THE NORTHERN SEAS PROGRAMME 2002

JCR CRUISE (JUNE 14TH JULY 11TH)

Leith, Edinburgh to Yermak Plateau, Arctic

SAMS Northern Seas JCR cruise 2002: Scientific rationale and proposed sampling sites

1. Relevance to SAMS Northern Seas programme

The cruise work will directly address the following programme elements:

Theme A, Question 4

- *How does bioturbation vary in response to environmental forcing and what are the consequences for redistribution of anthropogenic contaminants?*
- *How does the anthropogenic burden change along a northern transect of 4 stations (67 to 81 N)?*

Theme A, Question 5

- *To deliver an understanding of the effect of abrupt climate change and land use on fjordic/sea loch systems, which link the marine and terrestrial environments at high latitudes in Northwest Europe.*

Theme B, Question 2

- *To what extent does benthic faunal composition and size structure determine processes of carbon dynamics ?*
- *Can we link changes in regional patterns in sediment biogeochemistry with disparate patterns in benthic distributions?*

Bioturbation processes form the interface between seabed biology and geochemistry. The 'environmental forcing' referred to in the programme is likely to vary both with depth (eg. fjordic-shelf-slope-abyss) and latitude (north-south gradients in intensity and interannual variability of pulsed OM input). Bioturbation therefore provides a crossover between the two main themes of the Northern Seas programme.

Work to be carried out from JCR should be seen as an essential supplement to the Wyville-Thomson work carried out on D257. To test the reality or otherwise of benthic biogeochemical 'provinces' we require comparable data from a range of sites in the water masses north and south of the WT Ridge (differences between our WTN and WTS stations does not in itself amount to a demonstration of 'provinces'). The WTS results can be put alongside existing data from previous studies in the Atlantic water mass (BENBO, SES), but at present we need more stations north of the ridge to compare with WTN.

2. Proposed study sites for JCR : Norwegian - Barents Sea continental margin

- Continental margin Norway - Barents Sea - Svalbard - Yermak Plateau, approx. N-S course without major undersea geographic barriers. Benthic faunal distribution therefore determined by gradients in seabed environmental conditions without confounding by biogeographic factors.

- This line also forms the approx. course of the northern 'conveyor' carrying contaminants from W. Europe to the arctic.
- Overall northwards trend in OM supply to the benthos will be one of increasingly pulsed flux and greater inter-annual variation in the timing and total supply of OM derived from water column primary production.

- Local factors superimposed on overall northwards trend, ie. winter 'outbursts' of fine-grained material off Barents Sea shelf, relative contributions of ice algae and phytoplankton on Yermak Plateau

- Data from series of sites along this N-S margin will therefore show how benthic community varies (biomass, bioturbator community structure) in response to forcing factor of OM supply, and consequences of this for sediment mixing rate, biogeochemical process rates and sediment contaminant distribution.

At **MAIN** sites all major equipment and techniques will be deployed. In addition to these main sites CTD and coring deployments may take place at intervening sites.

2.1 Deployment of Photo Lander

In addition to the transect sites the SAMS Coral Lander will be deployed at the Sula Ridge at the start of the cruise and will be recovered on the return journey. The co-ordinate and depth of the station are as follows:

- 280m depth
- 64 05.0340N 08 02.3374E

Before deployment a quick multibeam (+TOPAS) survey will be run over the deployment site to ascertain site conditions as the lander is designed to sit on flat seabed beside the reefs, not in amongst the live coral areas. Estimated time of the survey is 1 to 2 hours but this requires finalising with the ship's personnel.

On the return leg a sediment sample will be collected from the lander position, a box core would be ideal. If time permits a sample of live coral should be obtained from the reef area.

2.2 Proposed main sampling sites Northern Transect

Sampling all at depth similar to top of Voring Plateau, ie. ~ 1400 m

1. **Voring Plateau: High Priority Site:** (Gravity coring Site) Nyk Drift, this site is similar supply to other 3 northern transect sites. **Alternative site:** Central Plateau: Purely pelagic OM supply, no advection off shelf. Much published information on nature and distribution of benthic fauna, will facilitate interpretation of our samples. Few data on biogeochemical process rates.
2. **Bear Island Fan:** Not far from Voring, but receives advected material off Barents Sea shelf as well as pelagic OM flux.

3. **Margin W. of Svalbard, no ice cover:** No ice algae, but will receive pelagic OM and northwardly-advected material from West Spitzbergen Current (WSC)
4. **Western margin of Yermak Plateau:** Within influence of WSC, with additional contribution from ice algae.

These four stations will form the northern transect. If time constraints or ice thickness prevents work at the Yermak Plateau, the remaining ice-free sites will still provide us with a 3-station northward transect.

2.3 Additional Deployment Northern Transect, Kongsfjord (1400m)

There will be a trial of the Elinor chamber at the Kongsfjorden 1400m station. The deployment duration will hopefully be 2-3 days.

3. Proposed study sites for JCR : Svalbard margin out from Kongsfjord

This is intended to tie in with April 2002 LSF work (post-bloom data from Kongsfjord stations). The transect will consist of four main stations, nb there are 5 main stations however the 1400m station will be completed during the execution of the northern transect.

The transect will continue out from fjord in a series of stations across the shelf (where soft sediments exist) and down continental slope. This will allow changes in benthic community and biogeochemistry to be recorded along a depth/OM supply gradient not confounded by other factors.

This bathymetric transect will intersect with the N-S margin transect proposed above.

3.1 Proposed main sampling sites Kongsfjord Transect

1. The inner station occupied by the lander April 2002 (station 22 141m depth N79° 0.33′ E11° 54.20′)
2. Mooring station April 2002 (200m depth N79 03.25’ E011 17.96)
3. Station outwith fjord approximately 800 m?
4. Station 1400 m this is the same station as northern transect (count only once)
5. Fram Strait, station as far west as possible in time constraints (no further than 0°)

3.2 Proposed additional coring sampling sites Kongsfjord

Coring sites LSF April 2002:
Megacore and box core

Station	Gear	Longitude	Latitude	Depth
52 (Fjord)	Sholkovitz (S1)	N 79 02	E 11 24.6	260 m
KB3 (Fjord)	Sholkovitz (S1)	N 78 57.5	E 11 56.7	347 m

Deep Hole (Molloy Deep): In addition to the above stations a limited amount of coring will take place at the deep hole 5500m if time permits.

4. Summary of main stations and equipment to be deployed

Station/sampling	**Lander (profiler)**	**Oxygen Incubations**	**Nutrient Incubations**	**CTD**
Voring Plateau (1400m)	Yes (auto)	Yes	Yes	Yes (2drops)
Bear Island Fan (1400m)	Yes (auto)	Yes	Yes	Yes (2drops)
Off Kongsfjord (1400m)	Yes (auto)/**Elinor trial**	Yes	Yes	Yes (2drops)
Yermak Plateau (1400m)	No (ice?)	Yes	Yes	Yes (2drops)
Kongsfjord (141m)	Yes (moored)	Yes	(to be decided)	Yes (2drops)
Kongsfjord (200m)	Yes moored)	Yes	Yes	Yes (2drops)
Kongsfjord (1200 m)	Yes (auto)	Yes	(to be decided)	Yes (2drops)
Fram Strait (3000m)	Yes (auto)	Yes	(to be decided)	Yes (2drops)

Station/sampling	**Multicorer**	**Megacorer**	**Box corer**
Voring Plateau (1400m)	Yes (3 drops)	Yes (min 3 drops)	Yes (min 2 drops)
Bear Island Fan (1400m)	Yes (3 drops)	Yes (min 3 drops)	Yes (min 2 drops)
Off Kongsfjord (1400m)	Yes (3 drops)	Yes (min 3 drops)	Yes (min 2 drops)
Yermak Plateau (1400m)	Yes (3 drops)	Yes (min 3 drops)	Yes (min 2 drops)
Kongsfjord (200m)	Yes (3 drops)	Yes (min 3 drops)	Yes (min 2 drops)
Kongsfjord (350m)	Yes (3 drops)	Yes (min 3 drops)	Yes (min 2 drops)
Kongsfjord (1200 m)	Yes (3 drops)	Yes (min 3 drops)	Yes (min 2 drops)
Fram Strait (3000m)	Yes (3 drops)	Yes (min 3 drops)	Yes (min 2 drops)

Station/sampling	**Bedhop Camera**	**Gravity corer**
Voring Plateau (1400m)	Yes (min 2 drops)	**For details see below**
Bear Island Fan (1400m)	Yes (min 2 drops)	
Off Kongsfjord (1400m)	Yes (min 2 drops)	
Yermak Plateau (1400m)	Yes (min 2 drops)	
Kongsfjord (200m)	Yes (min 2 drops)	
Kongsfjord (350m)	Yes (min 2 drops)	
Kongsfjord (1200 m)	Yes (min 2 drops)	
Fram Strait (3000m)	Yes (min 2 drops)	

In addition to the above sampling higher resolution longitudinal sampling will be undertaken using the mega corer and box core. This will provide samples for benthic biomass and sediment cores for solid phase geochemistry.

Also limited sampling of the Molloy Deep.

5. Geochemical and benthic sampling to be carried out at each selected station

5.1 Benthic sampling requirements at each main station

- **Seabed photos: Minimum 2 drops of bedhop camera** (= 50 photos) More if time allows. Will process colour slide film from each station on board ship to give on-the-spot information on seabed type.
- **Boxcoring: Minimum 2 good ones per station** More if time allows. Will be subcored for X-ray analysis (working with John Howe), dissected for burrow features, burrow contents/animal gut contents sampled for geochemistry if any found. Sediments will be sieved for larger fauna (> 500 µm in fine sediments, coarser sieve necessary if material is sandier)
- **Megacoring** Will be used as standard sampler for sediment macrofauna **8 cores per station** (as used in AFEN protocols), but do not have to come from 8 separate drops. Cores will be sieved on 250 and 500 µm. Some depth-sliced for data on vertical distribution. If megacorer fails, boxcores will be sub cored for sieving on 250µm, and back-up with multicores as done on D257.

5.2 Geochemistry sampling requirements at each main station

The solid phase and pore water analysis of sediment cores in conjunction with the lander data, radionuclide data and organic data will be used to determine the biogeochemical processes that are dominating the system under study and investigate the role of carbon (quantity and type) and benthic biota with respect to changing environments. This will be done for both the latitudinal gradient (change in supply but constant depth) and longitudinal gradient (change in depth and water masses). The redistribution of pollutants will also be investigated on both transects.

This data will be intimately linked with the biological data and flux data and will be modelled with respect to the benthic/geochemical system.

