WORLD CLIMATE RESEARCH PROGRAMME

Arctic Climate System Study (ACSYS)
and
Climate and Cryosphere (CliC) Project

Workshop on Sea-Ice Thickness Measurements from Moored Ice-Profiling Sonars: Calibration, Data Processing and Application

(Tromsø, Norway, 1-3 July 2002)

October 2004

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Table of contents

SUMMARY

Arctic and Antarctic sea ice properties are rather different, in particular the ice thickness distribution. This is an important fact for upward looking sonar (ULS; also called Ice Profiling Sonar – IPS) ice thickness measurements in these regions, i.e., 10%-thickness accuracy for the Arctic ice cover is ~ 0.3 m which can be achieved with moored ULS. The same accuracy cannot be achieved in the Southern Ocean, or the marginal seas in the Arctic. Iceberg occurrence and frequency are much larger in the Antarctic compared to the Arctic; hence the ULS are commonly mounted at 200 m depth in the southern Ocean, whereas in the Arctic they are mounted at 50 m depth. Snow cover on sea ice (depth and distribution) is poorly known in polar regions but a curial element in the derivation of ice thickness from ULS moorings because of the snow load affecting the free-board.

Moored ULS measure sea ice thickness (or more correctly, sea ice draft) as the difference between the sonar range to the underside of pack ice and the pressure depth of the instrument. ULS are widely acknowledged within fora such as GOOS, WCRP-CliC, etc. as the best method of in-situ measurement of pack ice draft. They are considered essential for the calibration of other ice thickness measurement techniques, for determination of sea ice flux and mass budget, and for monitoring seasonal variability and perhaps longer-term changes in sea ice. Numerous ULS have been deployed in the Arctic over more than a decade. Considerably fewer instruments have been used in the Antarctic, and only Germany and Australia have had successful southern deployments. But despite this history there is considerable uncertainty on the best way to interpret the ULS measurements and on what variables should be archived in a standard ULS data format. Because of these uncertainties, and although the data are urgently sought by the wider sea ice community, few ULS data have been lodged with international data archives. The Tromso workshop was convened to address these problems.

- The workshop structure had sessions on:
- Scientific issues and past activities
- Instruments and moorings
- Data processing and calibration
- Archiving ULS data
- Interpretation of Eulerian ice drift data with spatial surveys, and
- Future directions.

The ULS instruments are typically moored at a depth of 50-200 m below the ocean surface and changes in the density and speed of sound in the water column above the instrument are unknown. In order to achieve the required ice draft accuracy of 5-cm or better, in-situ calibration of the instrument is essential. At present this can only be done by detection and identification of open water above the instrument (zero ice draft). There are 4 different ULS instruments in common use: ASL Environmental Sciences (ASL, Canada); Christen Michelsen Research AS (CMR, Norway); Applied Physics Laboratory, University of Washington (APL, USA); and Centre for Marine Science and Technology, Curtin University (CMST, Australia). These use different sonar frequencies, have different sampling regimes, record different auxiliary parameters, and use a variety of methods for discriminating open water for calibration. The analysis of the data from each type of instrument is also quite different. The ASL instrument has the highest sampling rate and is the closest to an "industry norm" (it is also the lightest and cheapest) whereas the CMST instrument has the most sophisticated measurement technique and the most advance method of semi automatic open water detection. The CMST instrument is able to achieve >85% open water discrimination based purely on characteristics of the echo (primarily measurement of the acoustic reflection coefficient of the surface). In contrast, the normal technique with other instruments is to eliminate all extreme negative drafts and then simply to set the remaining lowest draft values as open water (sometimes using ancillary data for validation). This is both very time consuming for processing and also introduces a positive bias in the ice draft results.

Other sources of significant error that were also discussed included the overestimation of ice drafts because of the finite beam width of the acoustic transducer; reverberation and false returns from within unconsolidated ridges; and the effects of bubble clouds, waves, and frazil.

The workshop provided a very fruitful exchange of ideas. Discussions clarified the issues of open water discrimination and this will help all groups improve their methodology. Broadly standard protocols for data analysis were established and a common format was set for archiving both time series and statistical summaries of the ice draft data. These formats are compatible with the formats used for archiving ice draft data from manned-submarines in the Arctic. Overall the workshop cleared the way to archive existing ULS data, and all users undertook to submit the metadata of their records with the CliC Project Office, and the analysed data with National Snow and Ice Data Center (Boulder, CO) within the next 12 months.

The workshop also proposed intercalibration comparisons of the different instruments. This should be done both as in situ experiments (for example Germany providing a CMR instrument for deployment within an Australian CMST array, or vice versa) and as a "virtual experiment" using a standard high-resolution, narrow-beam width data set from a new 'super' IPS to simulate the performance of the different instruments. Other technical recommendations included the development of narrower beam width instruments for standard deployment and the operation of ADCP instruments with ULS whenever possible to provide spatially averaged data sets, rather than just time series.

The workshop participants agreed to release approximately 60-years of IPS data from Arctic and Antarctic regions to be archived at the National Snow and Ice (NSIDC) data center in Boulder, Colorado. Additional theoretical work was identified to be crucial in the study of under-ice morphology with synthetic IPS data.

The workshop was sponsored by the UK Met Office, and hosted by the International ACSYS/CliC Project Office at the Norwegian Polar Institute. Participants were from Norway, Germany, United Kingdom, Canada, United States, Australia, and Japan.

1. Scope of the Meeting

The thickness of sea-ice in both polar regions and in sub-polar seas is a critical parameter, influencing the fluxes of energy and moisture between the warm ocean and the cold atmosphere above. Sea-ice thickness may also serve as an indicator of climate change, with global warming likely to reduce ice thickness, particularly in the Arctic and some marginal seas. Recent publications by *Rothrock* et al. (1999) and *Wadhams and Davis* (2000) examining records from submarine sonars have suggested that over a large area of the Arctic, sea ice has thinned by as much as 40% over the last few decades. However, other authors have found that the thinning is less substantial, and some models suggest that the sea ice has not actually thinned significantly, but that it has merely been redistributed by changed patterns of atmospheric circulation (*Holloway and Sou*, 2001). In a detailed examination of the available information the ACSYS/CliC Observation Products Panel concluded that at least part of the uncertainty is the inevitable result of sparse data coverage of the Arctic and high seasonal and interannual variability in sea ice thickness. Of course, data coverage of the Antarctic is even poorer than the Arctic.

While submarine data have been used in most of the relevant analyses to date, another potential source of information exists that has not yet been fully utilized. Moored ice-profiling sonars do not have wide spatial coverage, but, because they can be left collecting data in one place for periods of up to two years, and are then often directly replaced, they have the potential to provide long-term records for determining trends and cycles in the sea-ice thickness spectrum. Valuable time-series of data gathered from moored upward looking sonars in the last 10-15 years is difficult to process. Lack of resources to carry out this task has meant that these data remain unpublished and unavailable (*Melling and Riedel*, 1995). Some data from the Norsk Polar Institute has been released and published but there are still concerns about the accuracy of some draft estimates in the record.

There is a pressing need for all available historical ice thickness data to be provided in a consolidated and quality controlled manner to the ice modeling community.

Processing the data from moored IPS is time consuming and therefore expensive. Each group will be asked to present details of their data processing systems, and the problems that they have encountered in carrying out this processing. Solutions to common problems will be discussed. Where possible the aim is to improve the accuracy and precision of the data, but where problems prevent this, protocols for presentation of uncertainties will be agreed. Overall protocols for presentation of data will also be discussed. Previous protocols will be used to facilitate this discussion, but it should be noted that these protocols are now considered to be out of date.

For the foreseeable future moored IPS will serve as one of the major methods for collecting information on sea-ice thickness. Not only will the time-series from fixed locations be useful in themselves, but they will also serve an important function in validating other measurement techniques, including satellites and models. However, there is a need for data to be available in more timely fashion. Participants will be asked to suggest mechanisms whereby the data collected can be processed, quality controlled and published more rapidly in order to meet the needs of other climate scientists. If possible, a detailed plan for future deployments, data processing and publication will be developed.

The workshop had two overall goals:

1. To develop a framework for the processing, quality control, archiving and publication of all previously collected moored ice-profiling sonar (IPS) data in formats that are of use to the broad community of climate scientists.
2. To determine whether improvements can be made in the systems by which moored IPS data are collected, processed, archived and published, in order to facilitate the timely publication of high quality IPS data in the future.

The objectives of the workshop were to identify all previous data collections by IPS and record the status of the data collected; exchange information on mooring problems and the solutions to these problems; document what is known regarding systematic and random errors in ice draft measurements; agree on new protocols for data processing and archival (to replace outdated protocols developed in earlier years); and, identify all manufactured IPS instruments and their status (i.e., their suitability for future deployment).

2. SUMMARY OF PRESENTATIONS

2.1 Previous Workshops (Konrad Steffen)

The ACSYS Workshop on sea ice thickness measurements and data analysis – Monterey, 7-11 April 1997

- The recommendation of the ACSYS sea ice modeling panel and ice thickness workshop participants were mainly concerned with the release and the analysis of existing submarine data and the generation of long-term data set with wide spatial coverage.
- Sea ice thickness data collected digitally should be processes with high priority and should be released to archival sites.
- Top ACSYS priorities were: Sonar and signal processing development, evaluation of topside techniques, topside/bottom side correlation, and ice draft error analysis
- Three presentation by Humfrey Melling on IPS ice draft measurements, sounds scattering and statistical processing.

Submarine upward looking sonar ice draft profile data and statistics, Boulder, NSIDC Sept., 2000.

- Summary of released submarine ULS data sets from 1976- 1998.
- Discussion of data format
- Comparison of segment length, ice draft statistics, keel location, keel statistics. APL (Applied Physics Lab) and BHA (Bronson Hills Associate) software gave slight different results.
- No recommendations or conclusion provided in the report.

Recent variations in Arctic sea-ice thickness, IACPO Informal Report, No. 7 from ACSYS/CliC Observation Products Panel Meeting in Cambridge, England, Sept, 2001.

