ITC00-1	70	20.075	133	44.908	NB-ADCP	307	15		2	50	55

Site	Year	Deployment Name	Location	Latitude (deg min N)		Longitude (deg min W)		Instrument	Sonar (kHz)	Sample Interval (mm ss)		Mooring Type	Sonar Depth (m)	Water Depth (m)
1	2001	01IPS4-0	ITC01-1	70	19.977	133	44.471	IPS4	420		3,1	1	50	55
1	2001	M464	ITC01-1	70	19.896	133	44.232	NB-ADCP	307	30		2	50	55
1	2002	02IPS4-0	ITC02-1	70	19.977	133	44.470	IPS3	200		3,1	1	50	55
1	2002	N464	ITC02-1	70	19.972	133	44.410	NB-ADCP	307	30		2	50	55
1	2003	03IPS4-1	ITC03-1	70	19.937	133	44.274	IPS4	420		3,1	1	52	57
1	2003	O506	ITC03-1	70	19.973	133	44.463	NB-ADCP	307	30		2	51	56
2	1990	90IPS2-1A	ISC90-2A	70	48.620	133	43.410	IPS2	200		15	1	74	79
2	1990	A318	ISC90-2A	70	48.660	133	43.250	NB-ADCP	307	30	25	2	70	76
2	1990	90IPS2-1	ISC90-2B	70	58.090	133	41.500	IPS2	200		15	1	77	82
2	1990	B318	ISC90-2B	70	58.120	133	41.090	NB-ADCP	307	30		2	76	82
2	1991	91IPS1-1	ISC91-2	70	52.779	133	44.976	IPS1	200		10	0	78	80
2	1991	91WASP-1	ISC91-2	70	53.269	133	43.842	WASP	200	1	30	1	75	80
2	1991	C318	ISC91-2	70	53.178	133	43.939	NB-ADCP	307	45		2	75	81
2	1992	92IPS3-1A	ISC92-2	70	57.211	133	44.076	IPS3	200		10	1	77	82
2	1992	92IPS3-1B	ISC92-2	70	57.267	133	43.848	IPS3	200		10	1	78	83
2	1992	D506	ISC92-2	70	57.134	133	43.812	NB-ADCP	307	30		2	77	82
2	1993	93IPS3-1	ISC93-2	70	56.849	133	42.823	IPS3	200		10	1	73	78
2	1993	E506	ISC93-2	70	56.774	133	42.677	NB-ADCP	307	30		2	73	78
2	1994	94IPS3-2	ISC94-2	70	57.628	133	42.697	IPS3	200		10	1	74	79
2	1994	F506	ISC94-2	70	57.681	133	42.629	NB-ADCP	307	30		2	74	79
2	1995	95IPS3-2	ISC95-2	70	56.088	133	43.873	IPS3	200		10	1	72	77
2	1995	G318	ISC95-2	70	56.052	133	44.017	NB-ADCP	307	30		2	72	77
2	1996	96IPS3-2	ITT96-2	70	56.536	133	41.695	IPS3	200		6	1	74	79
2	1996	H464	ITT96-2	70	56.519	133	41.578	NB-ADCP	307	30		2	74	79
2	1997	97IPS4-0	ITT97-2	70	56.563	133	41.567	IPS4	420		3	1	74	79
2	1997	I464	ITT97-2	70	56.615	133	41.679	NB-ADCP	307	20		2	74	79
2	1998	98IPS3-2	ITT98-2	70	56.369	133	41.134	IPS3	200		5	1	75	80
2	1998	J464	ITT98-2	70	56.381	133	41.116	NB-ADCP	307	30		2	75	80
2	1999	99IPS4-1	ITT99-2	70	56.370	133	41.090	IPS4	420		2,4,3,6	1	75	80
2	1999	K506	ITT99-2	70	56.380	133	41.070	NB-ADCP	307	40		2	75	80
2	2001	01IPS4-1	ITC01-2	70	59.310	133	45.042	IPS4	420		10, 6	3	48	116
2	2001	M506	ITC01-2	70	59.310	133	45.042	NB-ADCP	307	40		3	111	116

