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Abstract

Altogether 163 observations of the Sechi disk depth, collected from April to October in the Nordic Seas, are presented together with salinities, other environmental parameters and positions. The Sechi disk depth ranges from 2 to 28 m, and the surface salinity from 25.4 to 35.2. There is no apparent correlation between Secchi disk depth and salinity in this data set. In Storfjorden in August 2001 the product of the coefficient of beam attenuation at 660 nm and the Secchi disk depth had the mean value and standard deviation of 4.3±0.7.

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Foreword

Since the 1960's the students of physical oceanography at the Department of Geophysics have participated in ocean-going cruises onboard research vessels from the Norwegian Polar Institute in Tromsø, and the Institute of Marine Research and the Geophysical Institute in Bergen. This experience has been regarded as a small, but important part of their education. The tradition has persisted throughout four decades, but the educational reform introduced by the Norwegian Government in 2003 may well put an end to it. The time has therefore been considered right to present some of the results from the field reports written by our students. In order to make this collection of hitherto unpublished data as complete as possible, additional observations made by our graduates Jo Høkedal and Trond Kristiansen have been included.

The date of publication for this report is exactly 140 years after the first Secchi disk measurement in the Mediterranean Sea.

April 20, 2005

Eyvind Aas

1. Introduction

The visibility of the Pacific Ocean was studied by the Russian naval officer Otto von Kotzebue as early as 1817 by means of a red piece of cloth being lowered into the sea, and on one occasion by a white plate (Krümmel, 1886). This is probably the first known scientific investigation of the optical properties of the ocean. Other early transparency measurements and occasional observations are mentioned by Boguslawski (1884) and Krümmel (1907).

In 1866, almost fifty years after von Kotzebue's measurements, Alessandro Cialdi, Commander of the Papal Navy, published a report containing a section by Frater Pietro Angelo Secchi, where the factors influencing the visibility in the sea of submerged disks of different sizes and colourings were discussed. In the years to come the white version of this device became a standard instrument in marine investigations. The disk is sometimes referred to as “the white disk”, but more often “the Secchi disk”, although the suggestion of using a white disk came from Cialdi.

The method of measurement is to lower the disk, supported on a cord and with its plane horizontal, from the ship rail and into the sea, to a depth where the disk cannot any longer be seen. The disk is then hauled upwards to a depth where it once again can be recognized. The mean value of the two threshold depths is termed “the Secchi disk depth”.

This depth is a measure of water transparency, and today it is one of several parameters used by environmental authorities to describe water quality. It is determined by the optical properties of the water and can therefore be related to the depth of the euphotic zone as well as to the particle content of the water, as will be shown below.

However, during the first century of Secchi disk measurements a satisfactory theory describing the relationship between the threshold depth and the optical properties of the sea was missing. Within the scientific community of the Soviet Union optical theory had been developed to a very high level, and according to Shifrin (1988) Gershun had solved the problem as early as 1940. Unfortunately these results were unknown in the western world, where the breakthrough first came in 1968 when John E. Tyler applied a contrast formula, derived sixteen years earlier by Seibert Q. Duntley, to the Secchi disk depth. Tyler’s result can be written

$$Z_{SD} = \frac{\ln\left(C(Z_{SD})/C(0)\right)}{c + K} \tag{1}$$

Here Z_{SD} is the Secchi disk depth, $C(Z_{SD})$ the inherent contrast between the disk and its surroundings at the depth Z_{SD}, $C(0)$ the apparent contrast as observed at the surface, c the beam attenuation coefficient and K the vertical attenuation coefficient of downward irradiance in the sea. $C(Z_{SD})$ depends on the reflection properties of the disk and the waters surrounding it, while $C(0)$ depends on the water reflectance and the human eye’s ability to detect a contrast. The attenuation coefficients c and K are not coefficients of monochromatic light, but of daylight measured in photopic units defined by the spectral sensitivity of the human eye. Another complicating factor is the contribution of reflected sky- and sunlight from the surface of the sea.

Discussions of these problems and appropriate references can be found elsewhere (Tyler, 1968; Højerslev, 1977, 1986; Shifrin, 1988). Tyler estimated the value of $C(Z_{SD})$ to be 40, and he chose the threshold value of $C(0)$ as 0.0066. Eq. (1) then becomes

$$Z_{SD} = \frac{8.69}{c + K} \tag{2}$$

or

$$(c + K) Z_{SD} = 8.69 \tag{3}$$

Højerslev (1977) calculated similar average values for different daylight conditions

$$(c + K) Z_{SD} = 9.0 \tag{4}$$

$$c\, Z_{SD} = 6.15 \tag{5}$$

$$K\, Z_{SD} = 2.85 \tag{6}$$

From observations of c for green light (525 nm) and Z_{SD} in Icelandic waters he found

$$c_{525}\, Z_{SD} = 6 \tag{7}$$

This empirical result is of special interest to us, because it demonstrates that Z_{SD} can be linked to other optical coefficients than those defined by the spectral sensitivity of the human eye. Sørensen et al. (1993) used a data set of c_{525} and Z_{SD} from the Oslofjord and Norwegian lakes and obtained the same numerical value 6.

However, in an earlier investigation in the Oslofjord Mikaelsen and Aas (1990) had found the relationship

$$c_{525}\, Z_{SD} = 7.1 \pm 2.3 \tag{8}$$

for green beam attenuation, where the number after ± is the standard deviation, and for red beam attenuation

$$c_{630}\, Z_{SD} = 5.2 \pm 1.9 \tag{9}$$

Since the contribution from yellow substance or CDOM (coloured dissolved organic material) to c at 630 nm usually is negligible compared to the contribution from suspended particles in the sea, c_{630} can be regarded as a measure of the particle content. Thus eq. (9) makes it possible to estimate the particle content in the Oslofjord from observations of the Secchi disk depth.