Geochemistry sampling will involve

- **Lander deployment:** in profiler mode and possibly Elinor mode (off Kongsfjord, 1400m),
- **Incubations:** O_2 and nutrient fluxes from incubated cores.
- **Radionuclide**: One sediment core will be collected from each station for down core Pb-210, Th-234 (only at fjordic sites) and Cs-137 (all stations)(sliced and stored at 4°C). The radionuclide and chlorophyll data will provide rates of mixing on different scales, Th-234 and chlorophyll days to months and Pb-210 years. The Th-234 and Chlorophyll will be targeted to the fjordic sediments where we might expect a higher concentration of biota and hence mixing.
- **Trace metals and particle size**: One sediment core will be collected at each station for trace metal analysis and PSA. (sliced and stored at 4°C). The solid phase sediment data will be used to characterise sediment type and identify major changes in type along both the latitudinal and longitudinal gradients.

- **OM and stable isotopes**. 2 sediment cores (if possible) will be taken at each station sliced and kept frozen. These cores will be used for Chlorophyll and stable carbon isotope analysis.
- **Pore water extraction**: Pore water extraction will be performed on one core at all of the main sites (or as many as possible).

From each main station geochemical analysis will require a total of **5 mega core** this could be reduced to 4 if organic analysis can be performed on another core ie solid phase.

Analysis	Pore water extraction	Solid phase	Radionuclide	Chlorophyll	Organic analysis
Megacore	1	1	1	1	1

Each core will be sectioned as follows;

- 0.5cm increments to 10cm depth,
- 1 cm increments to 20cm depth
- and thereafter 2cm to bottom of the core.

The samples will be bagged and kept at a max of 4°C or in the case of the organic samples frozen.

As stated above, from further stations in Kongsfjord or on the shelf (deep hole) we will require 2 megacores per station for solid phase analysis, and radionuclide analysis

5.3 Shipboard Analysis

- Shipboard analysis of porewater nutrients will be required. A maximum of 50 samples at 8 stations will be required = 400 analysis.
- Nutrient analysis of CTD water will also be required at each main station.

6. JCR75 – Gravity Coring Programme

6.1 Rationale

The timing and effects of deglaciation in high latitude deep-water environments and its impact on bottom current circulation. Regions of high sedimentation rates in the Polar North Atlantic will be targeted (3-100 cm/ky) allowing abrupt climatic events to be detected at a high temporal resolution allowing the timing and onset of deglaciation and its relationship to sediment supply and productivity to be examined.

6.2 Methods

A 6 m-long (BGS) gravity corer will be used to obtained sediment records spanning the last glacial-interglacial cycle. Sampling stations are selected from sites of current-influenced sedimentation on the Voring Plateau, Western Svalbard Margin and Fram Strait and the Yermak Plateau. Core site selection will be based on a short (< 3hrs) acoustic survey (Topas and Multi-Beam) to identify key areas of current influenced sedimentation. The study targets key regions of oceanic circulation as well as complementing the interdisciplinary SAMS sampling stations. Cores will be split digitally photographed and logged onboard RRS James Clark Ross.

6.3 Sampling Stations (All Sites 6 m core with exception of Konsfjord 3m).

Station		Priority	Approx. Location	Water Depth	Acoustic Survey	Depositional environment	Science Target
Voring Plateau	1	High	67N 7.5E	1000-1400	Topas (nearby Nyk slide)	Nyk Drift, extreme sedimentation rates (1.2m per 1000 year)	Atlantic Surface & Intermediate water flow?
Voring Plateau	2	Med.	65.5N 5E	1400-1500	Topas	General SAMS	Atlantic Surface & Intermediate water flow?
Outer Voring Plateau	3	High	68N 2E	2000-2500	Topas	Contouritic	NSDW flow
Bear Island Fan	4	Low	tbc	1400-1500	Topas	Downslope sediment fluxes General SAMS	LGM-Holocene sediment transport, Trough Mouth Fan
Kongsfjord	5	High	tbc	<350	Topas + Multibeam	General SAMS	Fjordic Proxy
Kongsfjord	6	High	tbc	<350	Topas + Multibeam	General SAMS	Fjordic Proxy
Kongsfjord	7	High	tbc	<350	Topas + Multibeam	General SAMS	Fjordic Proxy
W. Svalbard Margin	8	Med	79N 8E	1400	Topas	General SAMS	Konsfjord Trough Mouth Fan & alongslope currents
W. Svalbard Margin	9	Med	79N 6E	2000	Topas	Contouritic	Konsfjord Trough Mouth Fan & alongslope currents
Fram Strait	10	High	79N 3E	2000-3000	Topas	Contouritic	Bottom water flow influence of Molloy Deep Eddy
Fram Strait	1	High	79N 0E	2000-	Topas	Contouritic-	Molloy - SW

	1			3000		hemipelagic	Hovgaard Fracture Zone - Bottom water flow influence of Molloy Deep Eddy
Fram Strait	12	High	79N 0E	3000-5669 (Molloy Deep)	Topas	Contouritic-hemipelagic	Molloy - SW Hovgaard Fracture Zone - Bottom water flow influence of Molloy Deep Eddy
Yermak Plateau	13	Low	81N 3E	1000-1500	Topas	Contouritic - glaciomarine	Arctic deep water flow. Seasonal ice, productivity
Yermak Plateau	14	Med	81N 3E	1500-2000	Topas	Contouritic - glaciomarine	Arctic deep water flow. Seasonal ice, productivity
Yermak Plateau / Lena Trough	15	Med	81N 0E	2000-2500	Topas	Contouritic - glaciomarine	Arctic deep water flow. Seasonal ice, productivity

Station Times (based on 3 hours MAX survey* using Topas and winch speed of 40m/min)

* No account of slow surveying for ice conditions

Station	**Water Depth**	**Estimated Time on Station (Survey+Wire Time)**	**Problems & Comments**
1. Voring Plateau	1400	4 hrs 10 mins	Care surveying as slides on both side of drift.
2. Voring Plateau	1500	4 hrs 15 mins	Unknown sediment type
3. Outer Voring Plateau	2500	5 hrs 10 mins	Unknown sediment type
4. Bear Island Fan	1500	4 hrs 15 mins	Possible coarser seds. Debris flows and Turbidites common.
5. Konsfjord	350	3 hrs 9 mins	Need 3 m barrel for all fjord sites: Diamict common! ONE Topas & Multibeam survey could identify all three core sites in Konsfjord
6. Konsfjord	350	3 hrs 9 mins	ONE Topas & Multibeam survey could identify all three core sites in Konsfjord
7. Konsfjord	350	3 hrs 9 mins	ONE Topas & Multibeam survey could identify all three core sites in Konsfjord

8. W. Svalbard Margin	1400	4 hrs 10 mins	Unknown sediment types poss diamict in shallow water
9. W. Svalbard Margin	2000	4 hrs 30 mins	Contouritc + Ice Rafted Debris
10. Fram Strait	3000	5 hrs 50 mins	Contouritc + Ice Rafted Debris
11. Fram Strait	3000	5 hrs 50 mins	Contouritc + Ice Rafted Debris
12. Fram Strait	5669**	8 hrs	Contouritc + Ice Rafted Debris
13. Yermak Plateau	1500	4 hrs 15 mins	Contouritc + Ice Rafted Debris + Diamict!
14. Yermak Plateau	2000	4 hrs 30 mins	Contouritc + Ice Rafted Debris + Diamict!
15. Yermak Plateau	2500	5 hrs 10 mins	Contouritc + Ice Rafted Debris

Total MAX Time Surveying and Gravity Coring: <u>69 hrs 53 minutes (approx. 3 days)</u>
** Assumes sampling Molloy Deep alternative sites may be found in depths < 3000 m

7. Marine Physics: proposed physical oceanographic support to projects

Each SAMS project have requirements for water column properties. This will be via a planned program of CTD stations with water samples from strategic depths. Vessel mounted ADCP will be logging continuously throughout the cruise. In addition to data collected about water movement which has been requested by certain projects (sediments, benthic, …) and a proposed survey of entrance of Kongsfjord, backscatter data will be of value to biological programmes (Mike Burrows).

[It may be possible to provide support to organisations or groups on other vessels in the Arctic to fill gaps in their own surveys or time-series. This is **<u>very low priority</u>** and only feasible if stations lay on our intended cruise track. Though this is not part of the SAMS core program there may be mutual and future benefits.]

7.1 Vessel mounted ADCP survey of Kongsfjord and beyond the shelf break.

- An ADCP survey of Kongsfjord will contribute to the physics element of Theme A and give a baseline for other activities within the fjord.
- The survey will take place in the vicinity of the mooring position and conceivably be attempted whilst the mooring is being turned around There is an opportunity to observe T/S and flow characteristics along the shelf edge and in the deep-water exit from Kongsfjord on the planned transect into the Fram Strait.

7.2 Potential mooring/survey work in conjunction with Norsk Polar Institut (NPI)

NPI are undertaking a program of physical observations of Kongsfjord as part of OAERRE (although this is not within our own OAERRE commitments). We will be able to contribute to this in collaboration with Harald Svendsen as part of Theme A. Using an ADCP we can get good tidal information and make observations of the changes in baroclinic flow through the fjord as the system changes from stable stratification to one influenced by convection through cooling and salt injection. At high latitudes internal tides are not expected to exist; we hope to investigate this.

Two possibilities include

1. revisiting NPI hydrographic stations and
2. servicing and possible redeployment of the moored instruments that were deployed in April as part of the LSF work. These moorings may be recovered by JCR or alternatively in September with *Hakon Mossby* (needs confirmation). Each recovery and deployment require **0.5 days ship time** with a 1 day interval for instrument turn around.

7.3 Primary Measurements:

- CTD and VM-ADCP
- Moored 300 kHz ADCP and T/S loggers

7.4 Onboard facilities/personnel:

- 150 kHz ADCP with data logging and 1 Hz ship's navigation data.
- Technician/scientist to operate and download the ADCP data.

7.5 Collection of water samples for d^{18}O measurements

Water samples from CTD casts will be taken for d^{18}O analysis. This will be used to trace water of fjordic origin up the coast to the Yermak Plateau. The data will be of use in interpretating the geochemical data with respect to sources. It has also been found to be useful in determining the contribution of sea ice melt to water in the Fram Strait.

8. Order of priorities

After considering the scientific objectives of the cruise and the feedback from SAMS Programme Advisory Board the following order of priorities have been assigned;

1. The 4 stations of the Northern Transect are of highest priority although it is understood that the ice conditions at the Yermak plateau will have to be assessed during the cruise.
2. It is important that deployment of all equipment and recovery of the necessary samples at each main station is complete. It is more important that fewer stations are completed than all stations are visited but not completed. Answering the scientific questions requires benthic, geochemical and physical data.
3. The highest priority for the Kongsfjord transect are the 2 stations occupied April this year and the Fram strait stations.

9. External and internal requests for sample collection and measurements

9.1 Surface Sediment sites requested by Prof. McCave

Prof. McCave is interested in obtaining surface sea-bed samples, (top 1 cm preferably) from Bear Island Fan, Fram Strait and by Jan Mayen.

