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AMOC

Task 1

Compilation and analysis of existing ocean and ice data

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Project coordinator: Ola M. Johannessen,
Nansen Environmental and Remote Sensing Center,
Edv. Griegsvei 3A,
N-5037 Solheimsviken-Bergen
Norway

Authors:

Torill Hamre, Ola M. Johannessen, Peter Wadhams, Klaus Hasselmann, Leonid Bobylev, Vibeke Jensen Haugen, Hanne Sagen, Norman R. Davis, Arthur Kaletzky, Ernst Maier-Reimer, Igor B. Esipov and Konstantin A. Naugolnykh,

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Nansen Environmental and Remote Sensing Center

Edv. Griegsvei 3a,
N-5037 Solheimsviken, Bergen
NORWAY.
Phone: +47 55 29 72 88 Fax: +47 55 20 00 50
e-mail: administrasjonen@nrsc.no
Internet: http://www.nrsc.no/

NERSC

a non-profit environmental research center affiliated with the university of Bergen

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AMOC partners:

Nansen Environmental and Remote Sensing Center, Bergen, Norway
Max Planck Institute for Meteorology, Hamburg, Germany
Scott Polar Research Institute, United Kingdom
Nansen International Environmental and Remote Sensing Center, Russia

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1. Introduction

This report describes the work done in Task 1 in the first year of the AMOC project, and outlines plans for data handling in other tasks in the remainder of the project.

In this report, the focus is on establishing a list of data sources which can be used to generate input data to the simulation models in Task 2, 3 and 4, and on providing references from which more details can be retrieved by the partners, as needed, when more scenarios are defined.

1.1 Project objectives and goals

The overall objective of AMOC is to develop and design an acoustic system for long-term monitoring of the ocean temperature and ice thickness in the Arctic Ocean, including the Fram Strait, for climate variability studies and global warming detection.

The approach of AMOC is to detect and quantify global warming in the Arctic Ocean, using gyre scale acoustic long range propagation for basin wide ocean temperature and ice thickness changes. Acoustic propagation, which has been successfully tested for climate monitoring in other oceans, will be an important component in addition to remote sensing of sea ice from satellites, in situ observations and modelling. An acoustic monitoring system can potentially be used to verify such warming in the Arctic Ocean. AMOC has the following specific objectives which are organised as separate tasks:

1: Data compilation and analysis: Compilation and analysis of existing ocean and ice data (i.e. temperature, salinity and speed of sound fields, ice thickness, concentration and extent) from the Arctic Ocean for use in climate and acoustic models.

2: Climate and ice modelling: Simulation of present and future ocean temperature, salinity and speed of sound fields, ice thickness, concentration and extent in the Arctic Ocean, caused by natural variability and global warming scenarios, to be used as input to acoustic modelling.

3: Acoustic modelling of Arctic basin: Simulation of present and future basin-wide acoustic propagation using natural variability and global warming scenarios (input from climate and ice modelling) to investigate the sensitivity of acoustic methods for global warming detection.

4. Acoustic modelling of the Fram Strait: Simulation of present and future acoustic propagation in the Fram Strait to investigate the sensitivity of acoustic methods for monitoring heat and volume fluxes in an area of strong mesoscale eddy activity.

5: Acoustic monitoring: Design of an optimal acoustic monitoring system for climate change detection in the Arctic Ocean including volume and heat fluxes in the Fram Strait.

The unique combination of the underwater acoustic remote sensing with satellite remote sensing of the ice cover including modelling and data assimilation, in the predicted sensitive climate region of the Arctic Ocean, is perhaps the key solution to monitor global climate changes and early detection of global warming. The elements and structure of AMOC is shown in Figure 1, illustrating that Task 1 will provide the other tasks with input data for model runs. This input will be through distributing sample data sets along a first set of profiles chosen in year 1, and by compiling a common repository of ice and ocean data that can be used by the modellers in the remainder of the project.

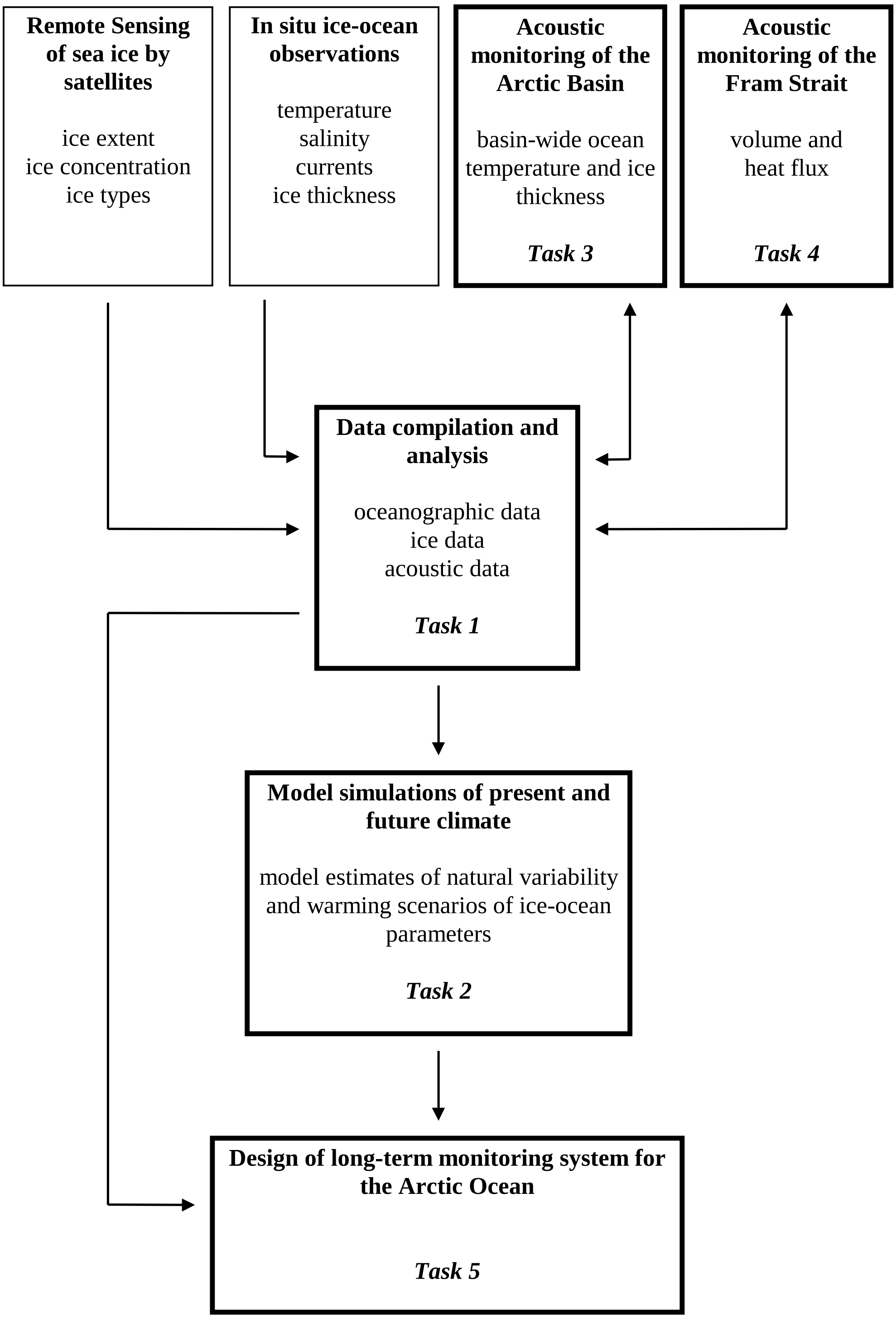


Figure 1. The elements of AMOC. The tasks indicated by bold boxes will be addressed in this study.

1.2 Task 1 objectives and methodology

Task 1, “Compilation and analysis of existing ocean and ice data” is divided into two subtasks:

- Subtask 1.1 Compilation and management of ice-ocean data
  - The goal of this subtask is to collect and document available data on ocean temperature, salinity, density, speed of sound, ice thickness, ice concentration, ice extent, and acoustic data, in the Arctic Ocean and the Fram Strait.
- Subtask 1.2 Analysis and preparation of data sets for climate and acoustic modelling
  - The goal of this subtask is to generate input data for the numerical models in Task 2, 3 and 4, after having ascertained their quality through analysis of parameter values and associated documentation (i.e metadata, such as calibration, error estimates, etc.).

For Task 1 the objectives have been further elaborated as:

- collect information on data sources with relevant ocean and ice parameters for the Arctic Ocean to be used as input to climate and acoustic models
- document the contents of the data sets that are found
- get an overview of where data are located and their time of acquisition (season)
- perform data analysis to ensure that realistic values are generated for the simulation models
- obtain specifications of desired model input (area, season, resolution, etc.)
- prepare input data for Task 2, 3 and 4
- determine procedures for data transfer
- recommend a common data format to be used in the project
- prepare and distribute data to the partners

Collecting information about available data sources and their extension in space and time has finished, and is documented in Chapter 3 and 4. However, some of the activities defined above will continue throughout the remainder of this project, as outlined in the next section. Some initial profiles have been selected and data distributed to the partners (Section 2.3-2.5), using a format agreed upon by the partners (Section 2.5). The first data delivery was prepared on CD and diskettes, while the final data delivery from Task 1 will be gathered on a new CD to be made available to the partners at the 12 month progress meeting.

1.3 Data handling needed in other tasks

Task 1 has to major outcomes:

1. a sample set of of input data to the climate/acoustical models
2. a repository of data sources from which input for new scenarios can be generated

The first part will be used in the initial runs of the various models (Chapter 4), while the second part will be used for extracting input data for new scenarios to be defined in year 2+3. The work of extending the data repository and making new data sets known to the partners will be the responsibility of Task 2-4, and all partners will be involved in this work. Which types of data and what resolution/accuracy are needed will depend on the scenarios developed and the partner owning or obtaining the data will be responsible for providing a description of their contents and structure to the other partners that want to use the same data sets within the AMOC project.

2. Work performed in Task 1

2.1 Subtask 1.1 Compilation and management of ice-ocean data

2.1.1 Work carried out at NERSC

This subtask started with an investigation of data sources listed in the Work Programme [1], and additional sources which are currently available through Internet, on CD-ROM or by the courtesy of the AMOC partners. Some of these data are available on a grid, but with a coarse resolution, on the order of 50-200 km, making them best suited for the climate models and for intial runs of the acoustical models. Other data sets, typically from field experiments, have a much higher spatial resolution, but are available for a shorter period of time, and most often obtained in the seasonal ice zone in the Fram Strait. These high resolution oceanographic and ice data will be used in the acoustic models in Task 4.

A summary of oceanographic data sets found is presented in Table 1, including an outline of data source, parameters included in each data set, season of data capture, area covered, resolution and medium on which the data are held. Examples of data sets are shown in Chapter 3, along with descriptions of the respective data sources.

NERSC has obtained the data sets from external sources on CD-ROM, and extracted data from own projects from local media. The list will serve as a reference for the rest of this project, from which mode input data can be extracted as new scenarios are defined.

Table 1. Oceanographic data sets.

Data source	**Parameters/Season**	**Area/resolution**	**Medium**
LEVITUS	temp, sal, NO3, O2SAT, PO4, PO4, O2, SIO2 / annual, monthly (temp) and seasonal (sal, temp)	Global coverage / 1 value per 1.0 square deg.	CD [7] and WWW (ftp)
Arctic Ocean Atlas	temp, sal, density, water layer depth, dynamic height, bathymetry / annual (water layer depth and dynamic heigth), winter and summer stations (temp, sal), decadal (temp, sal, density - 1950-59, 1960-69, 1970-79, 1980-89, 1950-89)	Arctic Ocean Basin / ca. 170 km grid (water layer depth), ca. 180 km grid (dynamic height), 200km grid (winter stations), 50 km grid (decadal data and bathymetry).	CD [4]
CEAREX-1 CD	bathymetry (single tracklines and 10x10km grid), biophysical data (CEAREX), hydrographical data (also other experiments), met.data (also other experiments), acoustical data, positions (of camps), sea ice data (accel., deformation, stress) / mainly CEAREX Sep.’88-May ’89, other exp. from ’78 to ’87.	Fram Strait and the Arctic Ocean Basin / varying resolution, point measurements	CD [5]

NCEP/NCAR REANALYSIS	Pressure level data, surface data, surface flux data, other flux data, tropopause data, T62 spectral coefficients / every 6 hour from 1 January 1958 - 31 December 1996	Global coverage / 1 value per 2.5 square deg.	CD [6] (one CD per year) and WWW
AOGC'96 and '97 (NERSC)	Temperature, salinity, speed of sound / summer '96 & '97	Fram Strait (79 deg.N) / varying resolution in range	File Data report [3] [8]
VEINS'96 and '97 (NPI , Norwegian Polar Institute)[1]	Temperature, salinity, speed of sound / summer '96 & '97	Fram Strait and Arctic Ocean Basin / varying resolution in range	
Dept. of Geophysics, University of Bergen	Ocean currents, 1984-85, 1985-86	Fram Strait / data from separate locations where moored buoys were put	Data report [21] [22]

[1] Ocean current data from VEINS'97 data will become available in the first half of 1999. Agreements on the use of these data must be agreed upon with the responsible scientist, Dr. Ole Anders Nøst, at NPI. The other parameters have not been requested since these can be provided by the AOGC cruises.

2.1.2 Work carried out at SPRI

Analysis of UK and US submarine sonar data

An analysis of upward-looking and sidescan sonar data collected by the Royal Navy in a series of submarine voyages between 1976 and 1996 has been carried out and presented in an agreed statistical format for comparison with US datasets currently being released, in collaboration with Dr. W.B. Tucker III at CRREL (US/UK agreements on data presentation). The analysed data will be included in an international data management system to permit greater coverage of the Arctic Basin for the study of changes to the ice cover in response to climate variation.

The relevance of the work carried out here is to measure systematic changes in ice thickness which may be persisting within a region of high climatic sensitivity repeatedly sampled by UK submarines since 1971. This will provide essential input to ice-ocean modellers seeking ice thickness data to test models which use real-time forcing; and will be helpful for understanding Arctic ice mechanics. As part of a continuing long-term collaboration with the Royal Navy, Peter Wadhams sailed aboard a Trafalgar-class submarine to the Greenland Sea and Arctic Ocean in August-September 1996, during which 5000 km of under-ice sonar profile and along-track oceanographic data were acquired. These data have now been released and the present task has been to analyse and interpret the ice thickness data to test for Arctic climatic trends in ice thickness to keep in step with US investigators working with data from a near-concurrent US cruise. In addition we have been reanalysing past submarine datasets, in the same format, in order to make them more readily available to the scientific community, and have identified four earlier cruises (1976, 1979, 1987, 1991) as being suitable for analysis in this way.

Objectives

To analyse upward-looking sonar from the August-September 1996 RN submarine cruise to the Greenland Sea and Eurasian Basin of the Arctic Ocean, in the same way as similar datasets collected almost simultaneously (1-2 months later) in the Canada Basin of the Arctic Ocean by the US SCICEX (SCientific ICe EXperiment) civilian submarine programme of NSF, and thus achieve a basin-wide compatible dataset for comparison with ice-ocean models.

Technical Approach

The Royal Navy carried out a submarine survey of the Greenland Sea and Arctic Basin during August-September 1996 which was similar in concept to those of "Superb" in 1987 and "Sovereign" in 1976. In addition, SPRI has US data collected by "Gurnard" in the viscinity of the Beaufort Sea and the Alaskan Shear Zone, Figure 2 is a schematic map of this cruise and the regions covered by earlier cruises including East Greenland Current through Fram Strait to the North Pole. The timing of the 1996 cruise was almost simultaneous with a US cruise in the 6-year SCICEX series of submarine cruises for civilian scientific purposes (1993-9), covering a region of the Canada Basin extending to the North Pole during October 1996. Figure 3 shows the area covered by successive SCICEX cruises, the so-called "Gore Box" together with the area covered by RN cruises since 1971. The operational regions are complementary, with a small overlap in the vicinity of the North Pole, permitting data compatibility tests. There is thus an opportunity to achieve full trans-Arctic coverage in ice thickness data so long as near-concurrent UK and US cruise data are analysed in the same way. This was a major conclusion and recommendation of a recent Sea Ice Thickness Workshop in Monterey, convened in April 1997 by the ACSYS Programme, and we have already designed analytical procedures which are identical with those of the responsible US data analyst (Dr. W.B. Tucker III, Head of Snow and Ice Branch, US Army Cold Regions Res. & Engineering Lab., Hanover NH) with whom we are closely in touch.

Data Preparation

The Type 780 chart-roll data has beeen processed in the same way as data from several previous cruises in 1976, 1979, 1985, 1987 and 1991, which used the same instrument. Firstly the raw data has been reduced, taking account of submarine speed and depth variations, and regional changes in sound velocity profile above the boat, defined by XBT and XSV launches (which rise close to the sea surface before sinking). In summer there are sufficient open leads to use to define a sea level, rather than rely on a pressure sensor corrected for atmospheric pressure variations using data from the International Arctic Buoy Program, although this technique can be used in regions where leads are scarce. A further correction is applied for the effect of the beamwidth, using the method developed at SPRI and previously reported, then a primary set of statistics is generated for individual 50 km sections and mean statistics for degrees of latitude. These are a standard set of of submarine statistics recommended for extraction from all submarine cruises by the WMO ACSYS programme as a result of the April 1997 Monterey Sea Ice Thickness Workshop.

Submarine Statitics

These analyses of upward looking sonar include data which has been pre-processed to consecutive series of ice draft measurements at 1 metre intervals, for analysis in 50 km sections and then combined to furnish statistics for each degree of latitude. The statistics will include probability density functions for ice draft, level (undeformed) and rough (deformed) ice, polynya/leads and pressure ridges, all of which are tested for goodness of fit for exponential and log-normal distribution. Draft pdf’s will cover the range -1.0 (to allow for sonar discrepancies) through 50 metres expressed as % probability for the pdf defined in 0.1 metre categories and as % probability/% cumulative probability for pdf’s defined in 0.5 and 1.0 metre categories.

Open water is defined as less than a minimum draft of 0.3, 0.5 and 0.7 metres for the distribution of polynya and leads, which will be expressed as along track width and spacing pdf's for each of the designated minimum drafts. The range of widths covered is 5 to 1000 metres and the spacing range is 5 to 5000 metres expressed as % probability, % cumulative probability and number per 100 km.The level/rough ice type criterion is based on the occurrence of between point slopes greater than 1:20 over an interval length greater than 10 metres, and the analysis includes a draft distribution for each ice type, a distribution of level, rough and all segment lengths and a distribution of level, rough and all segment mean draft. The range of drafts and segment mean draft is -1.0 to 50.0 metres which, as for overall draft, are defined in 0.1,0.5 and 1.0 metre categories and the segment length analyses cover the range 10 to 2000 metres; all pdf's are expressed as % probability and % cumulative probability. Pressure ridges are defined by the Rayleigh criterion, subject to a minimum draft of 2.5 metres and ridge draft and spacing distributions are calculated for all ridges detected, greater than 5.0 metres and greater than 9.0 metres. The ridge drafts are again analysed in the range -1.0 t0 50.0 metres in 0.1, 0.5 and 1.0 metre categories, and ridge spacing in the range 5 to 5000 metres; the pdf's are expressed as % probability and % cumulative probability for each of the draft criteria.

With the ice thickness data analysed, comparisons have been made with earlier data sets obtained since 1976 in the same region (Table 2), to test for interannual and interseasonal variations and trends in thickness and other morphological parameters. There is evidence of a significant decrease in mean ice draft between 1976 and 1987 and this trend appears to have continued, based on an analysis of data received from 1991 and the very open ice conditions experienced at all latitudes in 1996.

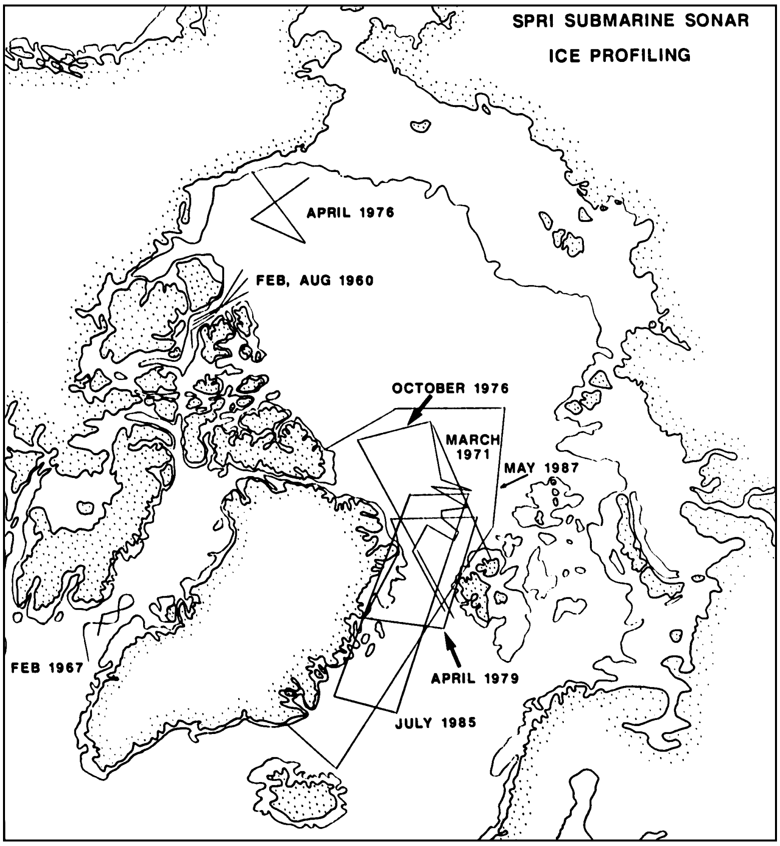


Figure 2. Submarine Profiling Areas

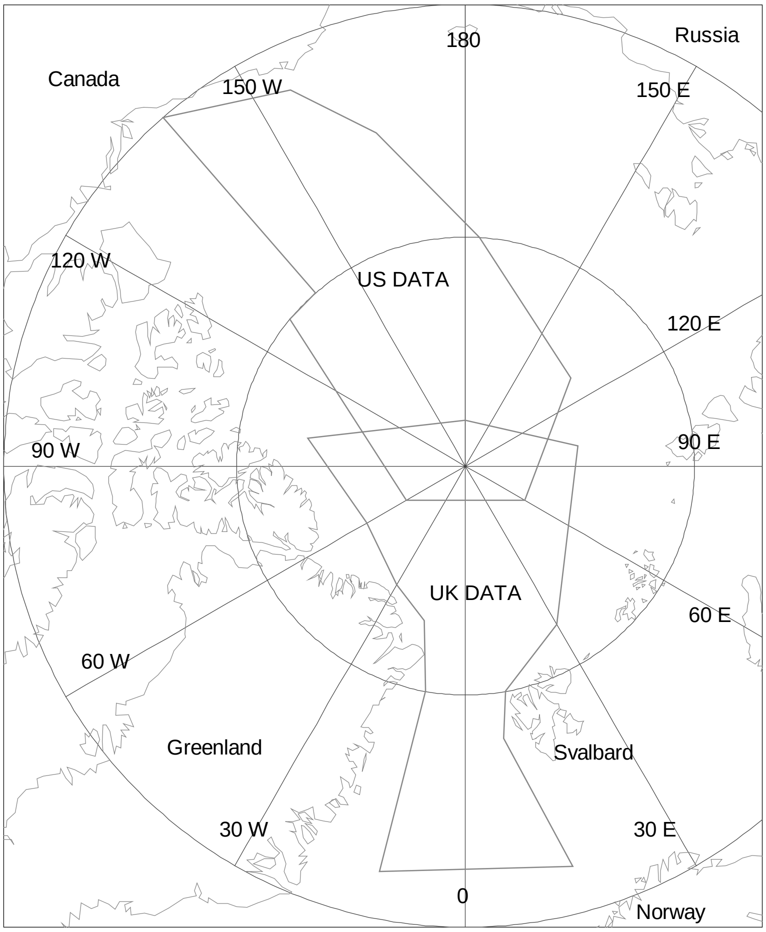


Figure 3. SCICEX Cruise Area (Gore Box) & Overlapping UK Areas.

Table 2. RN/US cruises analysed.

Year	Boat	Route
1976	Sovereign	80-90°N, 25°E - 70°W
1976	Gurnard	See Figure 2
1979	Sovereign	Fram Strait, 79°-84°N
1987	Superb	73°-90°N, Eurasia
1991	Tireless	Fram Strait and NW
1996	Trafalgar cl.	As Figure 2.

2.2 Subtask 1.2 Analysis and preparation of data sets for climate and acoustic modelling

2.2.1 Work carried out at NERSC

The following data sources have been investigated to extract input oceanographic data for the acoustical models in Task 3 and 4:

- The Arctic Ocean Atlas CD [4]
- The CEAREX-1 CD [5]
- AOGC'96 and AOGC'97 field experiments [3] [8]

The first CD contains both profiles and gridded data, while the latter two sources contain only profiles. The gridded data have a low resolution compared to that of the field experiment data, but cover the entire Arctic Basin. Data from field experiments, on the other hand, have much higher spatial resolution, but are available for a much smaller area (and for a shorter period of time).

The location of these data sets have been plotted, and used in Task 3 and 4 to select case study areas. There are two main categories of study areas: (1) the Arctic Basin, which will be investigated using profiles across the North Pole in Task 3, and (2) smaller, strategic areas in the Fram Strait, which will be studied in Task 4.

Data from the Arctic Ocean Atlas CD and the CEAREX-1 CD have been investigated, and some examples of these data are included in Section 3.2. For the data deliveries in Task 1, selected profiles have been extracted (see Section 2.3).

Data from AOGC'96 and AOGC'97 field experiments have been compiled and analysed, and from the measured parameters, sound speed has been derived from the CTD and Seasoar data sets, using Medwin's formula [9].

Other potential data sources for the acoustical and climate models to be used in AMOC have also been investigated with the aim to get an overview of available parameters for a region-wide or global area. These data sources include the LEVITUS database [7] and data from the NCEP/NCAR Reanalysis project [6]. Data from these sources will be used to augment the other data sources, based on requests from the modellers working on the project.

The issues of format of the data to be exchanged have been discussed, and the conclusion is that ASCII files will be the most suitable form for these data. This will make the files readable on all computer platforms, and hence make it easier to use the files, provided that a proper description of the format is distributed along with the data. The drawback of pure text files is that they will be larger than a binary file with the same contents, but this is not likely to cause any problems for the data deliveries of Task 1, since these will only consist of a limited number of data sets.