The spectrally integrated quanta irradiance (400-750 nm), also termed the PAR (Photosynthetically Available Radiation), is one of several factors determining the primary production in the sea. The vertical attenuation coefficient K_q of the downward quanta irradiance, averaged between the surface and the Secchi disk depth, was in the Oslofjord (Mikaelsen and Aas, 1990) found to be related to Z_{SD} by

$$K_q \, Z_{SD} = 2.7 \pm 0.6 \tag{10}$$

In the investigation by Sørensen et al., already referred to, the number on the right-hand side of eq. (10) is reduced to 2.4. By using observations from the Nordic Seas and the Barents Sea the number is reduced even further to 1.7 (Aas, 1980).

The depth of the euphotic zone, defined as the surface layer where there is a net positive production from photosynthesis, is often estimated as the depth $Z_q(1\%)$ where the quanta irradiance is reduced to 1 % of its surface value. In principle, if K_q was constant with depth, $Z_q(1\%)$ depth could be determined from the equation

$$1\% = 0.01 = e^{-K_q Z_q(1\%)} \tag{11}$$

which gives

$$Z_q(1\%) = \frac{4.61}{K_q} \tag{12}$$

By inserting K_q from eq. (10), the result becomes

$$Z_q(1\%) = \frac{4.61}{2.7 / Z_{SD}} = 1.7 \, Z_{SD} \tag{13}$$

indicating a linear proportionality between $Z_{q(}1\%)$ and Z_{SD}. The analysis by Mikaelsen and Aas (1990) of the same relationship resulted in the same numerical constant of proportionality, namely 1.7.

The corresponding result for the Nordic and Barents Seas is (Aas, 1980)

$$Z_q(1\%) = 3.3 \, Z_{SD} \tag{14}$$

Obviously the relationships suggested by eqs. (7)-(14) do not have a universal validity, and consequently they should all be locally calibrated.

The equations (7)-(14) demonstrate different types of useful relationships involving Z_{SD}. The Secchi disk is cheap; the measurement takes usually less than one minute and is easy to perform; and the result is surprisingly reliable, considering the varying conditions at sea. Consequently measurements of Z_{SD} are widely used to describe and monitor the environmental and optical conditions in the sea. According to the Secchi data base for the Baltic and North Sea collected by Thorkild Aarup (Aarup, 2002; www.ices.dk/ocean/project/secchi/) Norway has contributed only 10 % of the

observations in the Skagerrak-Belt area, although this is the area where Norway makes most of its Secchi disk observations. In the Nordic Seas such measurements are practically non-existent. In order to remedy this situation a little, our students have observed the Secchi disk depth whenever possible during their cruises in the Nordic Seas since 1994.

In a study by Aas and Berge (1976) of the vertical attenuation of blue irradiance in the Nordic Seas it had been found that the Atlantic waters, characterized by salinities above 35.0, on an average were more transparent than the less saline surrounding waters of coastal and Polar origin. One of the objectives of the Secchi disk measurements presented in this paper has been to investigate whether they will demonstrate a similar difference in transparency between the water types.

2. Data material

Altogether 163 observations of the Secchi disk depth have been collected from April to October:

April:	22
July:	2
August:	78
September:	35
October:	26

The data are presented chronologically in Tables 1-9. At all stations the standard observations are the Secchi disk depth, latitude, longitude, date and UTC (Universal Time Coordinated). At some stations the angle of the rope supporting the disk was reported. The depths presented in the tables have been corrected for this angle.

Additional observations included in the tables are salinity, temperature, wind speed, wind direction, wave height, weather and cloud amount. In some of the tables salinities and temperatures are reported for the recording depth as close to the surface as possible (corresponding to the depth of the sensors in the submerged CTD, approximately 1 m), as well as for the Secchi disk depth. The magnitude of the difference between these values indicates whether the Secchi disk depth is above or below the depth of the upper mixed layer.

Rather than the observed wave height in m, some tables report the sea state according to the WMO Code 3700:

Code	**Description**	**Height (m)**
0	Calm-glassy	0
1	Calm-rippled	0-0.10
2	Smooth-wavelets	0.10-0.50
3	Slight	0.50-1.25
4	Moderate	1.25-2.50
5	Rough	2.50-4
6	Very rough	4-6

7	High	6-9
8	Very high	9-14
9	Phenomenal	Over 14

The weather at the time of observation is reported in accordance with WMO Code 4501:

Code	**Description**
0	Clear (no cloud at any level)
1	Partly clouded (scattered or broken)
2	Continuous layer(s) of cloud(s)
3	Sandstorm, duststorm, or blowing snow
4	Fog, thick dust or haze
5	Drizzle
6	Rain
7	Snow, or rain and snow mixed
8	Shower(s)
9	Thunderstorm(s)

The cloud amount is reported in oktas according to WMO Code 2700, that is in parts of eight. The number 9 means that the sky is obscured, or that the cloud amount cannot be estimated.

Not all of the environmental parameters were included in the original field reports. Consequently we have tried to supply as much of the missing data as possible. The tables are nevertheless incomplete.

1991-1993
In August 1991 Jo Høkedal measured UV, blue and quanta irradiance in the Greenland and Northern Barents Seas for his cand.scient. thesis (Høkedal, 1993) onboard the *RV Lance* (Fig.1). He took additional measurements in August 1993 (for locations see Fig.2) while he was employed by the Norwegian Polar Institute. The observations of Z_{SD} were never published and are presented here for the first time. Their range is 7.0-28.5 m. Observations of Z_q(10%) and Z_q(1%) are also included (Tables 1-2).

1994
Helene Hanken and Brith Korsbø (Figs. 3-5) participated in a cruise during August-September from 66 ºN to 78 ºN in the Nordic Seas (Fig. 6) onboard the *RV Håkon Mosby* (Fig. 7), with corresponding surface temperatures decreasing from 12 to 2 degrees. The Z_{SD} range was 5.5-15 m (Table 3).

1996
Cecilie Wettre (Fig. 8) was the Secchi observer in the September cruise to the Fram Strait (Fig. 9) onboard the *RV Lance* (Fig. 10). The conditions were characterized by surface temperatures below zero, surface salinities below 32, and varying amounts of drifting ice around the ship. The water transparency was remarkably high, with Z_{SD} varying from 13.5 to 25 m (Table 4).