Depths and Locations

UW/BI-CM2	1712 m	73° 43.9'N	13° 05.4'E
UW/BI-CM3	1686 m	73° 49.6'N	13° 27.3'E
Berg/FS-1	1094 m	78° 58.7'N	05° 16.1'W
Berg/FS-1B	1043 m	78° 58.6'N	05° 18.9'W
Berg/FS-3	2539 m	78° 54.9'N	03° 17.7'W
Berg/FS-4	2345 m	78° 39.4'N	04° 05.7'E
Berg/FS-7B	979 m	78° 50.3'N	08° 04.2'E
Berg/FS-9B	2572 m	79° 01.0'N	00° 55.0'W
Berg/107	2045 m	71° 12.0'N	07° 44.0'W
WHOI/FS-1	2527 m	78° 52.0'N	01° 22.0'E
WHOI/FS-2	2430 m	79° 00.0'N	04° 55.0'E

9.2 Underway sampling UAE/THURSO

Stuart Gibb Thurso:
Collection of samples from both CTD and underway (ideally every 2 hours) for chemotaxomomic pigments inclusing CHLa. These will be collected by Mona Larsen of the ERI for analysis back in the lab.

UAE

Louise Darroch PhD project on *Dimethylsulphoxide: Origin, Fate And Cycling In Marine Waters.*
(Supervisors Malin & Liss,UEA. External Supervisor Angela Hatton, DML).
DMSO is the oxidation product of dimethylsulphide (DMS). Louise is using the GC - DMSO reductase linked method for the analysis of DMSO in seawater, natural particulates and culture samples/expts. During JCR75 she will focus on the distribution of particulate DMSO. Louise would be interested to analyse any deep water, near sediment water, marine snow or coral samples that are collected by other participants. If time permits some incubation experiments to determine

whether artificially induced oxidative stress enhances DMS/DMSO production by phytoplankton and to look at DMS photoxidation may be done. Louise was on a cruise onboard Discovery in the North Sea in 1999 (prior to her PhD) and has also worked at the Bergen Mesocosm facility.

Claire Evans PhD project on *How do viruses influence the production of DMS?* (Supervisors Malin & Liss, UEA. CASE with Willie Wilson, MBA).
To date Claire's project has focused on laboratory studies of cultures of *Emiliania huxleyi* and its specific viral pathogens. During JCR75 she will analyse some of the DMS related compounds with Louise, and look at DMSP lyase activity by GC. Areas that might support populations of *Ehux* or *Phaeocystis* would be of particular interest. Claire will also collect samples for viral and bacterial enumeration by AFC, analysis of particulate phase viral DNA and isolation of *Ehux* viruses. If time permits she will also conduct some incubation expts. Previously Claire has worked onboard the MBA's Squilla during an Ehux bloom off Plymouth, and she worked with us on a Bergen Mesocosm study while studying for her MSc. This is her 1st major offshore research cruise.

Susanne Kadner PhD project on *Acrylic acid: the forgotten part of the DMS story* (Supervisors Malin & Liss, UEA. External Supervisor Stuart Gibb, ERI).
Acrylic acid (AA) + DMS = DMSP the recognised precursor of DMS, the idea here is to investigate the biogeochemical cycle of DMS from the AA viewpoint. Very few previous studies have had this focus and many assumptions have been made as to the origin and fate of acrylic acid. Where such studies have been done the detection limit for AA has been rather poor. Susa has developed an HPLC method which allows analysis of dissolved AA with direct injection of seawater with a detection limit of approx 10nM – far more sensitive than anything else reported in the literature. The JCR75 cruise will allow the 1st at-sea trial of this method and further development of a method for analysis of particulate AA.. AA will be analysed in surface and profile samples. Bacterial enumeration data will be obtained using onshore DAPI counting of filters prepared at sea (as a back up to AFC counts mentioned above) and bacterial activity will be monitored using a tritiated Leucine incorporation method. Some experiments will also be done to determine directly whether bacterial activity is affected by AA and to assess the turnover time of AA in whole seawater and the bacterial fraction. This is Susa's 1st research cruise.

Claire Hughes PhD project on *Biological Mechanisms for the production of organo-halogen gases*
(Supervisors Malin and Liss, UEA. CASE with Phil Nightingale, PML).
Claire is using a Hewlett Packard (now Agilent) GC – MS system for this project which focuses on volatile bw molecular weight iodinated compounds and their production by seaweeds and phytoplankton. During JCR75 she will look at production/turnover of volatile halocarbon compounds in incubations of concentrates of seawater prepared using the non-toxic supply. The aim being to follow up some interesting data collected on a previous cruise. Bacterial counts will be done via DAPI stained filters and bacterial activity will be monitored using a tritiated Leucine incorporation method. Samples will be taken for HPLC analysis of pigments indicative of phytoplankton degradation by e.g. zooplankton grazing. Surface and profile samples will also be analysed as time permits. It would be of interest to analyse any marine snow, sedimenting diatom mat or coral samples

collected during the cruise. Claire sailed with PML onboard Discovery earlier this year and on a research cruise in the Atlantic whilst doing her MSc at Dalhousie.

Martin Johnson PhD project on *The Air-Sea flux of Ammonia.*
(Supervisors Liss & Jickells, UEA. External Supervisor Stuart Gibb, ERI).
The aim of Martin's project is to quantify the air-sea exchange of ammonia. This is important as a significant exchange process in euphotic zone N budget and an important influence on atmospheric aerosol composition and hence climate. To quantify the air-sea flux of ammonia seawater and atmospheric ammonia concentrations are measured, as well as meteorological parameters (especially wind speed) that affect the rate of transfer. Surface seawater and profile samples will be analysed onboard for ammonium concentration using the OPA fluorometry method and pH. Together these allow calculation of ammonia concentrations. Ammonia concentrations are also measured in the atmosphere, requiring that the ship be heading into the wind for periods of several hours to collect enough sample and to avoid ship derived contamination. For this we are developing a rotating annular denuder sampling method which should give an atmospheric ammonia concentration for every 1-2 hours of sampling. With the water and atmospheric ammonia concentrations measured, the direction and rate of ammonia transfer between the atmosphere and the ocean can be determined. During his PhD studies Martin has already taken part in research cruises in the Atlantic and North Sea.

Sample coordination for UEA projects

As far as possible routine CTD and non-toxic system sampling will be coordinated so that the whole group samples the same water, to enable direct comparison of data. This is particularly important for the DMS related projects (Darroch, Evans and Kadner).

Link to other data to be collected on JCR75

Beyond the possibility of opportunistic joint experiments, wherever possible we would like to maximise the possibility of interpreting UEA data with reference to data collected by other JCR75 participants. As with other NERC cruises our data will be available to others for the same purpose. Where possible e.g. profile samples, non-toxic supply samples it would be most ideal to coordinate the timing of sampling with others. We haven't a complete view of what will be done during the cruise but examples of the sort of data that would be of interest are as follows:

- Standard fluorometric chlorophyll data
- HPLC pigments
- Nutrient data
- Primary production
- Phytoplankton speciation and count data ~ + any general information that becomes available during the cruise due to visual observation, satellite imagery, that might be relevant to taking survey samples and setting up experiments etc.
- Microzooplankton Grazing
- Zooplankton speciation and count data
- DOC
- Met data
- Light data

9.3 Microbial Samples (SAMS)

Samples to be collected by Ivan Ezzi

The objective is to collect samples for analysis of microplankton, nanoplankton and bacterioplankton. It is not intended to obtain a full and complete data set for a paper but rather to collect occasional samples in support of other work (e.g. Stuart Gibbs phytoplankton HPLC analysis) and to give some preliminary data on microbes from the Svalbard area.

Up to 40 samples can be taken during the cruise. The positions of sampling have not been decided but will be surface waters from different stations along interesting transects (e.g. Kongsfjord to open ocean, or north sea to arctic).

Sampling involves gently decanting water from Niskin bottle into bottles containing preservative. Two types of sample:
1. 200 ml into amber glass bottle containing 2 ml lugol's iodine
2. 100 ml into amber plastic bottle containing 4 ml glutaraldehyde.

The preservatives will already be in the bottles. The bottles should be filled in a fume hood/cupboard. The bottles should be stored in their plastic storage boxes, preferably in the cool room.

9.3 TOPAZ, Northern Triangle

A high resolution survey (using Topaz) of a representative selection of diapers (Northern Triangle, north of Shetland (1000 to 2400m) will be carried out for GEOTEC (AREA C). This will take place on the return leg of the cruise.
Below is an image of the mud diapirs north of Shetland.Objective is to obtain a TOPAZ (hull-mounted profiler on JCR) profile (or a few profiles) crossing the diapirs. A top to bottom profile across the image shown will take 1 hour at 8 kt, so this profile and maybe one or two at right angles to this could be obtained in < 4 hours.