Selection of high resolution oceanographic and ice data from the data delivery CDs and internal archives will continue in the remainder of the AMOC project, as part of the simulations performed for the different areas of interest in Task 3 and 4.

2.2.2 Work carried out at SPRI

The data used for the ice model was obtained using upward-looking sonaron a submarine cruise in 1987. The cruise was between latitude 80N and 90N, longitude 005W and 005E.

Data is granularized by 1 deg lat. granules in all cases. Long. is classified. Within each granule we have the following data classes:

- Ice drafts in 0.1m bins, 0-50m range
- Level ice drafts, as above
- Rough ice drafts, as above (level:rough ice criterion: 10.0 slope) etc.
- Leads and polynyas.

The ice classification and statistics are done according to well defined criteria specified in a data description document. At present, the document is available only in rich text format (.rtf). Both the data description document and the data have been made accessible to the AMOC partners on the SPRI ftp server:

ftp://amocdata@pwd5-sig.spri.cam.ac.uk

The password is available from A. Kaletzky of SPRI (ak283@cam.ac.uk).

The data are described in Wadhams (1998) [48].

The above ice model is to be used as a-time independent model of the ice cover. It shall be used with atmospheric and ocean models from different epochs.

2.2.3 Work carried out at MPI

The main objective is the deliverance of time-varying hydrographic sections and the velocity components within and perpendicular to the sections along the proposed sound tracks by use of a general circulation model. Three requirements for the configuration of the model follow from the basic goals of AMOC:

1) High spatial resolution in the Arctic Ocean.
2) Suitability for multiple medium range (i.e. several decades) runs.
3) Minimization of erroneous signals that may evolve almost inevitably at open boundaries of regional models.

To compromise these requirements we develop a circulation model that is formally global but with strongly enhanced resolution in the region of interest. This is achieved by a conformal shift of the geographical poles to the location "summit" on Greenland at 77 N and 40 W, and "Tura" at the lower Tunguska at 64 N and 100 E. Denoting the vectors from the center of earth to the defined poles by X1 and X2,

$$(X1+X2)Y = 2.$$

By projection from -(X1+X2)/2 of the globe on this plane we get a stereographical projection which is known to be conformal.

The focussing onto the Arctic Ocean is now achieved by identifying the polar positions with the points (2,0)and (-2,0) from a standard stereographic projection from an equatorial point. We choose formally a two degree model with refinement of "meridional" resolution towards the Greenland pole according cos(phi) in the standard projection. Figure 4 shows the gridlines for the Arctic Ocean. The light grey indicates shelf regions with depth less than 200 m. The vertical resolution is in 20 layers, starting with 20 m at the top and increasing by a factor 1.24 towards depth.

The model is the HOPE (Hamburg ocean model in primitive equations), modified for a C-grid. The construction of the ray tracks is performed similarly to the construction of the grid: denoting by X1 and X2 the geographical position of transmitter/receiver station in cartesian coordinates, the normalised vector product X3=X1*X2 is a unit vector perpendicular to the plain of the great circle running through the two points. The length of the arc follows from the scalarproduct:

phi = arccos(X1X2).

The triple X1,X3,X1*X3 form the complete matrix of transformation from the elementary rotation matrix in the equatorial plain to the geographical coordinates for any line increment n/N. The computation of hydrographic properties, and sound speed respectively, is performed by bilinear interpolation of the nearest surrounding gridpoints.

cos n phi/N	- sin n phi/N	0
sin n phi/N	cos n phi/N	0
0	0	1

The main effort was invested into the development of the model in the given configuration and to code the construction of ray paths according the given recipe. The model was spun up with climatological forcing of Hellerman-Rosenstein windstress, COADS atmospheric temperature, and annual mean surface salinity from the Levitus atlas [7], to which the model salinity is restored in ice-free parts of the water. Figure 4 shows the position of the grid. The resolution around Greenland is approx. 15 km. Parallel to the tuning and spinup of the model MPI started to extract daily forcing fields from the ECMWF analyses. It is expected that the model with this forcing will produce a realistic estimate of the natural variability.

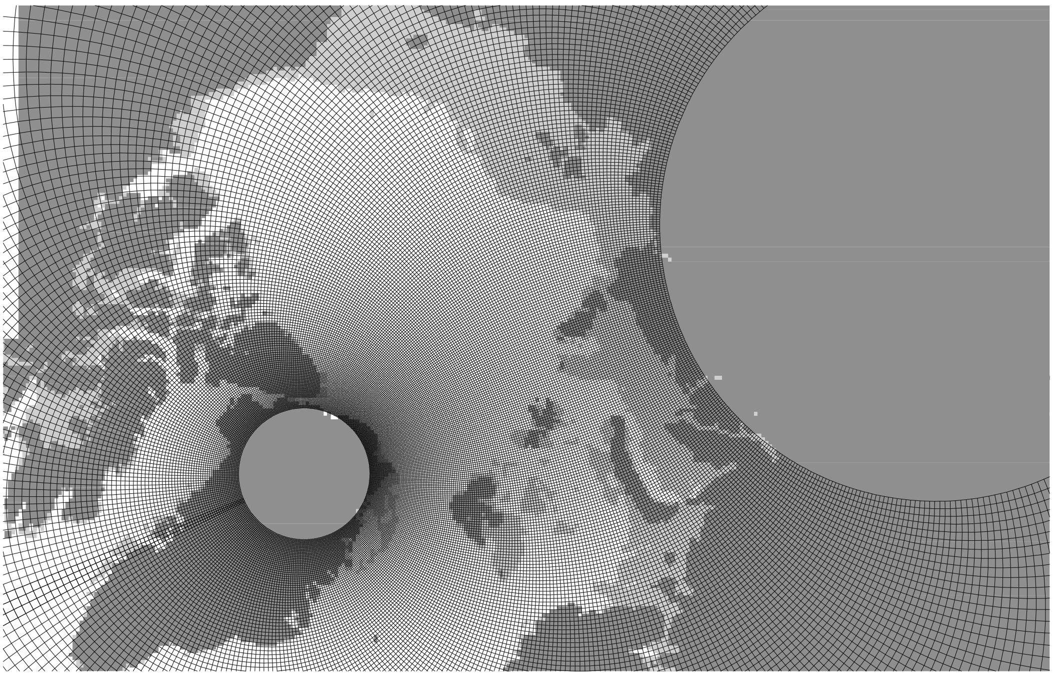


Figure 4. Gridlines for the Arctic ocean climate model run at MPI.

2.3 Data selected for the acoustical models

Based on the availability of acoustic data from the TAP experiment [20], two basin-wide sections have been selected (Figure 5).

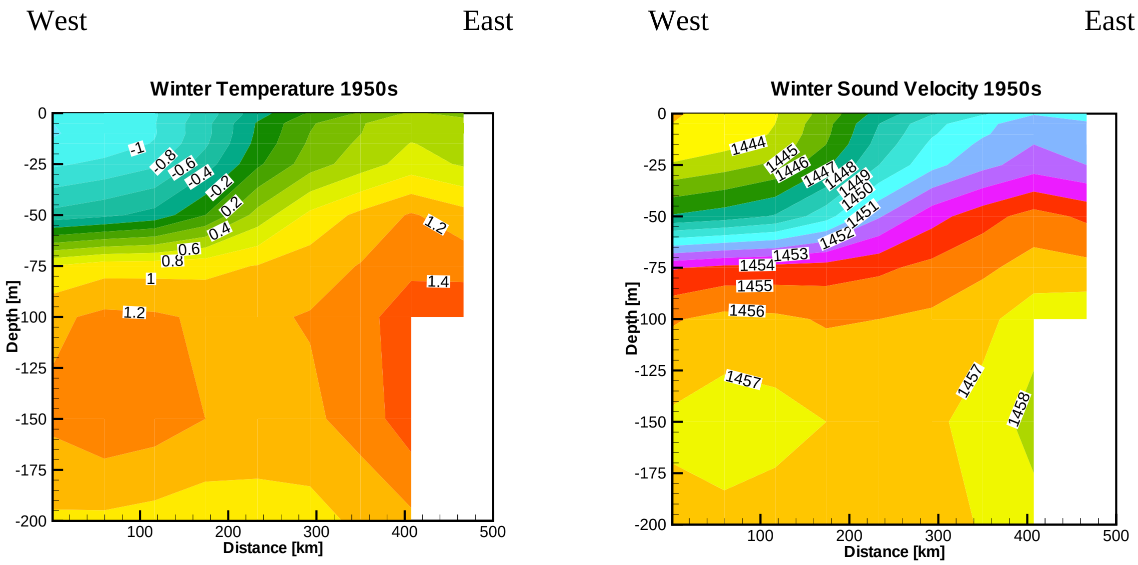
1. TAP profile A: from the Russian source camp “Turpan” at 83.5 deg. N, 26 deg.E across the North Pole and along the 210 deg.E meridian to the receiver camp “Simi” at 72 59.9’ deg.N, 149 35.8’ deg.W.
2. TAP profile B: from the same source camp as for profile A, but ending at the receiver camp “Narwhal” at 83 62.5’ deg.N, 26 deg. E.

Furthermore, a third section has been chosen across the Fram Strait based on the availability of high resolution oceanographic data.

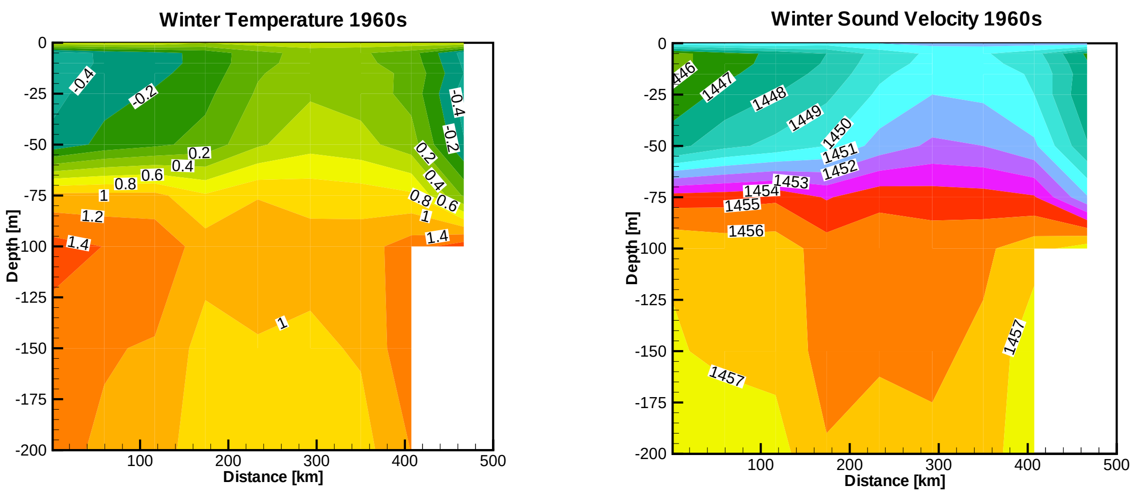
3. Fram Strait profile along 79 deg.N.

From this third profile, data will also be extracted from the Arctic Ocean atlases provided by the Environmental Working Group [4], i.e. averaged decadal data for winter and summer period (Figure 6a-j). On the final data delivery CD these profiles will be included, along with decadal data for the two selected TAP profiles.

Figure 5. Location of TAP-A and TAP-B profiles.

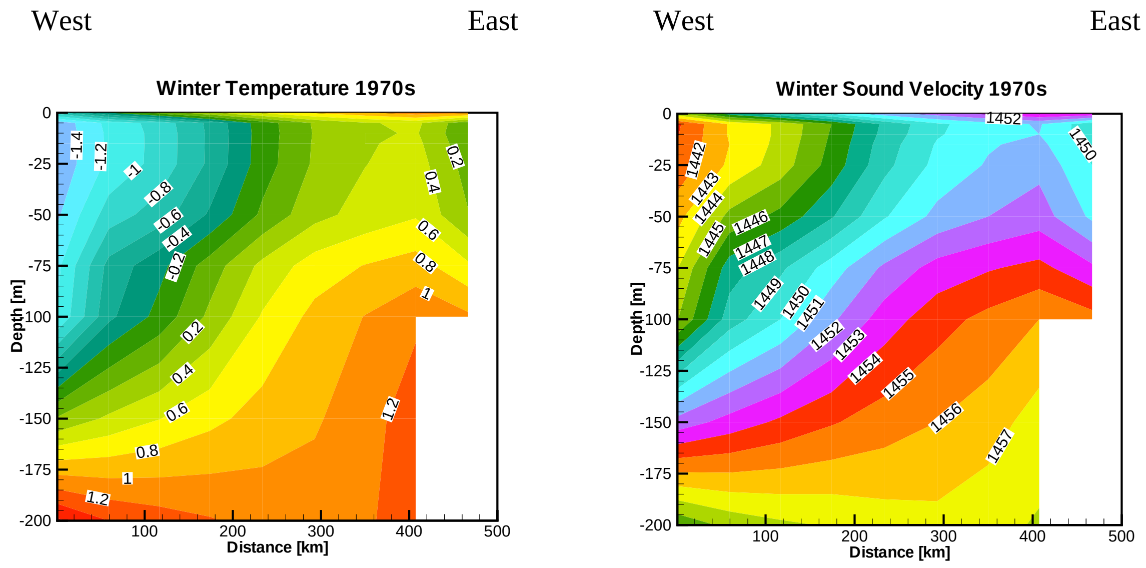


(a) Temperature and sound speed profile across the Fram Strait, 1950-59, winter data.

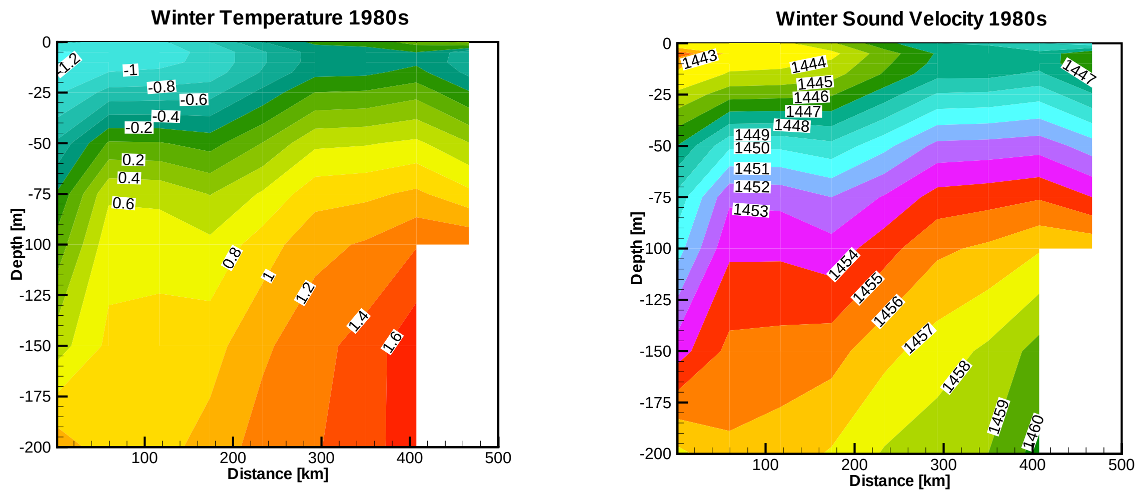


(b) Temperature and sound speed profile across the Fram Strait, 1960-69, winter data.

Figure 6(a-b). Sample profiles of temperature and sound velocity across the Fram Strait from 11°W to 11°E at 79°N, obtained from the Arctic Ocean Atlas CDs **[4]**, where winter data are averaged over months March to May, and summer data are averaged over months July to September. Range resolution is 50km.

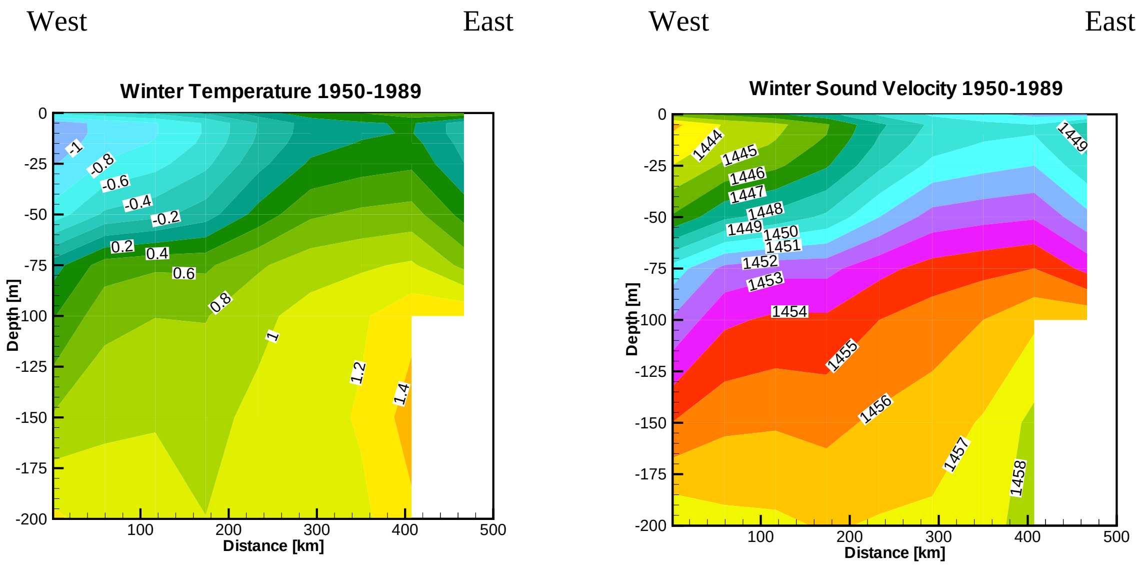


(c) Temperature and sound speed profile across the Fram Strait, 1970-79, winter data.

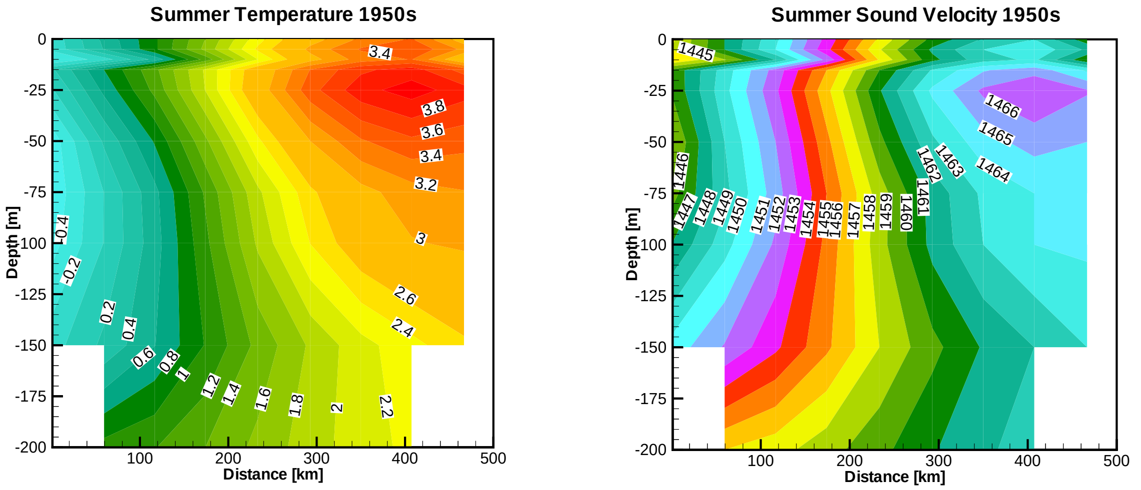


(d) Temperature and sound speed profile across the Fram Strait, 1980-89, winter data.

Figure 6(c-d). Sample profiles of temperature and sound velocity across the Fram Strait from 11°W to 11°E at 79°N, obtained from the Arctic Ocean Atlas CDs **[4]**, where winter data are averaged over months March to May, and summer data are averaged over months July to September. Range resolution is 50km.

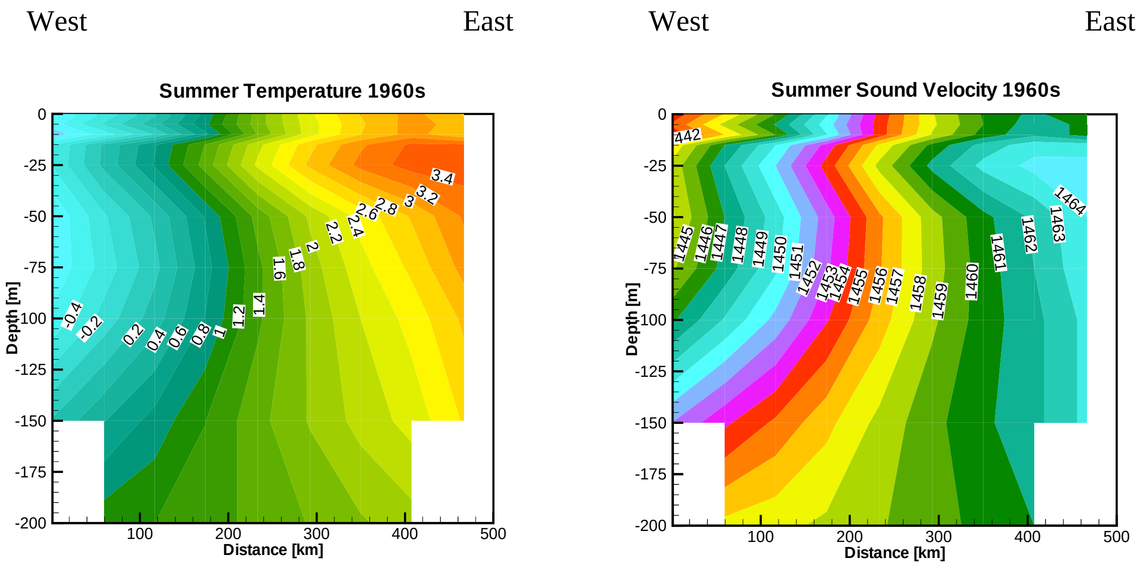


(e) Temperature and sound speed profile across the Fram Strait, 1950-89, winter data.

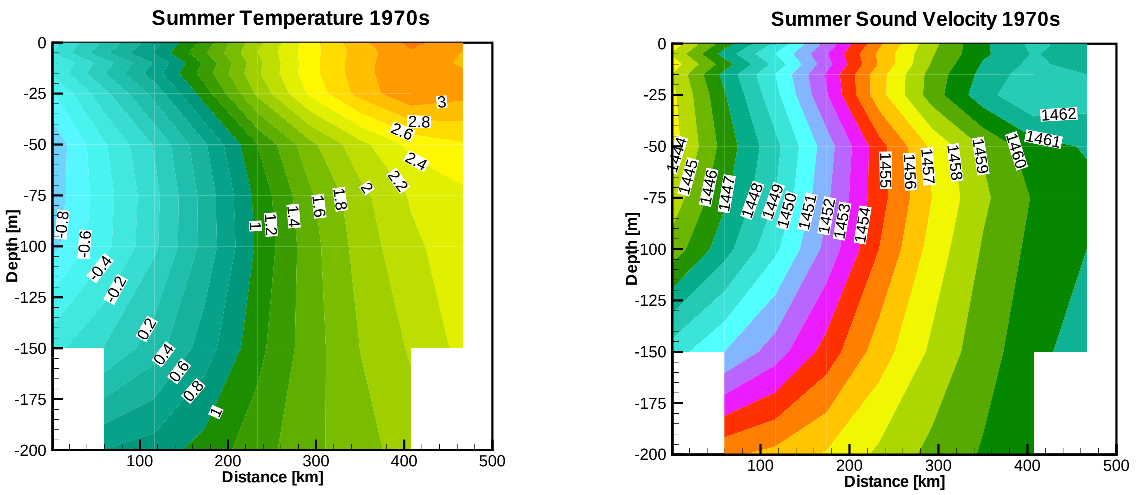


(f) Temperature and sound speed profile across the Fram Strait, 1950-59, summer data.

Figure 6(e-f). Sample profiles of temperature and sound velocity across the Fram Strait from 11°W to 11°E at 79°N, obtained from the Arctic Ocean Atlas CDs **[**4**]**, where winter data are averaged over months March to May, and summer data are averaged over months July to September. Range resolution is 50km.

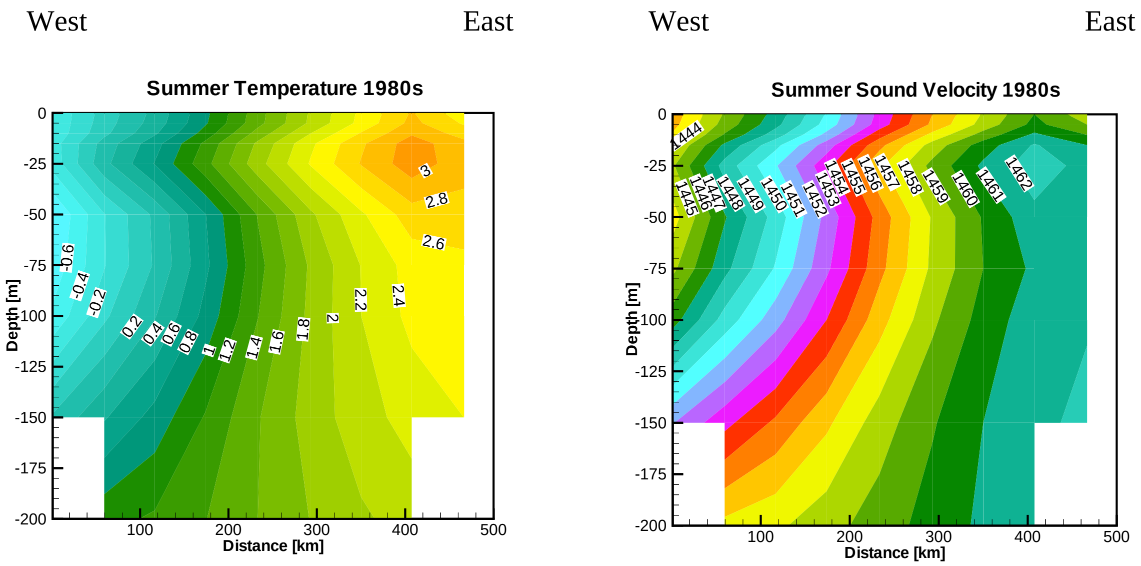


(g) Temperature and sound speed profile across the Fram Strait, 1960-69, summer data.