1999
The vertical visibility in the Barents Sea and in Storfjorden south of Spitsbergen was observed by Trond Kristensen to vary in the range 5-18 m (Table 5).

2001
When Ingerid Fossum (Figs. 11-12) visited Storfjorden in August (Fig. 13), the Z_{SD} range was 2.5-20 m (Table 6). In addition to the standard hydrographic quantities the beam attenuation at 660 nm was measured by means of an ALPHA^{tracka} II transmittance meter, manufactured by Chelsea Technologies Group, Surrey, UK. The path length of this instrument was 0.25 m. Two months later Kai Håkon Christensen (Fig. 14) observed the Secchi disk depth in the Atlantic waters of the Svinøy Section. Z_{SD} had values from 9.5 to 12 m (Table 7).

2002
Jan Mayen (Fig. 15) is a desolate, mountainous and volcanic island with a surface area of 380 square km, located in the Greenland Sea north of Iceland. The Beerenberg volcano (2277 m) is the northernmost active volcano on earth. The island has no natural harbours and is not easily accessed from the sea. Trond Kristiansen was stationed on the island for six months as a meteorological officer. In Alkevika on the east side of the island not far from the meteorological station, he found a shelf on the top of a vertical cliff situated 3 meters above sea level (Fig.16). This made it perfect for observing the Secchi disk depth, except on days with rough weather. It is characteristic of the weather on the island that only one of the six months presented conditions where it was possible to take such measurements. The range of Z_{SD} was 2-7 m (Table 8). The salinity and temperature of the ocean were measured at a nearby location at 0.5 m depth using a hand-held salinometer (Testo-Term 240).

2004
The final group of students - Michaela Ferbar, Paula Moreno Sanz, André Staalstrøm, Karina Thill, and Anders Åman (Fig. 17) – made their observations onboard the new *RV G. O. Sars* (Fig. 18) during the Easter week of 2004. The course of the cruise is shown in Fig. 19. The station numbers 306-323 belong to the Gimsøy Section, while 327-341 belong to the Fugløya-Bjørnøya Section. The surface salinities at the stations were in the range 34.2-35.2 and the Secchi disk depths lay between 5 and 19 m (Table 9).

3. Results

No extensive analysis or discussion of the results will be conducted here. Only a few points will be mentioned.

Fossum's results from Storfjorden (Fig. 20) reveal a beautiful correlation between the particle content, expressed by the beam attenuation coefficient c_{660} for red light, and the inverse Secchi disk depth, $1/Z_{SD}$:

$$c_{660} = \left[-0.02\ m^{-1}\right] + \frac{4.54}{Z_{SD}} \qquad r = 0.98 \qquad (15)$$

where r is the correlation coefficient. The product of c_{660} and Z_{SD} has the mean value and standard deviation

$$c_{660}\, Z_{SD} = 4.3 \pm 0.7 \tag{16}$$

The observations by Høkedal of Z_{SD}, $Zq(10\%)$ and $Zq(1\%)$ produce the relationships

$$Z_q(10\%) / Z_{SD} = 1.21 \pm 0.34 \tag{17}$$

$$Z_q(1\%) / Z_{SD} = 2.7 \pm 0.8 \tag{18}$$

$$Z_q(1\%) / Z_q(10\%) = 2.2 \pm 0.4 \tag{19}$$

The results of Eq. (16) and (18) seem reasonable when compared to Eq. (9) and (14). The number 3.3 of Eq. (14) is 22 % larger than the 2.7 of Eq. (18), but still within the standard deviation of the ratio in Eq. (18).

The relationship between the Secchi disk depth and the salinity, based on all data presented in this paper, is shown in Fig. 21. Clearly there is no correlation for this data set. The spatial distributions of the stations, the surface salinities and the Secchi disk depths are presented in Figs. 22-24. The ranges of the grid-averaged Z_{SD}s coincide approximately with the ranges 0-10 m and 10-20 m presented in Fig. 25 by the US Naval Hydrographic Office (1958). Not surprisingly the corresponding ocean colours presented by the Hydrographic Office varied from green to blue (Fig.26)..

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Table 1. July-August 1991

Student: Jo Høkedal **Cruise leader:** Torgny Vinje **Project leader:** Norwegian Polar Institute

Ship: Lance **Area:** Greenland Sea, Northern Barents Sea

Station no.	Secchi disk depth (m)	Salinity close to surface	Salinity mean 0-10 m	Salinity mean 0-5 m	Temp. close to surface (deg)	Latitude (°N)	Longitude (°E)	UTC	Date (ddmm)	Wind speed (m/s)	Wind dir. (deg)	Wave height (m)	Weather code	Clouds (1/8)	Zq(10%) (m)	Zq(1%) (m)
2	15.0	31.57	32.16		3.6	77.67	29.00	1040	3107	3.6	230	1.5	0	2	13	30
3	17.0	31.55	31.93		4.3	77.67	26.45	1650	3107						18.2	
4	17.0		32.13		3.75	77.67	26	0405	0108	8.6	320	1.5	2	8	16	
5	10.0	31.35	31.88		2.2	77.67	25	0445	0108	8.0	330	1	2	7	12.5	22
6	16.5	30.69	31.59		1	78	26.98	1300	0108	2.9	340	0.2	2	7	16	
7	13.0		30.72		0.1	78.17	25	1515	0108	3.6	10	0.2	2	8		
9	12.5		31.95		2	78.5	27	1810	0108	1.0	10	0	0	5	9	
10	18.5		32.56		1.2	79.17	30.33	0450	0208	3.0	200	0	1	5	11.5	
12	9.0		32.96		1.2	79.33	30.33	0725	0208	5.7	180	0	1	5	10.5	16.5
15	10.5	32.54	32.76		0.1	79.75	28.58	1735	0208	4.1	190	0	4	9		
16	13.0	33.26	33.38		0.6	79.75	30	2005	0208	5.3	170	0.4	4	9		
17	15.5		32.28		1.2	78.93	26.58	1430	1008	1.5	150	0	4	9	19	
18	15.5		32.91		2.5	79.07	26	1650	1008	1.7	160	0	4	9		
19	15.0		33.48		2.6	79.18	25.5	1835	1008	2.1	170	0	4	9		
20	9.5			31.80	2.3	76.87	1.53	1245	1308	2.4	60	0	4	9	16	34
21	13.0			34.50	4.9	76	-1.5	0035	1408	5.9	260	1	2	8		
24	15.0				5.6	75	-6	0650	1508	2.9	180	1.5	2	8	15.1	
25	10.0			30.48	1.3	75	-8	1130	1508	7.2	290	1	2	9	12.2	
26	15.5	30.06	31.07		0.5	75	-10	1655	1508	7.4	280	0.2	1	3	8.5	27
27	16.0	29.95		30.28	-0.4	75	-11.5	2215	1508	7.2	250	0	1	3		
28	10.0	30.39		30.58	-0.1	75	-12.52	0250	1608	7.2	240	0	4	9		
29	14.0	28.91		28.95	-0.1	75	-13.5	0635	1608	5.5	240	0	2	8	9	
31	11.0	31.85	32.47		4	77.02	-0.5	1845	1808	10.3	330	1.5	2	8		
32	8.5	30.36	32.21	30.36	-1	78.93	-5.02	0920	2008	10.3	170	0.2	2	8	12.5	31
33	8.5			30.40	-0.9	79	-3.75	0450	2108	8.9	160	0	2	8	19	