Site	Year	Deployment Name	Location	Latitude (deg min N)		Longitude (deg min W)		Instrument	Sonar (kHz)	Sample Interval (mm ss)		Mooring Type	Sonar Depth (m)	Water Depth (m)
2	2003	03IPS4-0	ITC03-2	71	02.251	133	24.180	IPS4	420		4,5	3	45	113
2	2003	O586	ITC03-2	71	02.251	133	24.180	NB-ADCP	307	40		3	108	113
3	1991	91IPS3-1	ISC91-3	70	32.076	131	30.368	IPS3	200		10	1	47	52
3	1991	C506	ISC91-3	70	32.138	131	30.167	NB-ADCP	307	30		2	46	52
4	1991	91IPS3-1		71	14.276	130	59.686	IPS2	200		10	1	72	77
4	1991	C464	ISC91-4	71	14.392	130	59.629	NB-ADCP	307	30		2	71	77
4	1992	92IPS3-3A	ISC92-4	71	26.986	130	13.298	IPS3	200		10	1	82	87
4	1992	92IPS3-3B	ISC92-4	71	26.847	130	13.115	IPS3	200		10	1	79	84
4	1992	D464	ISC92-4	71	26.991	130	12.937	NB-ADCP	307	30		2	82	87
4	1993	93IPS3-3	ISC93-4	71	27.888	130	15.779	IPS3	200		10	1	75	80
4	1993	E464	ISC93-4	71	27.845	130	16.065	NB-ADCP	307	30		2	75	80
4	1994	94IPS3-3	ISC94-4	71	26.811	130	16.828	IPS3	200		10	1	75	80
4	1994	F586	ISC94-4	71	26.728	130	16.833	NB-ADCP	307	30		2	75	80
4	1995	95IPS3-3	ISC95-4	71	24.667	130	14.921	IPS3	200		10	1	56	61
4	1995	G586	ISC95-4	71	24.738	130	14.867	NB-ADCP	307	30		2	78	83
5	1996	96IPS3-3	ITT96-5	73	27.133	126	36.051	IPS3	200		10	3	45	108
5	1996	H586	ITT96-5	73	27.133	126	36.051	NB-ADCP	307	30		3	103	108
6	1997	97IPS4-1	ITT97-6	74	09.096	125	54.373	IPS4	420		5	3	48	85
6	1997	I506	ITT97-6	74	09.096	125	54.373	NB-ADCP	307	45		3	80	85
7	1998	98IPS3-1	ITT98-7	73	29.561	125	34.635	IPS3	200		10	1	49	54
7	1998	J318	ITT98-7	73	29.560	125	34.826	NB-ADCP	307	30		2	49	54
8	1998	98IPS4-1	ITT98-8	72	34.955	127	19.274	IPS4	420		10,5	3	45	105
8	1998	J506	ITT98-8	72	34.955	127	19.274	NB-ADCP	307	30		3	100	105
8	1999	99IPS4-0	ITT99-8	72	34.689	127	18.403	IPS4	420		8,3,6	3		
8	1999	K586	ITT99-8	72	34.689	127	18.403	NB-ADCP	307	40		3	96	101
8	2001	01IPS3-2	ITC01-8	72	34.745	127	26.246	IPS3	200		5	3	50	110
8	2001	M318	ITC01-8	72	34.745	127	26.246	NB-ADCP	307	30		3	105	110
8	2003	03IPS4-33	ITC03-8	72	34.680	127	27.174	IPS4	420		2,4	3	48	113
8	2003	O318	ITC03-8	72	34.680	127	27.174	NB-ADCP	307	40		3	108	113
9	2001	01IPS4-2	BMH01-9	70	04.976	133	29.884	IPS3	200		3,1	1	31	35
9	2002	02IPS4-2	BMH02-9	70	04.980	133	29.983	IPS4	895		3,1	1	31	35
10	2003	03IPS4-2	BMH03-10	70	53.761	129	45.721	IPS4	895		4,3	1	30	33

Table 12 describes the types of sonars used.

Table 12. Sonar Type Descriptions

Sonar Type	Description
IPS1	IPS Model 1
IPS2	IPS Model 2
IPS3	IPS Model 3
IPS4	IPS Model 4
NB-ADCP	Narrow-band ADCP
WASP	Self-contained echo sounder

Table 13 lists the mooring type codes used in Table 11.

Table 13. Mooring Type Codes

Mooring Code	Description
0	Unconventional mooring
1	Stand-alone mooring for IPS
2	Stand-alone mooring for ADCP
3	Mooring supporting both IPS and ADCP

Location type names in Table 11 have the following convention and are described in Table 14.

PPPYY-X[X]

Table 14. Location Type Codes

Variable	Description
PPP	Project Acronym (over time this project has had different names) ISC: Ice Subsurface Characterization project ITT: Ice Type and Thickness project ITC: Ice Thickness and Climate project BMH: Beaufort Marine Hazards project
YY	2-digit year of when sonar was deployed
X[X]	Site number: 1 - 10 (Note: some sites have an A and B location)