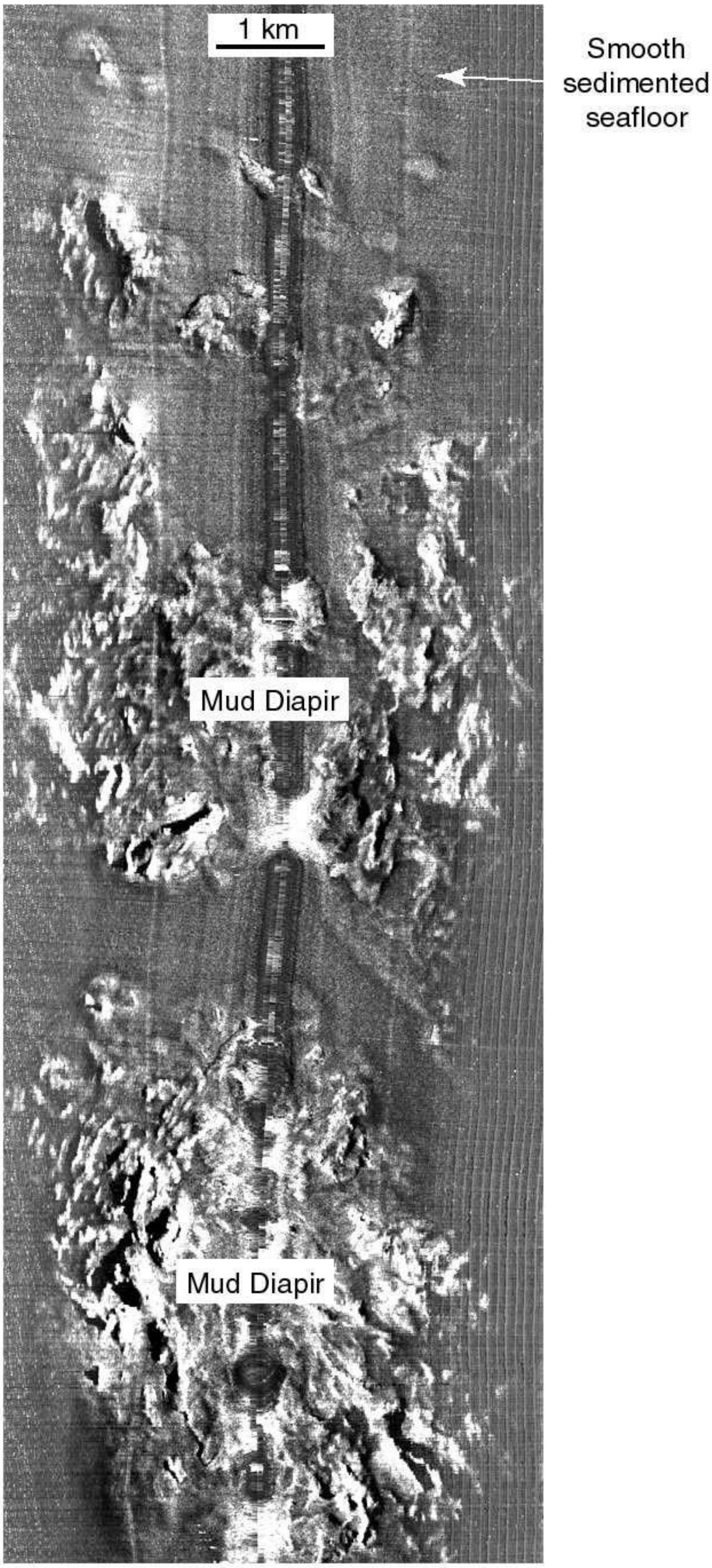
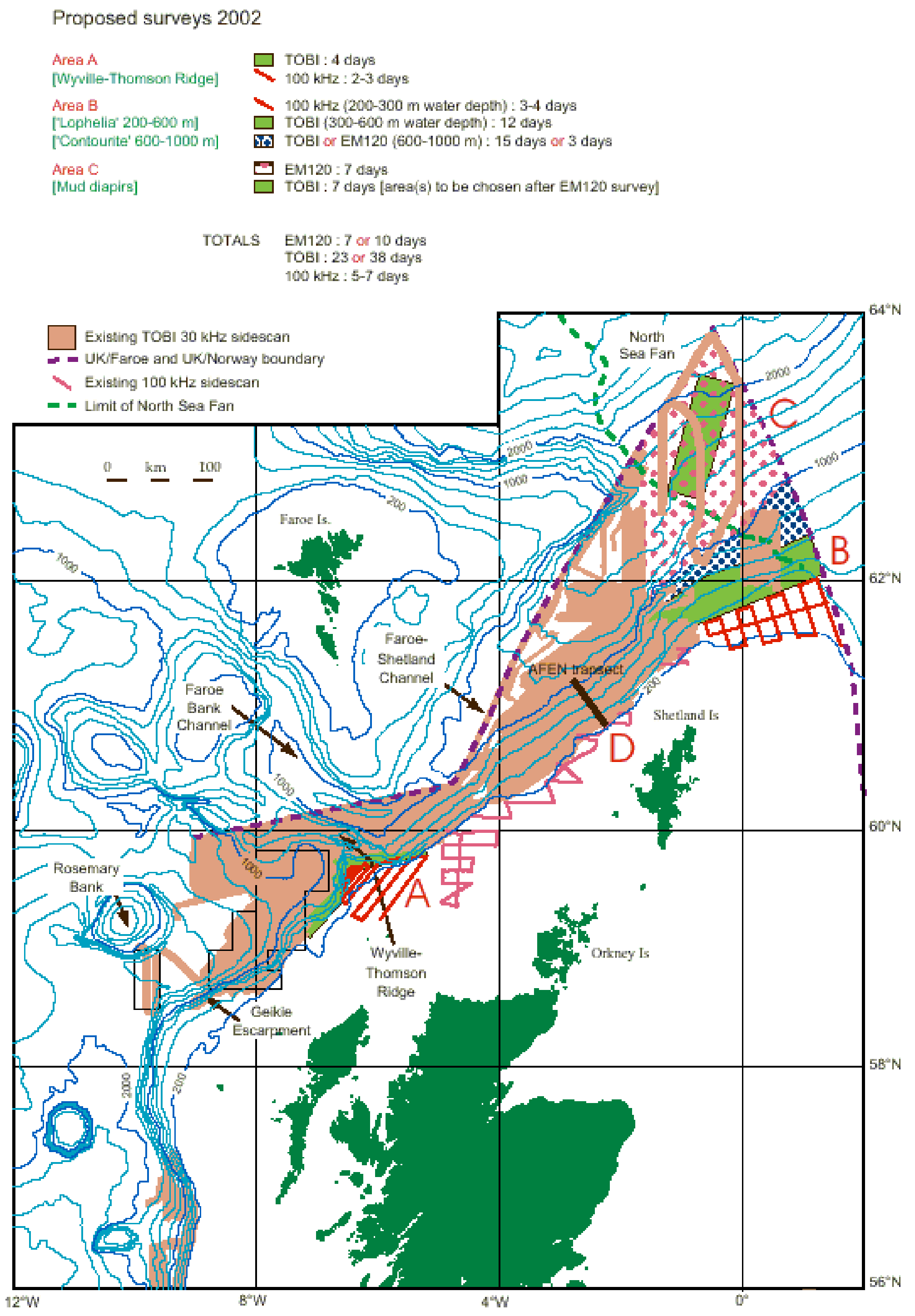


Fig. 16. TOBI image showing two mud diapirs, shown as rough high backscatter targets (white). These contrast strongly with the smooth moderate backscatter background seafloor (uniform grey). See figure 2 for location.



9.5 Surface sediment from box cores

Collection of surface samples from boxcores for Prof. Amann, at main stations with depths greater than 1000m. These samples will be used for microbiological analysis.

9.6 Surface sediment multicore for Foraminifera analysis

A 1cm section from a multicore tube at each of the stations will be collected and preserved in formalin and Rose Bengal. These samples will be added to the foram database.

10. Further information supplied

10.1 Benthic environments around Svalbard

Information supplied by Thomas Soltwedel

You might know that in summer 1999, we established a deep-sea long-term station (AWI-"Hausgarten") to the West off Svalbard to carry out multidisciplinary work to assess seasonal and interannual variabilities in various parameters. This "station" consists of a central experimental field at 2500m water depth at about **79°04'N, 4°10'E** and a depth transect of 9 stations (500m steps) crossing that area.
There are several moorings in that region: if you intend to work in that area, please ask for exact positions of the moorings to avoid any "accidents".
The shallowest sampling site along the transect is at approx. 1250m on a plateau off Kongsfjord (79°08'N, 6°05'E); the deepest site lies in the central Molloy Deep at about 5500m (79°12'N, 2°34'E). Originally we planned to extend this transect to a **500m site, however, for very coarse sediments (with pebbles and stones!)** in front of the fjord there was no chance to get sediment samples further to the East. At deeper sampling sites you will find "normal" fine-grained deep-sea sediments.
Observations with the French Remotely Operated Vehicle "Victor 6000" in summer 1999 at **2500m showed single larger drop stones or even small patches of larger drop stones - this, however, is probably typical for the whole region. To hit such aggregations is just bad luck.** By now, we successfully deployed our chamber lander twice at the central "Hausgarten" site at 2500m, and once in the central Molloy Deep at 5500m. This summer, we plan to carry out 3-4 deployments with the lander at 1500m, 2500m and 3500m along the transect. Polarstern will be at "Hausgarten" in the first week of August - is there a chance to meet RRS James Clarke Ross?
Back in 1997, we carried out an extensive sediment sampling programme (no lander work!) along two transects crossing the Yermak Plateau and another two (shorter) transects at the northern Svalbard continental margin. You will find all the station data we achieved in the paper Soltwedel et al. (2000) in Deep-Sea Research 47: 1761-1785.
Next year, we will have "Victor 6000" back on Polarstern. Starting beginning of June it is planned to work in the Porcupine Seabight and to the West off Ireland, than heading to the North for "Hausgarten" and finally working at the Hakon Mosby Mud Vulcano. There will be an international scientific party on board (France, UK, Ireland, Belgium, Netherlands, Germany) carrying out various scientific work (including work with the ROV, multicorer/box corer sampling, lander deployments etc.). There is still some space/time available for additional work. What about to extend the group by a (another) Scottish team ? (It would be interesting to compare results from both of our chamber landers !) If you are interested to participate, please let me know.

Benthic work at "Hausgarten" by now encompasses mainly a number of biological parameters:

- sediment-bound pigments (to estimate the input of particulate organic matter from primary production)
- particulate proteins (indicating living + dead biomass)
- phospholipids (indicating cell wall material; living biomass)
- exo-enzymatic activity (esterase turnover)
- bacterial numbers/biomasses
- meiofauna abundances/composition/size spectra (nematode taxonomy)

Next year co-operation with Russian colleagues will allow the spectrum to macrofauna investigations to expand. This year we plan to run the OFOS system ("Ocean Floor Observation System"; photo/video cameras at a deep-sea cable) to assess large-scale mega/epifauna distribution patterns along the "Hausgarten" transect.
Carbon turnover rates were assessed using a free-falling grab-respirometers and (from this year additionally) with a free-falling micro-profiling unit. Near-bottom currents will be assessed in high resolution using a new designed device (see http://www.awi-bremerhaven.de/Research/ProjectGroups/DeepSea/ocean.html).
A sedimentologist joining the group will care for sediment properties (water content/porosity, grain sizes, terrigenous vs. marine input, etc).

10.2 Established sites with in-situ equipment

In addition, we have a mooring with sediment traps out there continuously recording the sedimentation of particulate matter since 2000.

- The mooring is anchored at **79°01,7'N/4°20,9'E**.
- experimental areas at **79°03,8'N/4°11,5'E** (metal frame with hard substrates --> colonisation experiment; small cages at the seafloor --> exclusion experiment) and
- **78°36,5'N/5°04,4'E** (mimic experiments; disturbance experiment).

There may still be other moorings from an EU project (VEINS) out there – to check please contact Dr. Ursula Schauer (uschauer@awi-bremerhaven.de).
As you see from the list of biological parameters, there is (by now) no-one working on the larger bioturbating infauna in that region. Again: next year we will have the ROV VICTOR 6000 on board Polarstern. I guess a tool like VICTOR, allowing a targeted sampling of biogenic structures at the deep seafloor, should be perfect to carry out your kind of investigations. If you are interested in participating the cruise next year, we need your reaction till mid of June at latest.