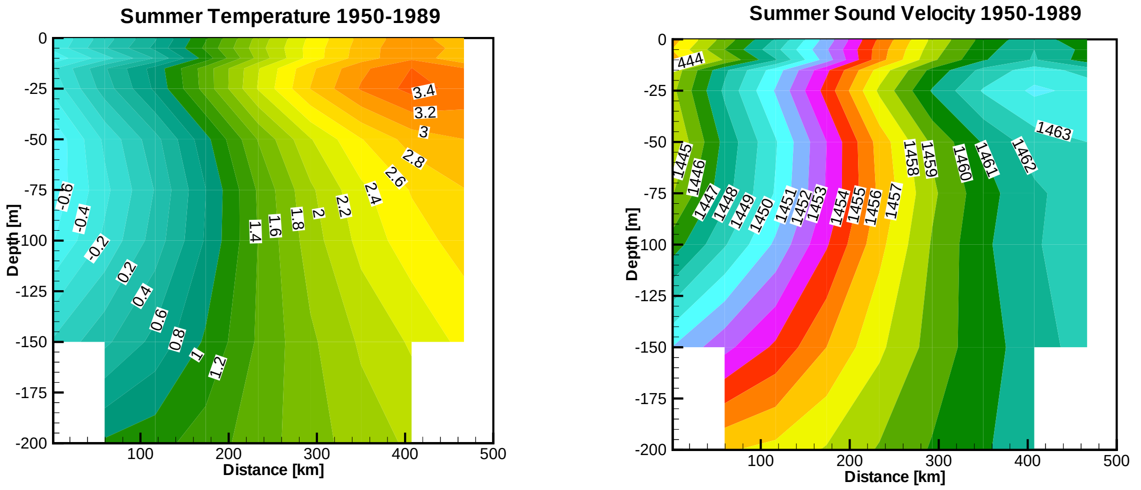


(h) Temperature and sound speed profile across the Fram Strait, 1970-79, summer data.

Figure 6(g-h). Sample profiles of temperature and sound velocity across the Fram Strait from 11°W to 11°E at 79°N, obtained from the Arctic Ocean Atlas CDs **[4]**, where winter data are averaged over months March to May, and summer data are averaged over months July to September. Range resolution is 50km.



(i) Temperature and sound speed profile across the Fram Strait, 1980-89, summer data.



(j) Temperature and sound speed profile across the Fram Strait, 1950-89, summer data.

Figure 6(i-j). Sample profiles of temperature and sound velocity across the Fram Strait from 11°W to 11°E at 79°N, obtained from the Arctic Ocean Atlas CDs **[**4**]**, where winter data are averaged over months March to May, and summer data are averaged over months July to September. Range resolution is 50km.

2.4 Data selected for climate models

For the climate simulations run in year 1 of the AMOC project input data as described in Section 2.2.3 were generated, on the grid shown in Figure 4. An example of output from the models run at MPI is shown in Figure 7.

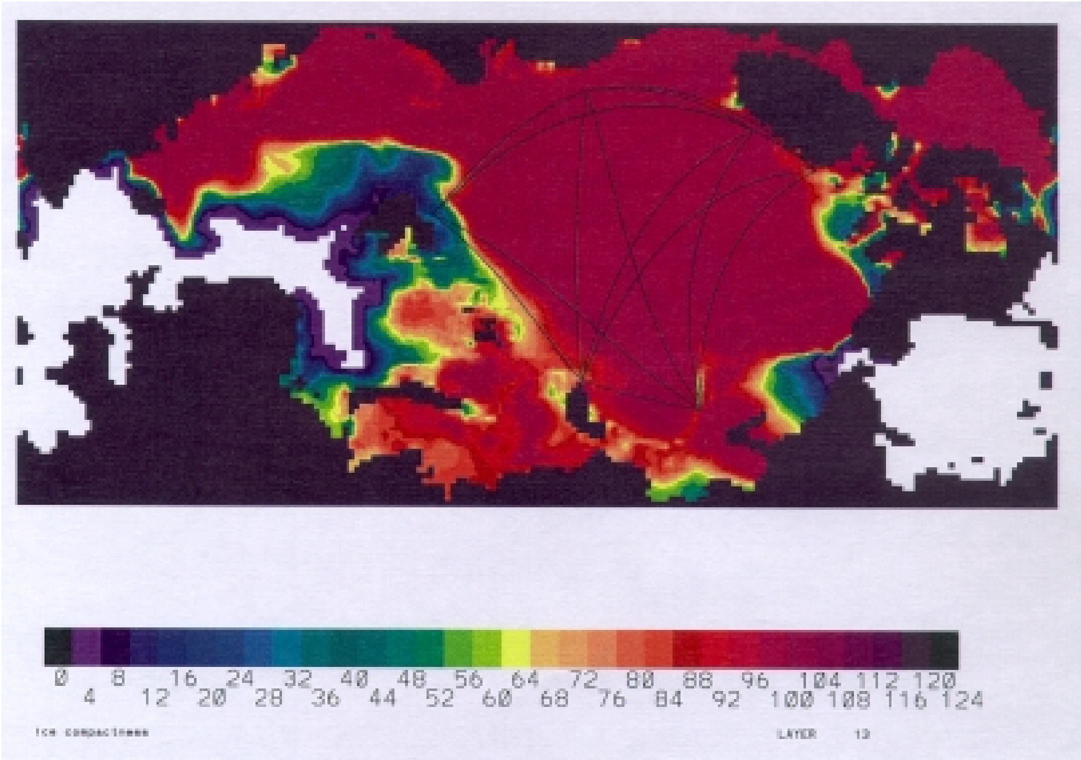
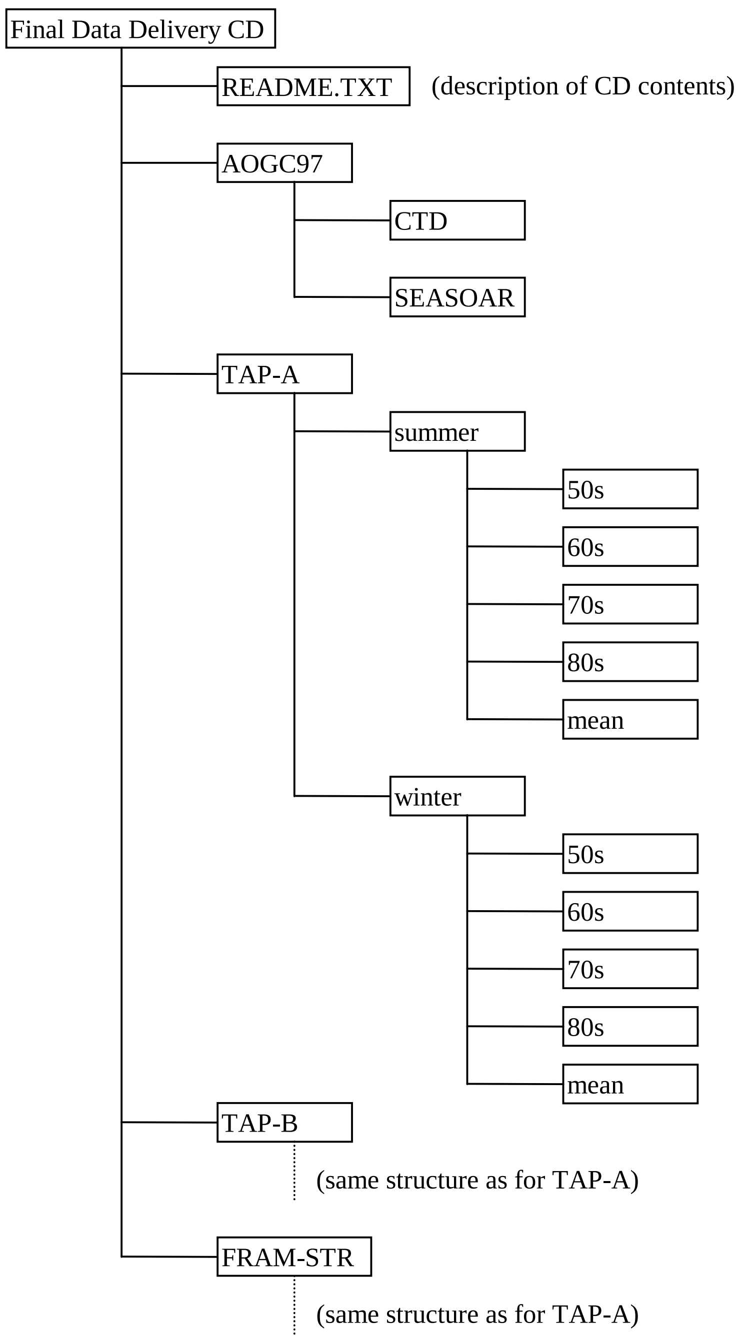


Figure 7. Ice compactness computed by climate models run at MPI.

2.5 Common format for data deliveries

Based on discussions between the partners, it was agreed that data exchange should be done by means of ASCII files, which can easily be read on both PCs and Unix computers. All data files should contain a header explaining its contents, before the parameters values are listed. The data owner is responsible for providing additional information about the data sets, which is required to understand and use them in AMOC. This information should be placed in a separate text file which will describe issues of data values and/or organisation that apply to all data sets of a given type, e.g. all CTD station selected from the AOGC'97 cruise. The descriptive file will be put on the final data delivery CD, which will also contain a overall description of the contents and contact persons for the different data sets, as outlined below.



The following is an example of a data file for a CTD station from the AOGC’97 cruise:

```
* Sea-Bird SBE 9 Raw Data File:
* FileName = C:\SEASOFT\DATA\9718001.HDR
* Software Version 4.214
* Temperature SN = 1598
* Conductivity SN = 1337
* Number of Bytes Per Scan = 15
* Number of Voltage Words = 1
* System UpLoad Time = Sep 16 1997 00:02:48
* NMEA Latitude = 78 52.06 N
* NMEA Longitude = 002 59.71 E
* NMEA UpLoad Time = not available
* Store Lat/Lon Data = Add to Header Only
* Ship: "Haakon Mosby"
* Cruise:18/97
* Station: 001
* depth:  2364
*END*
*        Pr       T090   C0mS/cm     OxML/L      Sal00  Sigma-e00      S-vel
      2.000    -0.3214  27.429234   26.93658    33.2173    26.6820  1445.3533
      3.000    -0.3244  27.427727   27.08054    33.2180    26.6827  1445.3562
      4.000    -0.3248  27.427925   27.09311    33.2181    26.6828  1445.3704
      5.000    -0.3245  27.428436   27.10385    33.2179    26.6826  1445.3876
      6.000    -0.3244  27.429024   27.11576    33.2179    26.6826  1445.4041
      7.000    -0.3235  27.429918   27.12480    33.2176    26.6823  1445.4240
      8.000    -0.3265  27.429924   27.13571    33.2202    26.6845  1445.4294
      9.000    -0.3315  27.431261   27.15108    33.2268    26.6901  1445.4310
     10.000    -0.3324  27.432007   27.16009    33.2283    26.6913  1445.4448
     11.000    -0.3340  27.433350   27.16060    33.2312    26.6938  1445.4573
     12.000    -0.3400  27.437180   27.16724    33.2422    26.7029  1445.4601
     13.000    -0.3543  27.464495   27.18013    33.2938    26.7452  1445.4789
     14.000    -0.2666  27.605801   27.08347    33.3854    26.8154  1446.0258
     15.000    -0.0646  27.848024   26.85856    33.4851    26.8865  1447.1116
     ...
```

Here all header lines start with an asterisk (‘*’) or a letter (in the case of the line explaining the contents of the respective data columns). After that, the data values follow, with one (averaged) measurement per line. The respective columns contain (copied from the accompanying data description file):

```
Pr         - pressure/depth, in meters
T090       - potential temperature, in deg.C, T68 = T90*1.00024
C0mS/cm    - conductivity, in mS/cm
OxML/L     - oxygen, in ML/L
Sal00      - salinity in ppt
Sigma-e00  - sigma-theta, in kg/m^3
S-vel      - sound velocity, in m/s
```

The other data files on the final data delivery CD will be in a similar format, i.e. in ASCII and with a small header explaining the contents before the actual parameter values are listed.

3. Description of data sources

In this section, we provide a description of the contents of the investigated data sources, and give some examples of data sets therein.

3.1 The Arctic Ocean Atlas CDs

The Arctic Ocean Atlas CDs [4] contain oceanographic data from a number of U.S. and Russian sources. The two CDs contain winter and summer data for the Artic region in the period 1950-1989, in form of (1) annual fields, (2) station statistics and profiles for winter/summer periods for each of the four decadal periods 1950-59, 1960-69, 1970-79 and 1980-89, and (3) interpolated to a 50x50km grid over the entire region.

In brief, the parameteres available are:

1. Atlantic water layer depth fields
   - Area covered: central Arctic Basin
   - Grid size: approx. 171x171km.
   - Time range: 33 annual fields (1950, 1954-63, 1965-68, 1970-85, 1988-79), 4 EOF (empirical orthogonal function) fields and one mean depth field.
2. Dynamic height fields (for a reference layer from the ocean surface to a depth of 200m)
   - Area covered: Central Arctic Basin.
   - Grid size: approx. 180x184km.
   - Time range: 37 annual fields (1950, 1954-89), 3 EOF (empirical orthogonal function) fields and one mean dynamix height field.
3. Temperature and salinity station statistics
   - Area covered: Central Arctic Basin and the Nordic Seas.
   - Grid size: 200x200km in the Central Arctic Basin; 100x100km and 50x50km in the Nordic Seas.
   - Time range: 4 decadal periods (1950-59, 1960-69, 1970-79, 1980-89).
4. Verical profiles and transects
   - Area covered: 2 transects across the North Pole, and several profiles in different areas, e.g. the Barents Sea, the Fram Strait, the Greenland Sea and the Chuckhi Sea.
   - Grid size: not applicable (1D data).
   - Time range: 4 decadal periods (1950-59, 1960-69, 1970-79, 1980-89).
5. Gridded data fields of temperature, salinity and density
   - Area covered: entire Arctic region.
     Four interpolation methods were used:
     (1) Spectral Objective Analysis (SA)
     (2) Optimal Interpolation (OI)
     (3) a Russian method called the Vorontsov method
     (4) Generalised Digital Environmental Model (GDEM).
   - Grid size: 50x50km. Winter data on 23 depths from 0 to 4400m. Summer data on 22 depths from 0 to 4000m.
   - Time range: the four decadal periods given above and average for 1950-89.
6. Three-dimensional gridded temperature and salinity fields
   - Two sets of 3D grids, based on the 2D fields, with upper layer with depths from 0 to 500m and bottom layer from 500m to the bottom. The objective interpolation method (OI) was used to generate these 3D data sets.

  - Grid size: 50x50km, 2 layers in z direction. 10m depth resolution in upper layer of set 1 and 100m in the lower layer. 20m depth resolution in upper layer of set 2 and 200m in the lower layer.
7. Bathymetric mask
  - A bathymetric mask for selected depths is also available on the CD, marking which grid points is in the ocean (1) and not (0). This mask was used to generate the 3D grids on the CD.

All digital files are in ASCII format, with some header lines first, followed by the parameter values stored with one data point per line. Information about the location and time range for which the data set apply is usually *not* given in the header, and a combination of file name and organisation of files into directories on the CD has to be used to retrieve the correct file. However, extraction of files is easy by means of a web browser which will use the HTML documents on the CD to guide the way to the desired data sets. The CD also contains a lot of background material in HTML format, which can be displayed on the screen or printed from the web browser.

The grid used on the Arctic Ocean Atlas CDs is shown in Figure 8, and some examples of data sets from these CDs are shown in Figure 9.

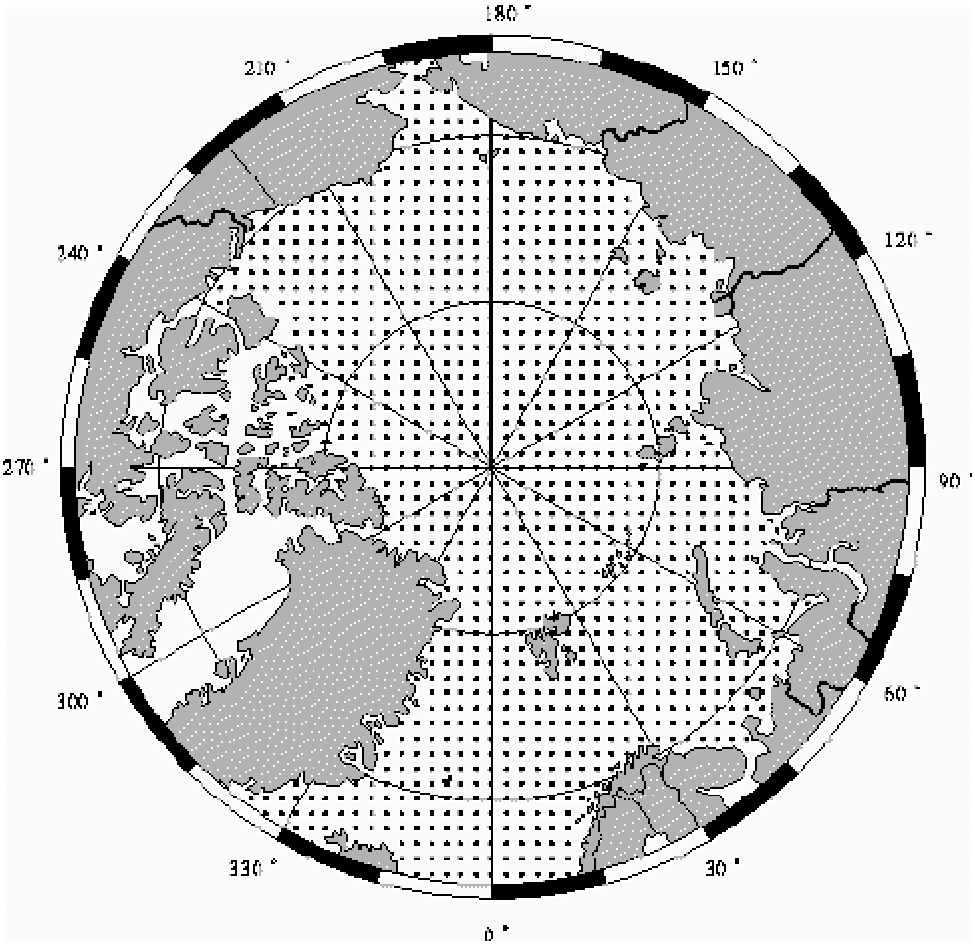
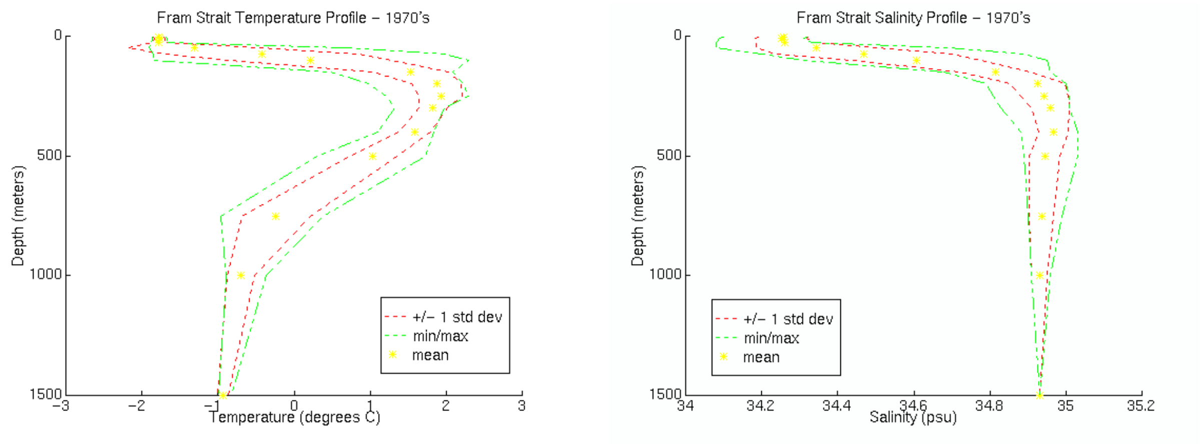
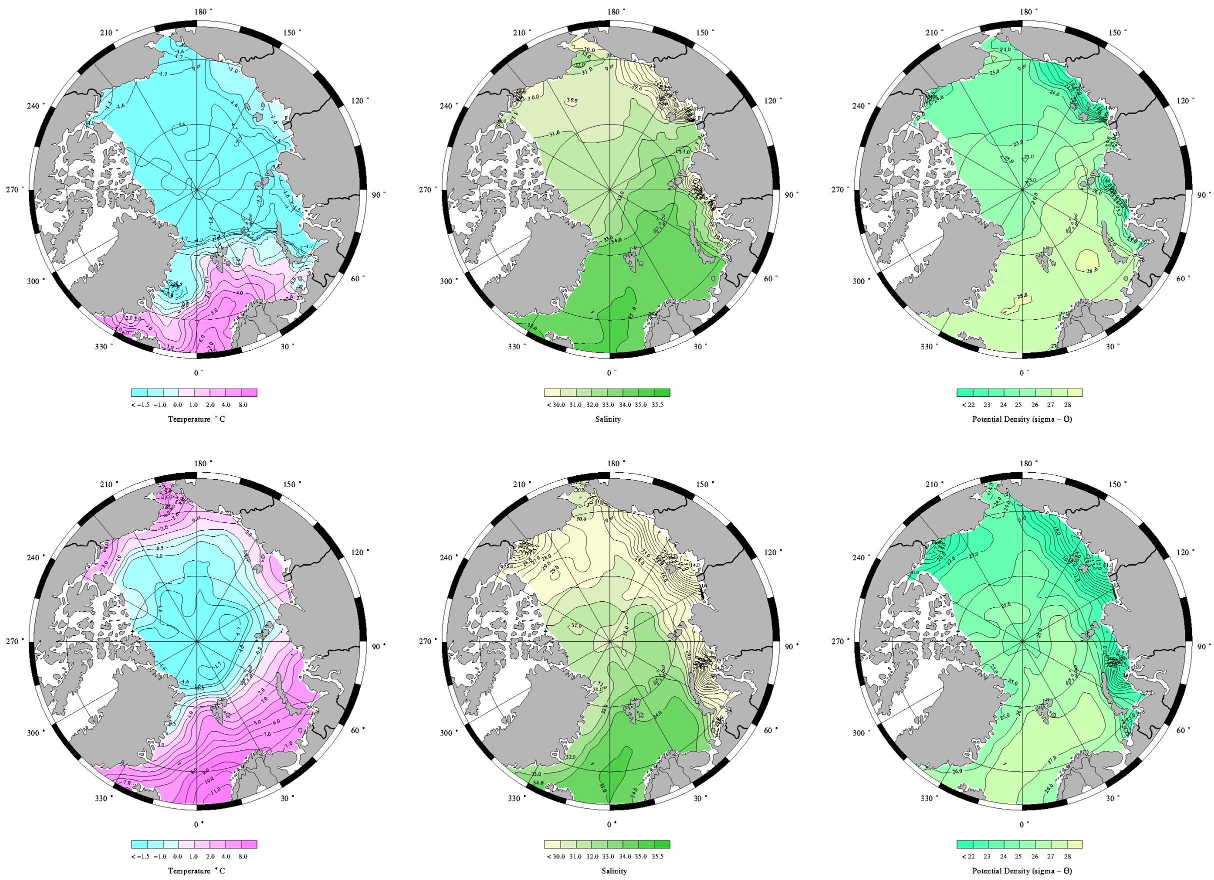


Figure 8. The 100x100km grid structure used for data on the Arctic Ocean atlases [4]. For the 200km gridded data, only every second grid point will be used. For the 50km gridded data there will be additional grid points in between those shown above.



(a) Vertical profile plots of temperature (left) and salinity (right) from station data in the Fram Strait in the 1970s. Winter data.



(b) Spectral Objective Analysis (SA) surface temperature (left), salinity (middle) and density (right) from the 1950s. Upper: winter data. Lower: summer data.

Figure 9. Sample data sets from the Arctic Ocean Atlas CDs [4].

3.2 The CEAREX-1 CD

Most of the data on the CEAREX-1 CD are from the Coordinated Eastern Arctic Experiment (CEAREX) carried out in the Norwegian and Greenland Seas north to Svalbard from September 1988 through May 1989. In addition, there is some other data, mainly CTD data, from other field experiments in the same region, including the MIZEX experiments in 1983, 1984 and 1987, as well as several SIZEX and EUBEX campaigns. All data files are in ASCII format, but not with the same layout.

The data sets on this CD are grouped into:
1. Bathymetry data
There are several single tracklines from the different experiment sites - and a gridded bathymetry for the Arctic Ocean Basin (approx. 74-88 deg.N, 60 deg.W - 60 deg.E, with a resolution of 10x10km). This gridded dataset was prepared by Thomas O. Manley, Marine Research Corporation, USA.
Experiment sites: (single tracklines)

- A-camp (on drifting ice floe): approx. 80.3-82.6 deg.N, 2W-0E.
- O-camp (in open ocean, drifting): approx. 82-83.6 deg.N, 4-12 deg.E.
- Other positions: from ship NorthWind: NE of Svalbard and in the Fram Strait.

Data format: MGD77 (description enclosed on the CD)

2. Bio-physical data
A number of biological parameters, e.g. chlorophyll-a, plus air temperature, humidity and wind. This CD section also contains som CTD data, but only for the depths where bottle samples were taken.

3. Hydrographical data
A large number of CTD stations from CEAREX, SIZEX'89 and a long list of other experiments, in the Barents Sea, Greenland Sea, Norwegian Sea, Fram Strait, etc. A large database of CTD stations from a 11-year period (1978-1987) is also included on the CD. Data here are subsampled to every 5 meter, and truncated at 800m depth. A total of about 4000 stations, with summer, fall and winter data. Most of the data sets are in the s87 format (described on the CD). Other data are also ASCII, but don't follow the s87 standard.

4. Meteorological data
Meteorological data from MIZEX-83, MIZEX-84, MIZEX-87 and CEAREX. Measured parameters include wind, pressure, temperature and humidity. Collected at the surface and in "upper-air" (i.e. from an instrument mounted e.g. on a bow mast, or from a sounding or weather balloon). Area and time covered: MIZEX-83 collected data in the East Greenland Sea in the period 14 July - 30 July 1983. MIZEX-84: East Greenland Sea from 3 June to 21 July 1984, and MIZEX-87 in the Greenland Sea from 19 March to 9 April 1987 and in the Barents Sea on 10-11 April 1987. Surface metorological data do not contain positions. Only date, time-of-day and the measured parameters.