4.1.1 Mooring Types

A Type 1 mooring is a taut-line configuration that is as short as practical to minimize the hazard from drifting ice in shallow water (less than 40 m depth). See Figure 3. Five plastic floats (Viny 12B3) support the in-water weights of the instrument and the acoustic transponding releases (4 floats are sufficient for the smaller 420 kHz IPS). Viny floats provide an excellent buoyancy-to-drag ratio; the drag of this float is only six percent of the buoyancy with a 0.5 m/s current. With this design, the IPS maintains a zenithal orientation within ±2° and moves vertically by less than two centimeters in such a current. The instrument is contained within a 316 stainless steel frame, which provides attachment points for other devices and grappling points for under-ice recoveries. Some frames were fitted with a low-frequency radio beacon (Pieps 457) and a pinger, both of which only switch on following release in response to lower ambient pressure. The deactivation of these beacons at working depth prevents interference with the sonar and conserves battery power over long deployments. The mooring is equipped with two transponding releases, connected in parallel for redundancy. The anchor weight is built from clumped chain, permitting the weight used to be no more than necessary. The mooring is assembled on the ice or the deck of a ship and deployed anchor first by free-fall to the seabed.

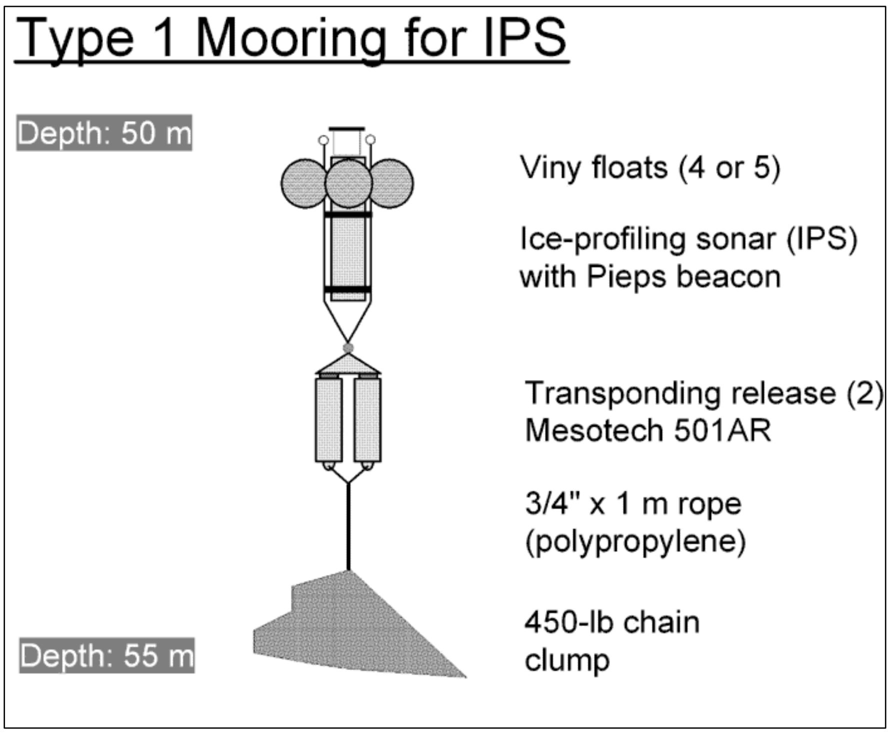

Figure 3. Type 1 Mooring

A Type 2 mooring is very similar to a Type 1 mooring. See Figure 4. Four plastic floats are sufficient, since the zenith-pointing constraints on the ADCP are much less severe than those for the IPS (±5° in 0.5 m/s current). The principal differences are a vane on the instrument frame and a swivel beneath it. By aligning with the flow, the vane reduces azimuthal oscillations of the instrument that are associated with vortex shedding. Azimuthal stability simplifies the correction of the time-averaged ADCP headings for compass non-linearity, since the necessary correction is well defined. This is not so if the ADCP rotates appreciably over the averaging interval. When Type 1 and Type 2 moorings were used at a site, they were placed no closer than the depth of water (50 to 80 m) to avoid acoustic cross-talk. In order for the two instruments to view the same ice as closely as is practical, the separation of the moorings has rarely exceeded 250 m.