- A well coordinated effort should be established to process and publish, all useable data so far collected by moored IPS instruments in the Arctic and marginal seas.
- Efforts should be made through appropriate channels to obtain the release to the scientific community of scientifically-useable, submarine IPS data currently held in Russia, the UK and the USA. Regions not covered by previous data releases should have priority.
- Data collection with a variety of measurement techniques, and in particular with ice-profiling sonars, should continue for the immediate future as the best current way of providing broad spatial and temporal coverage of ice thickness over the Arctic basin.

2.2 Scientific Issues (Ian Allison)

The discussion is limited to Antarctic sea ice, and what we know about its properties and processes. The typical maximum and minimum sea ice extent around Antarctica is shown in Fig. 2.2.1

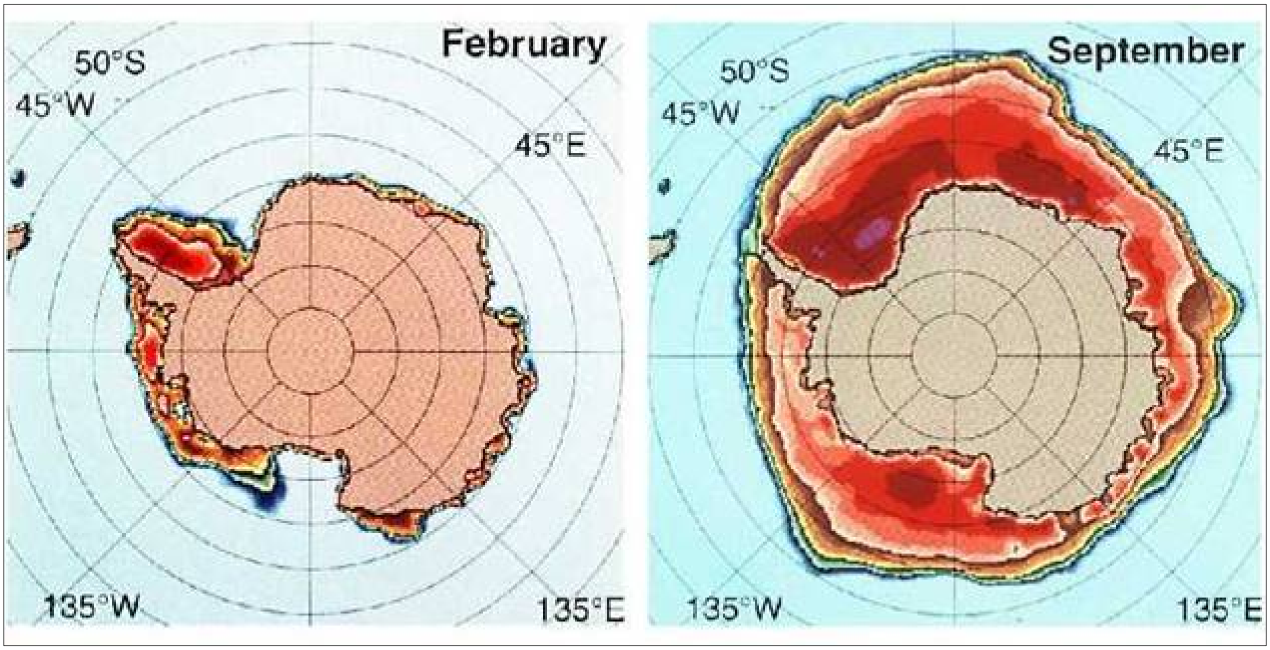


Figure 2.2.1 Typical maximum and minimum ice extent. As derived from passive microwave satellite data

The "pancake cycle" and rafting of new nilas are important early processes of increasing ice thickness and for thicker ice also processes of lead formation, rafting, and ridge-building are important in determining the growth and thickness of Antarctic sea ice (Fig. 2.2.2). Ice slabs of 0.3 to 0.6 m-thickness form the basic "building blocks" from which most of thicker Antarctic pack is formed (*Allison et al.,* 1995). Synoptic-scale meteorological systems are important in driving these processes and regular opening of leads with the passage of cyclones causes enhanced ice growth in the new open water (*Heil et al.,* 1998). The wintertime heat flux to the underside of the pack limits the thickness to which ice grows thermodynamically (*Lytle et al.,* 2000).

Examination of the crystal structure of ice cores differentiates frazil ice that forms by rapid freezing in newly created leads from columnar ice that forms by slow basal freezing. Stable oxygen isotope measurements of the melted cores also identify a third ice type, that which is formed when the snow cover on a floe is thick enough to depress the ice surface below the sea level and allow seawater to infiltrate and freeze within the snow. Off East Antarctica about 47% of the springtime ice volume is frazil, 39% is formed by basal freezing, and about 13% forms from flooded snow (*Worby et al.*, 1998). Nearly 40% of the individual textural layers in ice cores are less than 0.1 m thick, and the ice rarely grows thicker than about 0.5 m before being rafted or ridged.

Figure 2.2.2 New ice formation

Sea ice drift in the East Antarctic sector has been measured by satellite-tracked buoys deployed onto ice floes since 1985 (*Heil and Allison*, 1999). The average drift of the buoys ranged from 0.12 to 0.23 m s^{-1} (10 to 20 km per day) within the interior pack, with the average speed increasing significantly in the less concentrated pack near the ice edge (the marginal ice zone) where there was little stress between the floes (Fig. 2.2.3). Northward drift of the ice is important in determining the location of the ice edge, and once north of the Antarctic Divergence the pack ice drift is generally divergent. The occurrence of open water, the predominance of small grained frazil ice, and the wide variety of ice types and thicknesses within the winter pack are all a result of ice motion.

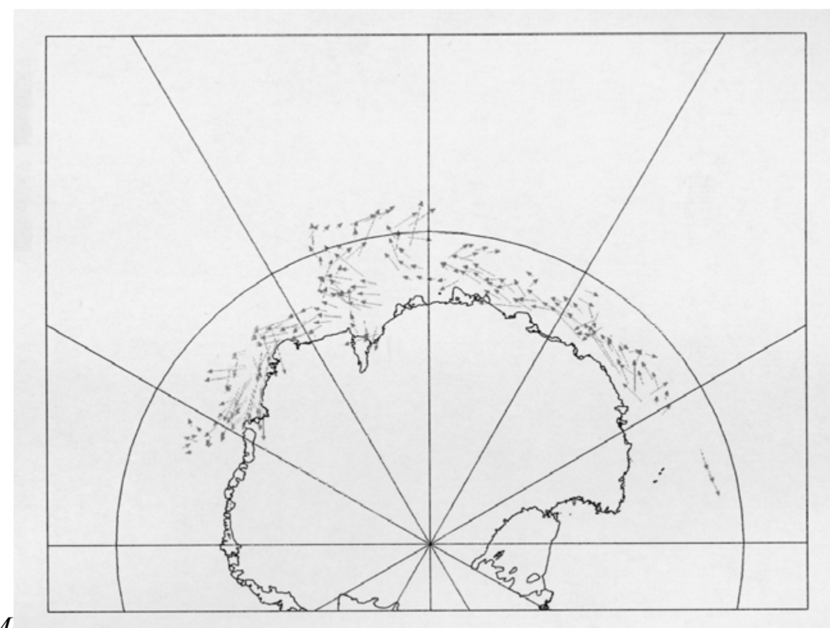


Figure 2.2.3 M

The ice and snow characteristics are strongly influenced by wind direction and temperature changes with the passage of synoptic weather systems. During periods when the wind field has a southerly component the ice expands northwards, creating open water within the pack. Air temperatures are cold as the air mass is typically of continental origin and new ice quickly grows in leads and also at the base of existing floes. As the wind shifts, the ice edge is compacted southwards and newly refrozen leads and older floes may raft or ridge to form thicker ice. Air masses from the north are relatively warm and moist, limiting ice growth and producing snowfall. On occasions rain and surface melt may occur, even in the middle of winter. The alternating warm and cold periods also constantly modify the grain size and density of the snow on the ice. The thickness distribution of the ice is determined by the interaction of these and other thermodynamic and dynamic processes including the effects of ocean swell and surface flooding (Fig. 2.2.4)

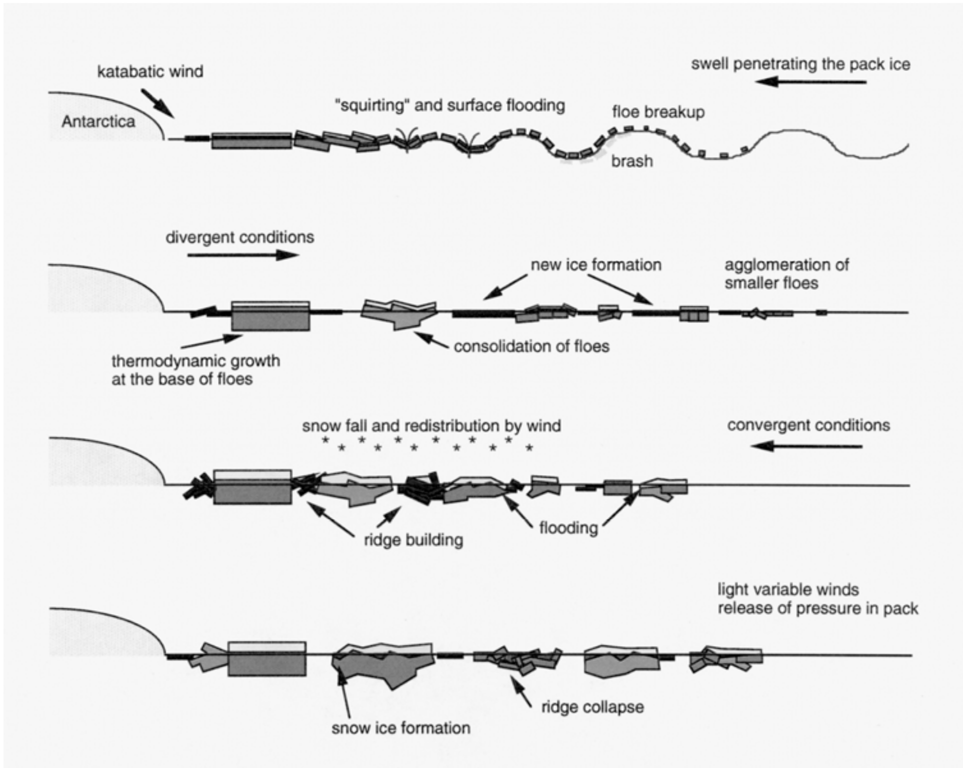


Figure 2.2.4 A conceptual model of the thermodynamic and dynamic forcing parameters that determine the thickness distribution and physical characteristics of sea ice and snow cover as observed in the East Antarctic pack (Worby et al., 1998).