5. Noise data
Acoustical data, including ambient noise, from the A-camp of the CEAREX experiment are on the CD. The acoustical data was collected from 23 March - 20 April 1989, and the ambient noise data from 16 September 1988 to mid January 1989.

6. Position data (from drifting buoys)
Positions of the two camps and all other experiment sites in CEAREX are included as ASCII files with date/time and lat/lon. Obvious errors are marked with an asterisk (*), so they can be easily removed before analysis, e.g. by the grep command in Unix.

7. Sea ice data
Ice acceleration data (in m/s^2), ice deformation data, ice stress data (stress invariants, prinicipal stress and direction of stress). All data are from the CEAREX experiment.

The map below shows the location of the CTD stations in the database on the CEAREX-1 CD. They are distributed over the Arctic Basin region, and can provide a valuable addition to the field data held by the consortium. The definition of new scenarios in Task 3 and 4 can use these data to fill in gaps in data needed to cover areas and seasons to be investigated.

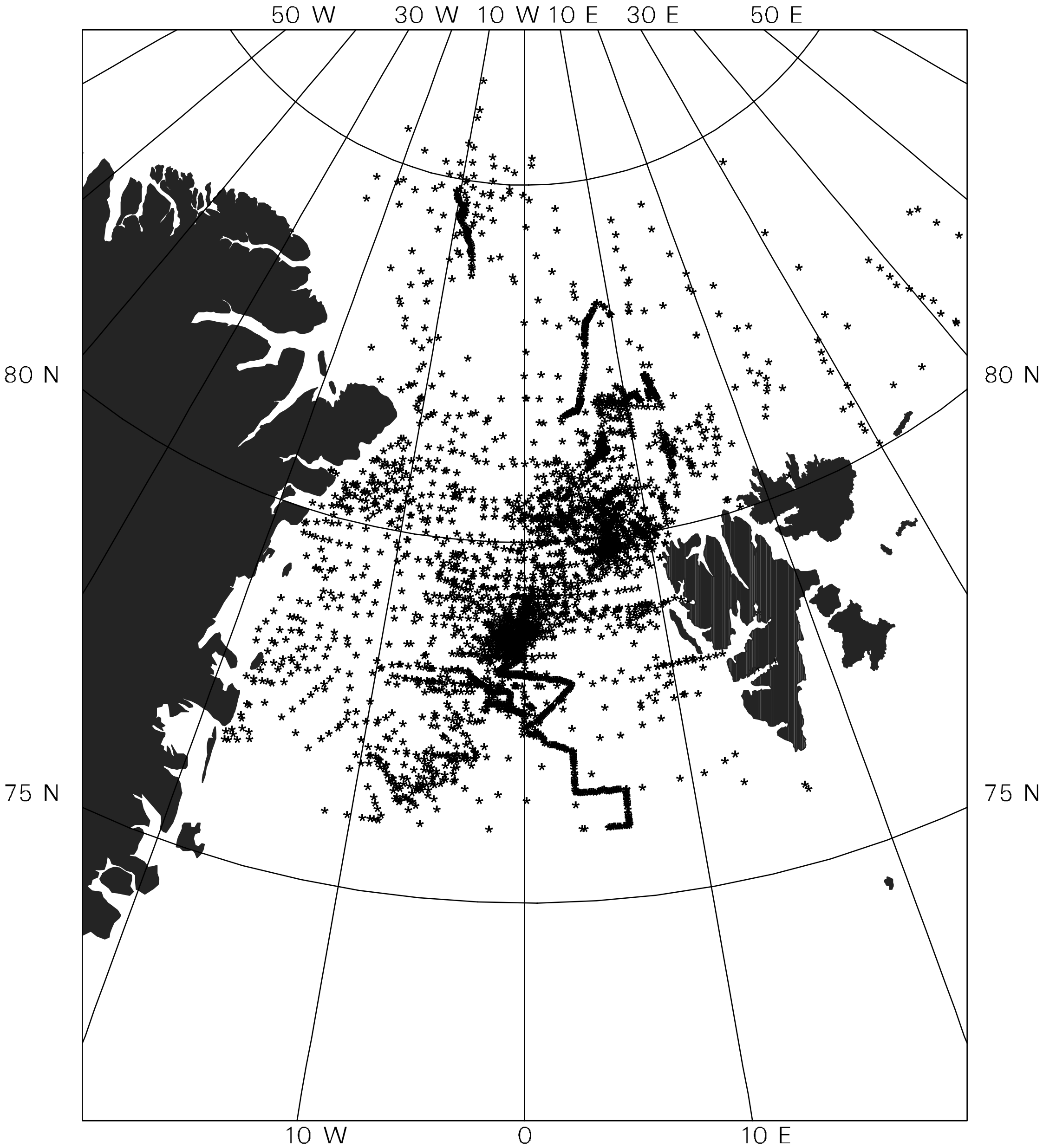


Figure 10. Map of CTD station in the database on the CEAREX-1 CD [5].

Table 3. List of CTD data sets on the CEAREX-1 CD.

Experiment	**Date**	**#stations**	**Minimum bounding rectangle (N,E)**	
Svalb-77	77/11/20 - 77/12/05	123	78.95 - 81.50	1.10 - 17.70
Odec-Fr1	79/03/24 - 79/05/01	100	83.12 - 86.41	÷23.17 - 4.60
Fram1-79	79/03/29 - 79/05/06	88	83.68 - 84.82	÷10.50 - ÷6.77
Westwind	79/08/19 - 79/09/25	154	76.47 - 83.63	÷18.38 - 0.00
Norsx-79	79/09/17 - 79/10/04	238	78.17 - 82.16	6.90 - 13.35
Ymer1980	80/08/13 - 80/09/19	113	78.17 - 82.50	÷16.46 - 46.88
Eubex 81	81/03/15 - 81/04/17	34	79.79 - 84.56	0.00 - 32.95
Fram3-81	81/03/30 - 81/05/07	191	80.74 - 84.37	÷5.96 - 22.40
Lance-81	81/07/28 - 81/08/12	63	77.98 - 80.59	÷3.60 - 13.49
Nwind-81	81/10/18 - 81/11/15	114	76.02 - 79.06	÷10.20 - 0.97
Hudson82	82/03/05 - 82/03/15	32	76.01 - 79.00	÷3.09 - 16.47
Meteor-82	82/06/19 - 82/06/23	19	76.24 - 79.90	÷5.13 - 10.50
Lance-82	82/07/19 - 82/08/03	97	77.49 - 80.50	÷14.29 - 10.27
Plrbjorn	83/06/19 - 83/07/09	225	79.92 - 81.44	3.91 - 11.57
Mizex-83	83/06/21 - 83/07/31	119	78.08 - 81.46	÷5,68 - 10.89
Lance-83	83/07/20 - 83/07/31	61	78.43 - 80.77	÷6,49 - 16.53
Lynch-84	84/05/21 - 84/06/21	26	78.76 - 80.18	0.14 - 10.62
Queen-84	84/06/12 - 84/07/17	46	79.88 - 80.79	1.12 - 5.99
Mizex-84	84/06/12 - 84/07/17	222	78.50 - 81.10	÷8.05 - 9.14
Kvtbjorn	84/06/12 - 84/07/22	309	78.15 - 80.64	÷3.21 - 8.18
Ps-05-84	84/06/15 - 84/07/18	170	78.25 - 80.66	÷6.45 - 9.46
Hknmosby	84/06/17 - 84/07/14	449	78.37 - 80.58	÷2.76 - 10.50
Ps-07-84	84/07/20 - 84/08/05	33	76.33 - 82.76	÷10.64 - 18.59
Nwind-84	84/08/22 - 84/09/15	313	76.00 - 81.29	÷18.18 - 9.36
Nwind-85	85/09/05 - 85/09/26	147	76.40 - 81.79	÷10.70 - 15.03
Mizex-87	87/03/27 - 87/04/08	489	76.00 - 78.99	÷3.76 - 6.04

The CEAREX-1 CD contains 4,114 CTD stations from 26 experiments in the Fram Strait area (Table 3), over a period of 11 years (1977-87). Data are available for every 5m (subsampled), and have been truncated at 800m depth. The data files reside in \HYDROG\FRAM directory on the CD, and contain primarily spring, summer and autumn measurement. However, three of the experiments were also during the winter period (Svalb-79, Hudson-82 and Mizex-87). The available parameters are:

- PR - pressure in db
- TE - temperature in °C
- PT - potential temperature in °C
- SA - salinity in PSU
- SO - sigma-0 or potential density
- HZ - dynamic height anomaly in dyn. m, using the surface (0 db) as the reference level.

The overall accuracy of the data sets is ±0.02°C and ±0.02PSU [5]. For further details on the data, see the file \HYDROG/Hydrog.doc.

From these parameters, sound speed can be derived for use in acoustical models in Task 4. Figure 11 shows the location of the CTD stations from the different experiment, ordered chronologically, as in Table 3.

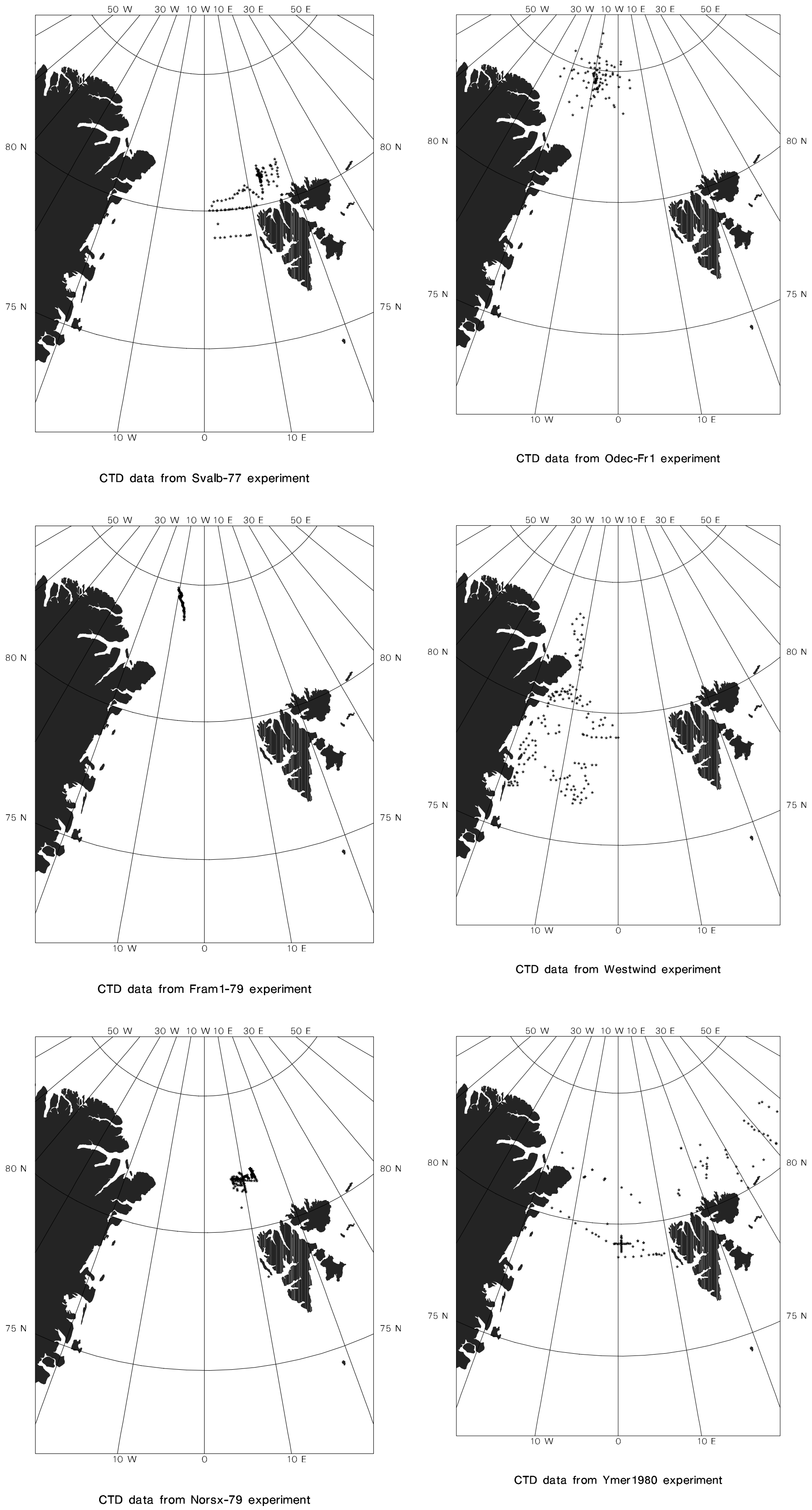
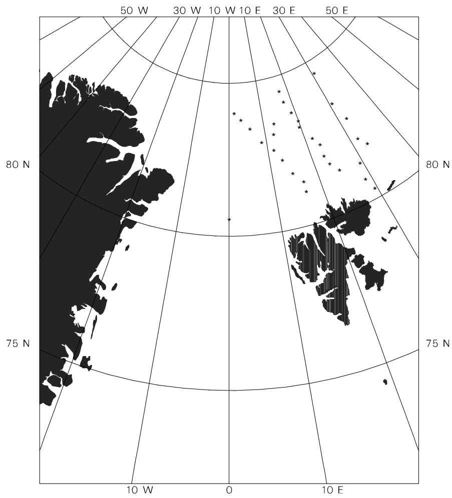
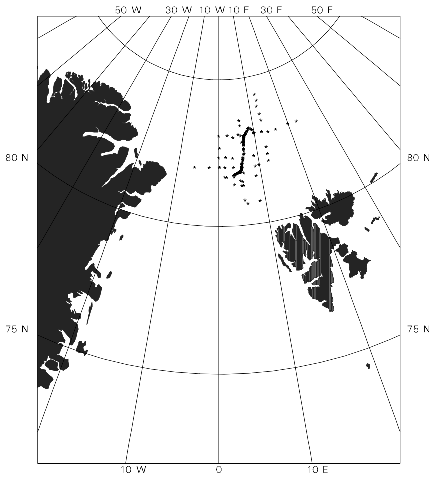


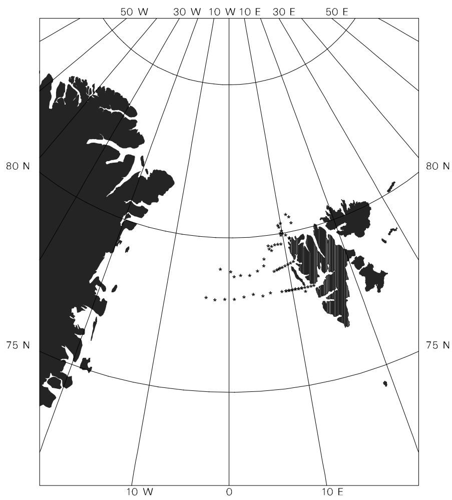
Figure 11. Location of CTD stations in the database on the CEAREX-1 CD [5].



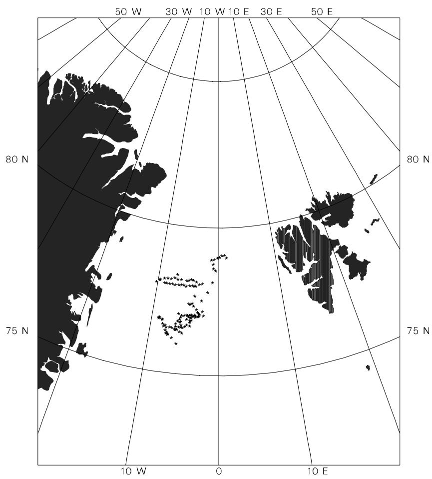
CTD data from Eubex-81 experiment



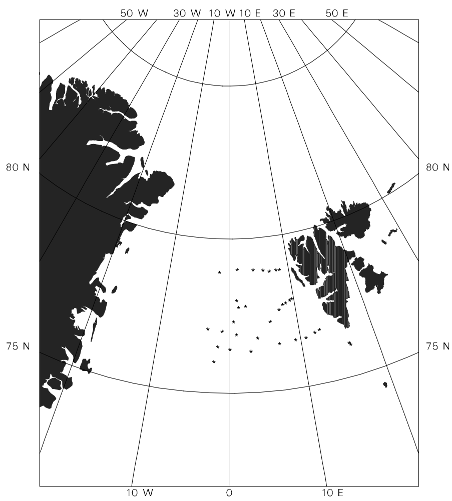
CTD data from Fram3-81 experiment



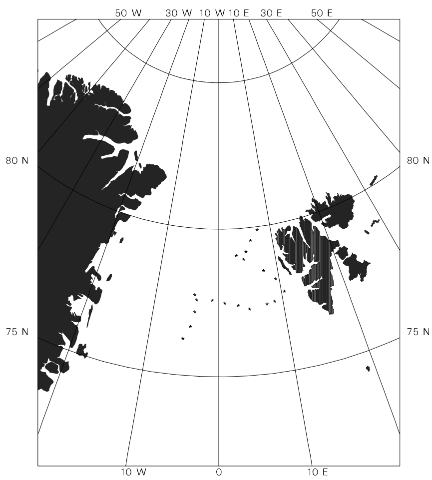
CTD data from Lance-81 experiment



CTD data from Nwind-81 experiment



CTD data from Hudson82 experiment



CTD data from Meteor-82 experiment

Figure 11(cont). Location of CTD stations in the database on the CEAREX-1 CD [5].

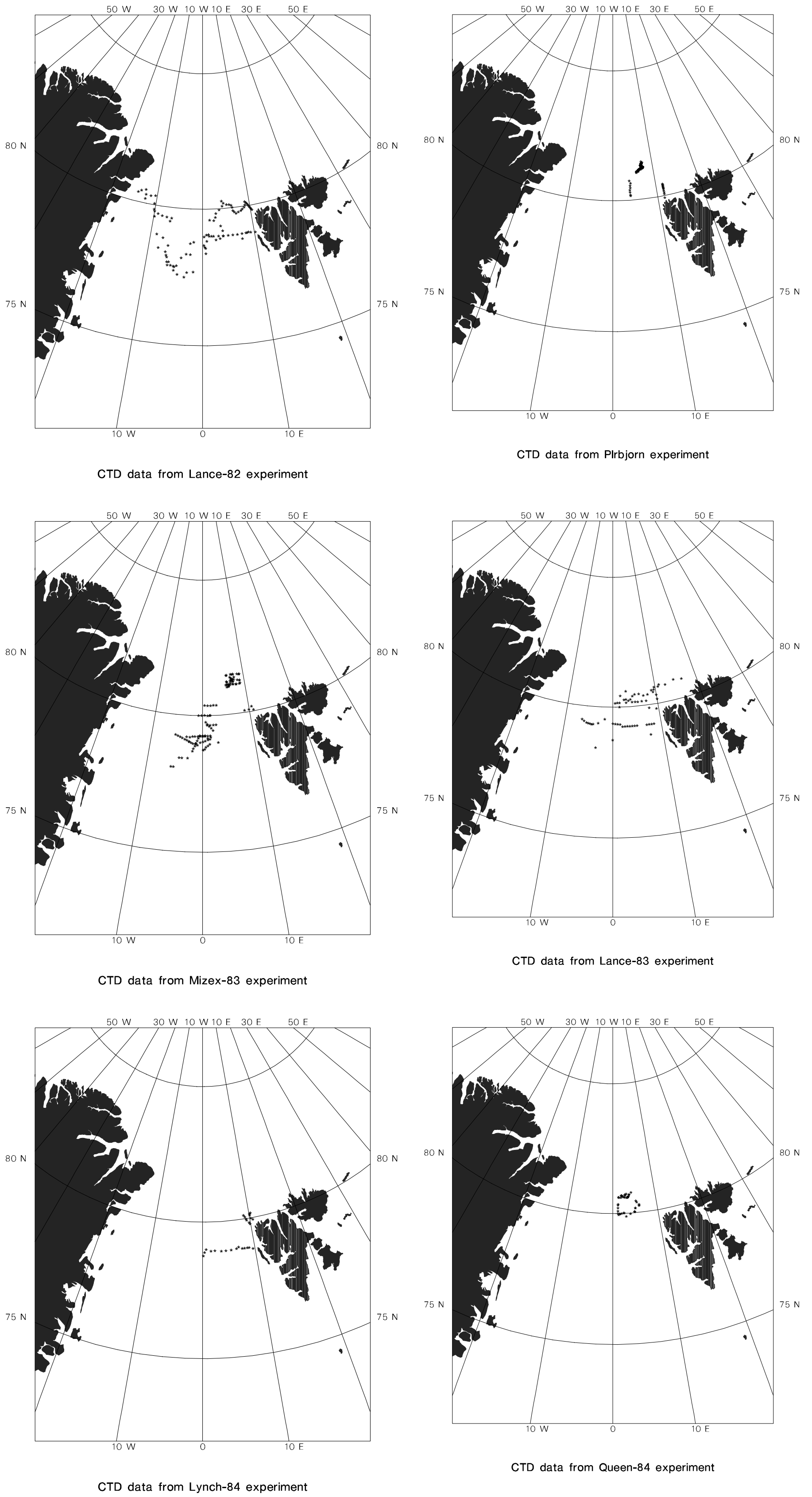
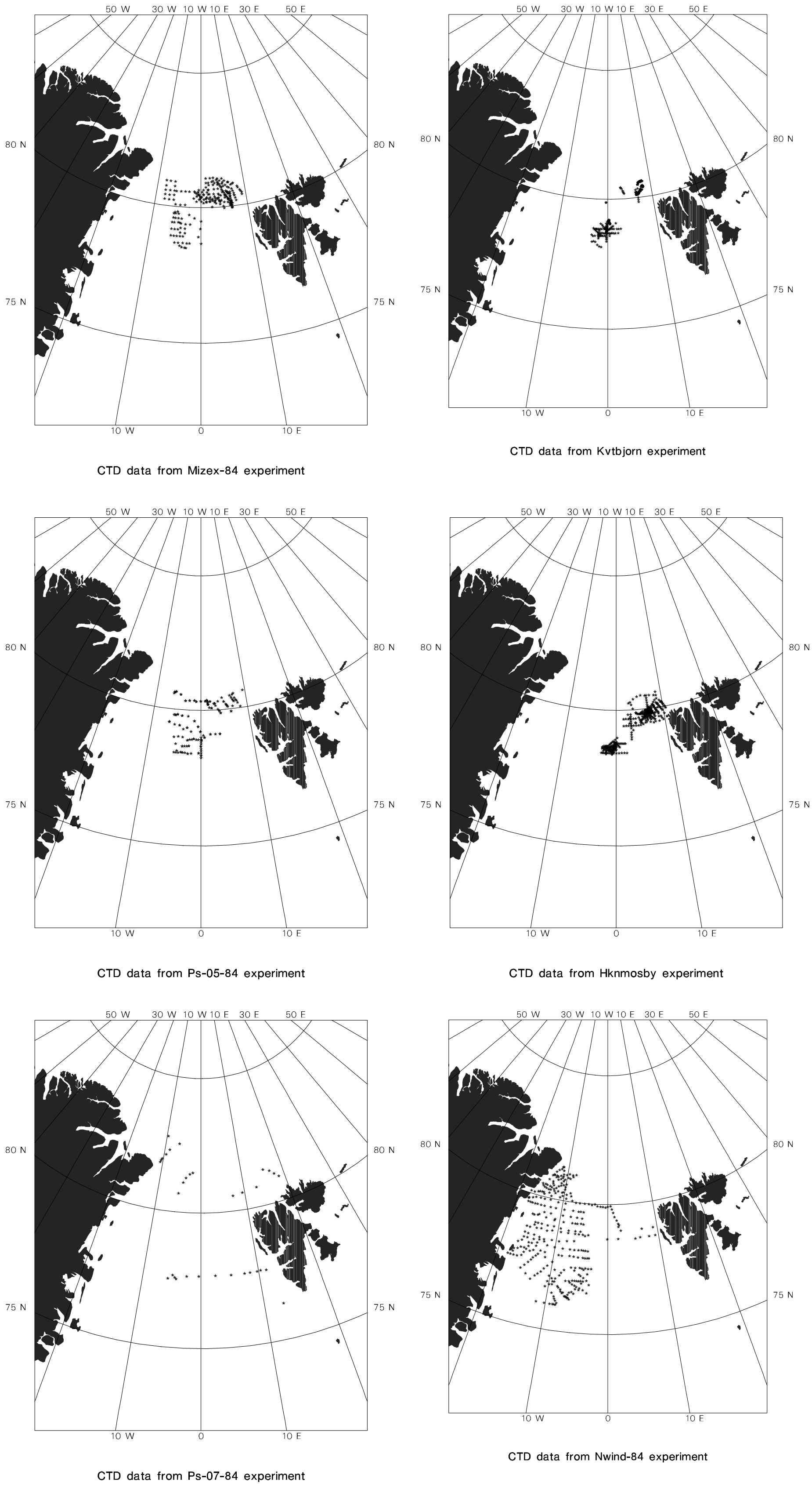


Figure 11(cont). Location of CTD stations in the database on the CEAREX-1 CD [5].



CTD data from Mizex-84 experiment

CTD data from Kvtbjorn experiment

CTD data from Ps-05-84 experiment

CTD data from Hknmosby experiment

CTD data from Ps-07-84 experiment

CTD data from Nwind-84 experiment

Figure 11(cont). Location of CTD stations in the database on the CEAREX-1 CD [5].