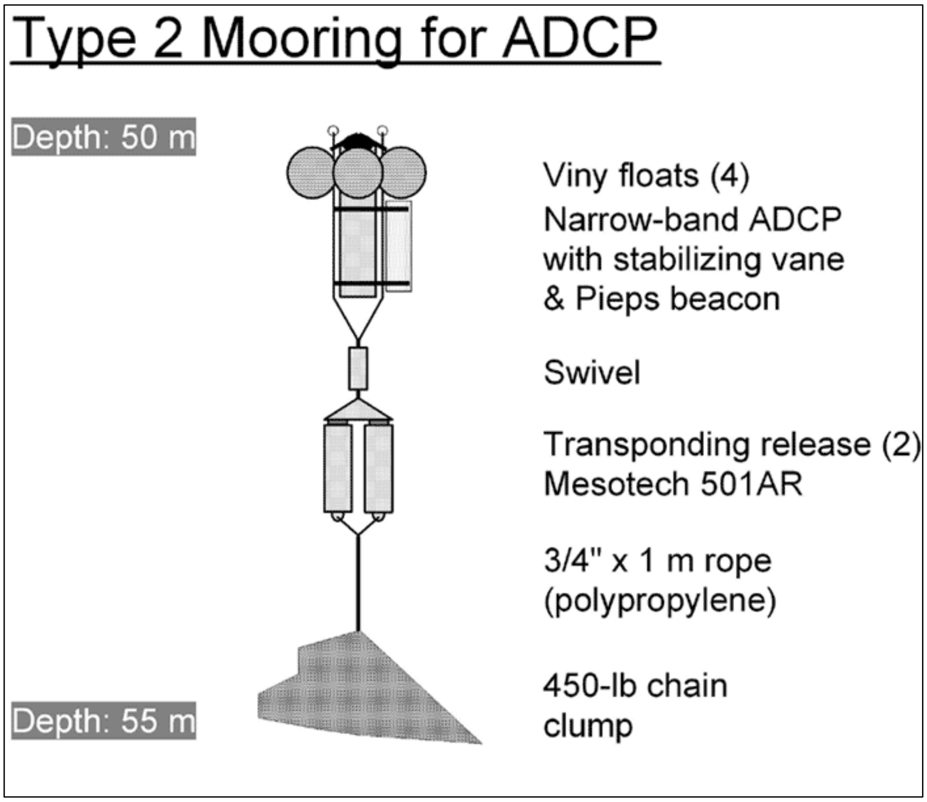

Figure 4. Type 2 Mooring

A Type 3 mooring is essentially a Type 1 mooring connected above a Type 2 mooring by approximately 50 m of line. See Figure 5. Since the IPS interferes with the ADCP operation if too close (less than 30 m), this mooring can be used in water deeper than 80 m. More flotation is needed if the depth of water exceeds 120 m. The IPS, which produces the best data if close to the ice, is best positioned deeper than 40 m to avoid impact with drifting ridge keels. A heavier anchor is required for the Type 3 mooring and deployment and recovery operations can be more complicated. The vertical stability of the IPS, which is important for the accurate calibration of ice draft, is degraded because the IPS may occasionally be pulled down as much as a meter by the stronger currents in this area. Vertical displacement of the sonar should be tracked by measuring pressure at more frequent intervals when using a Type 3 mooring, perhaps every two minutes or less.