Table 2. August 1993

Cand. scient.: Jo Høkedal **Cruise leader:** Torgny Vinje **Project leader:** Norwegian Polar Institute
Ship: Lance **Area:** Greenland Sea, Northern Barents Sea

Station no.	Secchi disk depth (m)	Salinity close to surface	Salinity mean 0-10 m	Temp. close to surface (deg)	Latitude (°N)	Longitude (°E)	UTC	Date (ddmm)	Wind speed (m/s)	Wind dir. (deg)	Wave height (m)	Clouds (1/8)	Zq(10%) (m)	Zq(1%) (m)
1 (40)	12.0	25.36	31.5	-1.29	78.67	33.43	1425	0708	0.0	0		8		
2 (41)	18.0	32.06	32.7	1.1	78.93	45.01	1400	0808	7.2	210		9	24	
3 (43)	14.0	31.44	32.5	-0.49	79.36	48	0705	0908	3.6	260		8	18.5	
4 (42)	14.0			-1	80.01	46.33	1640	0908	4.2	210		8	18.5	
5 (44)	16.0	30.01	30.9	-0.88	78.95	43.12	1630	1008	7.2	180		9	23.3	
6 (45)	8.0			-1.2	78.85	34.8	0900	1208	8.2	100		6	9.2	18.1
7 (46)	11.0			-0.9	77.74	27.07	1540	1308	6.1	70		8	11	22.9
8 (47)	10.0			3	78.12	11.01	2125	1508	6.2	160	1	8	14	
9 (48)	10.0			2.8	78.08	11.95	2325	1508	0.0	0		8	12	
10 (49)	8.0			2.9	78.28	15	0455	1608	0.0	0		8	13	25
11 (50)	7.0			2.9	78.38	15.5	0615	1608	0.0	0		8	9.5	23
12 (51)	7.0			3	78.42	16	0735	1608	0.0	0		8	9	20
14 (53)	11.0	31.28	32.2	3.79	79.02	8	1305	1708	8.8	180	2	8	16.8	
15 (54)	11.0	32.37	32.2	6.22	79	6	1655	1708	6.0	200	1	9	16	
16 (55)	7.0		30.6	0.2	78.48	-3.83	1825	1808	2.7	250		8	12	28.5
17 (56)	14.0		30.3	-0.2	77	-5.37	2225	2308	3.2	170		7	12.6	24.1
18 (57)	9.0	31.35	31.9	0.96	75	13.58	1845	2408	5.1	50	1	9	11.5	24.7
19 (58)	25.0		34.4	4.5	74.97	10	1610	2508	5.8	180	0.5	8	28	
20 (59)	26.0	32.11	34.4	4.80	74.13	-3	1840	2608	7.7	160	1.5	9	26	
21 (60)	28.5	26.39	33.9	5.68	75	0.83	1230	2708	6.7	130	1	6	25	
22 (61)	16.0			5.6	77.15	0	1350	2808	8.5	110	1	9	19.5	
23 (62)	10.0	27.58	33.4	5.37	77.75	10	1345	2908	6.2	110	1	8	14.5	
24 (63)	9.0	30.20		3.86	77.81	10.53	1535	2908	5.1	110	0.5	7	14	35

Table 3. August-September 1994

Students: Brith Korsbø and Helene Hanken **Cruise leader:** Lars Golmen
Project leader: Geophysical Institute - Arne Foldvik and Svein Østerhus
Ship: Håkon Mosby **Area:** Nordic Seas

Station no.	Secchi disk depth (m)	Salinity close to surface	Salinity at SDD	Temp. close to surface (deg)	Temp. at SDD (deg)	Latitude (°N)	Longitude (°E)	UTC	Date (ddmm)
4	11.0	34.99	34.99	12.55	12.56	66.0005	4.3165	0549	2808
5	8.5	34.89	34.89	12.98	12.87	66	2.6518	1022	2808
10	8.0	34.78	34.78	10.87	10.84	65.9998	-1.002	0833	2908
11	8.0	34.73	34.73	10.35	10.35	65.9997	-3.7417	1711	2908
13	7.5	34.71	34.71	9.36	9.36	65.921	-6.3005	0631	3008
16	7.5	34.64	34.64	8.63	8.65	65.841	-6.897	1743	3008
23	5.5	34.6	34.59	8.84	8.79	65.9732	-11.2235	1810	3108
26	10.5	34.66	34.66	7.79	7.79	67.8193	-10.6265	0652	0109
44	11.5	34.45	34.45	5.18	5.15	71.1785	-7.6785	0902	0409
48	10.5	35.03	35.03	10.83	10.82	68.5645	4.812	0654	0609
49	9.5	35.03	35.03	10.93	10.91	68.491	4.8327	0925	0609
51	9.5	35.02	35.03	10.82	10.8	68.2955	4.8783	1448	0609
52	10.0	34.63	35.03	10.71	10.69	68.184	4.9137	1650	0609
55	10.5	34.58	34.78	11.5	11.35	69.2347	14.484	1556	0709
62	15.0	34.56	34.92	11.41	11.16	69.5332	13.6625	0436	0809
77	11.0	33.46	33.47	2.05	2.06	77.8648	10.6583	0630	1109
78	9.5	33.01	33.01	2.3	2.3	78.0502	11.3882	0802	1109