10.3 Kongsfjorden-Krossfjorden and adjacent shelf area

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Norwegian Polar Institute.
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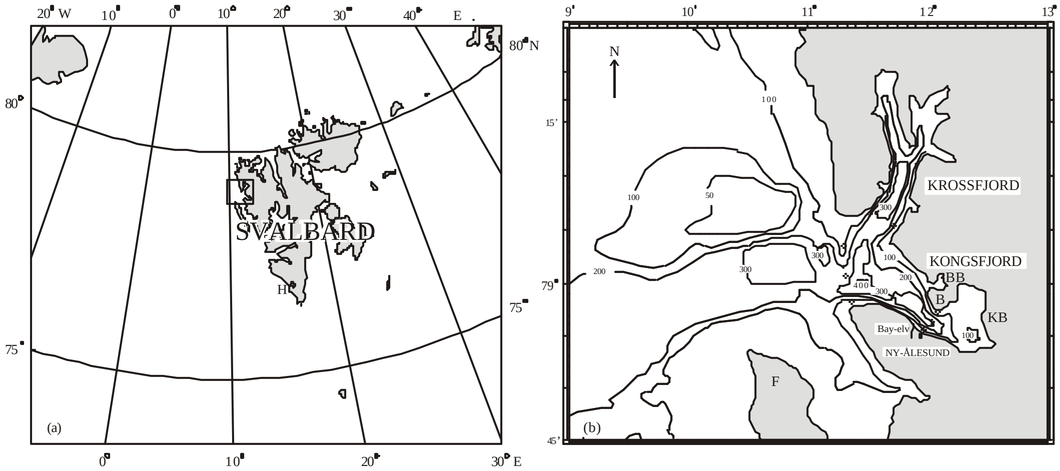
1. Physics

Topography

Other than Forlandet, a large island which covers almost the whole stretch of coast between Isfjorden and Kongsfjorden, the rest of the west coast of Spitsbergen is unsheltered with no skerries, Fig. 1a.



(a) (b)

Figure 1 Map of a) Svalbard and b)Kongsfjorden-Krossfjorden and adjacent shelf area.

The exchange between the fjords and the adjacent water at the wide shelf therefore takes place unobstructed. The shelf area off the mouth of the branched fjord system, formed by Kongsfjorden and Krossfjorden, is about 50 km wide. The near zone to the common mouth area of the fjord system is characterized by a deep trench, Kongsfjordrenna, which reaches its deepest part, about 300 m, just outside the mouth, Fig. 1b.
Ny-Ålesund is situated at the narrowest part (4 km) of the Kongsfjorden facing the peninsula Blomstrandhalvøyen (B) which separates the glacier Blomstrandbreen (BB) in two parts. A girdle of small islets and skerries cover the inner part of Kongsfjorden where also the large tidewater glacier Kongsbreen (KB) meets the fjord.

The Krossfjord branches into two arms in the inner part. At the head of the western arm there is a large glacier, Lillehøøkbreen. The eastern arm of the fjord has four small fjord arms each with a glacier at the head. Data for the fjords are listed below.

Dimensions of the fjords

Length (km)	Max. depth (m)	Name	Max. width (km)
24	400	Kongsfjorden	8
30	300	Krossfjorden	6

Climate and meteorology

Svalbard has a warmer climate than other Arctic areas at the same latitude. This is related to a net northward transport of heat by air and ocean currents through the Fram Strait. Central in this connection is the West-Spitsbergen Current; a branch of the North Atlantic current carrying relatively warm and saline water (> 35 psu) along the shelf slope.

Due to the exchange of air masses through the Fram Strait, the area is a convergent area for warm and cold air masses and the weather is usually unstable and stormy, especially in wintertime. The frequent passing of atmospheric lows raises the average air temperature. However, dramatic changes in temperature may take place in the front zone and temperature differences of more than 30 ^{o}C in a few hours have been observed. The coldest period is February - March and the warmest period is July-August, Fig. 2.

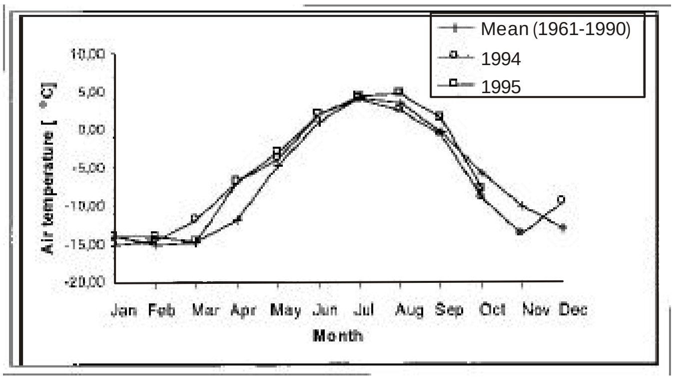


Figure 2 Monthly mean values of air temperature in Ny-Ålesund, 1994 and 1995.

When air masses are passing over cold land they are cooled, stabilized, and channeled along valleys, fjords and other depressions. The wind may therefore experience large local differences in both direction and strength. Prevailing down-fjord winds are dominating in wintertime, while in the summer the wind conditions are more variable.

Freshwater runoff

The water vapor content of the air masses passing West-Spitsbergen is small, and the precipitation rate is low, Fig 3. The main source of freshwater from the drainage area to the fjords are melt water from glaciers,

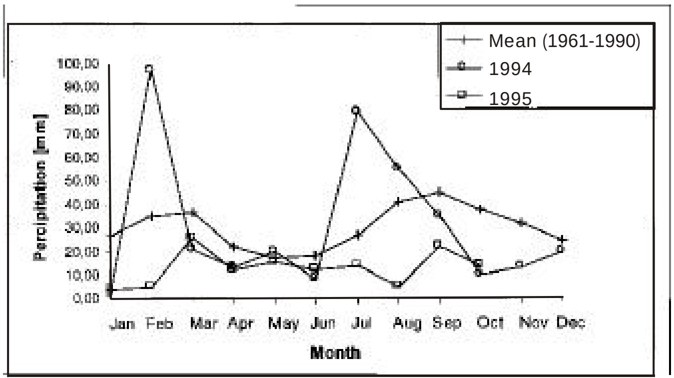


Figure 3 Monthly mean values of precipitation in Ny-Ålesund, 1994 and 1995

surface or sub-surface discharge, calving and water supplied from melting of snow stored elsewhere (Liestøl ,1988). At present the glacier Kongsfjordbreen is calving most frequently (Lefauconnier *et al.*,1994). Calving from Lillehøøkbreen (in the left fjord arm at the head of Krossfjorden) is believed to take place relatively frequently (Den Norske Los, 1992).

The glaciers in Svalbard are so-called “sub-polar” glaciers which means they produce freshwater the whole year (Liestøl,1988). An estimation of the freshwater supply in other fjord areas in Svalbard indicates however that the supply is small between November and May and increases gradually to a maximum during the summer (Weslawski *et al.*,1994). There are reasons to assume that this runoff pattern also is representative for the Kongsfjorden-Krossfjorden system since the climate characteristics are similar.

The tide

The tide appears as a progressive semi-diurnal wave propagating north-northeastward towards the shallow areas of Svalbard and appears as a progressive Kelvin wave propagating northward along the coast of West-Spitsbergen see e.g. Kowalik and Proshutinsky (1995), Kasajima and Svendsen 2001. The amplitude of the tide is small, with a sea-surface elevation about 0.5 m in the open sea. Passing the wide common mouth of Kongsfjorden-Krossfjorden the Kelvin wave turns into the fjord (see e.g. Svendsen 1995). It is expected that a part of the tidal energy is reflected at the head of the fjord and the rest is dissipated and/or propagates counter clockwise in the wide part of the fjord system.

The net transport related to the tide is small and is negligible in the upper layer where the circulation driven by the local wind and freshwater supply are far more important.

The upper layer

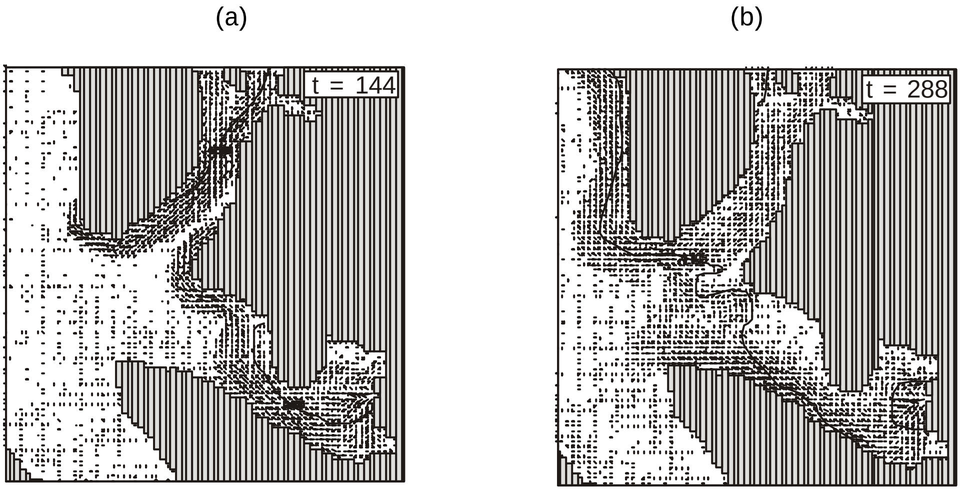
The following description of the physics of the fjord system is based on results from two short field experiments, one week in September 1994 and August 1995 respectively, and numerical simulations with the Princeton Ocean Model (Blumberg and Mellor 1987) carried out by Geophysical Institute, University of Bergen. Since the tide is weak in the fjord the simulations are done without tide. For details about the field experiments and simulations see Ingvaldsen *et al.* 2001. The measurements used to describe the physics of the intermediate and deep layer are placed to our disposal by Institute of Oceanology, Poland.

Three scenarios are simulated. Characteristics for the scenarios are a) Freshwater-driven. b) Freshwater-and wind (down-fjord)-driven. c) Freshwater- and wind (up-fjord)-driven. It is important to keep in mind that the effects of at least three governing forces (wind, freshwater supply and tide) are simultaneously present in the fjord system, i.e. none of the simulated scenarios are expected to exist isolated in the natural fjord system. It is expected that both the baroclinic and barotropic tidal velocity components in this wide fjord system without a sill are negligible compared to the components related to the two other main forces. This fact makes it easier to select situations from the field experiments which are suitable for comparison with the simulated scenarios. However, one has to keep in mind the “memory” of the fjord system, i.e. the inertia of the system. Based on an analysis of observed surface layer response to a varying wind field, Svendsen (1981) found that more than 10% of the current in 2 m depth was related to the wind action with a lag of 6 hours. Furthermore, remote forcing of the coastal waters outside the fjord system might in periods dominate the local fjord dynamics as shown by e.g. Svendsen 1977, Proehl and Rattray 1994, Stigebrandt 1990, Asplin *et al.* 1999.