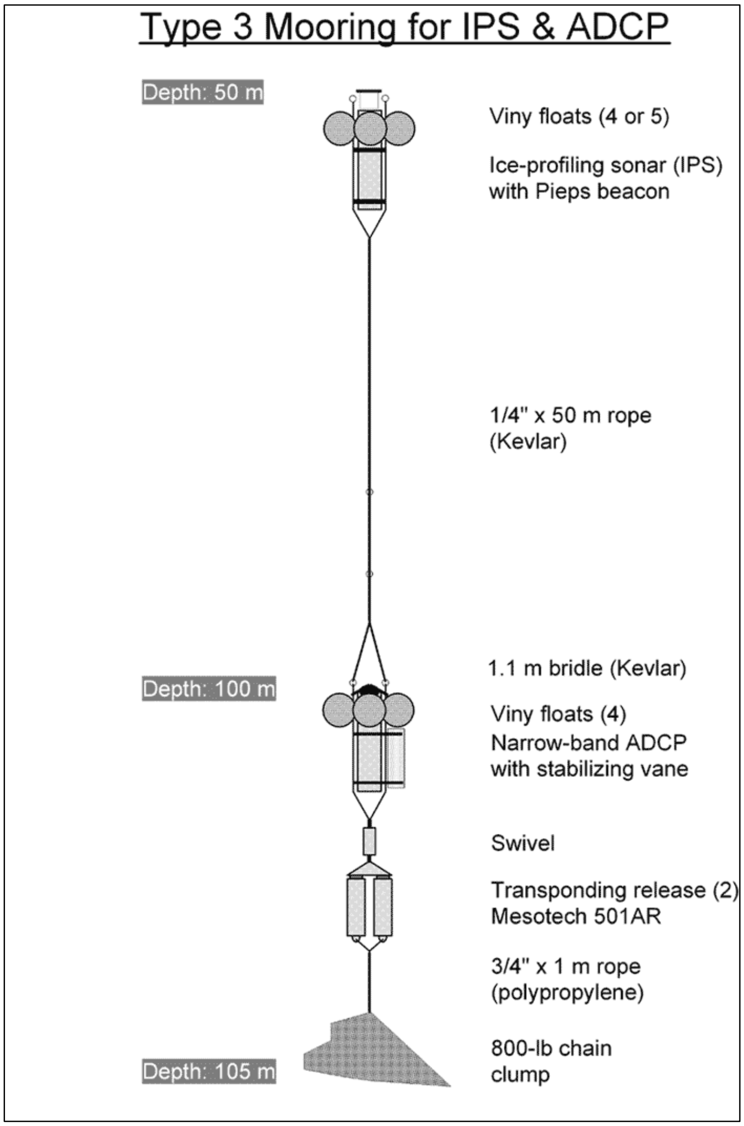

Figure 5. Type 3 Mooring

4.2 Data Processing

For a complete description of the processing steps used to obtain this data, please see Draft and Movement of Pack Ice in the Beaufort Sea: A Time-Series Presentation April 1990 - August 1999 (H. Melling and D.A. Riedel 2004). Download this document without graphics: draft_movement_beaufort_2004.pdf (PDF, 1.6 MB). Download this document in zip format with graphics: draft_movement_beaufort_2004.zip (zip file, 4.7 MB).

4.2.1 Ice Draft Data

A brief summary of the processing steps required to obtain ice draft data from an IPS follows:

1. Establish the relationships between travel time and range and between pressure and depth using observations made during sonar deployment and retrieval. These calculations establish the exact depth of the IPS, information that is essential to the calibration of ice draft.
2. Determine the drift in calibration of the pressure sensor caused by creep during deployment. Derive a time-dependent calibration for pressure values recorded by the IPS.
3. Determine the range correction factor, β(t), which is the ratio of the true target range to that calculated using the assumed depth-averaged sound speed. Preliminary values of range are calculated using an assumed average sound speed for the upper ocean (typically 1437 m/s).
4. Verify that the temporal variation of the range correction factor is consistent with plausible seasonal changes in the temperature and salinity of waters between the sonar and the surface.
5. Examine each target carefully as a potential ice-free surface suitable for use as a reference for zero draft.
6. If the preliminary draft of a verified ice-free target is not zero, adjust β(t) at the time of observation to obtain a zero value. Reiterate the preceding two steps until results are consistent with the ±0.05 m target for accuracy. Since calibration points for β(t) are highly asynchronous, a reasonable interpolation between values must be achieved.
7. Determine which portions of each record were obtained during prolonged ice-free conditions. Remove the ice-free (less than one tenth ice concentration) periods from the data files to facilitate further processing.
8. Edit the ice draft record using automated methods and then manual review.

Challenges in Processing Ice Draft Data from IPS

1. Identifying ice-free waters
2. Loss of echoes
3. Spurious echoes
4. Wind waves in leads

4.2.2 Ice Velocity Data

A brief summary of the processing steps required to obtain ice velocity data from an ADCP follows:

1. Edit the ice motion records obtained by the ADCP using automated methods and then manual review.
2. Where justifiable, repair gaps in the ice motion record using the best available estimates of ice drift from other sources.
3. Set the ice velocity identically equal to zero during intervals when the ice is stationary.
4. Calibrate the time series of ice drift. The narrow band ADCP stores values that are calculated with an assumed sound speed of 1536 m/s, whereas the value relevant to ice drift speed, that at the ice water interface, is about 1437 m/s (water at 2 db pressure, 32 salinity and -1.5° C). The conversion factor is 0.935.
5. Integrate ice velocity to a Eulerian displacement in UTM coordinates.

Challenges in Processing Ice Velocity Data from the ADCP

1. Signal degradation in ice free waters
2. Signal degradation under stationary smooth ice

4.3 Error Sources

For a complete description of the possible error sources, please see Draft and Movement of Pack Ice in the Beaufort Sea: A Time-Series Presentation April 1990 - August 1999 (H. Melling and D.A. Riedel 2004). Download this document without graphics: draft_movement_beaufort_2004.pdf (PDF, 1.6 MB). Download this document in zip format with graphics: draft_movement_beaufort_2004.zip (zip file, 4.7 MB).

4.3.1 Ice Draft Data

The following are a list of possible sources of error when collecting ice draft data:

- Relationship between pressure and depth:
  As density varies with time, the relationship between pressure and depth changes. Fortunately, the apparent depth change caused by the increase in density between summer and winter is negligible in this application where the IPS is at less than 100-m depth in Arctic waters (Melling and Riedel 1993).
- Impact of seasonal change in the sound-speed profile:
  The impact of seasonal change in the sound-speed profile on the apparent range to the surface is not negligible. Melling and Riedel (1993) demonstrate that changing sound speed introduces an error of at least 0.2 m between winter and summer. Temperature and salinity profiles by Conductivity, Temperature, and Depth (CTD) are rarely available other than at deployment and recovery. The only feasible method to adjust ranges for secular change in sound speed is to use corrections derived from the apparent draft of open-water areas which pass through the sonar beam. These occasional tie points constrain the selection of a plausible curve that can be used to correct ranges at all times between deployment and recovery. Tie points must be selected with great care, since mistakes in selection introduce systematic errors (under estimates) in ice draft.
- Sound speed varies with depth:
  Because sound speed varies with depth, an exact range correction will vary with the draft, or range, of the target as well as on the time of year. Thus, accuracy is best for thin-ice targets near the surface and deteriorates with increasing draft. In winter in the Beaufort Sea when open areas freeze very quickly, tie points for range correction are scarce. However, the temperature and salinity of water beneath continuous ice change only slowly from week to week. In summer, ice-free targets are viewed many times each day, but the temperature and salinity of the upper ocean are much more variable. River inflow, ice melt water, and solar heating are contributing factors. Our estimate for accuracy in the draft of level ice from moored sonar in this program is ±0.05 m.
- Rough ice:
  Under rough ice, the first contact of the transmitted sound pulse with the ice may not be exactly overhead, because the sonar beam has finite angular width. Thus the local draft of

ice will be overestimated on average in rough ice. The magnitude of the overestimate cannot be generally specified, since it depends not only on the beam pattern of the sonar, but on its source level and sensitivity and on the geometry, scattering cross-section and range of the ice. By reducing the field of view of the IPS to 0.8 m from a depth of 50 m (Melling 1998b), this systematic error has been reduced to a practical minimum.

4.3.2 Ice Velocity Data

The following are a list of possible sources of error in collecting ice velocity data.

- Sampling error in the estimation of mean Doppler shift:
  The sampling error is random and a function of the acoustic frequency and pulse length used by the ADCP, the signal-to-noise ratio, and the number of pings averaged. For the ADCP configuration of these deployments, the sampling error was 0.7 cm/s in each component of velocity at good signal-to-noise ratio. When an ADCP is tracking floes which have a very smooth under surface, much of the transmitted pulse, incident at 30°, is reflected onward at 30°. A weak backscattered signal may be buried in noise at the receiver. At poor signal-to-noise ratio, the sampling error, estimated from the root-mean-square value of the vertical velocity component, increases to several cm per second. Poor precision in Doppler velocity is only problematic when a weak target is stationary over the IPS.
- Uncertainty in the sound speed used to convert Doppler shift to velocity:
  The conversion of velocity components from a beam-referenced coordinate system to an Earth-referenced system is based on measurements of tilt and heading by the ADCP. The accuracy of the tilt measurement is not critical, since a (large) error of 5° in tilt generates an error of only 3% in a velocity component. Errors in the compass measurement of heading, however, translate directly into errors in the direction of ice drift. The non-linearity in the ADCP compass response can be quite large (±15°) in the Beaufort Sea because the horizontal component of the geomagnetic field is only 7000 nT. Corrections must be made.
- Uncertainty in ADCP heading, pitch, and roll:
  Compasses were calibrated in a non-magnetic enclosure located near the Polar Continental Shelf Project (PCSP) base at Tuktoyaktuk. The output of the compass was measured at 11.25° increments in heading and corrections for the observed non-linearity were entered into a look-up table in the Erasable Programmable Read-Only Memory (EPROM) within the ADCP. The ADCP rotation was repeated to determine the residual non-linearity. For the compass manufactured by KVH Industries, the systematic sinusoidal component residual was about ±2° and the random component about the same magnitude. For the compass manufactured by EG&G (s/n 0179), the residual was much larger. Compass rotations were repeated at greatly different temperature and after intervals of 3-5 years, but no significant differences dependent on temperature or elapsed time were noted.
  Corrections for systematic residual non-linearity in heading are applied during data processing, leaving a random error of ±2°. To permit assignment of a unique value of heading correction for each ensemble (which represents data gathered over 15-45 minutes of pinging), each ADCP mooring was equipped with a vane and a swivel. The action of current on the vane stabilizes the heading of the ADCP during acquisition of an ensemble.

4.4 Quality Assessment

The quality of the data has been established in two ways:

1. A meticulous attention to detail in calibration and processing
2. Published literature and the scientific use of data which has not turned up any obvious inconsistencies or enigmas and has generated new understanding of pack ice and Arctic change.

There are few independent means of assessing the accuracy of the ice-draft values in this set. Thickness measured via drill holes through the dominant first-year ice mode in late winter has been used as an occasional check on ice draft. The ice velocity data are occasionally compared with Lagrangian data provided by satellite-tracked ice-drift buoys that pass nearby. Generally, however, data quality is established by very onerous procedures in which the detection and identification of patches of truly ice-free water is critical. Such may be found only at intervals of several weeks during November through April. Strenuous precautions are taken to avoid misidentification of thin ice as open water, since this introduces bias that can seriously compromise the value of these data for climate study. Inter-comparison data indicate that the ±5 cm target accuracy for level ice is generally attained. Draft accuracy for rough ice of deeper draft is likely less good and quite variable; it may increase to ±30 cm at times.