The drifting buoy data show that the ice is highly mobile and constantly changes speed and direction. Sea ice may drift many hundreds of kilometres from the location where it first started to form and at every stage throughout its drift will be affected by the constantly changing ocean swell, air temperature, winds and precipitation. This high variability means that regional and long-term changes in many ice and snow properties are difficult to resolve.

Shipboard observations have been used to derive a climatology of the ice thickness and its regional and seasonal variations off East Antarctic. Preliminary results were reported by *Allison and Worby* (1994) and expanded to include results from additional observations by *Worby* (1998) and *Worby et al.* (1998). The average ice thickness distributions (excluding ridges) for March-April and July-December are shown (Fig. 2.2.5). By far the greatest seasonal changes in the ice thickness distribution are in the open water and thin ice categories. The amount of open water decreases from about 25% in March to little more than 10% in August, and then expands again in the spring and summer. The thinnest ice thickness category (0.0-0.2 m) shows a 30% seasonal change from March to December. In contrast, the amount of ice greater than 1.0 m shows very little seasonal variability.

In March, at the beginning of the growth season, most of the ice cover is thin new ice less than 0.4 m, with only a very small fraction of thick ice remnant from the previous season. By August, ice growth and deformation have led to a much wider mix of ice types with a greater modal thickness and only a small fraction of open water. As spring advances, leads do not refreeze as quickly as in August so that the October distribution has more open water and thin ice, typically with a thinner snow cover. With increasing solar radiation new ice stops forming altogether and melt removes the thinner ice types, so that the December distribution has a large open water fraction, no ice thinner than 0.2 m and a considerable decrease in the ice thinner than 0.6 m. The mean undeformed ice thickness increases from 0.36 m in March to 0.52 m in August, and then decreases to 0.31 m in December. Inclusion also of the ridged ice increases the mean thickness in the early spring by a factor of about 1.8 (to about 0.95 m in August). The mean snow cover thickness (not shown) varies seasonally from only 0.02 m on the new ice in March to 0.12 m in August.

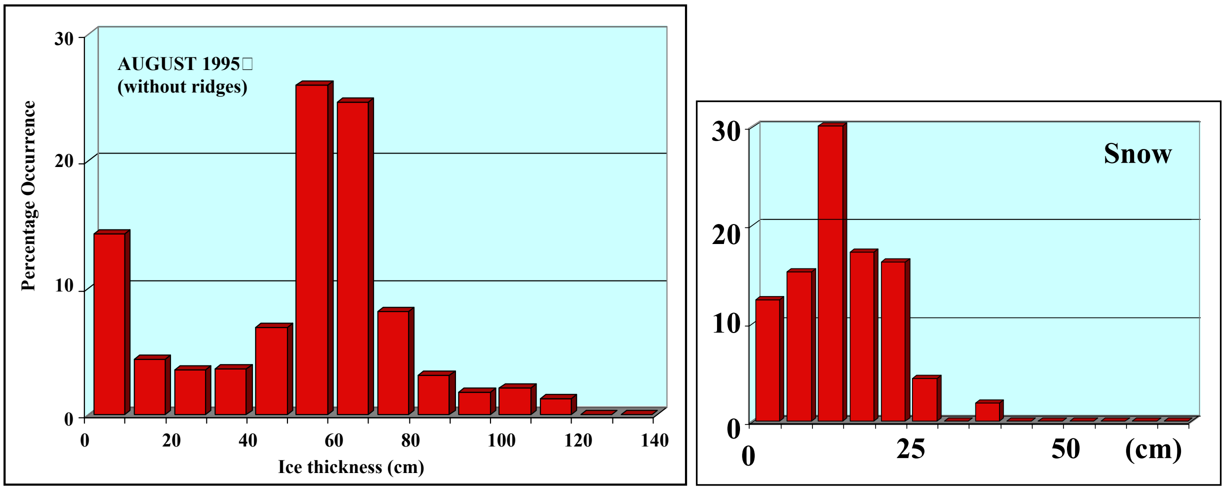


Figure 2.2.5 August ice and snow thickness distributions from shipboard observations

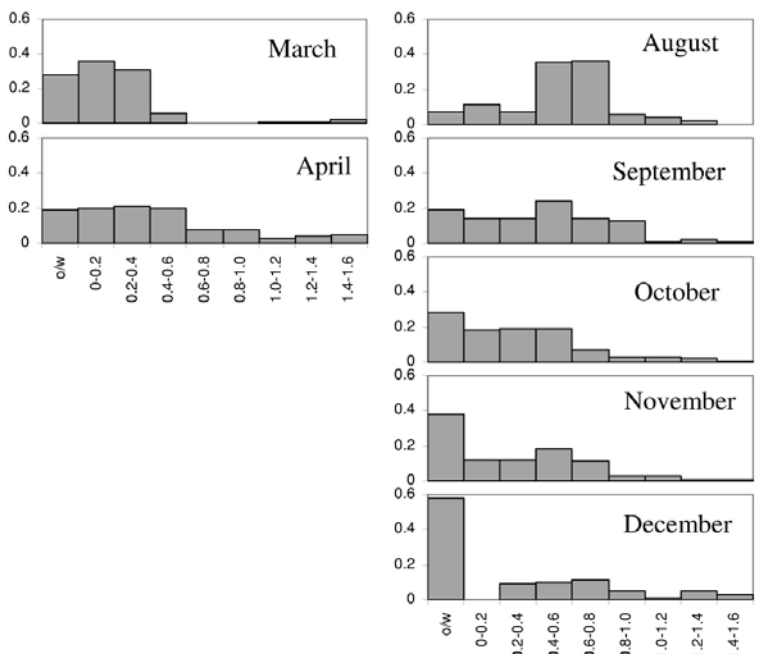


Figure 2.2.6 The seasonal changes in ice thickness distribution between 60ºE and 170ºE. This plot shows the probability of finding ice within a certain thickness range. This excludes the ice in ridges. Open water (o/w) is shown as a separate category (after Worby, 1998).

2.3 Mooring Technology (Eberhard Fahrbach)

An ULS has a limited acoustic range and consequently is exposed to icebergs. Because of the conical shape of floatation the instrument slides along the underside of the iceberg and is not be caught in cracks (Fig. 2.3.1)

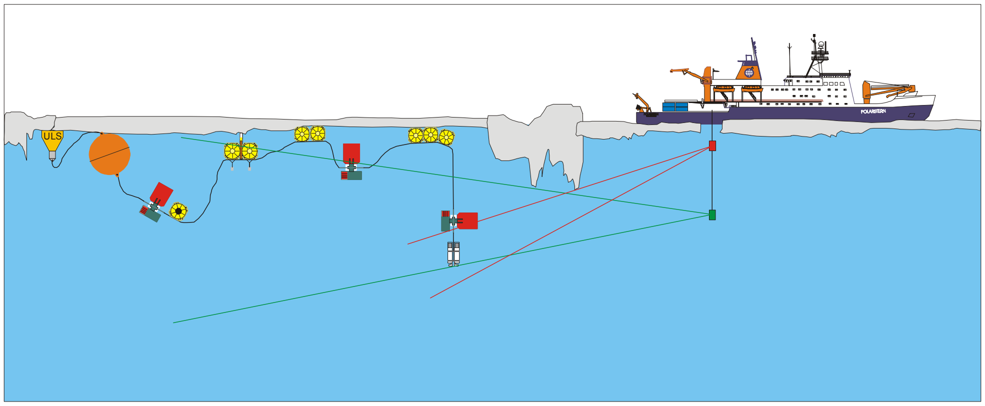


Figure 2.3.1 Limited acoustic range of moorings

Radio beacons, flash lights or satellite transmitters are typically placed at the top buoy to make sure that the antenna or the light is off the water. To avoid damages by icebergs the instruments are placed deep enough to be out of the range of icebergs. After the mooring has been released the satellite antenna is kept out of the water by counter weights.

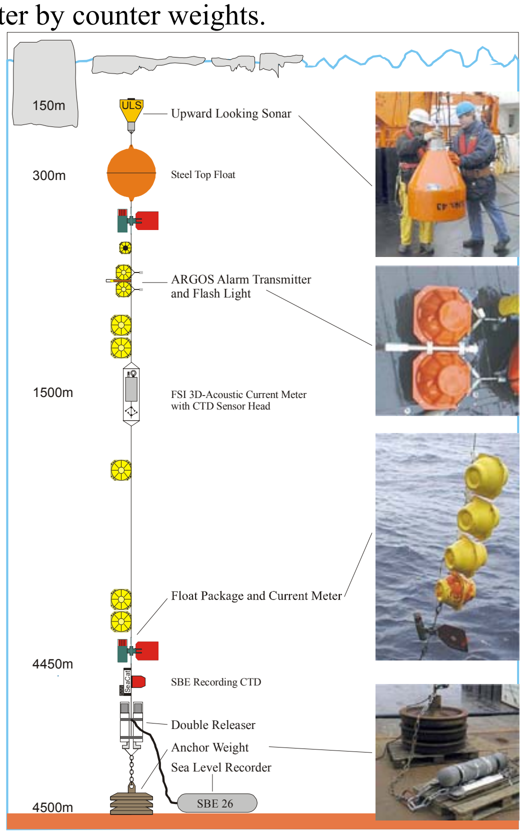


Figure 2.3.2 Mooring configuration

Inserting float packages and current meters during deployment must be easy and quick. This is made possible by clipping the floats directly at the mooring rope (Figure 2.3.3)

The sea level recorder must be placed at the bottom to avoid any effect of the mooring motion. For deployment the instrument is attached to the double releaser frame by a strip with a “corrosion link”. Thus the instrument reaches the bottom about 3 days after being deployed. AWI has deployed moorings since 1986. Because most of them were located in ice covered areas the deployment was made with “anchor first” in contrast to “anchor-last which is normally used in open water.