Table 4. September 1996

Student: Cecilie Wettre | **Cruise leader:** Svein Østerhus | **Project leader:** Norwegian Polar Institute

Ship: Lance | **Area:** Fram Strait

Stat. no.	Secchi disk depth (m)	Salinity close to surface	Salinity at SDD	Temp. close to surface (deg)	Temp. at SDD (deg)	Latitude (°N)	Longi-tude (°E)	UTC	Date (ddmm)	Wind speed (m/s)	Wind dir. (deg)	Sea code	Wea-ther code	Clouds (1/8)
1	24.0	30.01	33.75	-0.7	-1.39	77.502	-6.273	0640	0709	0	0	0	1	7
2	20.0	30.03	32.99	-1.05	-1.37	77.829	-5.282	0935	0709	1.8	40	1	4	6
3	22.0	30.08	33.24	-1.11	-1.61	77.852	-5.147	1022	0709	2.5	40	1	4	6
4	21.0			-1		77.863	-5.055	1123	0709	3.6	30	1	2	7
5	16.0	30.41	33.05	-1.17	-1.55	77.887	-4.862	1220	0709	3.6	30	2	2	7
6	15.6	31.13	31.85	-1.1	-0.42	78.057	-4.488	1735	0709	6.2	30	2	2	8
12	15.5	30.93	30.93	-1.56	-1.54	78.992	-4.683	0935	0909	6.7	350	2	1	5
13	15.0	31.27	32.63	-1.47	-1.45	79.012	-3.380	1804	0909	3.8	350	0	1	5
17	9.9	30.78	31.56	-1.46	-1.51	78.993	-3.733	1304	1009	8.7	180	3	2	8
18	16	30.73	31.67	-1.47	-1.57	78.958	-3.905	1808	1009	7.7	180	1	1	7
20	18.5	30.71	30.98	-1.52	-1.39	78.937	-4.988	0947	1109	3.1	190	0	2	8
21	16.0	30.99	31.02	-1.47	-1.49	78.975	-5.430	1151	1109	4.1	160	1	2	8
31	25.0	30.38	32.33	-1.27	-1.64	78.999	-13.000	0750	1209	0	0	0	2	8
64	17.5	33.31	33.33	-1.8	-1.80	80.427	6.483	0629	1709	4.1	220	1	1	7
74	13.5	28.44	31.81	-1.74	-1.69	78.866	-0.500	0748	1909	9.3	230	2	2	8

Table 5. October 1999

Student: Trond Kristiansen **Project leader:** Geophysical Institute, Bergen - Truls Johannessen
Ship: Håkon Mosby **Area:** Barents Sea - Storfjorden **Cruise leader:** Are Olsen

Station no.	Secchi disk depth (m)	Salinity close to surface	Salinity at SDD	Temp. close to surface (deg)	Temp. at SDD (deg)	Latitude	Longitude	UTC	Date (ddmm)
1 (28)	14.0	34.78	34.78	5.30	5.70	76° 11' N	17° 31' E	1005	0510
2 (29)	18.0	34.73	34.73	4.90	5.00	76° 06' N	17° 48' E	1101	0510
3 (30)	16.5	34.20	34.63	4.65	4.66	76° 01' N	18° 10' E	1159	0510
4 (32)	17.0	34.88	34.83	4.45	4.46	75° 51' N	18° 51' E	1340	0510
5 (33)	17.0	34.71	34.70	4.06	4.00	75° 57' N	19° 49' E	1524	0510
6 (48)	7.0	33.14	33.15	1.17	1.19	77° 49' N	18° 43' E	0609	0610
7 (49)	9.0	33.34	33.38	1.30	1.30	78° 04' N	19° 11' E	0802	0610
8 (50)	5.0	33.40	33.54	1.65	1.62	78° 16' N	19° 25' E	0930	0610
9 (53)	7.0	33.50	33.51	1.55	1.58	78° 10' N	20° 16' E	1130	0610
10 (54)	5.0	33.41	33.49	1.45	1.55	78° 07' N	20° 30' E	1202	0610
11 (55)	6.0	33.65	33.48	1.50	1.53	78° 04' N	20° 30' E	1235	0610
12 (56)	6.0	33.65	33.65	1.50	1.50	78° 00' N	20° 30' E	1305	0610
13 (57)	5.5	33.75	33.75	1.48	1.48	77° 57' N	20° 30' E	1337	0610
14 (58)	7.0	33.82	33.82	1.67	1.66	77° 52' N	20° 07' E	1432	0610
15 (59)	11.0	34.13	34.13	2.21	2.19	77° 46' N	19° 43' E	1528	0610
16 (74)	13.0	34.24	34.30	1.89	2.16	77° 02' N	20° 41' E	1148	0710
17 (75)	15.5	34.51	34.52	2.54	2.61	77° 01' N	20° 21' E	1228	0710
18 (76)	15.0	33.81	33.83	1.70	1.75	76° 59' N	19° 54' E	1317	0710
19 (77)	11.0	33.70	33.70	1.40	1.40	76° 58' N	19° 31' E	1410	0710
20 (78)	16.0	33.80	33.90	1.50	1.52	76° 57' N	19° 04' E	1512	0710

Table 6. August 2001

Student: Ingerid Fossum **Cruise leader:** Ragnheid Skogseth

Ship: Håkon Mosby **Project leader:** Geophysical Institute, Bergen - Harald Svendsen