5 REFERENCES AND RELATED PUBLICATIONS

Amundrud, T., H. Melling and R.G. Ingram. 2004. Geometric constraints on the evolution of ridged sea ice. Journal of Geophysical Research 109, C06005, doi:10.1029/2003JC002251

Amundrud, T.L., H. Melling, R.G. Ingram and S.E. Allen. 2006. The effect of structural porosity on the melting of ridge keels in pack ice. Journal of Geophysical Research 111, C06004, doi:10.1029/2005JC002895.

Birch, J.R., D.B. Fissel, H. Melling, K. Vaudrey, K. Schaudt, J.C. Heideman and W. Lamb. 2000. Ice Profiling Sonar: Upward looking sonar provides over-winter records of ice thickness and ice keel depths off Sakhalin Island, Russia. Sea Technology (August), 48-53.

Blasco, S.M., J.M. Shearer, P. Campbell, B. Wright and H. Melling. 2004. Reduction in sea ice scour impact rates on the seabed 1979 to 2003, Canadian Beaufort Sea. Eos Transactions 85(17), C43A-10.

Bowen, R.G. and D.R. Topham. 1996. A study of the morphology of a discontinuous section of first year Arctic pressure ridge Cold Regions Science and Technology 24, 83-100.

Dumas, J., E.C. Carmack and H. Melling. 2005. Climate-change impacts in the Beaufort shelf land-fast ice. Cold Regions Science and Technology 42, 41– 51.

Dumas, J.A., H. Melling and G.M. Flato. 2007. Late-summer pack ice in the Canadian Archipelago: Thickness observations from a ship in transit Atmosphere-Ocean 45, 1 450105.

Eicken, H., R. Gradinger, A. Graves, A. Mahoney, I. Rigor and H. Melling. 2005. Sediment transport by sea ice in the Chukchi and Beaufort Seas: Increasing importance due to changing ice conditions? Deep-Sea Research II 52, 3281–3302. doi:10.1016/j.dsr2.2005.10.006.

Falkingham, J., H. Melling and K.J. Wilson. 2003. Shipping in the Canadian Arctic: possible climate change scenarios. CMOS Bulletin SCMO 31(3), 68-69.

Fissel, D.B., J.R. Marko and H. Melling. 2002. Identifying "skylites" for AUV operations under pack ice: Insights from ice-draft profiling by moored sonar. Proceedings Oceans 2002, Biloxi, Mississippi. October 29-31, 2002. 6 pp.

Fukamachi, Y., G. Mizuta, K.I. Oshima, H. Melling, D. Fissel and M. Wakatsuchi. 2003. Variability of sea-ice draft of Hokkaido in the Sea of Okhotsk revealed by a moored ice-profiling sonar in winter of 1999. Geophysical Research Letters. Geophysical Research Letters 30(7), 2002GL016197.

Galloway, J.L. and H. Melling. 1997. Tracking the motion of sea ice by correlation sonar. Journal of Atmospheric and Oceanic Technology, 14(3), 616-629.

Holt, B., C. Haas, H. Melling, S. Hendricks. 2007. Determining deformed sea ice properties using multi-sensor observations. Eos Trans. AGU 88(52), Fall Meet. Suppl., C11B-0431

Kovacs, A., Weeks, W.F., Ackley, S. and Hibler, W.D. III. 1973. Structure of a multiyear pressure ridge. Arctic 26(1): 22-31.

Maykut, G.A. and Untersteiner, N. 1971. Some Results from a Time-Dependent Thermodynamic Model of Sea Ice. Journal of Geophysical Research 76: 1550-1575.

Melling, H. 1998a. Detection of features in first-year pack ice by synthetic aperture radar (SAR). International Journal of Remote Sensing, 19(6), 1223-1249

Melling, H. 1998b. Sound scattering by sea ice: Aspects relevant to ice-draft profiling by sonar. Journal of Atmospheric and Oceanic Technology, 15, 1023-1033.

Melling, H. 2000. Scientific interpretation of measurements of sea-ice draft measurements by moored sonar. Joint Report on the 4th Session of the ACSYS Sea Ice/Ocean Modeling (SIOM) Panel and the ACSYS Workshop on Sea-Ice Thickness Measurements and Data Analysis, Monterey CA USA, 7-11 April 1997, P.

Lemke & R. Colony (editors). WMO/TD No. 991, World Meteorological Organization, Geneva. A5.10, 5 pp.