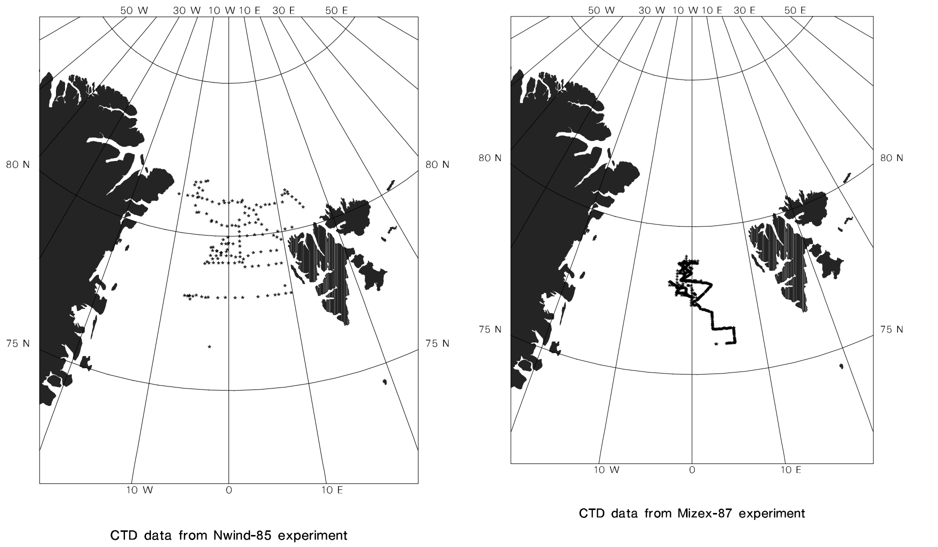
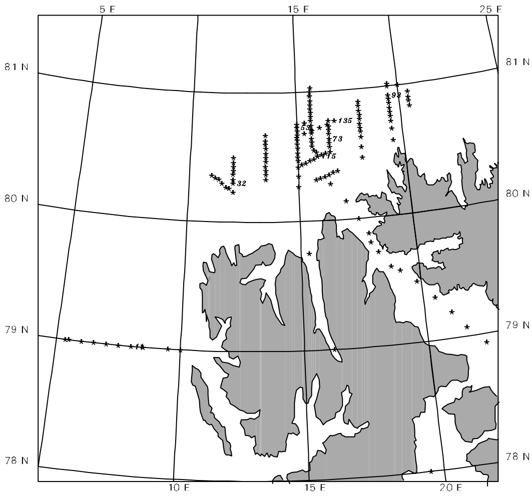


Figure 11(cont). Location of CTD stations in the database on the CEAREX-1 CD [5].

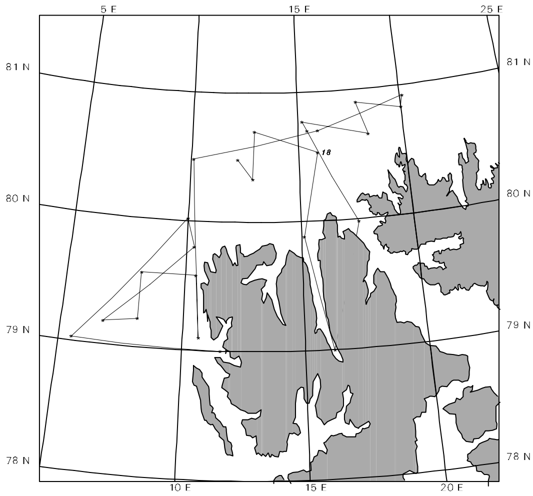
3.3 The AOGC'96 and '97 field experiments

NERSC has lead two Arctic Ocean Grand Challenge (AOGC) field experiments in the Fram Strait in 1996 and 1997. The main objective of these cruises was to determine the ways in which mesoscale phenomena determine the large scale behaviour of the Arctic Ocean and its ice cover. The physical processes which govern the Arctic Ocean system are critically dependent on scaling links with processes which must be understood through smaller-scale measurements. Examples of such scaling links are plumes of specific water masses from the shelf areas, such as fresh water from the rivers and dense bottomwater, which influence the water masses in the whole Arctic Ocean. Furthermore, in the Arctic Ocean meso-scale eddies of diameters tens of km have long life times which enable them to transport anomalous water over distances on the order of 1000 km and thus influence water mass structure at the location of their decay. Physical processes which have important implications on the biology are upwelling, fronts and eddies. The processes play an important role in vertical convection and mixing of the water masses, in particular along the ice edge.

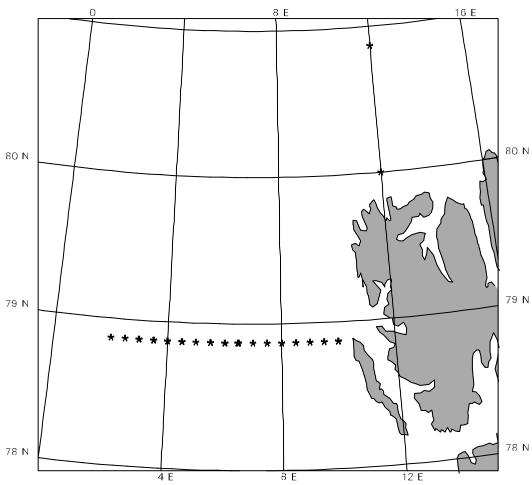
Oceanographic and meteorologic ship observations where taken from the Norwegian research vessel Haakon Mosby during the AOGC'96 (6 - 19 August 1996) and AOGC'97 (6 - 29 September 1997) experiments. During the 1996 cruise, 168 CTD stations, 19 Seasoar sections and 41 ADCP sections were collected. During the 1997 cruise, 33 CTD stations were taken, along with a total of 33 Seasoar and 19 ADCP sections. The location of the CTD and Seasoar stations in the AOGC cruises is shown in Figure 12.



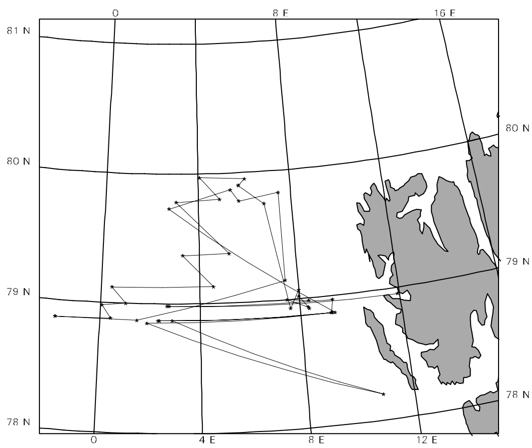
Håkon Mosby AOGC CTD data 1996



Håkon Mosby AOGC Seasoar data 1996



Håkon Mosby AOGC CTD data 1997



Håkon Mosby AOGC Seasoar data 1997

Figure 12. Location of CTD and Seasoar stations in AOGC'96 [3] and AOGC'97 [8].

From the measured oceanographic parameters in the CTD and Seasoar data sets, the sound speed (svel) can be derived, using Medwin's formula [9]:

$$svel = 1449.2 + 4.6t - 0.0555t^2 + 0.00029\,t^3 + (1.34 - 0.01t)(s - 35) + 0.016p$$

where

svel is the sound speed (in meters per second)
t is the temperature (in degrees Celsius),
s is the salinity (in parts per thousand),
p is the pressure (in mbar),

Examples of data from the AOGC cruises are shown in Figure 13, 14 and 15. Figure 13 shows the parameters for one of the CTD stations acquired during the AOGC'97 experiment. In Figure 14, a CTD section plot of potential temperature and sound velocity along a profile close to 79 degrees North in the Fram Strait (from about 9E to 6E) obtained during the same cruise is shown. These stations were all acquired on 16 September 1997. Finally, in Figure 15, plots of the same parameters for a Seasoar section obtained on the same day are shown. This section was also taken across the Fram Strait, close to 79 degrees North (from about 2.75E to 9.25E). The CTD data goes down to the sea bottom, while the Seasor instrument only provides data for the upper 200m layer of the ocean. In all cases the sound velocity was derived using Medwin's formula.

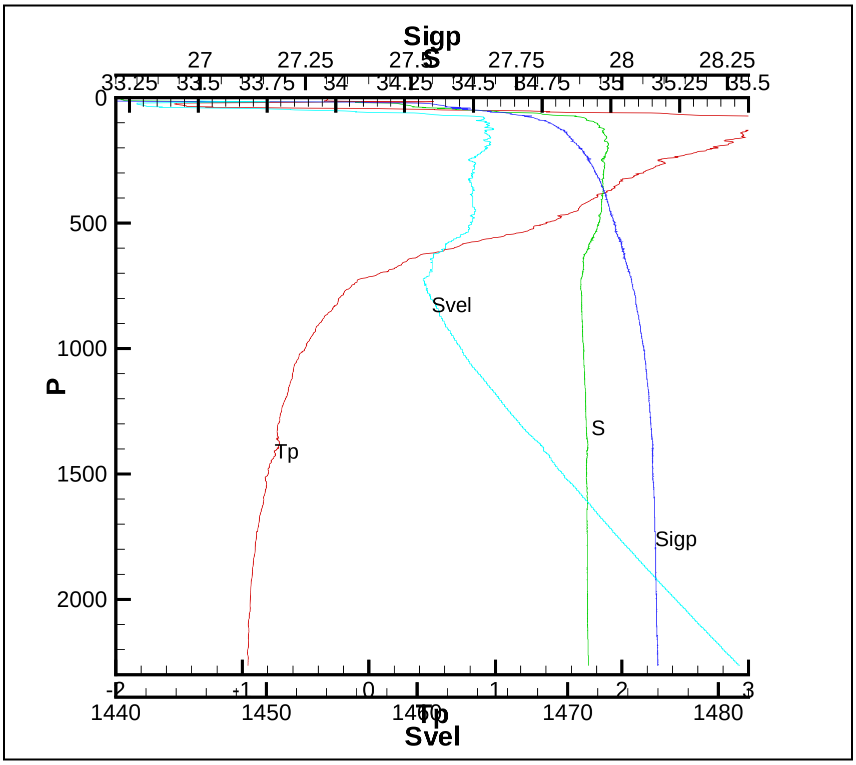


Figure 13. Parameters from a CTD station in the AOGC'97 experiment [8].

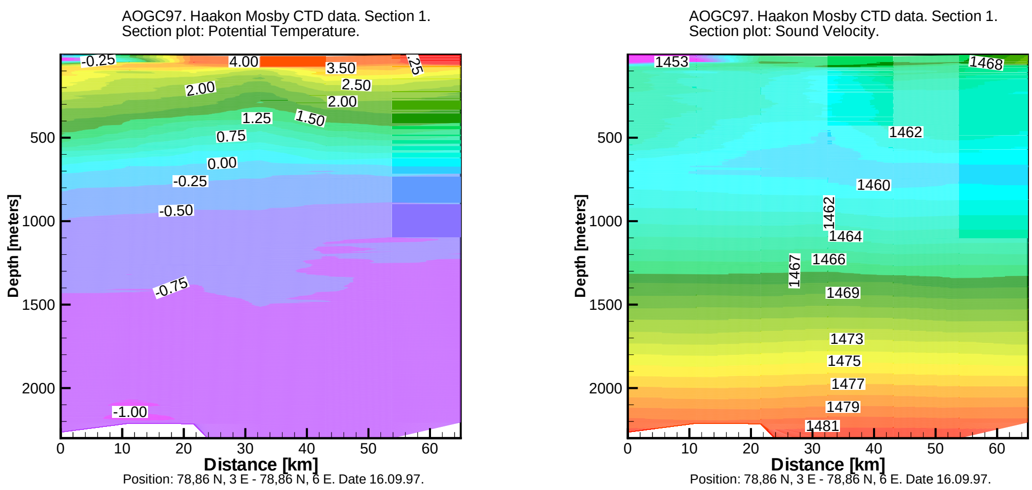


Figure 14. CTD section plot of potential temperature (left) and derived sound speed (right) from the AOGC'97 experiment, acquired on 16 September 1997 [8].

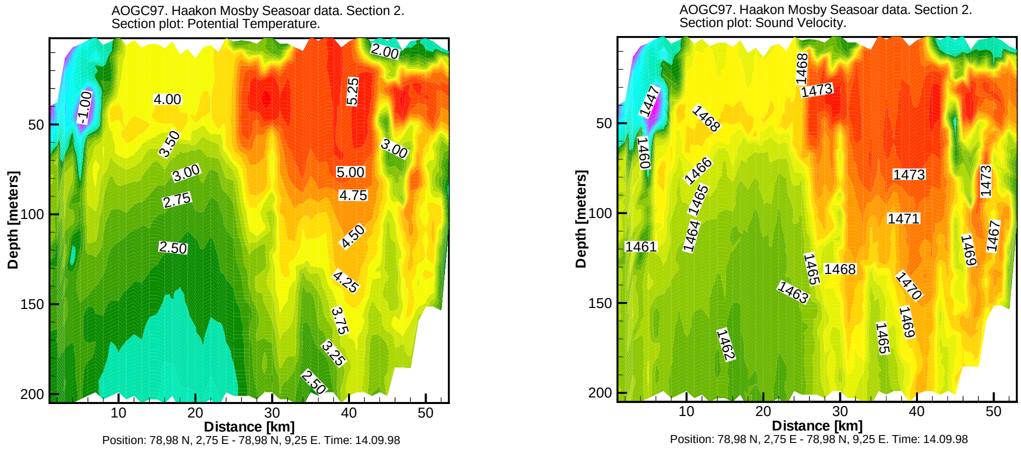


Figure 15. Seasoar section plot of potential temperature (left) and derived sound speed (right) from the AOGC'97 experiment, acquired on 14 September 1997 [8].

3.4 Ice data sets

The following listing is a routine statistical analysis of a single 50 Km section as agreed with US collaborators for standard statistical data base with some examples of plotted distribution functions for Total, Level & Rough Ice Draft and Pressure Ridge Distribution > 2.5, 5 and 9 metres minimum draft.

The Input Parameters
Region Number 82
Section No. 31 - Section No. 31
Number of Sections 1
Level Ice Parameters, Slope=10.00 Length= 0.05 Draught= 2.50
Polynya/Lead Minimum Draft Parameters 1,2 & 3= 0.30 0.50 0.70
Polynya/Lead Minimum Width Parameter= 25.00

Statistical Analysis for Region 82

Sectional Statistics Section- 31
Sectional Distance 49482

Ice Draft Distribution - Sectional/Regional

Regression Correlation Coefficients
Ice Draft [10cm bin] Distribution

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
0.32808	-1.18980	0.94113

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
3.20092	-0.53536	0.94855

Sea Ice Draft - Statistical Parameters

3.33815 Sea Ice Draft - Mean Value
4.56378 Sea Ice Draft - RMS. Value
9.68469 Sea Ice Draft - Variance
3.11202 Sea Ice Draft - Standard Deviation
2.64483 Sea Ice Draft - Median Value
0.00000 Sea Ice Draft - Modal Value

Level/Rough Ice Distribution

Level Ice Distribution per Section/Region

79890.3 Number of Level Ice Data points/100km
[Including Level/Rough Overlap]
80.40 Percentage of Level Ice

Level Ice Draft Distribution per Section/Region

Regression Correlation Coefficients
Level Ice Draft [10cm bin] Distribution

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
0.34170	-1.30627	0.94145

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
3.27986	-0.69539	0.95170

Level Ice Draft - Statistical Parameters

2.92931 Level Ice Draft - Mean Value
4.16564 Level Ice Draft - RMS. Value
8.77201 Level Ice Draft - Variance
2.96176 Level Ice Draft - Standard Deviation
2.39676 Level Ice Draft - Median Value
0.00000 Level Ice Draft - Modal Value

Rough Ice Distribution per Section/Region

20109.7 Number of Rough Ice Data points/100km
[Including Level/Rough Overlap]
19.60 Percentage of Rough Ice

Rough Ice Draft Distribution per Section/Region

Regression Correlation Coefficients
Rough Ice Draft [10cm bin] Distribution

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
0.27181	-0.72146	0.94878

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
2.55373	0.20244	0.91326

Rough Ice Draft - Statistical Parameters

5.07092	Rough Ice Draft - Mean Value
5.95751	Rough Ice Draft - RMS. Value
9.77870	Rough Ice Draft - Variance
3.12709	Rough Ice Draft - Standard Deviation
4.59042	Rough Ice Draft - Median Value
2.86991	Rough Ice Draft - Modal Value

Polynya-Lead Distribution per Section/Region

Minimum Draft 0.30m
Regression Correlation Coefficients
Polynya/Lead Width Distribution

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
1.22344	-6.12394	0.95964

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
23.11768	-16.89416	0.99139

Minimum Draft 0.50m
Regression Correlation Coefficients
Polynya/Lead Width Distribution

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
1.10483	-5.28939	0.94757

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
20.14835	-13.93283	0.99288

Minimum Draft 0.70m
Regression Correlation Coefficients
Polynya/Lead Width Distribution

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
1.07604	-4.85800	0.97058

Exponential Distribution

Slope Intercept Corr Coeff [R]
14.45452 -8.08767 0.98724

Lead-Polynya Occurance Analysis

Minimum Draft 0.30 0.50 and 0.70 metres
Total No Leads > 1.0 and > width 25.00m

No./100km > 1.0m	394.08270	450.66895	351.64304
No./100km > 25.0m	76.79560	103.06778	117.21434
No./km > 1.0m	3.94083	4.50669	3.51643
No./km > 25.0m	0.76796	1.03068	1.17214
No. Detected > 1.0m	195	223	174
No. Detected > 25.0m	38	51	58
% Open Water	14.39	17.79	20.67

Lead-Polynya Analysis - Statistical Parameters

Mean Width	36.50256	39.47534	58.78161
RMS. Value	136.77003	134.56155	180.31935
Variance	17463.16016	16623.05273	29227.76562
Std. Devn.	132.14825	128.93042	170.96130
Median	6.0	6.0	8.5
Mode (Est.)	4.5	4.5	0.5

Distribution of Lead/Polynya Spacing

Minimum Draft 0.30m
Regression Correlation Coefficients
Polynya/Lead Spacing Distribution

Log Normal Distribution
Slope Intercept Corr Coeff [R]
1.32291 -5.80081 0.96935
Exponential Distribution
Slope Intercept Corr Coeff [R]
15.77588 -7.93275 0.98690

Minimum Draft 0.50m
Regression Correlation Coefficients
Polynya/Lead Spacing Distribution

Log Normal Distribution
Slope Intercept Corr Coeff [R]
1.26357 -5.44897 0.96401
Exponential Distribution
Slope Intercept Corr Coeff [R]
15.88567 -8.01690 0.98713

Minimum Draft 0.70m

Regression Correlation Coefficients
Polynya/Lead Spacing Distribution

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
1.26357	-5.44897	0.96401

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
15.88567	-8.01690	0.98713

Pressure Ridge Draft & Spacing Analysis
[Rayleigh Criterion Relative 2.5m Min]

Distribution Pressure Ridge Drafts

Regression Correlation Coefficients
Pressure Ridge Draft Distribution

Min Draft >2.5m Max 50m

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
0.24305	-0.66587	0.98976

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
2.97348	-0.39042	0.93184

Min Draft >5.0m Max 50m

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
0.15133	0.08045	0.98966

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
1.62251	1.07546	0.92763

Min Draft >9.0m Max 50m

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
0.08875	0.58481	0.97632

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
1.04055	1.79001	0.95740

Pressure Ridge Statistical Parameters
Minimum Draft >2.5m - >5.0m - >9.0m

Total Number	850	256	65

Number/km	17.17796	5.17360	1.31361
Mean Draft	4.64496	7.83590	11.49536
RMS. Draft	5.32406	8.25531	11.71918
Variance	6.77798	6.77543	5.27716
Std. Dev.	2.60346	2.60297	2.29721
Median	3.62660	7.17045	10.57324
Mode	2.50038	5.16226	9.44435

Distribution of Pressure Ridge Spacing

Regression Correlation Coefficients
Pressure Ridge Spacing Distribution

Minimun Draft 2.5m

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
0.80084	-3.10279	0.98968

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
9.52087	-3.46673	0.91793

Minimum Draft 5.0m

Log Normal Distribution

Slope	Intercept	Corr Coeff [R]
0.69236	-1.79017	0.98779

Exponential Distribution

Slope	Intercept	Corr Coeff [R]
5.90855	0.91250	0.95622

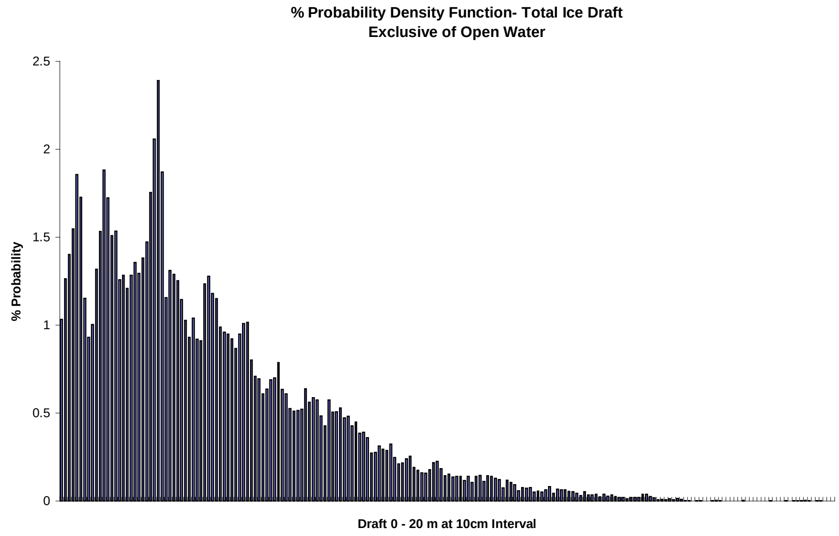
Minimum Draft 9.0m

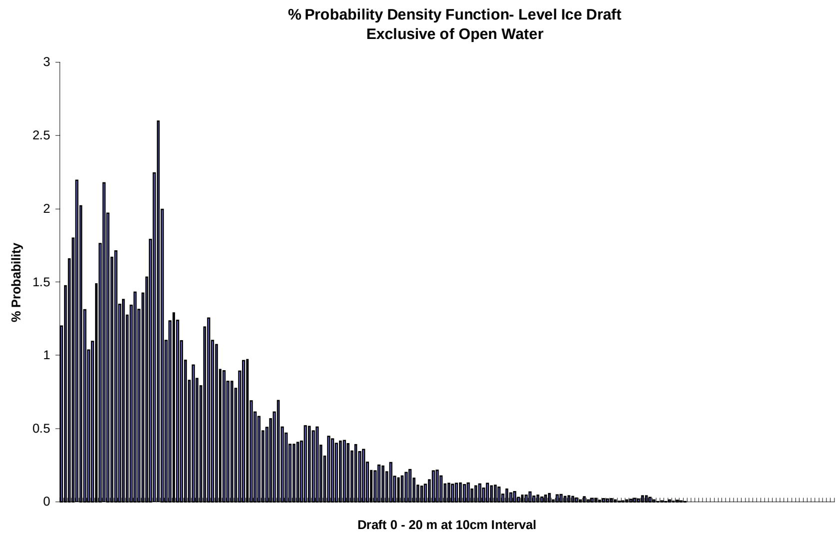
Log Normal Distribution

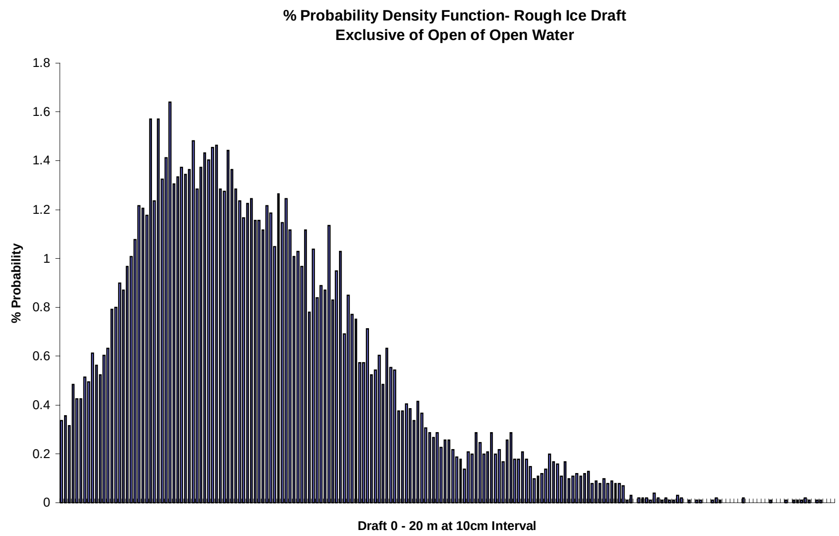
Slope	Intercept	Corr Coeff [R]
0.71135	-1.21628	0.97192

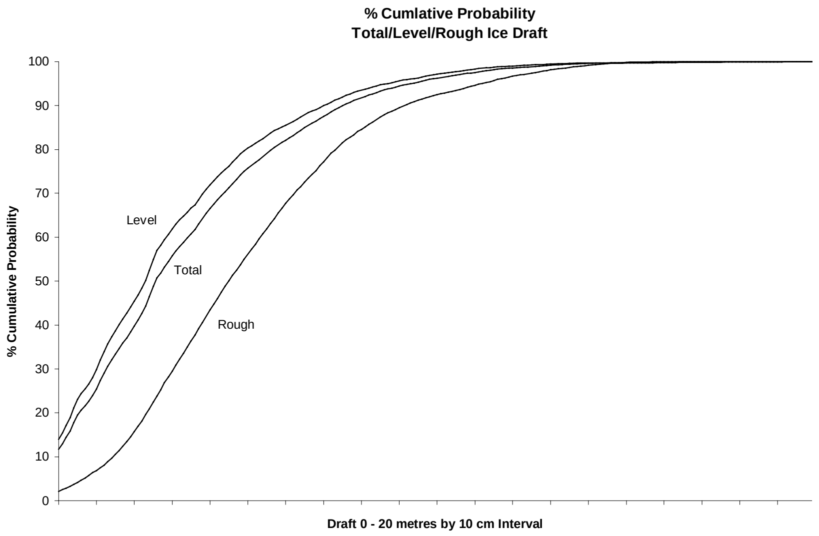
Exponential Distribution

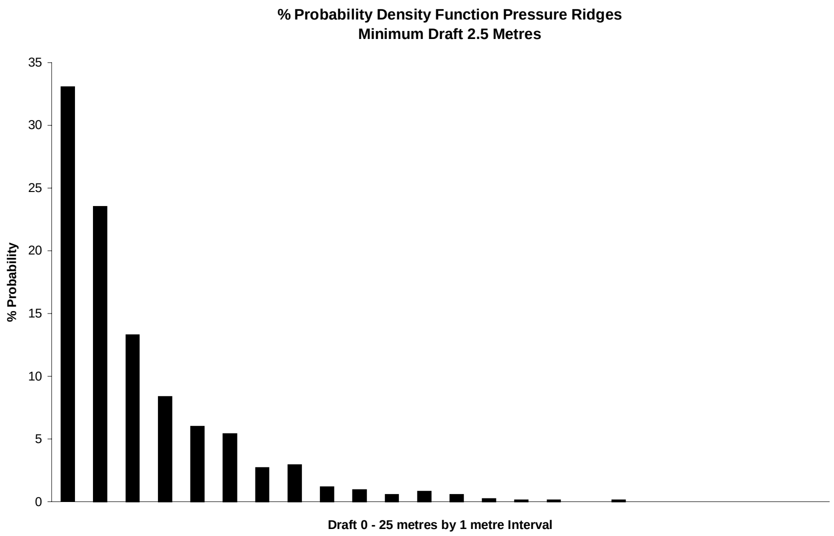
Slope	Intercept	Corr Coeff [R]
5.20291	2.81001	0.96313