This method of mooring deployment needs an area of open water which is at least as wide as the mooring length. The final mooring location must be determined with assumption about the descending behavior of the mooring which is subject to uncertainties. The advantage of this method is that the tension on the mooring string during the deployment is low.

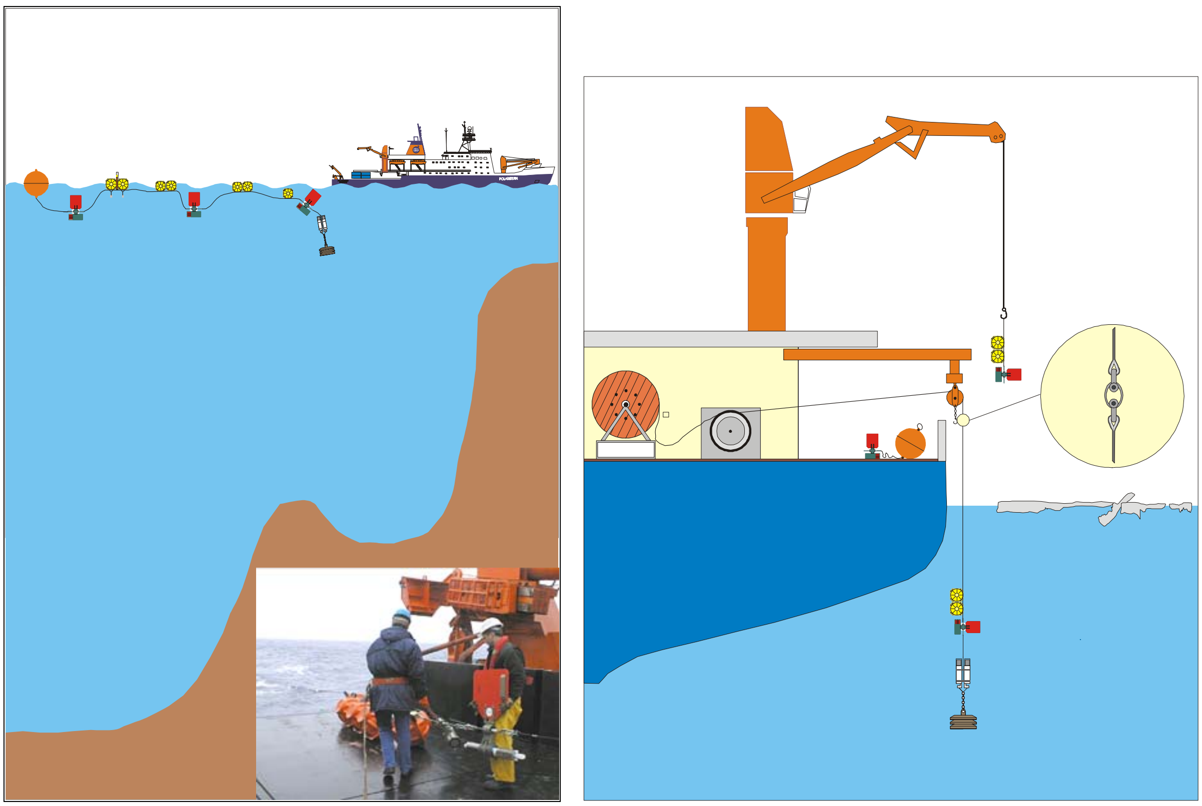


Figure 2.3.3 Mooring deployment in open water (left) and through a small hole in the ice (right).

The ship stays at the planned location when deploying a mooring with the “anchor-first”. Therefore moorings can be deployed through a relatively small hole in the ice. The mooring is lowered with the deep-sea-winch and deployed with a standard acoustic releaser on top of the mooring (Fig. 2.3.3). The ship can actually steam to find the water depth or position to place the instruments at the planned depth levels or location (Fig. 2.3.4). Because the full load of the anchor weight of about 1000 kg is on the mooring string this method cannot be used under rough sea conditions in open water.

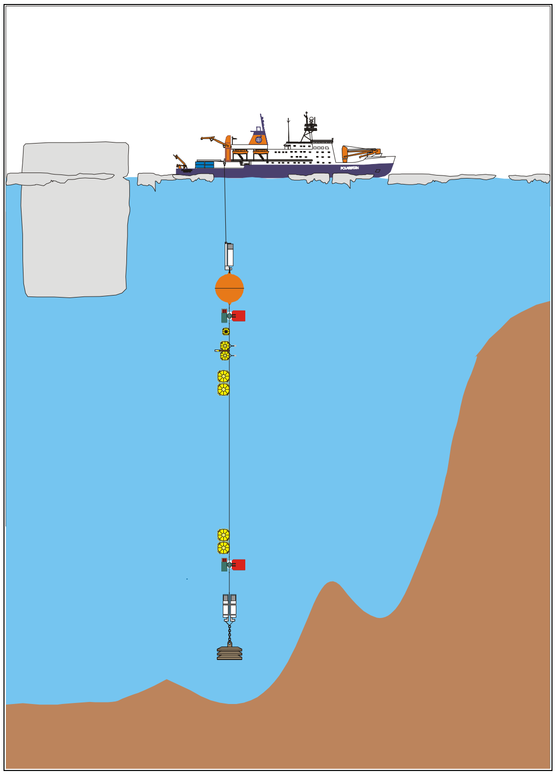


Figure 2.3.4 Lowering of mooring with deep-sea winch

Since 1999 Polarstern is equipped with the ultra-short-base-line navigation system "Posidonia". The releasers and transponders have been modified to operate with this new system. All moorings deployed form summer 2000 on will be provided with "Posidonia-releasers/transponders". To avoid acoustic shadowing by ice keels the transponder must hang deep enough to be off the acoustic shadow.

2.4 Past and Present Observations (Ian Allison, Wolfgang Dierking, Yasushi Fukamachi)

Australian IPS (also called ULS) deployments off East Antarctica are shown in Figure 2.4.1 and Table 2.4.1. Because of the low acoustic reflectivity of growing Antarctic ice there were many data losses from this prototype instrument. The data were analyzed statistically, not as a time series, and only for ice drafts >0.3 m (*Worby et al.*, 2001) (Fig. 2.4.2). The deployment of IPS during the Mertz Glacier Polynya (MGP) experiment in June 1999 is shown in Figure 2.4.3.

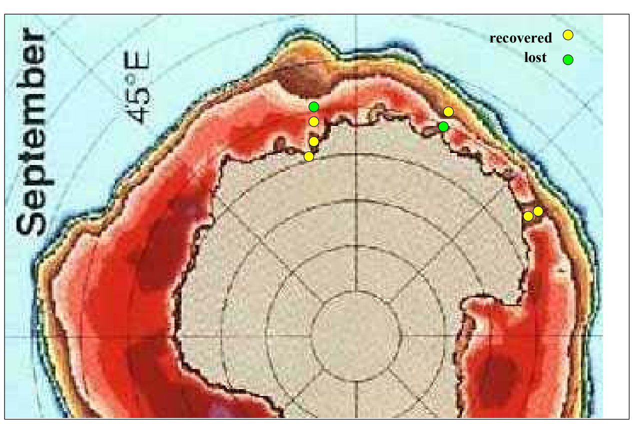


Figure 2.4.1 Australian IPS deployments

Mooring	Deployed	ULS-#	Name	Lat	Long	Water Depth	Recovered
ACRC-101	21/01/94	ULS-2	So-near	-65 07.35	107 46.13	520	**Lost**
ACRC-102	23/01/94	ULS-3	So-far	-63 17.75	107 49.43	3260	23/12/94
ACRC-103	28/01/96	ULS-5	So-on	-68 08.32	76 01.98	478	16/02/97
ACRC-104	29/01/96	ULS-4	So-forth	-66 15.31	77 02.74	2866	**Lost**
ACRC-105	17/04/98	ULS-3	So-far	-64 47.35	142 44.64	3213	19/02/00
ACRC-106	18/04/98	ULS-5	So-on	-65 52.96	142 55.49	421	19/02/00
ACRC-107	21/02/01	ULS-3	So-far	-69 00.02	75 18.68	717	20/02/02
ACRC-108	17/02/01	ULS-5	So-on	-69 33.69	72 42.30	544	21/02/02

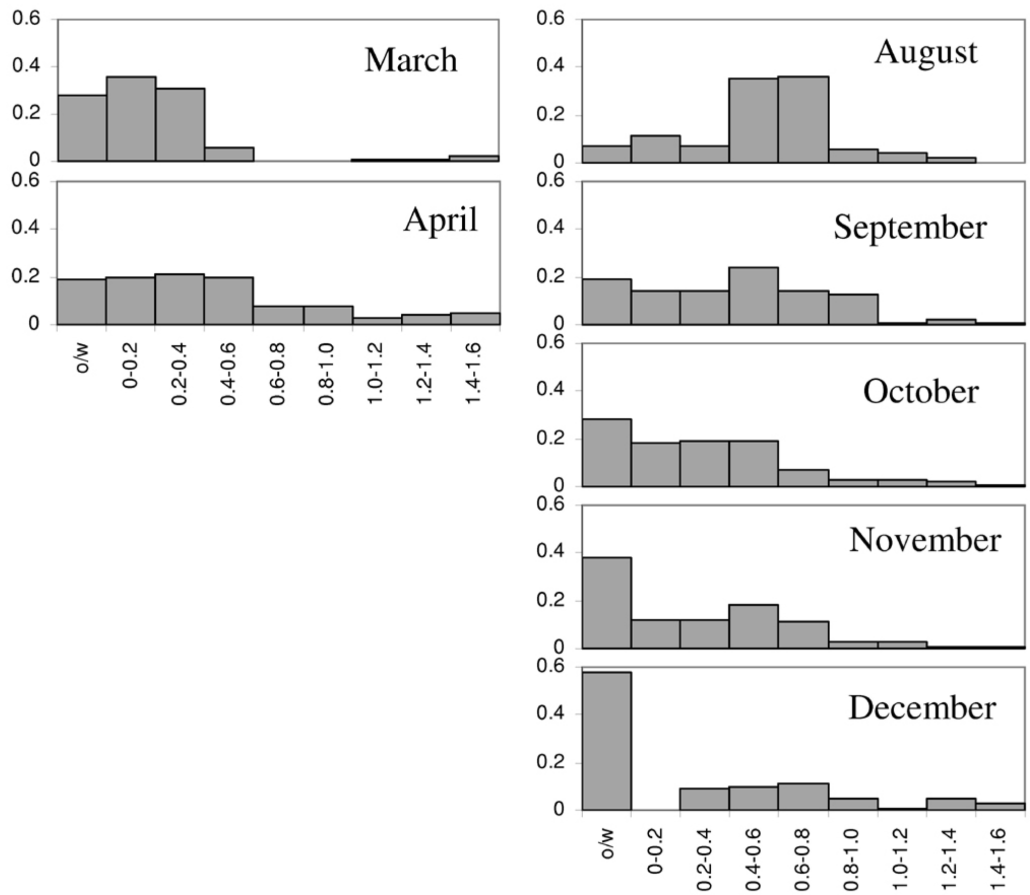


Figure 2.4.2 IPS data from an instrument deployed at -63.3, 107.8 in 1994.