“Freshwater-driven”:

As sub-surface supply of freshwater from the glaciers takes place the whole year there will always be a fresh water driven current component in the fjord system. All the field observations and also the simulations without wind show, however, the same main feature; a down-fjord flow in a wedge on the right hand side of the fjords, except in the bay outside

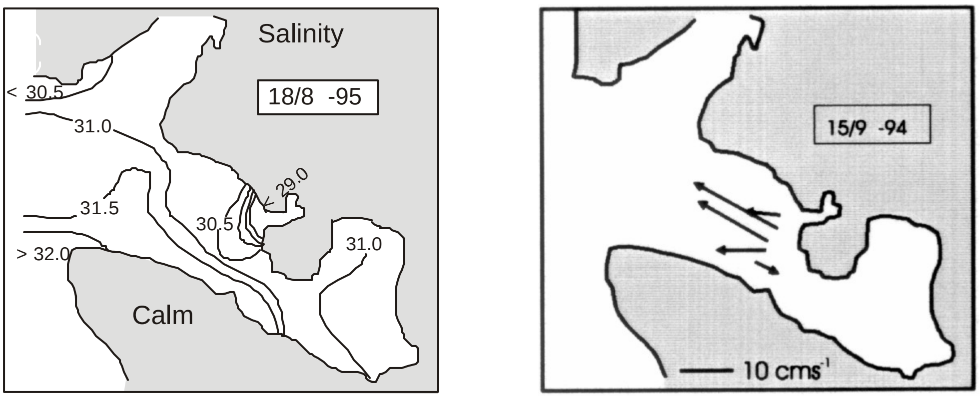
Blomstrandhalvøyen where the flow at times is displaced offshore (from the fjord side), Fig. 4 a.



(a) (b)

Figure 4 Current velocity in the surface layer after a) 144h and b) 288h simulation time with freshwater supply.

The baroclinic Rossby radius of deformation is usually less than the width of the fjord. A rough two-layer approach based on the observed vertical density distribution gives a radius less than 4 km. The Rossby radius is therefore less than the minimum width of the whole fjord system, and thus the rotation of the earth is the main explanation of the marked deflection of the flow. The flow in Kongsfjorden around Blomstrandhalvøyen and in the transition between Kongsfjorden and Krossfjorden describe a “semi-circle” movement, where the Coriolis acceleration acts in the direction of a “centripetal acceleration”. It is, however, likely that also the aggregate effect of friction, topography of the fjord sides and pressure gradients may have an effect in this connection. Due to friction a horizontal velocity shear appears along the “fjord wall”, and the resulting negative relative vorticity (down-fjord flow) causes a deflection towards the fjord side.



(a) (b)

Figure 5 Mapped salinity distribution (a) in the surface layer of the fjord system and surface velocity (b) observed with drifting drogues. Both the salinity and current are observed during calm conditions.

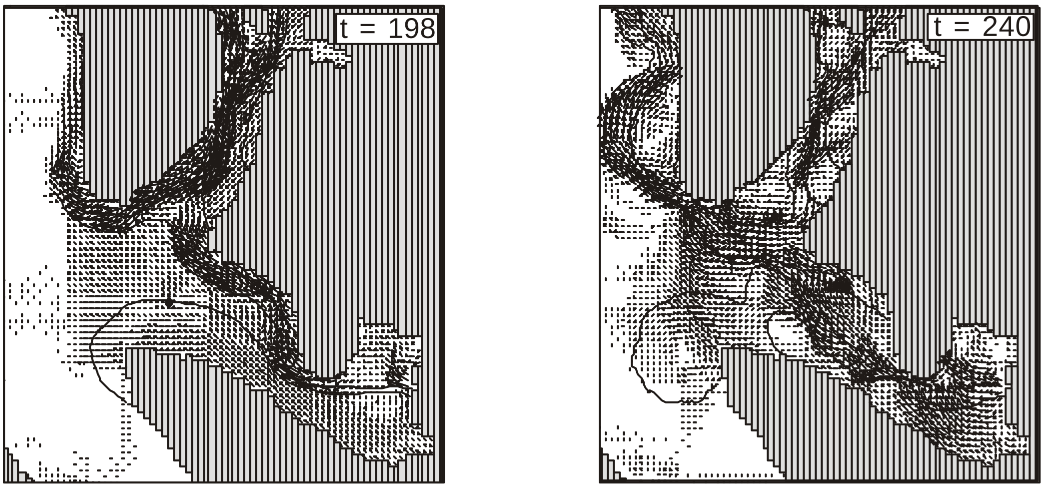
On 18 August 1995 it was almost calm in Kongsfjorden. The mapped surface salinity distribution these days, Figure 5a, reflects mainly the effect of the freshwater driven component. The saline and cold (not shown) water in the inner part has probably two reasons; entrainment of salt water to ascent freshwater from below the glacier and the fjords “memory” of the wind-driven up-welling the day before. The low saline water in the lagoon outside Blomstrandhalvøyen is related to discharge from the lagoon glacier. The observed current on 15 September 1994, Figure 5 b, is assumed to be representative for the surface layer flow during calm conditions.

It is expected that the marked turn of the flow towards the right hand side of the fjord, which is illustrated in the simulation shown in Fig. 4a, only exists in relatively short periods. Stacking up of water in the bight entering Blomstrandhalvøyen builds up a cross-fjord pressure gradient which displaces the flow towards the left hand side of the fjord, Figure 5b.

Model runs with large and small freshwater supplies gave less surface layer salinities than observed. The differences may be related to the fact that field data reflect also the effect of wind mixing and sub-surface supply of freshwater, while the model is run only with freshwater as the driving force. Another reason could be that the freshwater supply is underestimated.

Freshwater- and wind (down-fjord)-driven:

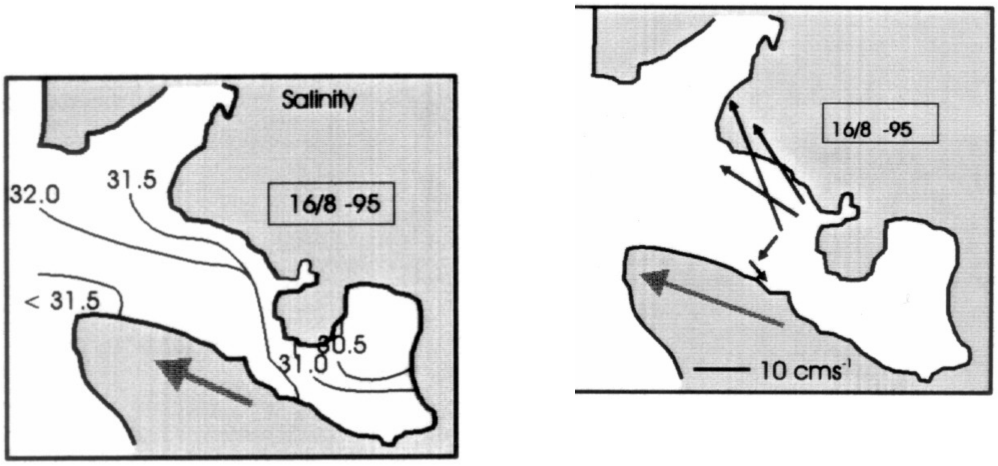
Such conditions were present in Kongsfjord on August 16, 1995, Figure 7. The surface layer salinity reflects a down-fjord flow along the northern side of the fjord, Figures 7a, which is in accordance with the findings by Cushman-Roisin *et al.* (1994) who studied the effect of rotational dynamics on fjord circulation. They found a deep brackish layer on the right hand side (looking in the direction of the current) and an out-cropping of the interface on the left hand side. Indeed rotational dynamics is important in the broad fjord Kongsfjorden.



(a) (b)

Figure 6 Current velocity in the surface layer after a) 198h and b) 240h simulation time with freshwater supply and down-fjord wind.

The wind field has a marked intensification effect on the flow in both fjordarms. Figure 6a show the current pattern 6 hours after the initiation of the wind (i.e. after 198 hours of simulation). The strong Ekman transport towards the fjord side increases the water level more than is “consumed” by thegeostrophic field resulting in a broadening of the flow caused by the “excess” cross-fjord pressure gradient. The drifting drogue experiment shown in Fig 7b represents probably an “intensification period”.

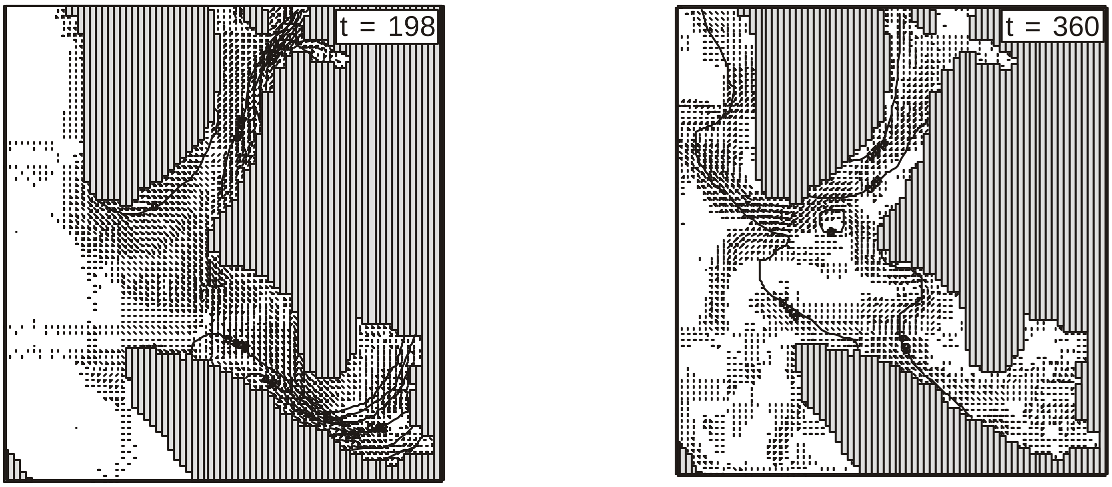


(a) (b)

Figure 7 Mapped salinity distribution (a) in the surface layer of the fjord system and surface velocity (b) observed with drifting drogues. Both the salinity and current are observed during down-fjord wind.

Freshwater-and wind (up-fjord)-driven:

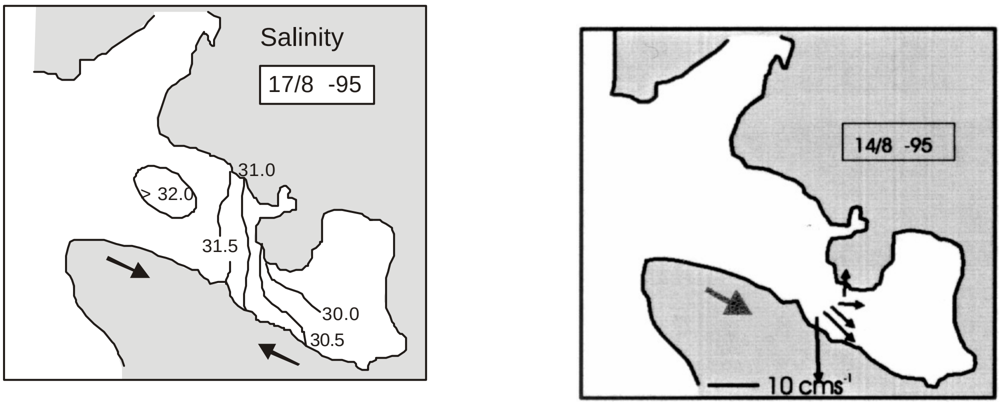
Such conditions did not appear during any of the surface layer mappings. However, on 17 August 1995, the conditions were close with the exception of the down-fjord wind in the inner part of the fjord. The effect of the up-fjord wind is mainly the stacking up of water which is reflected in the salinity distribution which indicates a cross-fjord front at the Blomstrandhalvøyen, Fig. 9a.