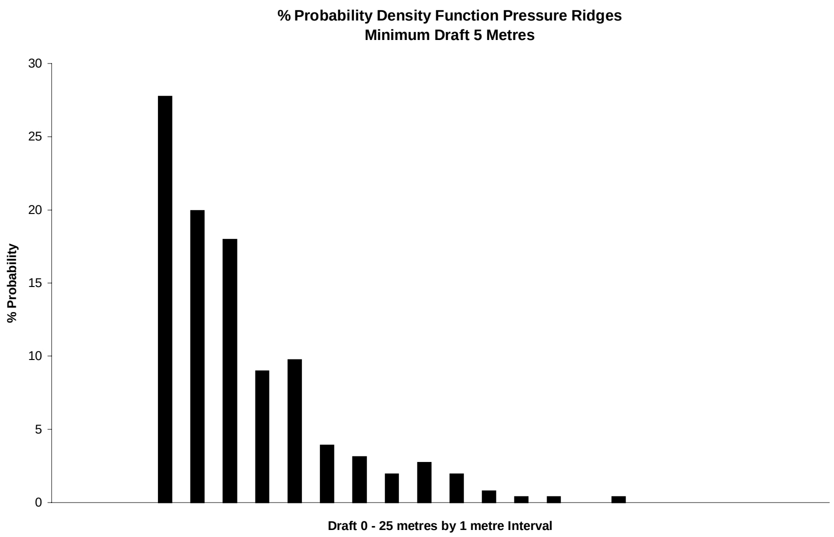

% Probability Density Function- Total Ice Draft
Exclusive of Open Water
% Probability
2.5
2
1.5
1
0.5
0
Draft 0 - 20 m at 10cm Interval

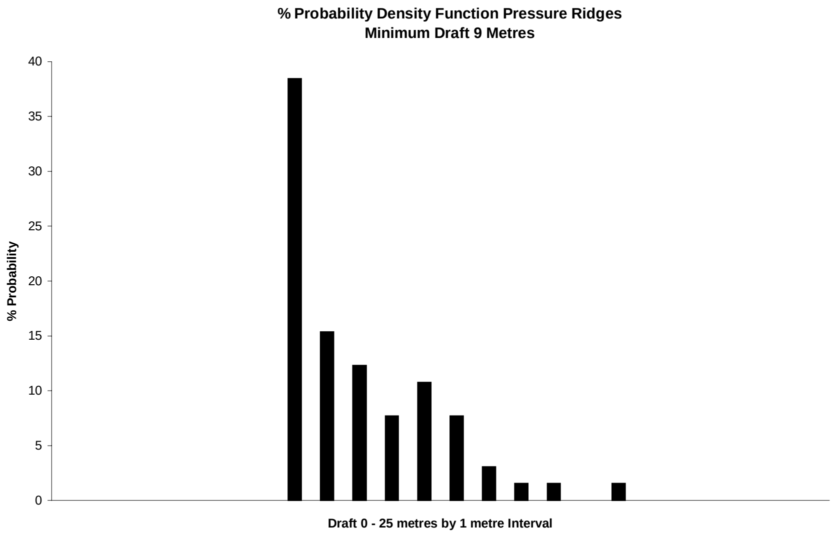

% Probability Density Function- Level Ice Draft
Exclusive of Open Water
% Probability
3
2.5
2
1.5
1
0.5
0
Draft 0 - 20 m at 10cm Interval

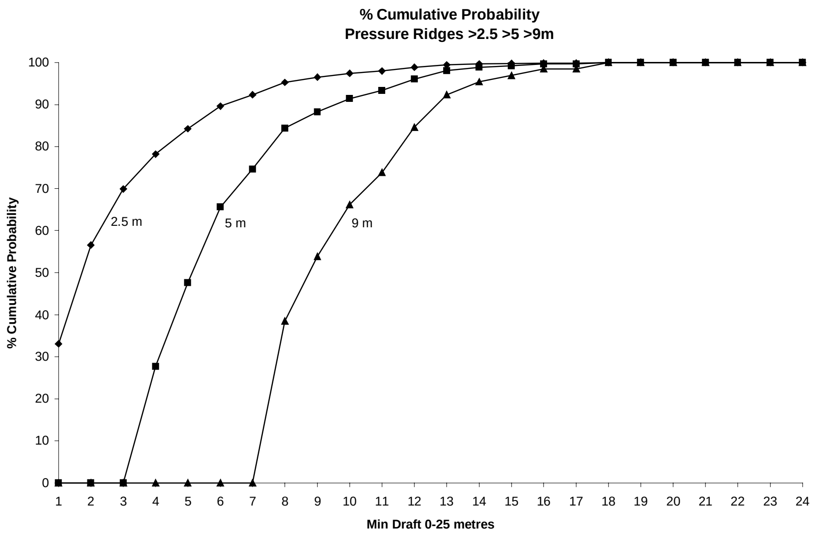

% Probability Density Function- Rough Ice Draft
Exclusive of Open of Open Water
% Probability
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Draft 0 - 20 m at 10cm Interval


% Cumlative Probability
Total/Level/Rough Ice Draft
100
90
80
70
60
50
40
30
20
10
0
% Cumulative Probability
Level
Total
Rough
Draft 0 - 20 metres by 10 cm Interval


% Probability Density Function Pressure Ridges
Minimum Draft 2.5 Metres
35
30
25
20
15
10
5
0
% Probability
Draft 0 - 25 metres by 1 metre Interval


% Probability Density Function Pressure Ridges
Minimum Draft 5 Metres
30
25
20
15
10
5
0
% Probability
Draft 0 - 25 metres by 1 metre Interval


% Probability Density Function Pressure Ridges
Minimum Draft 9 Metres
% Probability
0
5
10
15
20
25
30
35
40
Draft 0 - 25 metres by 1 metre Interval


% Cumulative Probability
Pressure Ridges >2.5 >5 >9m
% Cumulative Probability
0
10
20
30
40
50
60
70
80
90
100
2.5 m
5 m
9 m
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Min Draft 0-25 metres

3.5 The Acoustic Experiments 1984-1992

During the years between 1984 and 1992 five MIZEX/SIZEX field experiments were carried out in the marginal ice zone of the Greenland Sea and the Barents Sea. The overall objective of the acoustic studies was to investigate the effect of ice edge eddies on ambient noise and acoustic propagation. This section gives an overview of the acoustic experiments during the MIZEX (Marginal Ice Zone Experiment) and SIZEX (Seasonal Ice Zone Experiment) programmes with a brief description of data collection and data processing.

3.5.1 Summary of the acoustic experiments

Ambient noise studies were carried out in the deep part of the Greenland Sea during the experiments in 1984, 1985, 1987 and 1989 [10] [11] [12] [13]. The Barents Sea were investigated in 1989 [14] [15] and 1992 [16] [17]. A propagation loss study was performed during SIZEX 92 using CW sources and SUS charges [18]. The location of the experiment areas is shown in Figure 16.

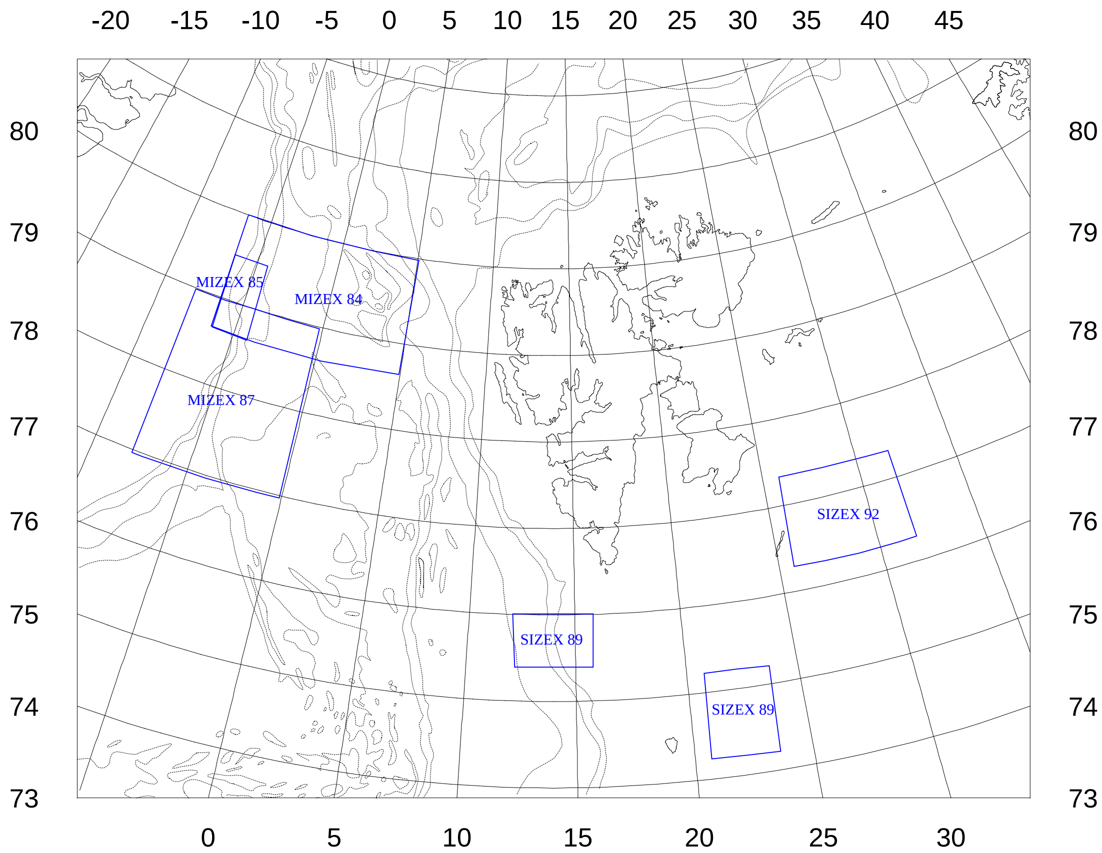


Figure 16. Location of the acoustic experiments during the MIZEX and SIZEX programmes.

All the campaigns, except MIZEX 85, were multi-disciplinary, international experiments, which employed various observational platforms such as ice strengthened ships, open ocean ships, drifting buoys, bottom-moored buoys, helicopters, aircraft, and satellites. In MIZEX 85 a dedicated acoustic experiment was carried out using a P3 aircraft to deploy sonobuoys and AXBTs. Satellite data were also used in the 1985 experiment.

In all the experiments remote sensing of the ice played an important role both for location of the experiments and in the interpretation of the ambient noise characteristics. In 1992, the ERS-1 satellite provided for the first time high-resolution spaceborne SAR images of the experiment area in the Barents Sea.

3.5.2 Data collection and processing

During the five field experiments twelve flights were conducted by Norwegian P3 aircraft. The aircraft deployed sonobuoys and AXBT's both in open water and in areas of open leads within the ice pack. In addition, helicopters were used for deployments in areas of high ice concentration. A total number of 169 operating sonobuoys at 154 different locations were deployed during the flights. The sonobuoy deployment depth was 18 and 122 m in the Fram Strait experiments and only 18 m in the Barents Sea experiments. An overview of the buoy deployment for each experiment is given in Table 4. An overview of data sets and data processing to be used in this project is given in Table 5.

These acoustical data were collected by the 333 Squadron of the Royal Norwegian Air Force, using P3-B aircraft equipped with AN/ARR-72 receivers and 28-track analog, FM wideband group II tape recorders. Details of the data collection, calibration and processing have been described in the previous data and technical reports. The MIZEX 84 and 85 data were processed by the Applied Research Laboratories (ARL), at the University of Texas, Austin, and are reported in [10]. The MIZEX 87 data are described in [11], and the SIZEX 89 data are reported in [14]. The SIZEX 92 data were initially processed at NDRE and reported in Engelsen [16,18], and along with environmental conditions in [17]. Then the SIZEX 92 data were re-processed in order to study short term variations, using software developed at NERSC based on calibration algorithms used at NDRE [18]. Raw data from the MIZEX experiments are located at ARL, Austin Texas, while the SIZEX 89 and 92 data are located at NERSC. The SIZEX 92 data are also located at DRA.

3.5.2.1 MIZEX 84-87

Six ambient noise case studies in MIZEX 84/85 were carried in the Fram Strait. In MIZEX 87 one ambient noise experiment was carried out in the Fram Strait. All MIZEX data were calibrated and processed at ARL in Texas. All the data for each recording sonobuoy in MIZEX 84, 85 and 87 are given by time averages at four selected frequencies 40, 100, 315 and 1000 Hz. All levels are given in dB re 1mPa^2/Hz, and the frequency domain was chosen from 12.5 up to 1000 Hz. The calibration, averaging and processing of the data are described in detail in [10], [11] and [24].

Table 4. The MIZEX and SIZEX acoustic ambient noise experiments.

Experiment date	**Area and center position**	**Number of sonobuoys /Number of AXBTs**	**Depth of acoustic buoys (m)**	**Recording period (Z)**
MIZEX 84	**Fram Strait**			
26 June	79° 03´N 00° 30´E	5/32	122	09:59 - 12:46
19 June	79° 36´N 03° 35´E	6/22	122	08:16 - 10:20
11 June	81° 30´N 01° 45´E	6/22	122	11:22 - 13:25
MIZEX 85	**Fram Strait**			
30 April	78° 24´N 01° 25´E	21/29	18, 122,305	11:15 - 19:07
25 April	78° 12´N 04° 30´E	15/8	18, 122,305	11:45 - 19:07
24 April	79° 14´N 01° 25´E	16/13	18, 305	11:00 - 14:35
MIZEX 87	**Fram Strait**			
2 April	78° 00´N 04° 00´W	21/0	18/122	10:00 - 17:00
SIZEX 89	**Barents Sea**			
February 27	75° 45´N 14° 00´E	24/7	18	11:30 - 16:00
February 18	74° 30´N 23° 00´E	18/4	18	14:00 - 17:45
February/ March		2 (RBS)/0		
SIZEX 92	**Barents Sea**			
March 9	77° 00´N 28° 30´E	26/2	18	12:49 - 15:15
March 6	77° 00´N 30° 30´E	11/5	18	11:00 - 16:00
March 1-2	76° 29.6´N 26° 00.2´E	1 (DATOS)	(Bottom mounted) 83 m	17:00 March 1- 20:00 March 2
March 6-9	77° 17´N 30° 14.5´E	6 (Ice array)	18,38	13:00 March 6- 01:23 March 9

Table 5. Summarised data processing.

Data sets used in this project	Averaged levels at at selected frequencies	Time series at selected frequencies	Frequency spectra	Sonogram	Data reports
MIZEX 85	x				[10]
MIZEX 87	x	x	x		[11]
SIZEX 89	x	x	x		[14]
SIZEX 92	x	x	x	x	[16] [17] [19]

The data from 1987 are presented by time series at selected frequencies and frequency spectra presented by 10, 50 and 90 percentiles as shown in Figure 17 [11]. Averaged values at each sonobuoy location for comparison to earlier experiments were calculated based on the times series [11].

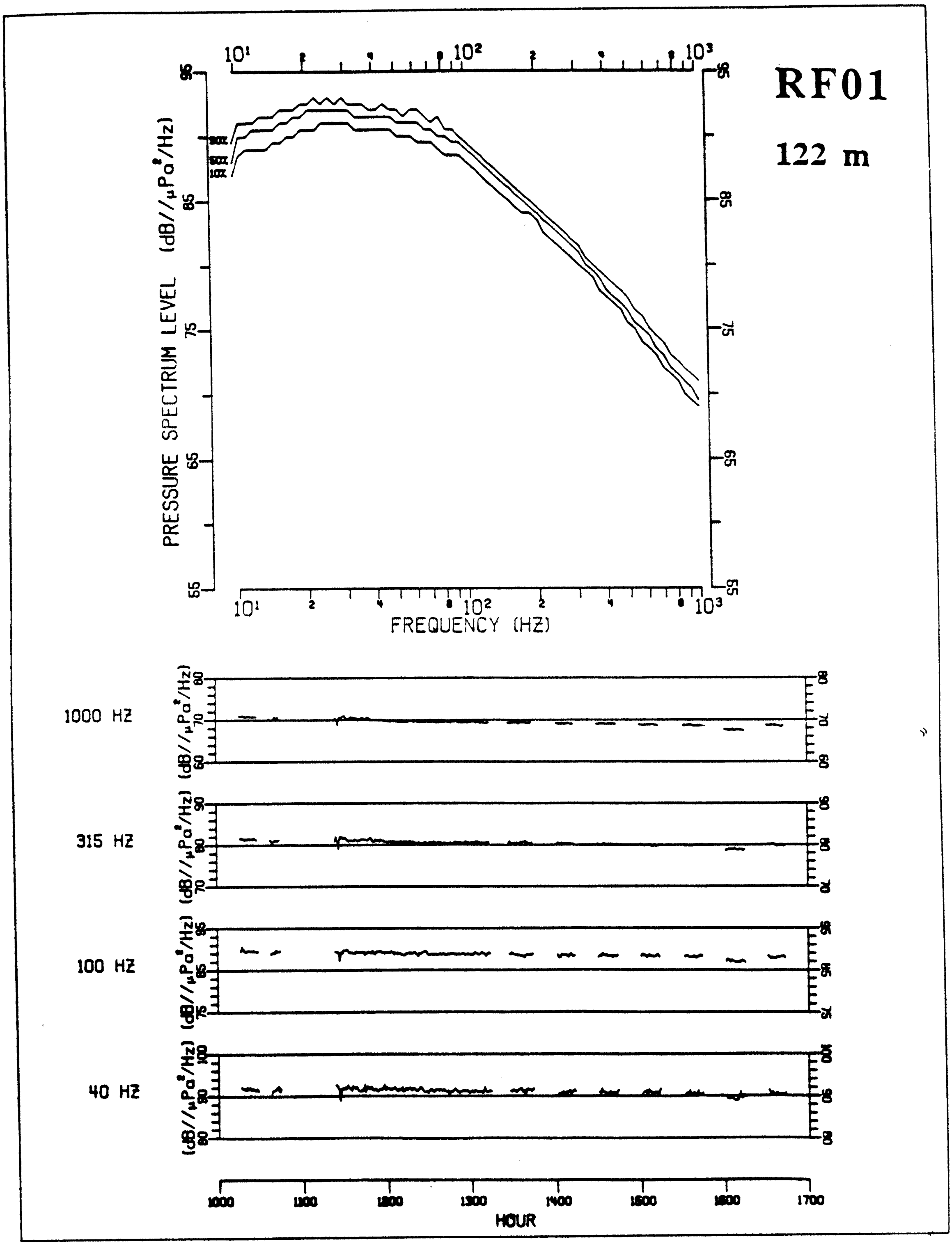


Figure 17. Upper graph: frequency spectra averaged over the whole recording period represented by 10, 50 and 90 percentiles. Lower graphs: time series of one minute averaged noise levels at selected frequencies. Data are from receiving buoy RF01 in the Fram Strait on April 2 1987.

3.5.2.2 SIZEX 89 and 92

During SIZEX 89 and SIZEX 92 several acoustic experiments were performed at three different locations in the Barents Sea (Figure 16 and Table 4). Acoustic data were obtained from sonobuoys, bottom mounted acoustic buoys and acoustic arrays deployed on ice floes.

During the two campaigns four case studies were performed focusing on effects of eddies, swell, tides, icebergs and other ice types on ambient noise in shallow waters. Sonobuoys were deployed from P3-aircraft and helicopters in arrays based on ice information from SAR data. The acoustical data were processed at NDRE and made available as raw data on tape and in data reports [14] [16] [18]. All processed data are represented as dB re 1 mPa/$\sqrt{\mathrm{Hz}}$, which is equivalent to values given in dB re 1 mPa^2/(Hz). The frequency bandwidth was from 12.5 Hz up to 5 kHz.

The acoustic data from four case studies were represented by frequency spectra averaged over 3 minutes (512 individual frequency spectra) at selected times when the data was of a good quality (Figure 18). Time series at selected frequency were generated based on the results from the frequency spectra. Averaged levels at selected frequency and selected times were plotted on ice maps generated from remote sensing data [16] [17].

A software system for data calibration, and processing is developed at NERSC which makes it possible to do more detailed and flexible analysis of the SIZEX 92 data. The system is used to make time series of 4 second averaged frequency spectra for 5 minutes recording intervals, called sonograms. The sonograms show the time variation in ambient noise at all frequencies in a 2-D contour plot. An example of a sonogram from March 6 1992 is shown in Figure 19. The system can also be used to produce averaged frequency spectra and plots of deviation from the averaged frequency spectra.

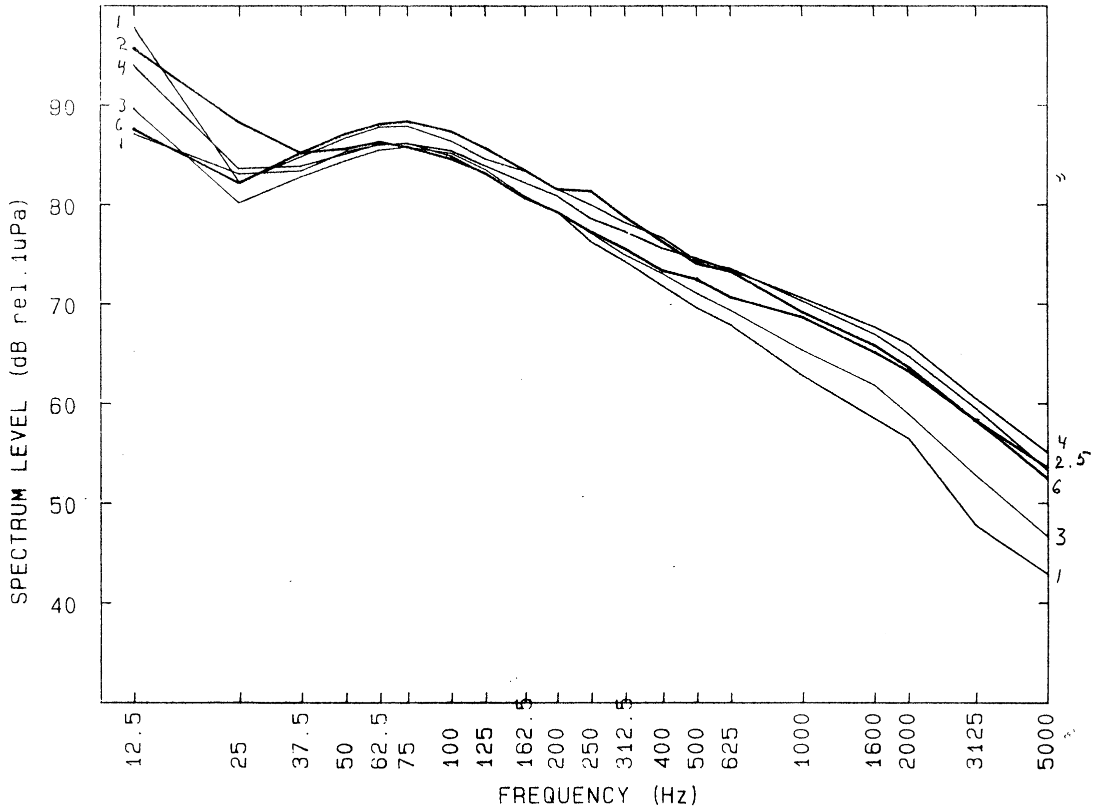


Figure 18. Frequency spectra averaged over 3 minutes from buoy 19 for six different periods on March 9 1992. Each averaged spectrum is derived from 512 individual frequency spectra

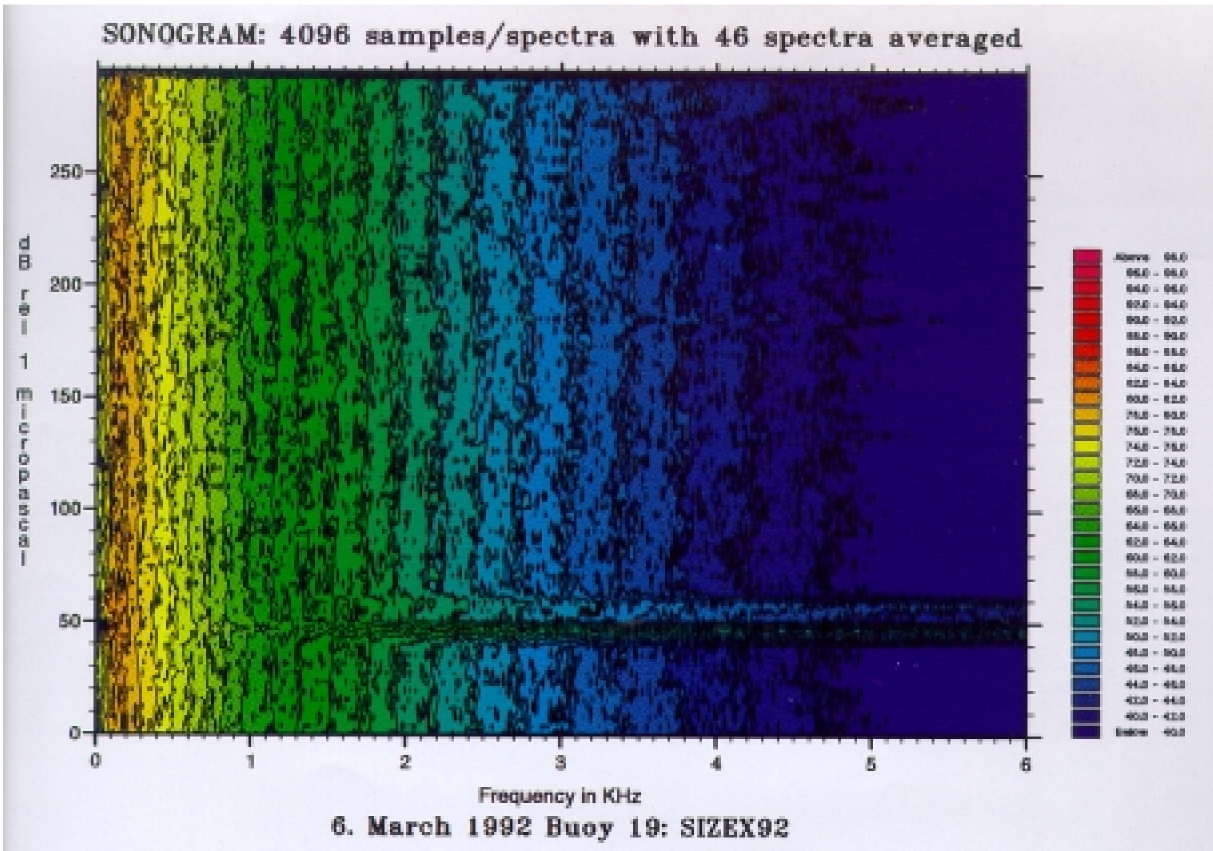


Figure 19. Sonogram from buoy 19 on March 6 1992. The vertical axis shows the time variability.