Area: Storfjorden

Station no.	Secchi disk depth (m)	Salinity close to surface	Salinity at SDD	Temp. close to surface (deg)	Temp. at SDD (deg)	Latitude	Longi-tude	UTC	Date (ddmm)	Wind speed (m/s)	Wind dir. (deg)	c(660) at the surface (1/m)	c(660) at the SDD (1/m)
1	6	34.55	34.55	9.51	9.54	72° 00' N	19° 20' E	1430	2208	2.7	85	0.812	0.858
2	4.3	34.9	34.9	8.42	8.39	73° 00' N	19° 20' E	2050	2208	1.8	85	0.977	0.995
3	18	33.68	34.03	3.95	1.73	76° 43' N	19° 10' E	1745	2308	1.4	336	0.249	0.274
10	4	30.89	31.7	4.28	3.86	77° 40' N	18° 55' E	0100	2408	1.2	17	1.260	1.339
11	9	32.72	33.14	3.16	2.06	77° 49' N	18° 44' E	0200	2408	7.6	313	0.559	0.469
12	11	33.05	33.4	3.47	1.35	78° 05' N	19° 12' E	0400	2408	3.2	315	0.284	0.447
13	2.5		31.98		1.56	78° 17' N	19° 10' E	0545	2408	1.5	287	1.966	2.087
24	17.5	33.08	33.54	3.50	0.90	78° 01' N	19° 07' E	1230	2408	7.9	12	0.283	0.386
25	7	32.81	32.92	3.01	2.79	78° 01' N	19° 00' E	1245	2408	4.6	0	0.597	0.581
26	2.5		32.35		2.23	78° 01' N	18° 49' E	1315	2408	6.7	57	1.550	1.644
42	10.1	33.33	33.46	2.75	2.83	77° 16' N	18° 00' E	0530	2508	2.9	356	0.561	0.565
50	9	33.54	33.57	2.03	1.99	77° 04' N	21° 04' E	1230	2508	4.8	345	0.540	0.522
51	11.3	33.73	33.73	2.16	2.09	77° 02' N	20° 41' E	1300	2508	8.2	67	0.344	0.346
52	14	33.88	33.9	2.79	2.81	77° 01' N	20° 22' E	1345	2508	0	0	0.345	0.344
53	15	32.32	33.83	3.96	2.65	77° 00' N	19° 55' E	1445	2508	1.1	200	0.283	0.298
54	15	33.54	33.89	3.87	2.61	76° 59' N	19° 32' E	1515	2508	3	130	0.266	0.382
55	14	33.59	34.13	3.79		76° 08' N	19° 17' E	1545	2508	2.9	211	0.264	0.283
56	15.5	33.76	34.11	3.33	1.89	76° 57' N	19° 05' E	1620	2508	4.1	225	0.323	0.257
57	17	34.74	34	3.31	1.56	76° 56' N	18° 39' E	1705	2508	2.6	141	0.296	0.401
58	13	33.76	33.94	3.33	2.44	76° 54' N	18° 20' E	1735	2508	1.6	139	0.323	0.327
77	12	34.02	34.18	3.42	2.34	76° 50' N	19° 32' E	1230	2608	5.8	82	0.348	0.512
78	18	33.59	34.18	3.16	1.95	76° 50' N	19° 09' E	1430	2608	5.8	33	0.260	0.223
79	20	33.91	34.22	4.23	3.30	76° 45' N	19° 31' E	1505	2608	8.5	60	0.176	0.185
80	15.5	33.65	33.91	3.39	2.14	76° 45' N	19° 18' E	1750	2608	6.8	53	0.261	0.330
93	16	34.03	34.03	4.30	4.26	76° 38' N	20° 05' E	0550	2708	7.9	55	0.214	0.200
99	16	34.17	34.21	3.16	3.24	76° 40' N	20° 44' E	1230	2708	9.6	62	0.320	0.318
100	13	34.15	34.16	4.07	4.06	76° 28' N	21° 49' E	1530	2708	8.4	21	0.306	0.279
101	11	34.25	34.25	2.98	2.99	76° 28' N	21° 04' E	1645	2708	7.8	61	0.449	0.447
102	11	34.13	34.13	3.41	3.41	76° 28' N	20° 35' E	1730	2708	6.4	34	0.336	0.333
118	15.6	33.94	34.43	3.88	4.76	76° 27' N	19° 01' E	1230	2808	7.7	253	0.177	0.284
119	17	33.98	34.02	4.01	3.83	75° 23' N	19° 06' E	1230	2808	8.3	111	0.190	0.164
120	15.5	33.89	33.92	3.59	3.66	76° 19' N	19° 01' E	1410	2808	9.1	77	0.218	0.219
121	18.7	34.21	34.21	4.94	4.92	76° 20' N	19° 13' E	1445	2808	10.7	84	0.312	0.308
122	16	34.13	34.14	4.55	4.56	76° 20' N	19° 40' E	1540	2808	13	100	0.276	0.275
123	14	34.15	34.15	4.76	4.76	76° 14' N	19° 22' E	1645	2808	9.1	76	0.236	0.233
133	13	33.42	33.71	3.09	2.08	76° 21' N	16° 56' E	1215	2908	7.1	1	0.327	0.361
134	17	33.84	34.5	3.87	4.97	76° 17' N	17° 12' E	1315	2908	3.6	54	0.215	0.235
135	13	34.32	34.31	5.34	5.23	76° 11' N	17° 32' E	1520	2908	3.1	40	0.335	0.311
136	13.0	34.31	34.32	5.01	4.88	76° 07' N	17° 48' E	1515	2908	1	99	0.303	0.307
137	10.0	34.54	34.54	4.73	4.72	76° 01' N	18° 11' E	1630	2908	1.7	77	0.485	0.458
138	16.0	34.56	34.64	4.34	4.44	75° 56' N	18° 30' E	1715	2908	2.3	161	0.279	0.317