(a) (b)

Figure 8 Current velocity in the surface layer after a) 198h and b) 360h simulation time with freshwater supply and up-fjord wind.

The drifting drogue experiment carried out during up-fjord wind in the Kongsfjord shows, as expected, an up-fjord current, Fig. 9b, being strongest along the left hand side of the fjord, in accordance with the simulations, Figure 8. At the headland of the Blomstrandhalvøyen, the current direction is down-fjord in the experiment but it is up-fjord in the simulations, a difference which may be due to differences between the wind field used in the simulations and the existing wind conditions during the field experiment.



(a) (b)

Figure 9 Mapped salinity distribution (a) in the surface layer of the fjord system and surface velocity (b) observed with drifting drogues. Both the salinity and current are observed during up-fjord wind in the main part of the fjord.

After some time a down-fjord pressure gradient builds up due to stacking up of water in the inner part of the fjord and the current is turned down-fjord, Figure 8b.

The intermediate and deep layer

Because of the strong pycnocline a circulation in the deep layers could be to some extent independent from the upper layer flow. Moreover, the remote forcing by the coastal wind and tide produce a vertical displacement of the density field outside the fjord and in this way generate a Kelvin wave travelling around the fjord coast to the right (see e.g. Svendsen 1995). An example of such disturbance can be observed in the ADCP measured sections across the fjord, Figure 10, as an up-fjord flow at the southern coast with a width of ca 4 km, thus comparable to the local Rossby radius. The opposite, down-fjord current along the northern side of fjord results in the bidirectional flow scheme in the outer basin. Maximum velocities measured in the deep layers are not higher than 8-10 cm/s.

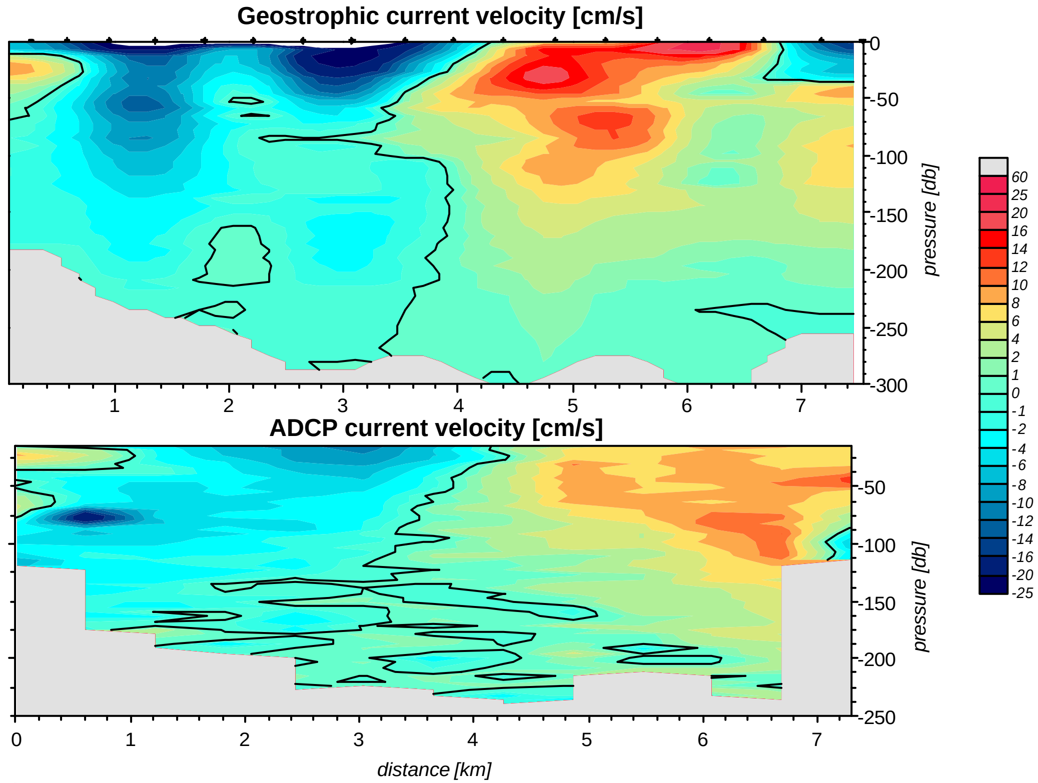
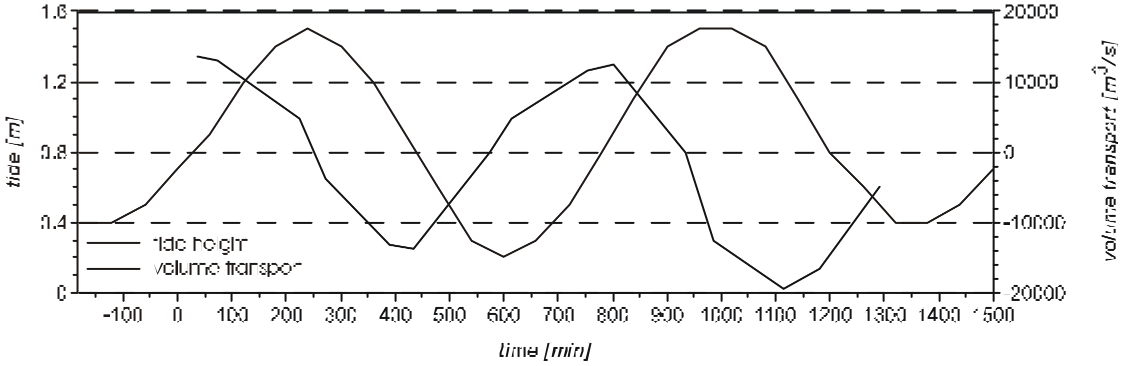


Figure 10 Current distribution in a cross section of the Kongsfjord

In the inner basin the Kelvin wave entering at the southern coast forces an outflow along the northern side. ADCP sections repeated continuously in the constriction between the inner and outer basin during 24 hours confirmed this layout of currents. Intensities of opposite flows were highly variable with maximum velocities exceeding 10 cm/s in the intermediate layer. The width of the dominating stream changed periodically and an up-fjord flow in the southern part of the constriction was less stable compared to a down-fjord outflow along the northern coast. But two-directional flow was maintained during almost the entire period. Net volume transport across the whole section in the layer below 20 m, thus excluding the surface flow, was revealed to be closely correlated with the tide (Figure 11).

Figure 11 Time series of tidal height and net volume transport across the constriction between the inner and outer part of Kongsfjorden.



Water exchange with the coastal area is a very complex process, driven by different mechanisms and only qualitative estimations are possible on the basis of current data. Few ADCP sections across the Kongsfjorden outlet reveal an up-fjord directed flow at the southern side with maximum velocities of about 6 - 8 cm/s found within the layer occupied by the Atlantic origin water. There is no shallow sill at the fjord entrance, so this dense water of open sea origin could be transported directly into the deep layers in Kongsfjorden. Hypothetical rate of the fjord water advection towards the coastal area was estimated at *ca* 5 cm/s on the basis of seaward displacement of the fjord origin intrusion observed in 1999. In that case water mass originating from Kongsfjorden was found in the intermediate layer between 50 and 110 m at a distance of about 15 km from the fjord outlet. Most frequently an outflow of the fjord water was found at the northern coast but the cold water of local origin transported by down-fjord current was also observed in a central part of the outlet.

Volume and properties of the Atlantic water supplied to Kongsfjorden are influenced not only by a coastal situation (wind and tide) but also, in a more general way, they are related to the West Spitsbergen Current year-to-year variability. A great amount of the Atlantic Water with high temperatures, carried on by the WSC in summer 1999, was reflected in Kongsfjorden, where the whole volume of the outer basin below the depth of 120 m was filled up with the Atlantic origin water.

Concluding remarks on physics

It is shown that rotational dynamics have a considerable influence on the circulation pattern in the fjord system. Down-fjord flows take place along the right hand sides of the fjords except off the Blomstrand-halvøyen lagoon where a pressure gradient forces the flow off shore. In central and outer parts of the fjord system, the flow seems to be limited to the upper 2-3 m. After a period with up-fjord wind (stacking up of water) the down-fjord flow of "released" water may be considerably deeper. The velocity of the brackish water core varies between 5-20 cm s^{-1} in periods without wind. In addition, the model simulations show just minor changes to the main structure of the circulation with increased runoff.

As the freshwater is supplied to the fjords from glaciers, the supply occurs in the form of events rather than as a steady trickle of water. This is also evident from the field data. Together with the fact that lasting calm winds for longer periods are rare events in the fjord system, it is likely that steady flow conditions seldom (if ever) appear in the fjords.

The qualitative agreement between the simulated and observed circulation pattern indicates that the sub-surface discharge may not have any particular influence on the circulation pattern in the central and outer part of the fjord system. This is because the freshwater is supplied to the surface in the model while it is expected that some part of the natural freshwater supply to the fjord system takes place as sub-surface discharge.

The simulated interactions between the fjord arms are, among others, reflected in the flow around the tip of the Kongsfjorden, continuing along the east side of the Krossfjorden. The simulations also show that in the common fjord mouth area, the circulation is dominated by an anticyclonic eddy. It is likely that this circulation pattern is present most of the year. However, more comprehensive field experiments will be necessary to give definitive explanations to these phenomena.

The main part of the exchange of the intermediate and deep water masses in the fjords is associated with non-local forcing resulting in a displacement of the vertical density field at the coast.

The results from this investigation support the strong three-dimensional dynamics which were found in both simulations and field experiments of the sub-arctic fjords, Porsangerfjord, Altafjord and Malangen (Svendsen, 1991, Cushman-Roisin *et al*. 1994, Asplin, 1994, Svendsen 1995, Leth 1995). Obviously, the classic assumption that the circulation in fjords is governed by a hydraulic control in the mouth is not present in broad fjords ie broader than the baroclinic Rossby radius of deformation.

Further investigations of broad fjords procure, in addition to 3-D simulations, a comprehensive field program based on time series of current and hydrography in selected sections across the fjords and across the adjacent shelf including the shelf slope.