3.5.2.3 Bottom mounted acoustic buoys

Five bottom mounted acoustic recording stations were deployed in the SIZEX 89 and 92 experiments, of which four were successfully recovered. The data were calibrated and processed in cooperation with NDRE. During SIZEX 89 three buoys with a bandwidth 10-630 Hz were deployed at two locations (two in February and one in June). The buoys provided data for about three weeks. Details of processing and results are presented in an NDRE report [16] and in a joint NERSC-NDRE report [17].

In SIZEX 92 two buoys with a bandwidth of 3-20000 Hz were deployed for long-term recording. The recording was set to 4 minutes every hour for 23 days. Only one buoy was recovered and the buoy recorded successfully for only 28 hours. Frequency spectra, with bandwidth 12.5-5000 Hz, were estimated for the 28 hour period with an averaging interval of 2 minutes every hour. Times series of 2 minutes averages at selected frequencies is also estimated. Additional statistics were computed by [16]. Sonograms at selected times were generated at NERSC similar to Figure 19.

3.5.2.4 The Acoustic Propagation Loss Study in SIZEX 92

As part of SIZEX 92 a dedicated propagation loss experiment was done in a 100 km section across the ice edge northeast of Hopen on March 6 1992. The experiment was performed using SUS Mk 82 charges with explosion depth at 18 m. Twenty SUS charges were dropped from a P3 aircraft, but only 11 detonated successfully and could be used in the propagation loss study. Source levels for the Mk 82 charges detonated at a nominal depth of 18 m. The sonobuoys used in the experiment was modified AN/SSQ 41B with a sensitivity reduction of 40 dB. In cases of overloading and low signal to noise levels the results are discarded from the analysis. Propagation loss between each detonated charge and the four receiving sonobuoys has been computed in 1/3 octave frequency bands from 12.5 Hz to 3150 Hz and then normalized to 1 Hz. Details of the data recording, calibration and processing algorithms are given in a data report [18].

3.6 Ocean current data from the Fram Strait

As a joint Norwegian-US project, between the Departement of Geophysics, University of Bergen and the School of Oceanography, University of Washington/National Oceanic and Atmospheric Administration, Washington, current meters were deployed in the Fram Strait area during two periods, 1984-85 [21] and 1985-86 [22]. These instruments provided long time series of ocean currents at different depths. The average velocities from the two periods are shown in Figure 20 and 22, while Figure 21 shows a time series from one of these current meters, FS-1, which was deployed on the East Greenland shelf from 15 June 1984 to 16 July 1985.

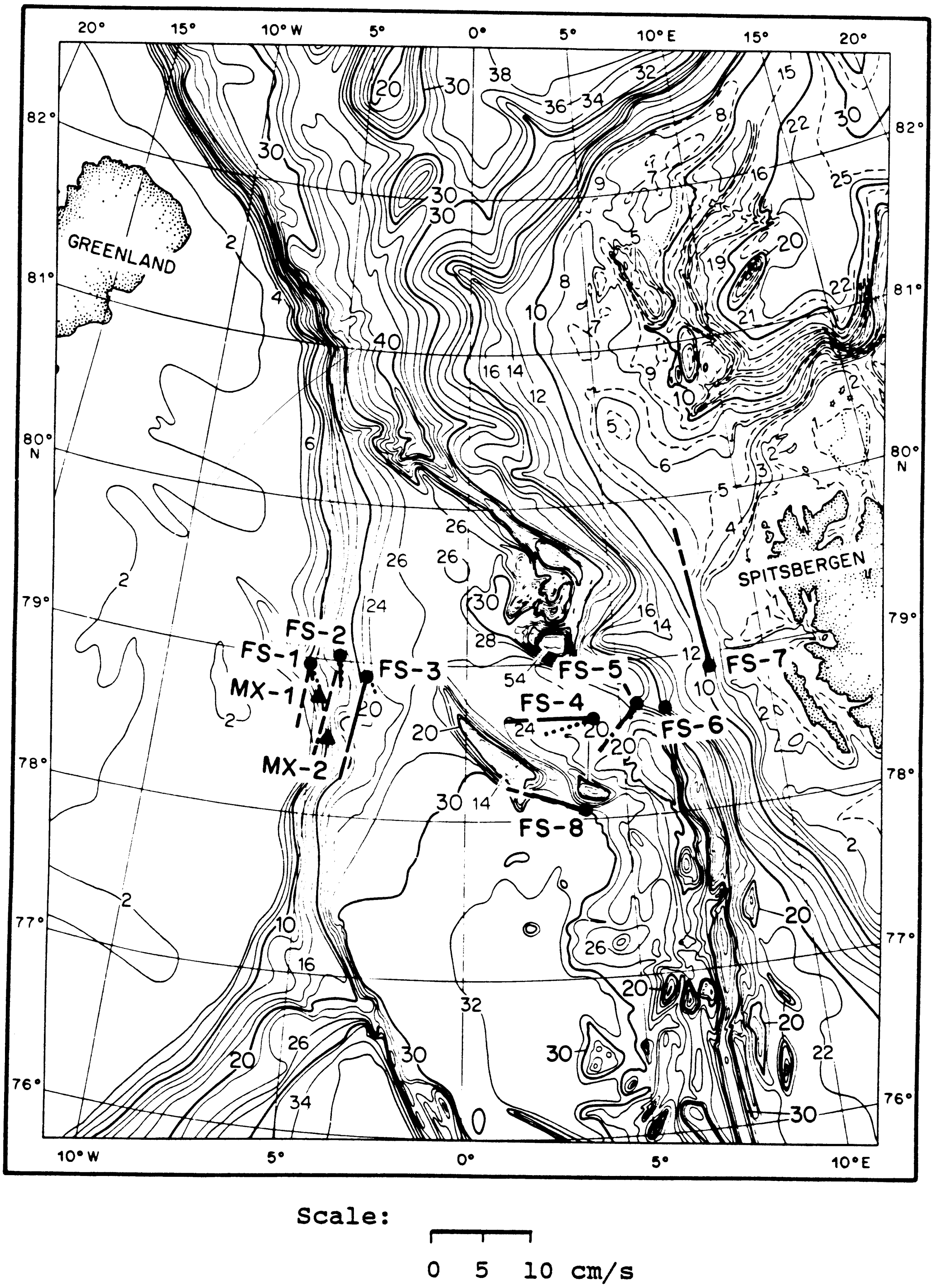


Figure 20. Map of the Fram Strait area where current meter moorings were put in 1984 [21]. The average current velocities at FS-1 to FS-8 for the individual observation periods are indicated. Dashed line: upper current meter. Solid line: intermediate current meter. Dotted line: deep current meter. Dashed-dotted line: deep current meter on FS-5.

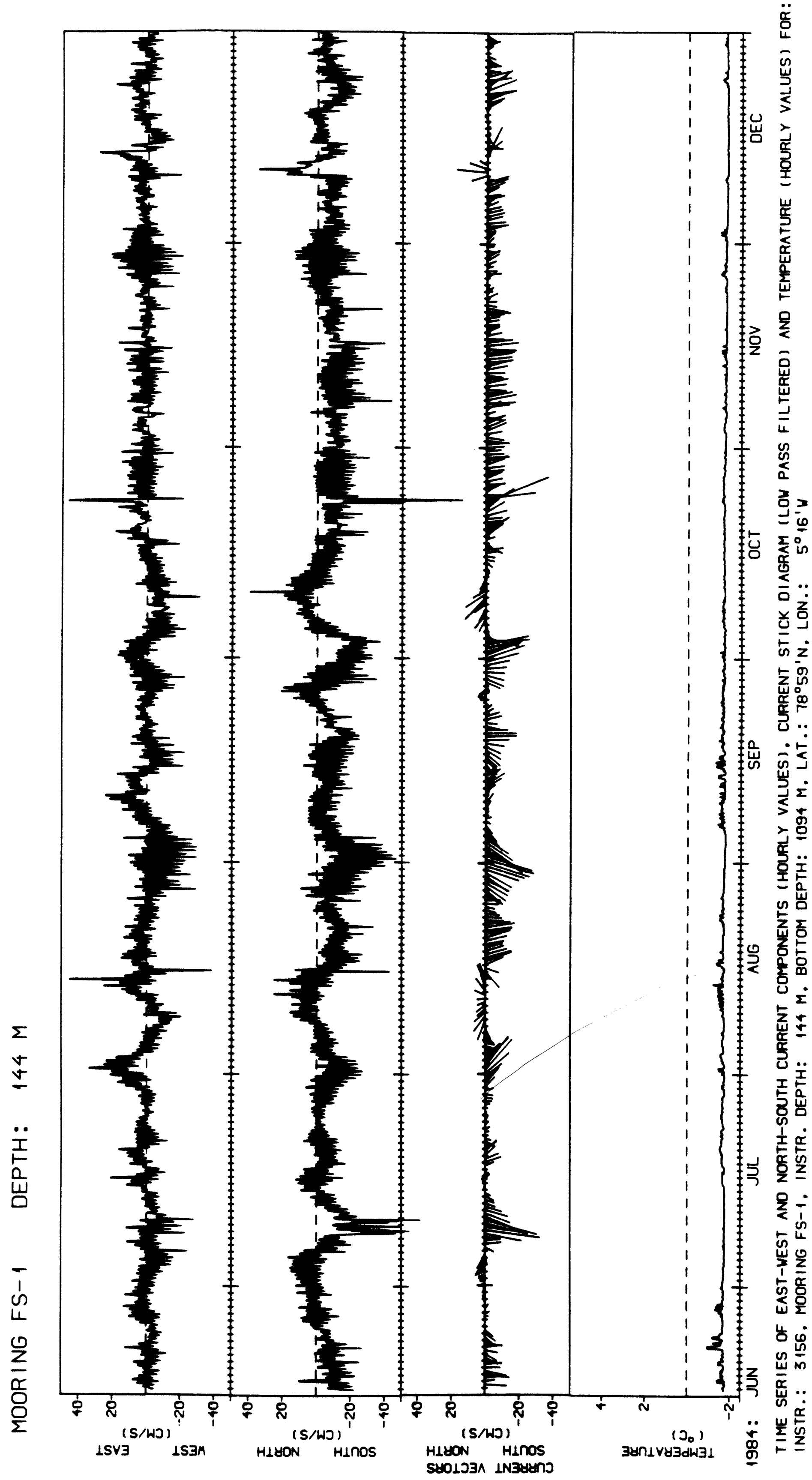


Figure 21. Time series of ocean current from mooring FS-1 in June - December 1984 [21].

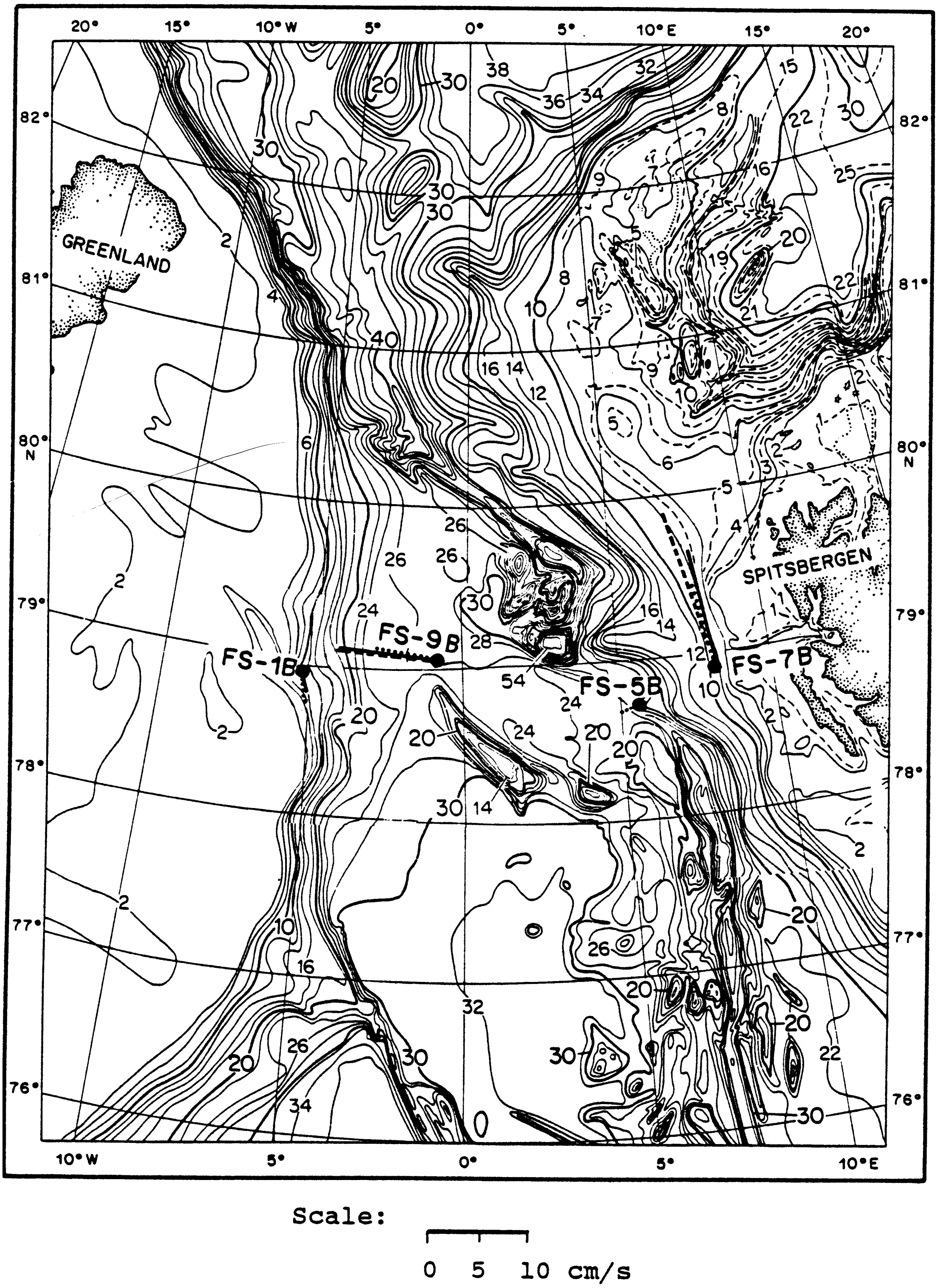


Figure 22. Map of the Fram Strait area where current meter moorings were deployed in 1985-86 [22]. Average current velocities at FS-1B to FS-9B for individual observation periods are indicated. Dashed line: upper current meter. Solid line: intermediate current meter. Dotted line: deep current meter.

3.7 Ancillary data

Bathymetry data will also be needed in AMOC. Data sources identified so far:

- Thomas Manley's data set on the CEAREX-1 CD [5], with 10km resolution bathymetry for parts of the Arctic Ocean. A bottom profile across the Fram Strait is shown in Figure 23. See Section 3.2 for further description.
- ETOPO-5, global bathymetry data, but at a much coarser resolution, approx. 5 minute grid. URL: http://www.ngdc.noaa.gov/mgg/global/seltopo.html.
- TerrainBase, improved 5-minute DTM based on ETOPO-5 data. URL: ftp://ftp.ngdc.noaa.gov/Solid_Earth/Topography/tbase_5min/tbase.txt.

Data from these sources will be extracted in year 2+3, as new scenarios with a more realistic bottom profile are defined. These scenarios may also need geo acoustic bottom information which need to be obtained from other sources, which are not yet identified.

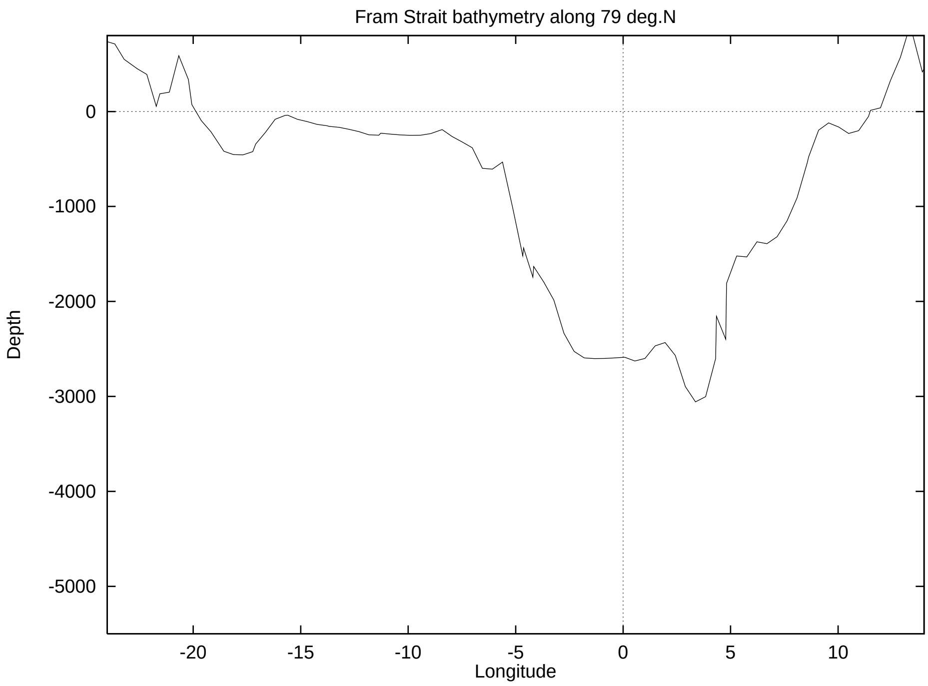


Figure 23. Bottom profile across the Fram Strait at 79N from data on the CEAREX-1 CD [5].

4. Data requirements for simulation models in AMOC

The physical environment in the Arctic is very complex, and there is no acoustic propagation model that treats the full environment in an accurate and general way. The ocean acoustic and seismo acoustic models evaluated for use in the project do all have some limitations and advantages depending on the problem on hand. A brief description of each of the acoustic propagation modules is included.

An appropriate propgation model for the Arctic Ocean has to include the effects of rough and elastic ice cover, ocean stratification, rough elastic bottom and range dependence in all layers. Such an acoustic propagation model will need environmental input such as ice thickness, roughness and elastic parameters to describe the ice cover, sound speed profiles to describe the ocean water layer, topology and geo acoustic information for the bottom.

The environmental input comes from historical data repositories (see Chapter 2) and from climate models (see Section 4.5). In order to incorporate this information into the propagation models data format conversion routines has to be generated. In this chapter the formats of the environmental input to acoustic propagation models used in AMOC are described briefly. Finally, the practical linking of the data repositories and simulation models will be outlined in Section 4.6. This is an important pre-analysis for the design of an efficient acoustic monitoring system for long term monitoring of climate changes in the Arctic environment. The structure of such a concept is indicated in Figure 24.

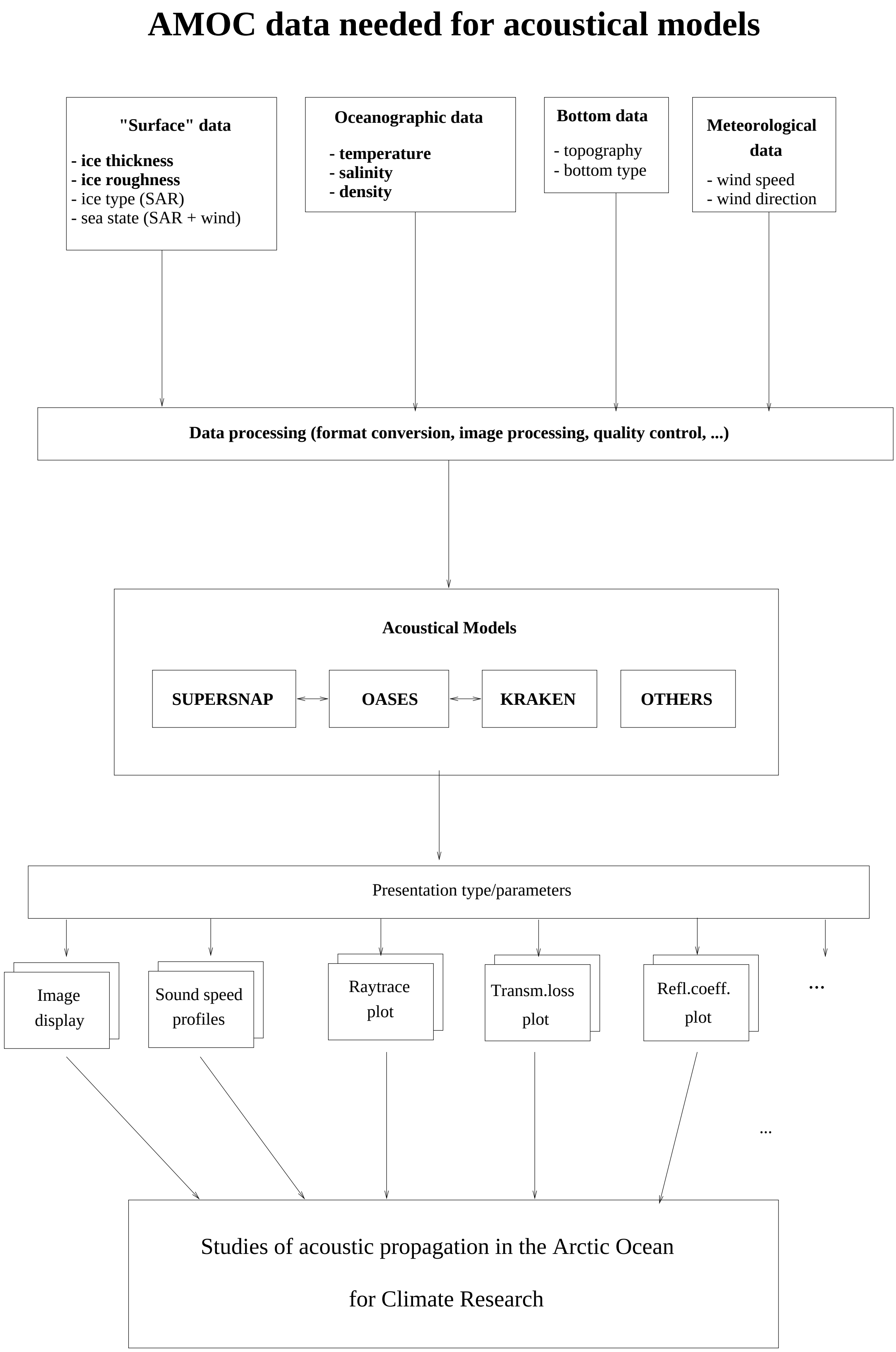


Figure 24. Overview of dataflow in an acoustical monitoring system.

4.1 Acoustic models used in AMOC

Existing and well documented acoustic models are used in AMOC. Based on evaluation work performed in Task 3, OASES, SUPERSNAP, KRAKEN and ray trace codes have been selected. Each of these models are described briefly below. Detailed documentation of the numerical models are found in technical and scientific reports (Table 6). The theoretical background of the different underlying theoretical approaches are described for example by Jensen et al., 1994 [42].

Range dependent propagation problems are solved by segmentation in range, that is that the environment is partioned into range independent segments where traditional solution techniques has been used and energy conservation principles has been used to match the solutions across the vertical boundaries. In practice this means that smooth variations either in bottom topology or horizontal gradients in ocean stratification are approximated with staircase functions which may cause false scattering effects.

In a recent paper this basic and important problem has been studied by Jensen, 1998 [49]. He finds that the strictest criterion are in the back-scattering calculations, where the horizontal step size should be smaller than a quarter of a wavelength. In forward calculations the horizontal step size can be increased to be a half acoustic wavelength. These considerations has to be taken into account in our construction of the environmental matrix.

Table 6. List of models used in AMOC.

Model Acronym	**Reports**	**Availability**	**Type of model**
OASES range independent version	Schmidt, 1988 [38] Schmidt, 1997 [40]	Free, http://acoustics.mit.edu/arctic0/henrik/www/oases.html	Wavenumber integration
OASES range dependent version	Schmidt, 1988 [38] Schmidt, 1997 [40]	Licenced, available through: Technology Licensing Office Massachusetts Institute of Technology Five Cambridge Center, Kendall Square Room NE25-230 Cambridge MA, 02142-1493 Tel (617) 253-6966 Fax (617) 258-6790 email: tlo-www@mit.edu	Wavenumber integration
SUPERSNAP	Jensen and Ferla, 1979 [45]	Free, http://acoustics.mit.edu/arctic0/henrik/www/snap.html	Normal mode
RAM	Collins, 1996 [44]	Free, FTP directory /pub/RAM/ at ram.nrl.navy.mil (e.g. via http://oalib.njit.edu/) Contact: Michael D. Collins	Parabolic Equation
Bowlin ray shadowing model	Brian Dushaw	Apl, University of Washington Report in html format is found at http://oalib.njit.edu/ Contact: Bruce M. Howe (howe@apl.wahington.edu)	
Acoustic tool box	Porter, 1998 [50]	http://oalib.njit.edu/ Responsible scientist: M. Porter (porter@mpl.ucsd.edu)	Normal mode

4.2 Models originating from SACLANT

OASES (Schmidt, 1997) [40] is a wave number integration model basically an extention of the SAFARI model which was developed at Saclant, (Schmidt, 1988) [38]. SUPERSNAP is a normal mode code also developed at Saclant (Jensen and Ferla 1979) [45]. The theoretical foundation and numerical schemes are described in detail by Jensen et al, 1994 [42]. Both models are range dependent, but only OASES has the possibility to include a rough elastic sea ice cover. OASES treats strong horizontal gradients, whereas SUPERSNAP only can be used in regions with small gradients.

4.2.1 Brief description of OASES

OASES model is basically a expanded version of SAFARI. There is one public domain version of OASES which is range independent. The range dependent version is licenced. In AMOC the licensed model have been installed at NERSC and at SPRI. The OASES model is the most appropriate model listed in Table 6, and will be used in AMOC to study of the effect of ocean and ice parameters on acoustic propagation in a range dependent region.

The model allows for arbitrary stratification’s incorporating fluids with depth dependent sound speed profiles, linearly visco elastic solids, transversely isotropic solids and poro-elastic layers. All common source representations are handled, including plane waves, point and line explosive sources, line arrays, and a variety of plane or axis symmetric seismic moment sources.