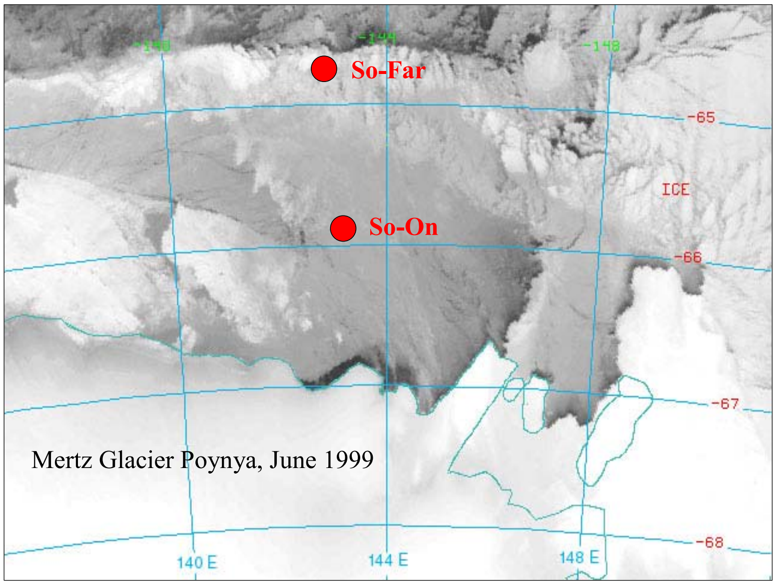


Figure 2.4.3 Location of IPS deployments during the Mertz Glacier Polynya (MGP) experiment

Antarctic Sea Ice Thickness Project (ANSITP)

In view of the importance of continued observations of sea ice thickness over large areas, methods to determine sea ice thickness from satellite data have been implemented or are under development. These efforts require appropriate validation by complementary ground-based measurements. In order to obtain time series of sea ice thickness at certain crucial locations, upward looking sonar systems are deployed on oceanographic moorings. In order to support and co-ordinate international efforts the World Climate Research Programme (WCRP) has initialized the Antarctic Ice Thickness Project (ANSITP) under the Arctic Climate System Study/Climate and Cryosphere (ACSYS/CLIC) in 1990. The project is coordinated by Eberhard Fahrbach (Alfred Wegener Institute).

Since the start of the project until October 2002, 53 moorings with upward-looking sonars were deployed - 40 by the Alfred Wegener Institute for Polar and Marine Research (AWI, Bremerhaven, Germany) in the Weddell Sea, 8 by the Antarctic Cooperative Research Centre (ACRC, Hobart, Australia) off East-Antarctica, 2 by Woods Hole Oceanographic Institute (WHOI, Woods Hole, MA, USA) west off the Antarctic Peninsular and 3 by the Norwegian Polar Institute (NPI, Tromsø, Norway) in the southern Weddell Sea. At present (Oct. 2004), 6 AWI ULS-moorings are located along the Greenwich Meridian in the Weddell Sea. These records exist since 1996 and 4 of these positions will be continued beyond 2004. The ACRC has deployed two ULS-moorings in February 2001 off the Amery Ice Shelf in Prydz Bay as part of a larger oceanographic array called AMISOR. Both moorings were recovered in March 2002, but the instruments had failed. The WHOI has deployed two ULS-moorings in March 2001 west off the Antarctic Peninsular were recovered in October 2002.

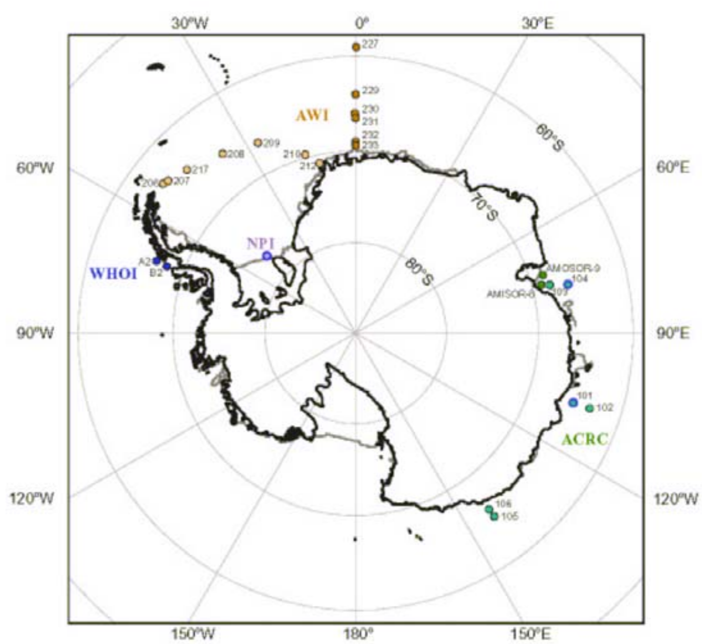
From the 47 instruments to be recovered up to now, 11 were lost, either the instrument only or the complete mooring. From the recovered instruments 9 failed completely resulting in 27 instruments with data, but some of them with shorter duration than expected, or with reduced data quality. Details of moorings recovered until October 2002 are presented in the following table, and locations are plotted on a map.

Additional information is available on:
http://www.awi-bremerhaven.de/Research/IntCoop/Oce/ansitp.html

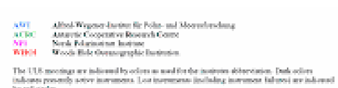
Institution	AWI	ACRC	NPI	WHOI	Sum of all ULS's
recovered (incl. lost and failures)	34	8	3	2	47
lost	6	2	3	-	11
no data recorded	7	2	-	-	9
obtained data	21	4	-	2	27

Publications related to the analysis of ULS data from the Antarctic:

- Strass, V.H., 1997: Measuring sea ice draft and coverage with moored Upward Looking Sonars, Deep-Sea Res.,45, 795-818
- Strass, V.H. and Eberhard Fahrbach, 1998: Temporal and regional variation of sea ice draft and coverage in the Weddell Sea obtained from Upward Looking Sonars. In Antarctic Sea Ice: Physical Processes, Interactions and Variability, edited by M.O. Jeffries, Antarctic Research Series, Vol. 74, AGU, Washington, 123-139
- Bush, G.M., Duncan, A.J., Penrose, J.D. and Allison, I., 1996: Acoustic reflectivity of Antarctic sea-ice at 300 kHz. 3rd European Conference on Underwater Acoustics, Heraklion, Crete, Greece 24-28 June 1996, Conference publ.
- Bush, G.M., 1997: Measuring Antarctic sea ice draft with an upward looking sonar. Ph. D thesis., Curtin University of Technology, Perth, Australia
- Harms, S., Eberhard Fahrbach, and Volker Strass, 2001: Sea ice transport in the Weddell Sea, Journal of Geophysical Research, Vol. 106, No. C5, 9057-9073



Antarctic Sea Ice Thickness Project (AnSITP)
Map of moored ULS-Systems
October 2002



A group at Hokkaido University has been carrying out the IPS (ASL's IPS4) mooring experiment near Hokkaido (143º 39' E, 44º 20' N) in the Sea of Okhotsk since winter of 1998-1999 with help from Humfrey Melling of Institute of Ocean Sciences and David Fissel of ASL Environmental Sciences. The mooring array contained an IPS and an ADCP along with several sensors to measure water properties. Good data were obtained from all the instruments in the first three years, but the IPS failed in the fourth year. A mooring experiment was also carried out off the northern coast of Sakhalin (143º 03' E, 54º 31' N) in 1999-2000. For this experiment, trawl-resistant bottom mounts were used for both of the IPS and ADCP. Unfortunately, the IPS failed for this experiment. The Hokkaido University group is planning to continue the mooring experiment near Hokkaido to accumulate more data in the region. Also, another mooring experiment off the northern coast of Sakhalin is planned as a cooperative project with Sakhalin Oil and Gas Institute.

2.5 Instruments and Instrument Comparisons (Ian Allison)

The technical specifications of the CMST (Curtin University) are summarized in the following and a cross sectional view is shown in Fig. 2.5.1.