Melling, H. 2000. Sound scattering by sea ice: Aspects relevant to ice-draft profiling by sonar. Joint Report on the 4th Session of the ACSYS Sea Ice/Ocean Modeling (SIOM) Panel and the ACSYS

Workshop on Sea-Ice Thickness Measurements and Data Analysis, Monterey CA USA, 7-11 April 1997, P. Lemke & R. Colony (editors). WMO/TD No. 991, World Meteorological Organization, Geneva. A5.11, 2 pp.

Melling, H. 2000. Statistical processing of ice-draft observations from moored sonar. Joint Report on the 4th Session of the ACSYS Sea Ice/Ocean Modeling (SIOM) Panel and the ACSYS Workshop on Sea-Ice Thickness Measurements and Data Analysis, Monterey CA USA, 7-11 April 1997, P. Lemke & R. Colony (editors). WMO/TD No. 991, World Meteorological Organization, Geneva. A5.12, 3 pp.

Melling, H. 2002. Sea ice of the northern Canadian Arctic Archipelago. Journal of Geophysical Research, 107(C11), 3181

Melling, H. 2007. The Thickness of Arctic Pack Ice - Advances and Challenges. In, Arctic Climate Change - The ACSYS Decade and Beyond. Chapter in monograph. Accepted.

Melling, H. and D.A. Riedel. 1995. The underside topography of sea ice over the continental shelf of the Beaufort Sea in the winter of 1990. Journal of Geophysical Research 100(C7), 13641-13653.

Melling, H. and D.A. Riedel. 1996. Development of seasonal pack ice in the Beaufort Sea during the winter of 1991-1992: A view from below. Journal of Geophysical Research 101(C5), 11975-11991.

Melling, H. and D.A. Riedel. 1996. The thickness and ridging of pack ice causing difficult shipping conditions in the Beaufort Sea, Summer 1991. Atmosphere-Ocean 34(3), 457-487.

Melling, H. and D.A. Riedel. 2004. Draft and Movement of Pack Ice in the Beaufort Sea: A Time-Series Presentation April 1990 - August 1999. Canadian Technical Report of Hydrography and Ocean Sciences No. 238. (PDF 1.6 MB).

Melling, H., D.A. Riedel and Z. Gedalof. 2005. Trends in the draft and extent of seasonal pack ice, Canadian Beaufort Sea. Geophysical Research Letters 32, L24501, doi:10.1029/2005GL024483.

Melling, H., D.R. Topham and D.A. Riedel. 1993. Topography of the upper and lower surfaces of 10 hectares of deformed sea ice. Cold Regions Science and Technology, 21, 349-369.

Melling, H., P.H. Johnston and D.A. Riedel. 1995. Measurement of the draft and underside topography of sea ice by moored subsea sonar. Journal of Atmospheric and Oceanic Technology 12(3), 591-602.

Melling, H. and Riedel, D.A. 1993. Draft and Movement of Pack Ice in the Beaufort Sea, April 1990 - March 1991. Canadian Technical Report of Hydrography and Ocean Sciences No. 151.

Mullison, J. H. Melling, W. Johns and P. Freitag. 2004. The role of moored current profilers in climate variability research. Sea Technology 45(2), 17-28.

Richter-Menge, J., et al. 2006. State of the Arctic Report. NOAA OAR Special Report, NOAA/OAR/PMEL, Seattle WA. 36 pp.

5.1 Related NSIDC Data Collections

AWI Moored ULS Data, Weddell Sea (1990-1998)
AWI Moored ULS Data, Greenland Sea and Fram Strait, 1991-2002
Moored Upward Looking Sonar Data
Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics
The Environmental Working Group (EWG) Joint U.S.-Russian Arctic Sea Ice Atlas

5.2 Other Related Data Collections

Mooring data from the Beaufort Gyre Exploration Project

6 CONTACTS AND ACKNOWLEDGMENTS

H. Melling and D. A. Riedel
Science Branch - Pacific Region
Institute of Ocean Sciences
P.O. Box 6000, Sidney, BC
Canada V8L 4B2

Acknowledgments:

Distribution of the data set from NSIDC is supported by funding from NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) and the National Geophysical Data Center (NGDC).

7 DOCUMENT INFORMATION

7.1 Document Authors

A. Windnagel and L. Ballagh compiled and created this document from correspondence with H. Melling and F. Fetterer and from *Draft and Movement of Pack Ice in the Beaufort Sea: A Time-Series Presentation April 1990 - August 1999* (H. Melling and D.A. Riedel 2004). Download the Melling and Riedel 2004 document without graphics: draft_movement_beaufort_2004.pdf (PDF, 1.6 MB) or download it in zip format with graphics: draft_movement_beaufort_2004.zip (zip file, 4.7 MB).

7.2 Publication Date

September 2008

7.3 Date Last Updated

December 2020