Elastic roughness conditions on elastic media are included in OASES by a perturbational approach (Kupermann and Schmidt, 1989; LePage and Schmidt, 1994) [43] [28].

The range dependent model, OASES, uses virtual panel sources (VISA), which is computationally less demanding than the models using the spectral super element method. While the spectral super element approach solves the coupled integral equation using a high-order panel-boundary-element formulation, the approximate approach is to solve reflections and transmission locally at a discrete number of depths (Schmidt, 1997) [40]. A benchmark study by Goh et al. (1997) [51] have shown that this model produces results that agree well with the spectral super element method.

The problem is the computer time which becomes large as the number of range segments (increasing as horizontal variation increases) and number of matching points along the vertical section boundaries increases with frequency and water depth. The computer time also increases rapidly in the case of a broadband study. OASES will therefore be run on a super-computer (Silicon Graphics/CRAY, Origin 2000 machine).

4.2.2 Brief description of SUPERSNAP

SUPERSNAP is a coupled normal mode code developed at SACLANT which is used as a “quicklook” model in AMOC. This model allows for elastic bottom, and range dependence both in bottom and in the ocean. Surface roughness can be specified, but ice cover is not included and the water depth has to be constant in the case of transmission loss as a function of depth and range. At low frequencies (40 Hz upto 100 Hz) the reflection is total and the effect of the ice cover is not important. SUPERSNAP is therefore proposed to be used as a first attempt to study the effect of mesoscale variability in the oceanographic field for lower frequencies and in open water. Errors can be introduced in the case of strong gradients and the results should be validated against OASES.

4.2.3 Data format

Input data formats for the OASES and SUPERSNAP model are different, but similar in structure. The input format for OASES is described in Table 7, and SUPERSNAP's input format in Table 8. The general idea is the same for both models: one part specifies computational parameters and one gives the plotting parameters. In this report we focus on the input structure of the computational parameters. The results generated from OASES and SUPERSNAP are in the same data format and results are plotted by using the same plotting routines, the public domain package plotmtv [41].

The OASES model consists of 5 different modules requiring slightly different computational input. On the other hand the structure of the environmental blocks are the same for all the modules. Therefore, since the structure of the environmental input is the essential theme in this presentation only one example is provided in this report (Table 7), for more details see Schmidt, 1997 [40]. Table 7 gives the input format to the range dependent transmission loss module (rdoast). Each layer are described by layer thickness, compressional wave speed, flexural wave speed, attenuation of compressional waves, attenuation of shear waves.

SUPERSNAP consists of only one module, and uses only one structure for the computational input, as described in Table 8. Details of the input and theoretical background of SUPERSNAP are described by Jensen and Ferla, 1979 [45].

Table 7. Input to rdoast.

INPUT PARAMETERS	EXPLANATION	UNIT	LIMITS
BLOCK I: TITLE			
TITLE	Text on plots	-	$\leq$ 80 characters
BLOCK II: OPTIONS			
A B C	Output options		$\leq$ 40 characters
BLOCK III: FREQUENCIES			
FR1,FR2,NF,COFF, [V]	FR1: First frequency FR2: Last frequency NF: Number of frequencies COFF: Integration contour offset V: Source/receiver velocity (only in case of moving source/receivers)	Hz Hz - dB/λ m/s	F>0
BLOCK IV: ENVIRONMENT			
NSEG	Number of segments in range		
NL SEGL(1) D,CC,CS,AC,AS,RO,RG,CL	NL: Number of layers SEGL(1): Length of SECTOR 1 D: Depth of interface CC: Compressional speed CS: Shear speed AC: Compressional attenuation AS: Shear attenuation R0: Density RG: RMS value of interface roughness CL: Correlation length of roughness	- km m m/s m/s dB/λ dB/λ g/cm^3 m m	$NL \geq 2$ - m $CC \geq 0$ - $AC \geq 0$ $AS \geq 0$ $R0 \geq 0$ - $CL \geq 0$
. . .	. . .	. . .	. . .
NL SEGL(m) D,CC,CS,AC,AS,RO,RG,CL	NL: Number of layers SEGL(m): Length of SECTOR m D: Depth of interface CC: Compressional speed CS: Shear speed AC: Compressional attenuation AS: Shear attenuation R0: Density RG: RMS value of interface roughness CL: Correlation length of roughness	- km m m/s m/s dB/λ dB/λ g/cm^3 m m	$NL \geq 2$ - m $CC \geq 0$ - $AC \geq 0$ $AS \geq 0$ $R0 \geq 0$ - $CL \geq 0$
SOURCES			
SD,NS,DS,AN, IA,FD,DA	SD: Source depth NS: Number of Sources in array DS: Vertical source spacing AN: Grazing angle of beam IA: Array type FD: Focal depth of beam DA: Dip angle (Source type 4)	m - m deg - m deg	- NS>0 DS>0 - $1 \leq IA \leq 5$ $FD \neq SD$ -
RECEIVERS			
RD1,RD2,NR,IR D1,D2,ND	RD1: Depth of first receiver RD2: Depth of last receiver NR: Number of receivers IR: Plot output increment * Depth sampling for plot generation options	M M -	- RD2 >RD1 NR>0
WAVE NUMBER SAMPLING			
CMIN,CMAX NW,IC1,IC2	CMIN: Minimum phase velocity CMAX: Maximum phase velocity NW: Number of wavenumber samples IC1: First sampling point IC2: Last sampling point	m/s m/s - - -	CMIN>0 - $NW=2^M$, -1(auto-sampling) $IC1 \geq 1$ $IC2 \leq 2^M$
PLOT PARAMETERS	Varies according to selected parameters to be plotted.		

Table 8. SUPERSNAP: Environmental input.

INPUT PARAMETERS	EXPLANATION	UNIT	LIMITS
TITLE	Text on plots	-	≤ 80 characters
NF	No of source frequencies	-	NF ≤ 26
F(1),…,F(NF)	Source frequencies	Hz	F>0
MMIN,MMAX	MMIN: First mode to be calculated MMAX: Last mode to be calculated		1≤MMIN≤MMAX≤500
LI0,LI1	LI0: No. of discretization points in water LI1 No. of discretization points in sediment		0< LI0+LI1≤2500
NSEG	Number of segments in range		NSEG≥1
SEGL(1)	Length of first segment	km	SEGL>0
H0,S0,S1	H0: Water depth in first segment S0: RMS roughness of sea surface S1: RMS roughness of sea bottom	m m m	H0>0 S0≥0 S1≥0
Z0(1),C0(1)	Z0(1): First sound speed profile depth (=0) C0(1): First sound speed profile value in water	m m/s	- -
. . .			. . .
Z0(n),C0(n)	Z0(n): Last sound speed profile depth (=H0) C0(n): Last sound speed profile value in water	m m/s	2≤n≤100
H1,R1,B1	H1: Thickness of sediment layer R1:Density of sediment B1: Compressional wave attenuation in sediment	m g/cm^3 dB/λ	H1≥0 R1>0 B1≥0
Z1(1),C1(1)	Z1(1): First sound speed profile depth(=0) C1(1): First sound speed profile value in sediment	m m/s	- -
. . .			. . .
Z1(m),C1(m)	Z1(m): Last sound speed profile depth(=H1) C1(m): Last sound speed profile value in sediment	m m/s	2≤m≤100
R2,B2,C2	R2: Density of subbottom B2: Compressional attenuation in sub-bottom C2: Compressional speed in sub-bottom	g/cm^3 dB/λ m/s	R2>0 B2≥0 C2>0
B2S,C2S	B2S: Shear attenuation in subbottom C2S: Shear speed in sub-bottom	dB/λ m/s	$0 \le B2S < 0.75 \cdot B2 \cdot \left(\frac{C2}{C2S}\right)^2$ $0 \le C2S << C1(H1)$
PLOT OPTIONS ..	Varies according to selected parameters to be plotted.		

4.3 Models from the Acoustic Tool Box

4.3.1 Brief description

The Ocean Acoustic Library contains acoustic modeling software and data. A large number of acoustic propagation models and programs for analysing and presenting oceanographic data are included in the library. The acoustic models are put into four categories:

(1) Rays,
(2) Normal modes,
(3) Parabolic equation and
(4) wave number integration.

For details visit the home page at *http://oalib.njit.edu/*.

The maintance of these models is supported by the US Office of Naval Research and responsible scientist is M. Porter. At NERSC we have downloaded the Acoustic Tool Box which contains well documented models such as

- BELLHOP: A beam/ray trace code
- KRAKEN: A normal mode code
- SCOOTER: A finite element FFP code
- SPARC: A time domain FFP code

The toolbox was selected because it contains the normal mode code KRAKEN, which includes the possibility to include a rough elastic ice cover. KRAKEN has been used by others in Arctic environments. (Pawlowicz et al., 1996; LePage and Schmidt, 1994) [46][28]. The toolbox also includes a ray trace model, BELLHOP, which will be used in AMOC.

At the point of writing this report we are just at the stage of start learning how to use KRAKEN. KRAKEN contains a module (KRAKEN) to calculate modes for range independent regions using a user defined environment file as input. Another module calculate the acoustic field (FIELD FIELD3D) using the modes calculated by KRAKEN. In the case of range dependence the KRAKEN module is first used to calculate the modes for each "range independent" sector. The acoustic field is then calculated in the field module where each mode file is included as descriptor for each sector, and the sectors are coupled either by adiabatic or coupled mode theory. KRAKEN includes the possibility to compute the acoustic field in 3 dimensions for varying sound velocity profiles using adiabatic theory.

The major benefits of KRAKEN are the inclusion of a rough elastic ice cover, and the possibility to calculate the 3-dimensional field.

4.3.2 Input data formats

A common input structure is used throughout the acoustic toolbox so that only minor modifications are needed to switch from one program to another. All the models produce shade files which can be processed using a common set of plotting routines to plot transmission loss vs. range or vs. range and depth. These plotting routines are contained in the GLOBAL directory. The toolbox includes programs for conversion to SACLANT format on output and vica-versa. In Table 9, a description of the environment input file is shown.

Table 9. Computational parameter input to KRAKEN.

INPUT PARAMETERS	EXPLANATION	UNIT	LIMITS
TITLE			
TITLE	Text on plots in single quotes	-	≤ 80 characters
FREQUENCY			
F	Frequency	Hz	
NUMBER OF MEDIA			
NMEDIA	Number of media excluding the upper and lower half-space		< 20
OPTION			
OPT(1:1),OPT(2:2), OPT(3:3), OPT(4:4)	OPT(1:1):Type of interpolation to be used for SSP OPT(2:2): Type of top boundary condition OPT(3:3): Attenuation units OPT(4:4): Slow /robust		See manual for available options
ENVIRONMENT- Top half space properties:			
ZT CPT CST RHOT APT AS	ZT: Depth CPT: Top P-wave speed CST: Top S-wave speed RHOT: Top density APT : Top P-wave attenuation AS: Top S-wave attenuaion	 m m/s m/s g/cm3	In accordance with units given by OPT(3:3)
BUMDEN ETA XI	TWERSKY scatter parameter BUMDEN: Bump density ETA: Principal radius 1 XI Principal radius 2		(ridges /km) m m
ENVIRONMENT Medium information.			
NMESH, SIGMA, Z(NSSP)	NMESH: Number of mesh points to use initially SIGMA: RMS roughness at the interface Z(NSSP): Depth at bottom of the acoustic medium	m	
Z(**i**) CP(**i**) CS(**i**) RHO(**i**) AP(**i**) AS(**i**)	For each layer **i** Z(**i**): Depth from surface CP(**i**): P wave speed CS(**i**): S wave speed RHO(**i**) AP(**i**) AS(**i**	 m m/s m/s g/cm3	
ENVIRONMENT- Bottom half space properties:			
BIOPT SIGMA	BIOPT: Type of Bottom boundary conditions SIGMA: Interfacial roughness		Options as described in manual
Phase velocity limits			
CLOW CHIGH	CLOW: Lower phase speed limit CHIGH: Upper phase speed limit	m/s m/s	
RMAX	RMAX: Maximum range	km	
Source/receiver depth info			
NSD SD (1:NSD) NRD RD (1:NRD)	NSD: The number of source depths SD: The source depths NRD: The number of receiver depths RD: The receiver depths	- m - m	

4.4 Ray trace codes

4.4.1 Brief description

Ray trace code BELLHOP from the acoustic tool box will be used in Task 3. This model uses the same environmental description format as KRAKEN and will not be discussed in more detail here.

4.4.2 Acoustical modelling at NIERSC by Russian subcontractors

Ocean current acoustic investigation is usually based on the travel time measurement for the sound signals propagated along some definite pathway. Travel time along the sound ray

$$\tau_i \approx \int_{\Gamma_i} \frac{ds}{c(\Gamma_i)}$$

Where $c(\Gamma_i)$ - sound speed along the signal travel ray Γ_i, ds the element of the ray between the source and the receiver (eigen ray). Travel time variation arises due to $c(\Gamma_i)$ changing. The main reasons that lead to $c(\Gamma_i)$ changing are the season variations, fluctuating water flow, mesoscale movement, and internal waves. That is why $c(\Gamma_i)$ can be regarded as the sum of the mean value of $c_0(\Gamma_i)$ and its variation with respect to environment changing $c(\Gamma_i) = c_0(\Gamma_i) + \delta c(\Gamma_i)$, where $\delta c(\Gamma_i)$ is defined by the spatial inhomogeneity patterns. The most significant are the temperature variation $\delta\theta(\Gamma_i)$ and water flow velocity fluctuation $u(\Gamma_i)$, $\delta c(\Gamma_i) \approx \alpha\delta\theta(\Gamma_i) + u(\Gamma_i)$ where temperature coefficient for see water is $\alpha \approx 4.72 \times 10^{-3} km(\ Cs)^{-1}$. Usually they regard the ratio $\delta c / c_0 << 1$, therefore we can define the travel time variation by the follow means

$$\delta\tau_i \approx -\int_{\Gamma_i} \frac{ds\,\delta\theta(\Gamma_i)}{c^2(\Gamma_i)} - \int_{\Gamma_i} \frac{ds\,u(\Gamma_i)}{c^2(\Gamma_i)}$$

The modeling of the influence of mesoscale ocean eddy on the sound propagation process for example is used by appropriate $c(\Gamma_i)$ consideration which should regard the eddy core position and its rotation velocity spreading. Horizontal ray refraction is negligible what makes it possible to use 2D range dependant ray program for calculation of sound propagation instead of 3D ones.

For the modeling of sound signal propagation through the number of mesoscale inhomogeneities it is necessary to simulate 3D inhomogeneity structure with definite parameters. Inhomogeneity movement in our case is regarded in frame of 'frozen turbulence' model, when the environment structure is shifted with the velocity with respect to regarded profile in the space. Taking in the mind vector type of relation between $\delta c(\Gamma_i)$ and water flow velocity one can exclude the temperature dependence for the sound speed by $\delta\tau_i$ measurement for the signals propagated on 16 paths network between the transducers of 4×4 tomography array. The main reason for the precise $\delta\tau_i$ calculation is the sound ray structure changing for the paths.

Computer modeling is based on the original data of $c(z)$ profiles of the Fram Strait environment. Regarded environment is characterized by minimum value of $c(z)$ at the sea surface (subsurface sound waveguide) what is typical for polar ocean. In the east part of the path there is one more minimum $c(z)$ at the depth of 600 m. It corresponds to the warm water income from the Atlantic. In the eastern part of the strait the cold and less salt Arctic water doesn't penetrate at the large depths and flows in subsurface layer. The second $c(z)$ minimum vanish there.

The sound source and the receiver should be placed in these conditions at the depths of 500 m in order. Rays from the shallower source will be propagating mostly in the subsurface waveguide through the number of inhomogeneity. They can strongly affect the rays so they change their structure (a number of refraction from sea surface). This makes the signal propagation process more comprehensives for the problem regarded. For the deeper source situation the length of the ray cycle increases and the number of ray incomes to perturbed subsurface layer is decreases at the strait width. Beside this the deeper rays can touch the bottom and scatters there. Hence the sea depth at the place of source and the receiver situation is needed sufficiently large for $c(z)$ at the bottom increases the same value in the inhomogeneity at the subsurface layer. Taking this consideration in mind we regard the pathway in the eastern part of the Fram Strait. Sound source is placed at the depth of 500 m at the distance of 60 km from Prince Karl Land coast. The receivers are placed at the distance of 200 km to the west from the source at the depths 100, 200 and 300 m respectively. Calculations revile the stable rays presence in this configuration source-receiver. This rays have four or five touching of the sea surface at the different environment variation.

As it was already mentioned the environment conditions at the eastern and the western parts of the pathway are different. West-Spitzbergen current dominated at the beginning of the pathway changes to the East-Greenland current. They have a constant configuration and therefore we cannot regard them as a random inhomogeneity. As for inhomogeneities we will presume them as a deviations from the regular dependence $c_0(z,r)$ where z - is a depth and r is a distance from the source. Here it was calculated a $c_0(z,r)$ regression on each horizon z_j. This regression dependence is defined by least square method. Therefore for inhomogeneity we presume the sound speed variation, $\delta c_0(z_j,r) = c(z_j,r) - c_0(z_j,r)$ which describe the spatial sound speed fluctuation at the z_j horizon with respect to initial $c(z_j,r)$ dependence. In process of computer simulation of $\delta c_k(z_j,r)$ the spatial spectrum of inhomogeneity and their variation are regarded. Initial value of inhomogeneity variation Δ^2 at the z_j horizon is calculated from $\delta c_0(z_j,r)$ realization. To generate another realization $\delta c_1(z_j,r)$ in each point (z_j,r) we add a random value from interval $\{-0.1\Delta \div +0.1\Delta\}$ with appropriate sign, which corresponds to derivative sign of initial function $\delta c_0(z_j,r)$. It is needed to maintain the relation between the generated realization and the initial one. Appropriate algorithm can be written as

$$[\delta c_k(z_j,r_i) - \delta c_{k-1}(z_j,r_i)] \times [\delta c_{k-1}(z_j,r_{i+1}) - \delta c_{k-1}(z_j,r_i)] \geq 0$$

$$[\delta c_k(z_j,r_i) - \delta c_k(z_{j-1},r_i)] \times [\delta c_{k-1}(z_j,r_i) - \delta c_{k-1}(z_{j-1},r_i)] \geq 0$$

To fit spatial property of generated realizations they weighted on initial power spectrum and passes through the Hamming window to avoid the edge effect. Power spectrum of generated realization can be corrected with respect to initial field of the inhomogeneity. To preserve the value of the δc fluctuation we normalize the variance of δc by the factor of Δ_0 / Δ where Δ is variance of δc. Data on 12000 environment realizations for were generated in the process of computer simulation. This volume of simulated environment realizations let 16% accuracy in the retrieval of spatial profile current velocity.

The following data and software is used by the Russian AMOC participants:
1. SSP data
2. SURFER 5.0 (64×64 equally spaced mesh of SSP data)
3. 2D range dependent ray code
4. Mathlab 4.2 + interface on Quick C

Table 10. Input data to the 2D range dependent ray code.

INPUT PARAMETERS	EXPLANATION	UNIT	LIMITS
TITLE	Text on plots	-	$\leq$ 80 characters
NF	No of source frequencies	-	NF $\leq$ 26
F(1),…,F(NF)	Source frequencies	Hz	F>0
SD RD NR PHI	Source depth Receiver depth No of receiver Ray exit angel	m m rad	m>0 -011< PHI<0.11
LI0	LI0: No. of discretization points in water		1< LI0 $\leq$12000
NSEG	Number of segments in range		NSEG$\geq$1
SEGL(1)	Length of first segment	km	SEGL>0
H0,S0,S1	H0: Water depth in first segment S0: RMS roughness of sea surface S1: RMS roughness of sea bottom	m m m	H0>0 S0$\geq$0 S1$\geq$0
Z(n) C(n,z)	Z (n): n-th sound speed profile depth C(n): n-th sound speed profile value in water	m m/s	$2 \leq n \leq 80$
H1,R1,B1	H1: Thickness of sediment layer R1:Density of sediment B1: Compressional wave attenuation in sediment	m g/cm^3 dB/λ	H1$\geq$0 R1>0 B1$\geq$0
R2,B2,C2	R2: Density of subbottom B2: Compressional attenuation in sub-bottom C2: Compressional speed in sub-bottom	g/cm^3 dB/λ m/s	R2>0 B2$\geq$0 C2>0
PLOT OPTIONS	Varies according to selected parameters to be plotted.		

4.5 Interfacing the different modules

By comparing Table 7-10 it is seen that the input parameters are the same but that the format of the input files varies significantly. In AMOC it is necessary to run different programs for many environmental cases. As the environments become more complex, it will be necessary to develop routines for producing the input files automatically, or at least semi-automatically. In AMOC it will be natural to select given tracks for numerical experiments and run for different environmental perturbations generated by historical data or by climate models.

A rough algorithm for AMOC for establishing the numerical experiments for sensitivity studies has been developed, and will be refined and implemented gradually in AMOC.

```
BEGIN Interface_Algorithm

/* Generation of matrix which describes the stationary environment. Common data format.*/
Select geographical position of the track to be studied.
Read bathymetry and geoacoustic information from data repositories.

/* Definition of the acoustic concept to be used in the numerical experiment */
Select model(s) and modules to be used
        Read manually the information about
                source/receivers
                numerical parameters (grid, ect)
                select the acoustical parameters to be studied
                select type of plots to be generated

/* Establish the environment matrixes to be used.*/
if new scenario then
        for each case in the scenario
                Read ice conditions along the track
                Read along-track sound speed profiles from data repositories or model output
                Perform a segmentation of the environment along the track
                Generate and store the environment matrix
        end for
else
        Give which scenario to be studied
        Read from archive the environment matrix
end if

/* Generation of input files for the selected model. This module will depend strongly on the selected model and required output*/

for each environment matrix
        Produce input files for the selected acoustic models
        Run the acoustic program(s)
        Write results to files and archive for later analysis
        Optionally start plot programs
end for

/* In order to do a sensitivity study we need to select the parameters to be analysed. In the case of temperature changes: Travel times, phases ect. In the case of changes in ice conditions: Intensity changes in the frequency domain */
Start statistical module to do a time analysis of  the selected acoustic parameters
Present results graphically.

END Interface_Algorithm.
```

5. Deliverables

According to the Work Programme [1], the deliverables after 6 months are:

1. First progress report on Task 1
   - This was included in the minutes of meeting from the 6-months progress meeting held at NERSC on 25-26th June 1998. The document was sent to all participants and the EC representative by email [23].
2. First delivery of Arctic Ocean data
   - CDs and diskettes were sent or delivered to partners at meetings. These data included:
     - Copy of the CEAREX-1 CD [5] to both SPRI and NIERSC.
     - Copy of the summer and winter Arctic Ocean atlases [4] to NIERSC.
     - AOGC'97 data (CTD and Seasoar) to NIERSC on CD.
     - First Fram Strait profiles (winter) along 79N to NIERSC on diskette.

After Task 1 has completed the deliverables are:

1. Technical report on Task 1
   - This document.
2. Complete delivery of Arctic Ocean data
   - CD delivered to partners at 12-months progress meeting.

6. Conclusion

Task 1 ends after 12 months, but the data sources identified and methods developed for extracting profiles will continue to be used in task 3-4-5 as new scenarios are defined for the acoustical models. During Task 1, the input formats of the selected acoustical models were inspected, and in the next six month period we plan to develop a graphical user interface that generates model input files automatically. This will do the work with running models more efficient both in Task 3 and 4, since preparing all input files manually will be time consuming.

7. Personnel and contact information

7.1 Personnel

Personnel engaged in Task 1 include:

- NERSC:
  - Ola M. Johannessen - overall coordination of NERSC activitites
  - Torill Hamre - task leader, data compilation and analysis
  - Hanne Sagen - data compilation and analysis, interaction with Task 3
  - Vibeke Jensen Haugen - data compilation and analysis
- SPRI:
  - Peter Wadhams - overall coordination of SPRI activities
  - Norman Davis - data compilation and analysis
  - Arthur Kaletzky - data compilation and analysis, interaction with Task 3
- MPI:
  - Klaus Hasselmann - overall coordination of MPI activities
  - Ernst Maier-Reimer - data compilation and analysis, interaction with Task 2
- NIERSC/Russian subcontractors:
  - Leonid Bobylev - overall coordination of NIERSC activities
  - Elena Evert - data analysis, interaction with Task 4
  - Igor B. Esipov - data analysis, interaction with Task 4
  - Konstantin Naugolnykh - data analysis, interaction with Task 4

7.2 Contact information

7.2.1 Nansen Environmental and Remote Sensing Center (NERSC)

Address: Edvard Griegsvei 3A, N-5037 Bergen-Solheimsviken, Norway
Phone: +47 55 29 72 88
Fax: +47 55 20 00 50
E-mail: administrasjon@nrsc.no
WWW: http://www.nrsc.no/

Contact: Prof. Dr. Ola M. Johannessen

7.2.2 Scott Polar Research Institute (SPRI) Max Planck Institute (MPI)

Address: University of Cambridge, Lensfield Road, Cambridge CB2 1ER, Great Britain
Phone: +44 (0)1223 336540
Fax: +44 (0)1223 336549
E-mail: pw11@cam.ac.uk (Peter Wadhams)
WWW: http://www.spri.cam.ac.uk/home.htm

Contact: Dr. Peter Wadhams

7.2.3 Max Planck Institut Meteorologie (MPI)

Address: Bundesstrasse 55, D-20146 Hamburg, Germany
Phone: +49 40 41173-236
Fax: +49 40 41173-250 or -298
E-mail: klaus.hasselman@dkrz.de (Klaus Hasselmann)
WWW: http://www.dkrz.de/

Contact: Dr. Klaus Hasselmann

7.2.4 Nansen International Environmental and Remote Sensing Center (NIERSC)

Address: Korpusnaya Street 18, 197042 St. Petersburg, RUSSIA
Phone: +7 812 235 74 93
Fax: + 7 812 230 79 94
E-mail: nansen@online.ru
WWW: http://www.nrsc.no:8001/niersc.html

Contact: Dr. Leonid Bobylev

NIERSC personnel working on the AMOC project:

- Leonid Bobylev - overall coordination of NIERSC activities
- Elena Evert - acoustical modelling in the Fram Strait

Russian subcontractors:

- Igor B. Esipov - acoustical modelling in the Fram Strait, Task 4
- Konstantin Naugolnykh - acoustical modelling in the Fram Strait, Task 4
- O. B. Ovchinnikov - acoustical modelling in the Fram Strait, Task 4
- Yu I. Tuzhilkin - acoustical modelling in the Fram Strait, Task 4

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