Maximum operating depth	200 m
Maximum survival depth	400 m
Active operational capability	2 years
Mass (including buoyancy)	300 kg
Excess buoyancy	70 kg mass equivalent
Physical dimensions	0.7 x 0.7 x 1.8 m
Operating temperature range	-2º to +20ºC
Data storage and capacity	PCMCIA card (20 Mb)
Sampling intervals	From 1 to 127 minutes with 5 different seasonal schedules
Acoustic centre frequency	300 kHz
Acoustic beamwidth (-3 dB)	2.5 degrees
Acoustic timing resolution	16 μsec (12 mm draft)
Pressure resolution	100 Pa (10 mm)
Pressure accuracy	1300 Pa
Temperature resolution	0.025ºC
Temperature accuracy	+/- 0.05ºC (after calibn)
Tilt measurement resolution	0.1 deg
Tilt measurement accuracy	+/- 0.3 deg

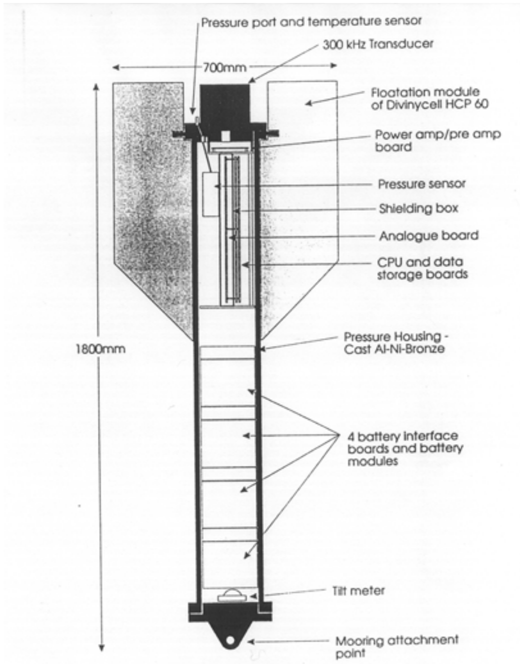


Figure 2.5.1 Cross sectional view of the Curtis IPS Mark I

Two-stage acoustic range measurements are compared in the following using onboard open water detection algorithm, signal energy and statistics record for post processing o/w detection, and wave form data record for more basic research.

Narrow-band Tx (approx)
- 1 ms tone-burst
- 1 kHz rx bandwidth
- 3 kHz sampling (24 cm)
- gain control determined by previous signal
- sets time gate for precise signal

Wide-band Tx (precise)
- 31-bit PRBS phase-modulated signal
- 20 kHz rx bandwidth
- 62.5 kHz sampling (1.2 cm)
- gain control (correlator)
- received signal correlated with replica of transmitted

CMST (Curtin University) IPS parameters recorded and typical sampling intervals:

PARAMETER	SCHED1 (min)	SCHED2 (min)
Compulsory data	1	5
Wide-band travel time		
Narrow-band reflection coefficient		
Pressure		
Environmental data	1	5
Tilt (x, y), temperature (2)		
Instrument status & time	60	60
Supply voltages, schedule number		
Time, sample interval		
Wide-band receive energy	1	5
Wide-band receive statistics	1	5
Narrow-band transmit & receive data	1	5
Raw receive pulse shape	60	1440
Wide-band (real, imag) (450)		
Wide-band (real, imag) (200)		
Error flags	As occur	as occur
Sonar error		
Other error		
Scheduled multi-ping (3)	30	120

Parameters for open water detection are:

Wide-band receive energy

- Transmit voltage
- RMS receive voltage
- Receiver gain
- Maximum receive signal (after correlation)

Wide-band receive statistics

- Wide-band receive energy (as above)
- Received signal-length
- SD of magnitude of received signal
- Start time of received signal relative to transmit

Raw receive pulse shape

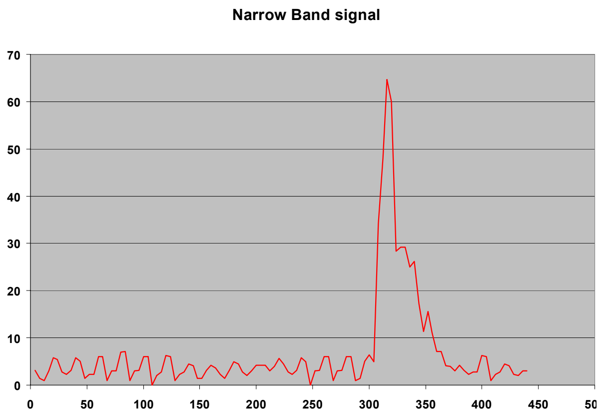
- Wide-band (real, image)
- Narrow-band (real, image

Narrow-band transmit/receive data

- Receiver gain
- Narrow-band travel time
- Start time of received NB signal relative to transmit
- Received signal-length
- Mean received signal magnitude

- Maximum received signal magnitude
- Transmit voltage

Scheduled multi-ping (3)
- Standard sounding PLUS 2 additional
- Record WB travel time and maximum WB signal strength
- Time interval between pings



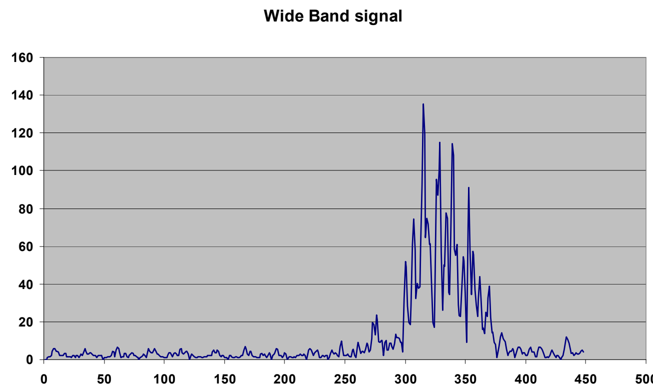


Figure 2.5.2 Examples of IPS ow band signal (left) and wide band signal returns (right)

2.6 Data Processing and Calibration (John Marko)

Descriptions were provided of the principal steps in extracting accurate and useful ice draft data from high sampling frequency range data of the type routinely acquired by ASL Environmental Sciences Inc.'s IPS4 Ice Profiler instrument. It was emphasized, at the outset, that the broad utility of this data, based upon its intrinsically high accuracy and information content, necessitates considerable commitments of time and resources to processing and interpreting the multivariate data sets provided by the Profiler in conjunction with information provided by adjacent ADCP instrumentation and from ancillary sensors such as atmospheric pressure mapping systems and satellite imagers. Key tasks in this effort include: accurate, unambiguous, recognition of areas of open water/thin ice to update local sound speed estimates and to account for changing atmospheric pressures and variations (tilts) in Profiler "look" directions. Some discussion was provided on complications introduced by the presences of bubble clouds, zooplankton concentrations and gravity waves of more than non-negligible amplitude. Information was presented to quantify the limited utility of return echo amplitudes in facilitating similar interpretation and accuracy increasing functions. This information also was used to justify use of near-saturation operating modes in the present generation of high frequency profilers. Nevertheless, it was recognized that further measurement improvements may be achievable by retaining echo amplitude information in the recorded data sets, provided the statistical character of individual echo returns is recognized.

Finally, results were presented as obtained in a recent attempt to quantify the accuracy or, at least, the consistency associated with draft measurements from moored Ice Profilers. This effort utilized quasi-spatial profiles produced from data collected by pairs of immediately adjacent IPS4- and ADCP ice velocity measuring-instruments positioned at a small separation (3 km) transverse to the mean flow of the broad southward flow of sea ice in the Sea of Okhotsk east of Sakhalin Island. Mean draft values as computed from consecutive, 50% overlapping, segments of various length profiles were compared between the two sites (which should have been in sufficient proximity to show neglible differences in true mean values). A typical comparison of means from 525 km worth of 150 km-long segments gathered simultaneously at the two sites is shown in Figure 2.6.1. The rms mean of the difference between the means of corresponding segments at the two sites was 0.17 m and the overall difference of the means over the full 525 km track segment was 0.07 m. Both differences are consistent with previous estimates of approximately +/- 0.15 uncertainties in individual moored profiler measurements and justify some confidence that such techniques are capable of detecting systematic changes in ice draft/thickness to similar levels of uncertainty. It was noted that equivalent levels of accuracy have not been demonstrated for either submarine- or less frequently sampled moored profiler-data sets (with- or without-accompanying sets of ice velocity data). Discussions noted the complex relationship between the length of sampling segments and the quality and representivity of the obtained statistical estimates. Reference was made to an earlier treatment of similar issues at the New Carrollton Workshop (*Moritz, R.E.,* 1991). Further work on draft statistic extraction methodologies was identified as advisable.

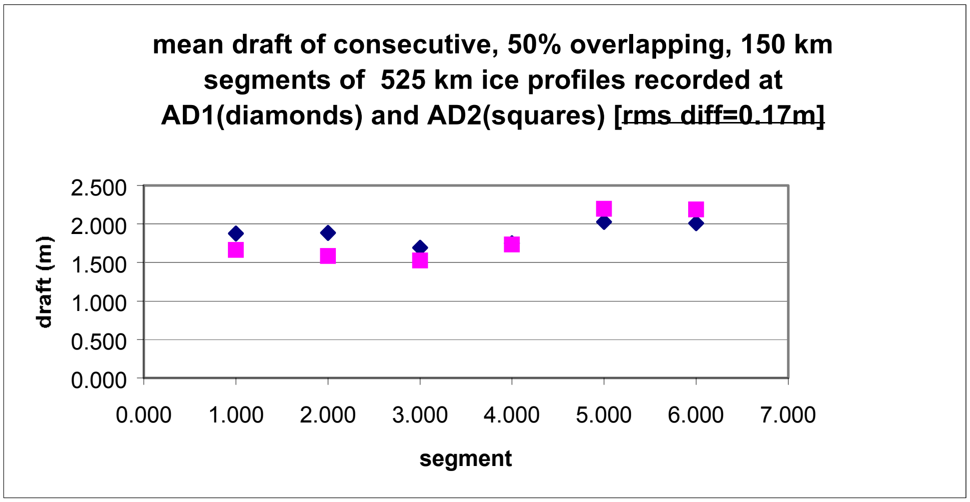


Figure 2.6.1 Comparisons of mean drafts derived for consecutive 50% overlapping 150 km long quasi-spatial profile data sets gathered simultaneously in March-April, 1998 at two different sites (AD1 and AD2) separated by approximately 3 km in the cross-stream direction of a southwardly drifting ice pack on the continental shelf off Sakhalin Island.

2.7 Manned Submarines (Florence Fetterer)

A growing amount of submarine ULS data is being distributed. The *Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics* (http://nsidc.org/data/g01360.html) contains data from 20 cruises, and has about 70 registered users. The data are made available through the efforts of the Arctic Submarine Laboratory, San Diego, CA; Cold Regions Research and Engineering Lab (CRREL), Hanover, NH; Applied Physics Laboratory, University of Washington, Seattle; Bronson Hills Associates; and Scott Polar Research Institute, Cambridge University, U.K. The U.S. data are from cruises that used the Digital Ice Profiling System (DIPS-II) to log digital data which started in 1986. Data from three U.K. cruises are now available, dating from 1976. Analog data from 40 U.S. cruises dating from 1958 is being converted to digital data at the University of Washington, and will be available over the next several years.