2. Biology

2.1 Zooplankton community

Zooplankton in Kongsfjorden is composed of representatives of most of the major marine zooplankton groups (Table 1) with the highest number of species/genera identified among Copepoda (20), followed by Amphipoda (4) and Euphausiacea (4).

Table 1. Major zooplankton taxa in Kongsfjorden

Taxon	No. species/genera identified
Hydrozoa	2
Ctenophora	2
Gastropoda	2
Polychaeta	1
Copepoda	20
Euphausiacea	4
Decapoda	1
Mysidaea	2
Cumacea	1
Amphipoda	4
Appendicularia	2
Chaetognatha	2

The presence of *Calanus finmarchicus* and *Metridia lucens* is indicative of the Atlantic bio-geographic province while *Calanus glacialis* and *Limacina helicina* inhabit the Arctic bio-geographic province. This suggests that the zooplankton in Kongsfjorden is shaped by water masses of different origin. The West Spitsbergen Current transports water of Atlantic origin while the Sørkapp Current transports a mixture of Arctic and Atlantic water masses.

On the regional basis the most important zooplankton components in terms of numbers in Kongsfjorden in July 1997 were Copepods, principally *Oithona similis*, *Calanus finmarchicus*, *Calanus glacialis* and *Pseudocalanus* spp. (Table 2). They were accompanied by some non-copepod taxa such as Bivalvia veliger, *Limacina helicina* juvenile or *Fritillaria borealis*.

Table 2. The most numerous zooplankton taxa in Kongsfjorden on regional basis

Taxa	Relative abundance July 1997
Calanus finmarchicus	23
Calanus glacialis	6
Calanus hyperboreus	1
Pseudocalanus spp.	13
Microcalanus spp.	4
Metridia longa	7
Bradyidius similis/Neoscolecithrix farrani	1
Oithona similis	29
Oncaea borealis	2
Copepoda nauplii	10
Bivalvia veliger	+

Limacina helicina	+
Fritillaria borealis	2

Abundance of zooplankton in Kongsfjorden differed clearly between the outer and innerepart of the fjord as well as between years and months. In July 1997 the abundance of zooplankton in the outer basin was higher than in the inner basin, Figure 12. The number of *C. finmarchicus* varied between 59535 and 30388 ind m^{-2} on the outer stations and between 41775 and 18648 ind m^{-2} on the inner stations.

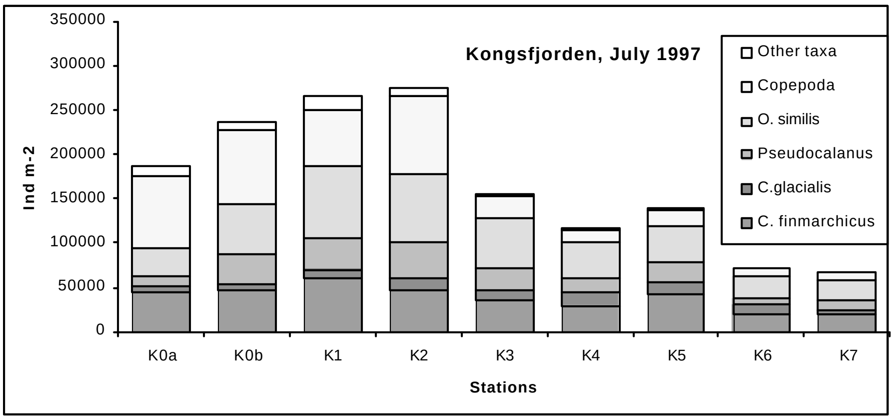


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Figure 12. Integrated abundance of zooplankton (ind m^{-2}) in Kongsfjorden in July 1997.

The larger zooplankton forms as the euphausiids (*Thysanoessa inermis, T.raschii and T. longicaudata*), the amphipods (*Themisto libellula, T.abysorum*), the pteropods (*Limacina helicina, Clione limacina*), and the ctenophores (*Mertensia ovum, Beroe cucumis*) can also be prominent members of the zooplankton communities . Weslawski found large abundances of *L. helicina* (1000 ind. m^{-3}) and euphausiids (600 ind. m^{-3}) at intermediate depths in the inner part of the fjords in 1996 using a net with 2 mm mesh size.

2.2 Benthic communities

Environmental factors influencing the benthos

The glacial complex debouching into the head of the Kongsfjord imposes sharp gradients in temperature, salinity, sedimentation rates and turbidity, all of which influence the distribution of benthic species throughout the fjord. The euphotic zone declines from about 20 m in width at the fjord mouth to less than 0.5 m at the glacier face. Particle concentrations reach 500 mg/dm^3 in the inner basin compared with less than 15 mg/dm^3 in the outer fjord and ice cover during 5-7 months of the year in the inner fjord further reduces light penetration. Sinking brine during winter freezing may produce cold and hypersaline conditions in bottom depressions in the inner basin, but in general, bottom salinities remain relatively high and stable throughout the fjord.

Physical disturbance of the sediments caused by extensive ploughing by calving icebergs is also a stress on benthos in the shallow inner basin but has little influence on the sediments of the deeper central and outer areas. However, in general the most influential factors affecting the distribution of benthos are sedimentation rates and turbidity.

Drop stones are common throughout the fjord and provide a substrate for the development of islands of hard ground communities in sedimentary areas. Hard substrates are found in the shallower areas on the slopes. These may be more subject to fluctuating salinities and temperatures than the deeper sedimentary areas but are also influenced by turbidity and sedimentation effects.

The different communities are:

1. Sublittoral macrophytes on stony grounds in the euphotic zone

Stones and boulders on bedrock or sedimentary substrates may cover extensive areas of both level bottoms and slope areas in various parts of the fjord at depths of between 2 and 30 m. Such areas are dominated by brown macroalgae (20 species), with *Laminaria saccharina* predominating in the outer and central areas of the fjord and *L. solidungula* in the inner basin and transitional zone between the inner and central basins. Some 10 species of red algae, typified by *Phycodrys rubens,* are also common in these areas. Many invertebrates are found within the kelp stands, notably the amphipod *Ischyrocerus anguipes* and the echinoid *Strongylocentrotus droebachiensis.* Some 50 species of epiphytic fauna are found on the macrophytes, including the gastropod *Margarites helicinus*, the hydromedusae *Lucernaria* and *Haliclystus* and many bryozoans. Both sessile and motile species are present and the dominant trophic modes represented are suspension feeding and carnivory. Species numbers vary up to 150, faunal densities average about 2-3000 m^{-2} and biomass varies between 0.2-20 kg wet weight (ww) m^{-2}.

2. Intertidal stony substrates.

Dense accumulations of pebbles, stones and boulders on bedrock or sediments occur in all areas of the fjord exposed to strong hydrodynamic activity. Such areas are subject to wave action, drying, freezing and ice scouring. Surfaces are frequently overgrown by microphytobenthic films and typically have accumulations of detritus between the stones. Dominant fauna include Harpecticoid copepods, large Lumbricillid oligochaetes, the amphipods *Gammarus setosus* and *G. oceanicus* and the snailfish *Liparis* sp. Species numbers are usually fewer than 20 m^{-2}, densities range up to a few hundred and biomass may reach a few g ww m^{-2}.

3. Intertidal soft substrates.

These consist of fine mud to medium sand sediments, typically flat and of restricted area, occurring in sheltered localities near fresh water outflows. They are subject to freshwater washout, wave action, sediment displacement and freezing. Typical macrofaunal species include the amphipod *Onisimus littoralis* and the bivalve *Thyasira* spp. Species number usually less that 20, with densities up to 300 m^{-2} and biomass up to 10 g ww m^{-2}. An abundant meiofauna dominated by Nematoda is also present.

4. Intertidal rock substrates

Stony flat or sloping bedrock occurs in all areas of the fjord exposed to strong hydrodynamic activity. Such areas are subject to wave action, drying, freezing and ice scouring. Surfaces are usually overgrown by macroalgae dominated in the central and inner areas by *Fucus disticus* and *Pilayella littoralis* and in the exposed outer areas by *Chordaria flagelliformis*. The cirripede *Semibalanus balanoides* and the gastropd *Littorina saxatilis* occur in sheltered places. Detritivorous and omnivorous gammarid and caprellid amphipods predominate. Fewer than 50 species occur, densities up to a few hundred individuals per m^{2} and biomass up to 1 kg m^{-2}.

5. Subtidal rock without kelp.

In steep, often vertical, slope areas. Ledges and cavities in such areas in the inner basin are often covered with fine sediment. In outer areas exposed to strong currents and, therefore, lower sedimentation rates, encrusting algae cover most of the surface and may extend to 50 m depth in some places. There a dense cover of sessile ascidians, anthozoans, chitons, bivalves and bryozoans occurs, together with occasional red algae. The presence of numerous megafaunal species may produce very high biomass levels of several kg m^{-2}.

6. Subtidal gravel substrates.

This occurs in patches throughout the fjord usually on flat or slightly sloping substrates. Encrusting algae do not occur but at depths below 20 m a fine sediment film may cover the gravel. Ophiurid echinoderms and detritivorous amphipods dominate the fauna.

7. Soft sediment substrates in the inner basin.

The sea floor of the inner basin of the Kongsfjord is composed of a poorly consolidated soft mud deposited from the outflow of the adjacent Kongsbreen glacier. The fauna is characterised by the protobranch molluscs *Portlandia arctica, Yoldiella lenticulata* and *Y. fraterna*. the lucinid bivalve *Thyasira dunbari,* the polychaete *Chone paucibranchiata* and a suite of tanaid crustaceans dominated by *Sphyrapus anomalus*. All of these are mobile surface feeding species of small body size. Throughout the basin cirratulid polychaetes, principally *Chaetozone setosa* are also abundant. There is a high degree of similarity in the species composition of samples taken throughout the basin although patterns of dominance are disturbed near the glacial fronts. Eighty five macrofaunal species have been recorded from this area; densities vary from 210-620 individuals m^{-2} and biomass from 1.2-4.2 g m^{-2}.

8. Soft sediments in the central and outer areas of the fjord.

The outer basin of the Kongsfjord is also of soft mud becoming slightly sandier towards the open sea. In general, sediments are far better consolidated than in the inner fjord. The fauna is characterised by the large tube-dwelling polychaetes *Maldane sarsi, Laonice cirrata* and *Spiochaetopterus typicus*. The smaller tubiculous polychaete *Prionospio cirrata*, the mobile polychaete *Lumbineris mixochaeta* and the suspension feeding bivalve *Bathyarca glacialis* are also typical. Changing patterns in the identity of the dominants define three faunal zones, a transitory zone to the west of Lovenoyane and Blomstrandoya (c.120 m), a deep zone (depths 250-400 m) and an outer zone close to the open sea. Two hundred and ten macrofaunal species have been recorded from these areas; densities vary between 230-500 individuals m^{-2} and biomass between 1- 15.5 g m^{-2}.

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