Table 7. October 2001

Student: Kai Håkon Christensen
Ship: Håkon Mosby
Area: Norwegian Sea - Svinøy Section

Cruise leader: Kjell Arild Orvik
Project leader: Geophysical Institute, Bergen - Kjell Arild Orvik

Station no.	Secchi disk depth (m)	Salinity close to surface	Salinity at SDD	Temp. close to surface (deg)	Temp. at SDD (deg)	Latitude	Longi-tude	UTC	Date (ddmm)	Wind speed (m/s)	Wind dir. (deg)	Wave height (m)	Weather code
S1	11.0					62° 49' N	4° 17' E	1010	1510	7.2	272	1.5	2
S2	10.5					62° 54' N	4° 05' E	1517	1510	6.1	159	1	6
CTD-9	11.0	35.02	35.09	10.92	10.91	63° 04' N	3° 40' E	900	1610	8.6	162	1.5	5
CTD-10	9.5	35.08	35.10	10.89	10.86	63° 11' N	3° 24' E	1025	1610	6.7	202	1.5	5
CTD-11	12.0	35.01	35.01	10.74	10.74	63° 19' N	3° 06' E	1148	1610	6.4	222	2	2
CTD-12	12.0	35.01	35.01	10.84	10.83	63° 27' N	2° 49' E	1320	1610	10.2	280	2	2

Table 8. August-September 2002

Cand. scient.: Trond Kristiansen
Location: Alkevika, Jan Mayen **Position: 70° 55' N 08° 43' W**
Institution: The Norwegian Meteorological Institute **UTC:** 1400-1600

Secchi disk depth (m)	Salinity at surface	Temp. at surface (deg)	Date (ddmm)	Wind speed (m/s)	Wind dir. (deg)	Wave height (m)	Weather code	Clouds (1/8)
7.0	32.8	5.3	2508	7.5	200	2.0	1	7
6.0	32.2	4.5	2608	4.0	120	4.0	1	7
3.0	33.2	6.2	3008	9.0	360	3.0	1	6
3.0	33.8	6.2	3108	6.0	350	2.0	1	6
2.0	33.2	6.2	0309	5.0	330	4.0	1	6
4.0	33.6	6.1	0409	3.5	340	2.0	1	1
6.0	33.9	3.7	1009	2.5	50	1.0	1	9
7.0	33.0	4.8	1309	2.1	200	0.5	1	2
7.0	33.6	5.1	1409	8.5	220	2.0	4	9
7.0	34.4	4.5	1509	2.6	170	1.0	1	4
5.0	33.8	4.8	1809	3.6	30	0.5	1	7
5.0	34.4	5.0	2009	0.8	170	0.5	1	7
5.0	34.8	4.9	2309	8.0	360	0.5	1	5
5.0	33.4	4.8	2409	5.9	10	0.5	2	7

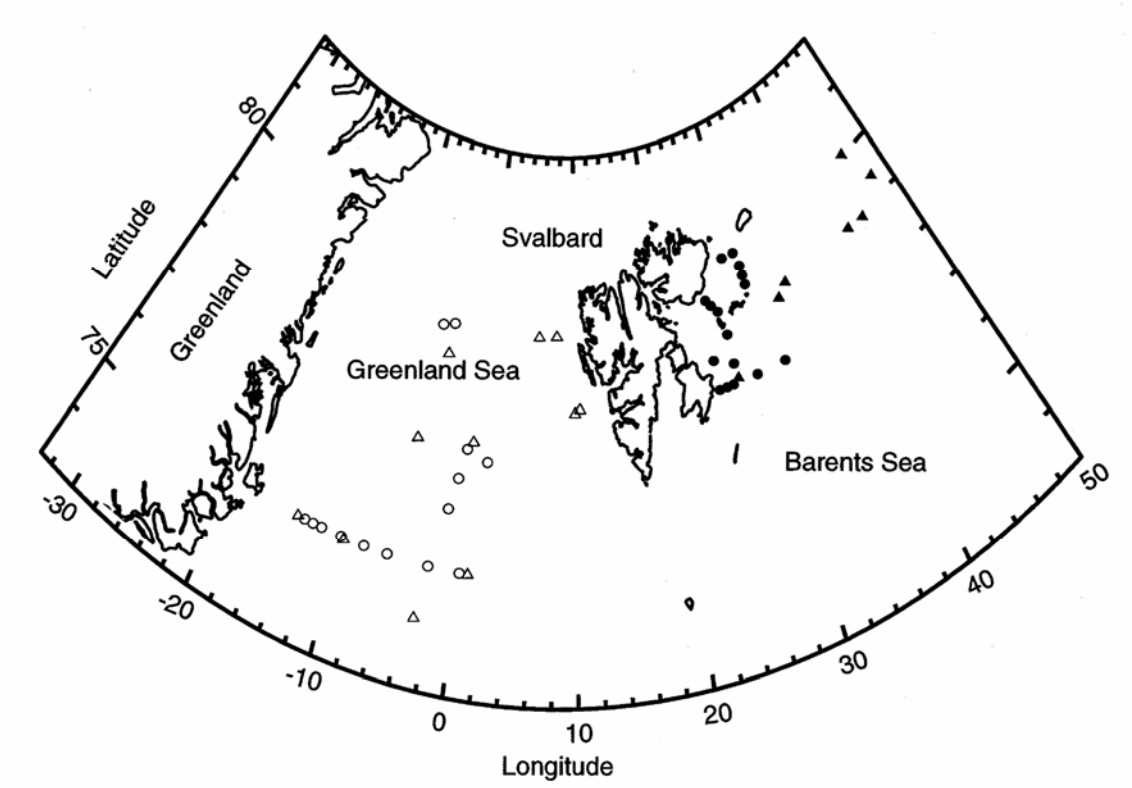
Table 9. April 2004

Students: Michaela Ferbar, Paula Moreno Sanz, André Staalstrøm, Karina Thill, Anders Åman
Cruise leader: Harald Loeng **Project leader:** Institute of Marine Research, Bergen
Ship: G. O. Sars **Area:** Nordic Seas