ULS data from submarines is subject to many of the same errors as data from moored instruments. Error due to beamwidth is exacerbated by changes in submarine depth.

2.8 AUV's (Yasushi Fukamachi)

Groups at Hokkaido University and National Institute of Polar Research have started to examine the possibility of using the IPS (ASL's IPS4) on an existing AUV. The AUV (called Aqua Explorer 2) is manufactured by Mitsui Engineering & Shipbuilding. So far, only the trial run within a port has been carried out. More trials are planned for next three years aiming for the actual observation in the Antarctic after 2005.

2.9 IPS Data Archive: Past, Present and Future (Florence Fetterer)

Terje Loyning summarized recommendations on the archival of IPS data sets. The data format had been developed and agreed upon at an earlier ACSYS ULS workshop. This data format was reviewed and several additions were suggested. The final data format is listed below in sections 2.9.2. Florence Fetterer discussed data set which have been published and are relevant to the IPS data format and archival implementation, i.e., the *Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics* and *AWI Moored ULS Data, Weddell Sea (1990-1998)* data sets. The following recommendations were given based on NSIDC's experience with these data sets and users::

- Encourage users to register so they can be sent information on changes, errors, or updates.
- Provide information on how to cite the data set in publications, in order to credit the provider, and contribute to precision in the literature.
- Work with data provider(s) for accurate documentation.
- Provide as full an explanation as possible of how summary statistics are calculated.
- Users want a statement about precision and accuracy.
- Should record date the data were processed, by whom, and software version used.
- Document known differences in processing methods from different data providers

Regarding archival and distribution of data, the following items were discussed:

- All data providers at the meeting agreed to archive raw data. All raw data, not only travel time, should be archived. These data need not be archived with processed data at the distributing data center (i.e. NSIDC) although that may be preferable, but they should be securely archived.

The ACSYS/CliC project office will maintain metadata records on all moored ULS data sets. NSIDC will archive and distribute the data in cooperation with contributors and the ACSYS/CliC project office.

2.9.1 Data available now

Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics

This data set consists of upward looking sonar draft data collected by submarines in the Arctic Ocean. The data set will be augmented by data from additional cruises dating back to 1986, as the data become available. The data set includes data from both U.S. Navy and the Royal Navy submarines. A map showing the submarine tracks is available.

Data in this data set are saved in two types of files: one for ice draft profiles and the other for statistics derived from the profile data. Ice draft files include a header that gives date and location information followed by a sequential list of drafts spaced at 1.0 m intervals that comprise the bottom-side sea-ice roughness profile. The length of the profile in any given file can be up to 50.0 km, but may be shorter if data dropouts create gaps greater than 0.25 km, or if changes in course cause deviations from a straight-line track. Statistics files that include information concerning ice draft characteristics, keels, level ice, leads, and undeformed- and deformed-ice are provided for all draft profiles that exceed 10.0 km in length. The majority of the upward-looking sonar data from the U.S. Navy have been interpolated and processed for release as unclassified data at the U.S. Army's Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire. Data from the SCICEX-97 and SCICEX-98 cruises were provided by the Polar Science Center, Applied Physics Laboratory, University of Washington. Data from British submarines were provided by the Scott Polar Research Institute, University of Cambridge. All data sources used the same basic processing methods in order to ensure a consistent data set.

If you choose to download these data, we strongly encourage you to become a registered user of the data set. Registered users are informed of corrections, changes and additions to the data set. To become a registered user, click on 'user services' and fill out the form. In the message field, identify yourself as a user of Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics.

Data Citation:
National Snow and Ice Data Center. 1998. *Submarine Upward Looking Sonar Ice Draft Profile Data and Statistics.* Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology. Digital media.

AWI Moored ULS Data, Weddell Sea (1990-1998)

This data set consists of moored Upward Looking Sonar (ULS) data from 14 stations in the Weddell Sea. Measurements have a sample interval of between 3 and 15 minutes. Data record length for individual stations ranges from under a year to about two years. Parameters in the processed data files are

- Water pressure at depth of instrument
- Water temperature at depth of instrument
- Draft (Distance between the ocean surface and the bottom of the ice.)
- A flag that indicates if the draft is a measurement of the water surface, or of sea ice

Raw data files contain additional parameters. These data were contributed by the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, in 1999. Data are available via ftp. Further information can be obtained from:
http://www.nsidc.org/data/docs/noaa/g01359_awi_mooring/index.html

Data Citation
Harms, S., E. Fahrbach, and V.H. Strass. 2001. *AWI Moored ULS Data, Weddell Sea (1990-1998).* Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology. Digital media.

2.9.2 Data available soon

AWI Moored ULS Data, Greenland Sea and Fram Strait (1991-2000) (contact F. Fetterer for more information)

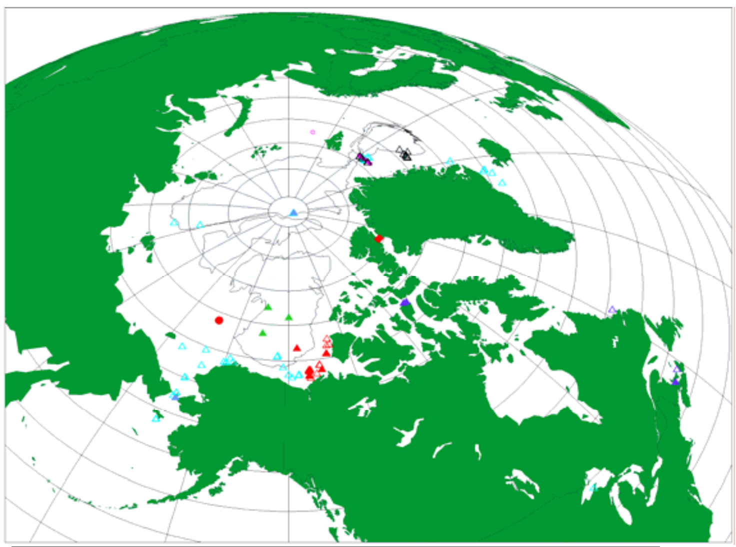
Anticipated additions to the archive, as of May 2004. The table below gives information on data that investigators expect to provide to NSIDC within the next year [update!!] or so. These data are from four different instrument types, that have been processed using four different methods. NSIDC will work with data providers to ensure accurate documentation, to appropriately credit providers and their institutions and funding agencies, and to restrict data as needed until investigators are ready to release it.

Area	**Provider**	**Notes**
Antarctic	I. Allison	Four buoy years. Statistics only, not draft. Available in

		2003.
Arctic	D. Moritz	About 90% of data from 45 stations available in next 12 months.
Arctic	H. Melling	Spring 1990 - autumn 1999, 26 station-years from eight sites (nearly continuous record from two of these sites).
Arctic	E. Fahrbach	EPOCH data. About 25 buoy years, about 10 more moorings.
Arctic	T.B. Løyning	Fram Strait, 79°N Latitude, 1990-2000
Arctic	A. Proshatinslag	Three moorings in Canada Basin. Deployed August 2003, to be recovered August 2004.

Mooring location map, current as of May 2004

The map and mooring information was provided by Humfrey Melling, Institute of Ocean Science, Sidney, British Columbia, and Ignatius Rigor, University of Washington, Seattle. Map isobaths are 2500 m. Oil company installations in the Okhotsk, Pechona, and Caspian Seas are not shown.



Investigator	Symbol	Status
Dick Moritz (APL UW)	◀	currently deployed
	◁	recovered deployments
Fahrbach (AWI)	◀	recovered
Hansen/Loyning (NPI)	■	recurring deployments in Fram Strait
Melling & collaborators	◀	currently deployed (IOS)
	◁	recovered deployments (IOS)
	●	currently deployed (IOS/NOAA)
	◆	currently deployed (IOS/NSF)
Proshutinsky (WHOI)	◀	currently deployed
Prinsenberg (BIO)	◀	currently deployed
	◁	recovered deployments

Figure 2.9.2.1 Map of IPS moorings in the Arctic Ocean

In the following, the contents recommended for data files for data provides of moored Ice-Profiling Sonar (IPS) is summarized. The protocol was finalized by T. Løyning, H. Melling, and F. Fetterer, 10 July 2003. Based on discussions at the ACSY/CliC Moored Upward Looking Sonar Workshop, in Tromso Norway, 1-3 July 2002, and at the ACSYS ULS workshop in Oslo, 1994.

1) Data File Description:

- For each mooring, archived data should include an ice draft time series file, a velocity time series file (optional), a raw data file, and a statistical data file. The contents of these are described below.
- Draft time series data file
- This file must contain a header with the following items:
- Latitude, Longitude
- Water depth (m)
- Depth of instrument (m)
- Start time, End time, Sampling interval
- Instrument type and serial number
- Sonar frequency (Hz)
- Sonar beamwidth (degrees)
- Sonar source level (dB re 1 micropascal at 1 meter)
- Sonar sensitivity (dB re 1 volt per micropascal)
- Responsible agency
- Processing algorithm (Include text describing the algorithm, or a reference to other documents that provide this information. The documentation should also indicate how estimates are corrected for offsets, including the footprint correction.)

The following variables must be included in the data file:

- Time (decimal days of the year of deployment)
- Ice draft
- Depth of sonar (Depth should be computed from total hydrostatic pressure, sea-level atmospheric pressure, and ocean-density profile when possible. Ancillary documentation should be provided describing how depth is computed and the data sources used.)

The following variables are optional:

- Pressure at sonar
- Temperature at sonar
- Flag

The flag indicates if the estimated value of ice draft is classified as open water (flag = 0), ice (flag =1), or not classified (flag = 2).

The dimension of the variables shall be as follows:

- Time: decimal days to five decimal places
- Ice draft: meters to two decimal places
- Sonar depth: meters to two decimal places
- Pressure: bars to three decimal places
- Temperature: degrees C to two decimal places
- Flag: dimensionless

Missing data should be denoted by -99.99.

2) Velocity time series data file

This file is optional. When ice velocity information is available, a velocity time series is a useful addition, given that PDFs of ice draft from temporal and pseudo spatial series can differ considerably, and ice velocity is needed to construct pseudo spatial series.

This file must contain a header with the following items:

- Latitude, Longitude
- Start time, End time, Sampling interval
- Averaging interval (relevant to resolution of tidal currents)
- Method of deriving ice velocity
- Type of velocity (Lagrangian or Eulerian)
- Instrument type and serial number (if relevant)
- Responsible agency
- Processing algorithm (with text describing the algorithm, or a reference to other documents that provides this information.)

The following variables should be included in the data file:

- Time (decimal days of the year of deployment with 5 decimal places)
- Ice speed east (centimeters per second with 1 decimal place)
- Ice speed north (centimeters per second with 1 decimal place)

Alternatively, the following variables may be used:

- Speed of drift (centimeters per second with 1 decimal place)
- Heading of drift (pointing direction of motion vector in degrees clockwise from true North with 1 decimal place)
- Missing data should be denoted by –999.9999 or –999.9 as appropriate, in time, speed, and heading fields, as appropriate.

3) Raw data file

It is important to archive raw data in case improvements in processing algorithms are made, or errors in processing are discovered. The raw data file should be archived at a data center (NSIDC/World Data Center for Glaciology, Boulder, for example) as well as with the home institution. The home institution is free to specify the terms under which the raw data file may or may not be distributed. The raw data file may remain in its original format, or in the format most convenient for the home institution.

4) Statistical data file

The statistical data file must contain the same header information as the time series data file. In addition, the header file should contain information on how statistics are computed, or alternatively, this information can be provided in separate documentation with a proper reference in the header file.

The following statistical variables should be calculated from the time series using month-long intervals. Drafts flagged as "missing data" are not included.

- Mean ice draft, including open water. This is the unconditional average.
- Mean ice draft, excluding open water
- The mean concentration of ice cover, computed as the fraction of data with draft exceeding the upper bound of the first bin
- The fraction of drafts not classified (that is, the fraction of drafts flagged as missing)
- The maximum, the minimum, the 5th percentile and the 95th percentile of ice drift speed (optional)
- The maximum, the minimum, the 5th percentile and the 95th percentile of ice draft
- The fraction of available data in bins for ice draft that are 0.1 m in width. Bins are centered at values of 0.0, 0.1, 0.2, ... M, where M is the largest integral multiple of 0.1 m that is less than the maximum ice draft. That is, Bin1 (-0.05, 0.05), Bin2 (0.05, 0.15), etc. The fraction of data with draft less than -0.05 m should also be reported.

5) Documentation

Ancillary documentation should be provided and should include at a minimum, a description of file naming conventions and file formats, and information on the following subjects:

For the draft time series data file:

A general description of the processing algorithms used, or a reference to other documents that provide this information. Details should include:

- A description of the procedure used to identify (and flag, if the flag is used) patches of the sea surface that are free of ice. If the procedure differs in the melting season from that used in the freezing season, that should be described as well.
- A description of how the apparent draft of these occasional ice-free patches has been used to calibrate the drafts computed for ice at all intervening pings. This will include, for example, information on the method used to interpolate the draft correction from ice-free calibration tie-points to the times of every ice observation in the record.
- An indication of the frequency of occurrence by month of zero-draft calibration points. This statistic will give users some indication of the density of calibration tie-points in the time series, and therefore of the relative precision of the calibration to zero draft.
- A description of how draft estimates are corrected for any other offsets, including the footprint (field of view) correction, and any corrections for mooring motion.
- Information on how the field of view is calculated.
- A description of or reference to any ancillary data sources used in calculations.

For the velocity time series data file, if included:

- Any additional information on the method used for deriving ice velocity that is not included in the header file.
- Any additional information on the processing algorithm that is not included in the header file. Documentation should indicate how estimates are corrected for offsets, including the footprint correction.

For the raw data file:

- A description of the format.

For the statistical data file:

- Information on exactly how the averages are computed. If, for example, the year is divided into 12 30-day "months" for convenience, this should be stated.
- Information on how open water drafts are identified for inclusion or exclusion from averages.

3. References

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4. Recommendation

1. Intercomparison of the four different ULS instruments in common use (ASL Environmental Sciences (ASL, Canada); Christen Michelsen Research AS (CMR, Norway); Applied Physics Laboratory, University of Washington (APL, USA); and Centre for Marine Science and Technology, Curtin University (CMST, Australia) is strongly encouraged. A practical solution might be to compare two instruments at a time in the Fram Strait, two instrument in the Southern Ocean, and a third intercomparison is needed between Arctic and Antarctic deployments.

2. A data processing intercomparison is suggested using data from one ULS at full time resolution. This data set should then be modified to the specifications of the other three instruments (see recommendation 1) to assess the difference due to processing.

3. Under-ice morphology should be studied using synthetic IPS data.

4. The development of a new IPS&V instrument is encouraged that measure the sonic distance to the ice surface and the ice velocity with Doppler Radar.

5. Data archival: Raw IPS data together with processing software should be archived at NSIDC and made available to this working group. Ice draft data (distance between sea level and the bottom of the ice) should be placed in a long-term archive (i.e., NSIDC). Data file description can be found in Chapter 2.9.2 and on the NSIDC home page: http://nsidc.org/noaa/moored_uls/

6. Only a few IPS measurements exist in the marginal ice zone (i.e., Antarctica) and no long-term ice thickness record does exist for the last-fast sea ice. Both regions are extremely sensitive to current changes in the sea ice cover and alternative methods should be developed to monitor these regions.

7. A minimum of 5-10 years continuous IPS measurements are needed in the Arctic and Antarctic to assess the impact of the Arctic Oscillation or the Antarctic circumpolar wave on ice thickness.

8. In the Antarctic, long-term IPS measurements are essential in least three locations: East Antarctica, Bellinghausen Sean, and Ross Sea/Weddell Sea. are essential

9. An IPS network should be part of the global ocean observing system to measure ice fluxes in certain key regions (i.e., Fram Strait, and others).

10. International collaboration is needed to gain access to National Economic Zones for IPS monitoring.

11. Combining IPS and Radarsat Geophysical Processor System (RGPS) in a modeling effort should be tested.

5. Meeting Attendees

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6. Meeting Agenda

Monday, 1 July 2002			
09:00-09:15	Meeting opens	Local arrangements Introductions	Koni, Chad, Tordis
	Session 1: Scientific Issues and Past Activities		
09:15-10:30	Scientific issues	Different pack-ice environments Estimating the global volume of sea ice Seasonal and interannual cycles of variation, trends Documentation of pack-ice features Pack-ice processes	Ian/Eberhard
	Previous workshops	Summary of reports Status of recommendations Continued relevance or changing context	Koni
10:30-11:00	Coffee Break		
11:00-12:30	Past and present observations	Deployments made (where, when, instrument type) Data status Data archives and access Current deployments Global inventory of IPS instruments	Representative from each group Terje/Florence on archives
12:30-13:30	Lunch		
	Session 2: Instruments and Moorings		
13:30-15:00	Instruments And instrument comparison	Comparability of data from different instruments Echoes from ice and the significance of target strength Advantages to operation with gain calibrated sonar Surface-detection algorithms in use Sampling intervals, gain and dynamic range of operating IPS Signal parameters recorded Deficiencies and possible improvements in surface detection Sensitivity to false targets (bubble clouds, icebergs) Measurement of ice velocity – sonar, satellite tracking, drift buoys	Povl Humfrey/Ian
15:00-15:30	Coffee		
15:30-17:00	Moorings	Influence of IPS depth on observational efficacy (field of view, correction for sound speed, calculation of depth, sensitivity to tilt, signal-to-noise factors) Iceberg avoidance Approaches to the reduction of mooring motion (pitch, roll, draw-down, draw-over) – eddy shedding, surface waves, response to ocean current Methods for deployment and recovery of moorings in ice-covered waters	Humfrey

Tuesday, 2 July 2002			
	Session 3: Data Processing and Calibration		
09:00-10:30	Processing	Ocean waves, non-hydrostatic conditions Identification and elimination of false targets (bubble clouds, icebergs, etc.) Corrections for mooring motions Methods for interpolation between calibration points of zero draft	John
10:30-11:00	Coffee Break		
11:00-12:30	Calibration	Identification of ice-free calibration targets Sea-level pressure in remote areas Corrections for bias associated with the sonar field-of-view. Sensitivity to ice topography	
12:30-13:30	Lunch		
	Session 4: Archival of IPS Data		
13:30-15:00	Required Data and Documentation	Specification of accuracy and precision Conversion of ice draft by sonar to ice thickness Consolidation of ridged ice and the relationship between ice draft by sonar and ice-mass per unit area Ideas on problems of low ice concentration – ice velocity, surface waves, bubble clouds. Are low-concentration data reported or disregarded?	Terje/Florence
15:00-15:30	Coffee		
15:30-17:00	Manned Submarines	Status of sonar data from US, UK, French and Russian nuclear submarines Strengths and weaknesses of submarine data Complementary aspects Combining data sets from moorings and submarines	Florence/Peter

Wednesday, 3 July 2002			
	Session 5: Integration of Eulerian Ice-Draft Data with Spatial Surveys		
09:00-10:30	Statistical Issues	Time-referenced or space-referenced statistical measures Sampling error: useful averaging distances and averaging times for statistical measures Uncertainty associated with pack-ice inhomogeneity and anisotropy	Peter
10:30-11:00	Coffee Break		
11:00-12:30	AUVs	Present initiatives in AUV-deployed IPS Aspects complementary to moored IPS, and vice versa Challenges Insights to AUV deployment from operation of moored IPS	Peter/Yasushi
12:30-13:30	Lunch		
	Session 6: The Future		
13:30-15:00		Field inter-comparison trials (different instruments and deployment strategies) National and international initiatives Reducing the costs Emerging technology Expanding the observational network in the Arctic Expanding the network to the seasonal sea ice zone and the Antarctic	Ian/Eberhard
15:00-15:30	Coffee		
	Session 7: Summary and Recommendations		
15:30-17:00		Discussion Recommendations Timetable	Koni/Chad