Station no.	Secchi disk depth (m)	Salinity close to surface	Temp. close to surface (deg)	Latitude	Longi-tude	UTC	Date (ddmm)	Wind speed (m/s)	Wind dir. (deg)	Sea code	Wea-ther code	Clouds (1/8)
306	16.0	34.32	5.65	68° 30' N	13° 48' E	0602	0704	5.0	134	2	1	3
308	14.5	34.43	5.65	68° 35' N	13° 36' E	0925	0704	7.2	174	2	2	5
310	19.0	34.21	5.44	68° 44' N	13° 11' E	1123	0704	7.6	191	2	2	5
311	13.5	34.75	6.56	68° 48' N	12° 59' E	1302	0704	7.7	193	2	2	3
312	18.0	35.15	7.13	68° 51' N	12° 49' E	1450	0704	9.9	193	2	1	6
313	10.0	35.00	6.96	68° 54' N	12° 39' E	1855	0704	13.6	191	4	1	4
314	5.0	35.09	6.96	68° 57' N	12° 34' E	2010	0704	12.9	200	4	2	7
318	9.2	35.18	7.00	69° 14' N	11° 37' E	0620	0804	10.1	237	3	2	6
319	11.0	35.19	6.51	69° 30' N	10° 58' E	1540	0804	17.5	210	4	6	8
320	5.5	35.18	6.49	69° 42' N	10° 16' E	2127	0804	13.4	325	5	2	8
321	12.0	35.19	6.42	69° 57' N	9° 52' E	0820	0904	9.0	296	4	1	3
322	13.0	35.19	6.33	70° 10' N	8° 55' E	1300	0905	8.6	225	5	2	8
323	13.0	35.18	5.64	70° 24' N	8° 13' E	1535	0906	17.0	170	5	7	8
327	14.0	35.13	5.62	73° 13' N	19° 20' E	0620	1104	15.5	164	5	1	4
328	13.0	35.10	6.09	73° 15' N	19° 24' E	0830	1104	16.0	181	5	1	4
329	14.0	35.11	5.68	73° 00' N	19° 27' E	1030	1104	16.5	187	5	1	4
330	18.5	35.09	6.10	72° 44' N	19° 32' E	1303	1104	13.8	219	5	1	5
331	14.5	35.11	5.56	72° 30' N	19° 34' E	1504	1104	8.3	258	5	1	4
332	10.5	35.08	5.98	72° 15' N	19° 38' E	1718	1104	20.0	255	5	1	4
333	9.0	35.10	5.70	72° 00' N	19° 41' E	1915	1104	11.1	268	5	1	4
340	8.5	34.73	5.81	70° 40' N	19° 58' E	0622	1204	13.3	320	5	7	8
341	10.8	34.60	5.61	70° 30' N	20° 00' E	0740	1204	12.5	289	5	1	6

Fig. 1 (left). *RV Lance*

Fig. 2 (below). Locations of the stations in 1991 and 1993 (Aas and Høkedal, 1996).



Figs. 3-4 (upper and lower, left). Brith Korsbø and Helene Hanken.

Fig.5 (lower, right). Helene and cruise leader Lars Golmen.

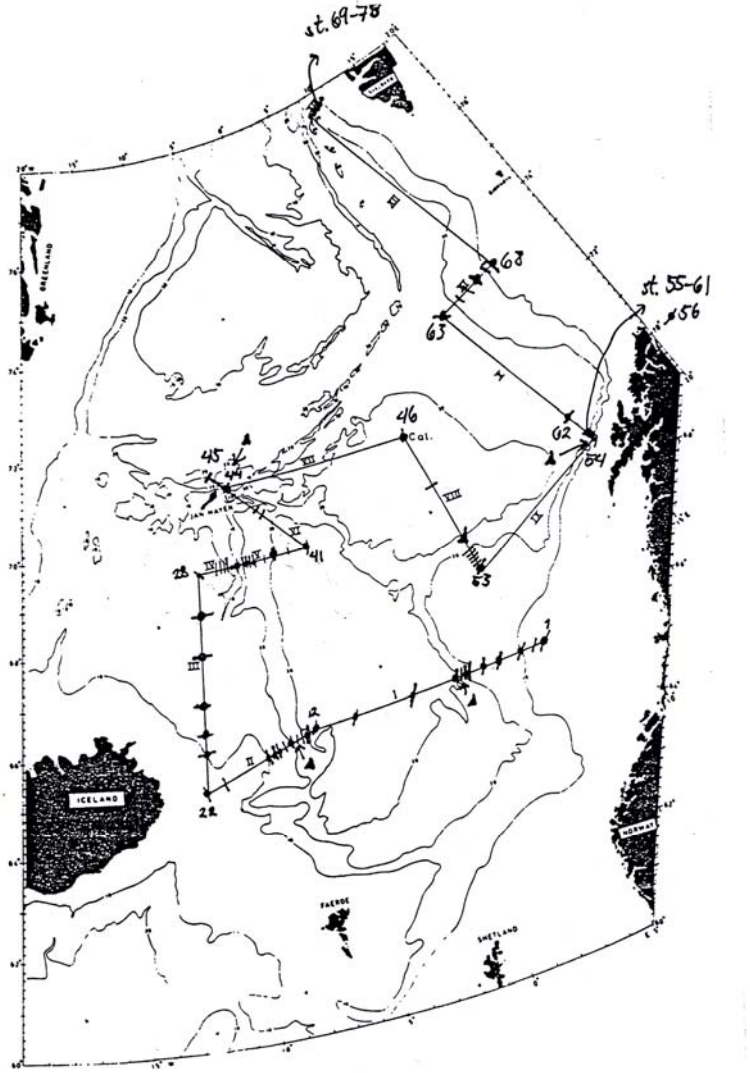


Fig. 6. Cruise track in 1994.

Fig. 7. *RV Håkon Mosby* (http://www.gfi.uib.no/)

Fig. 8 (left). Cecilie Wettre.

Fig. 9 (below). Locations of Secchi disk depths in 1996.

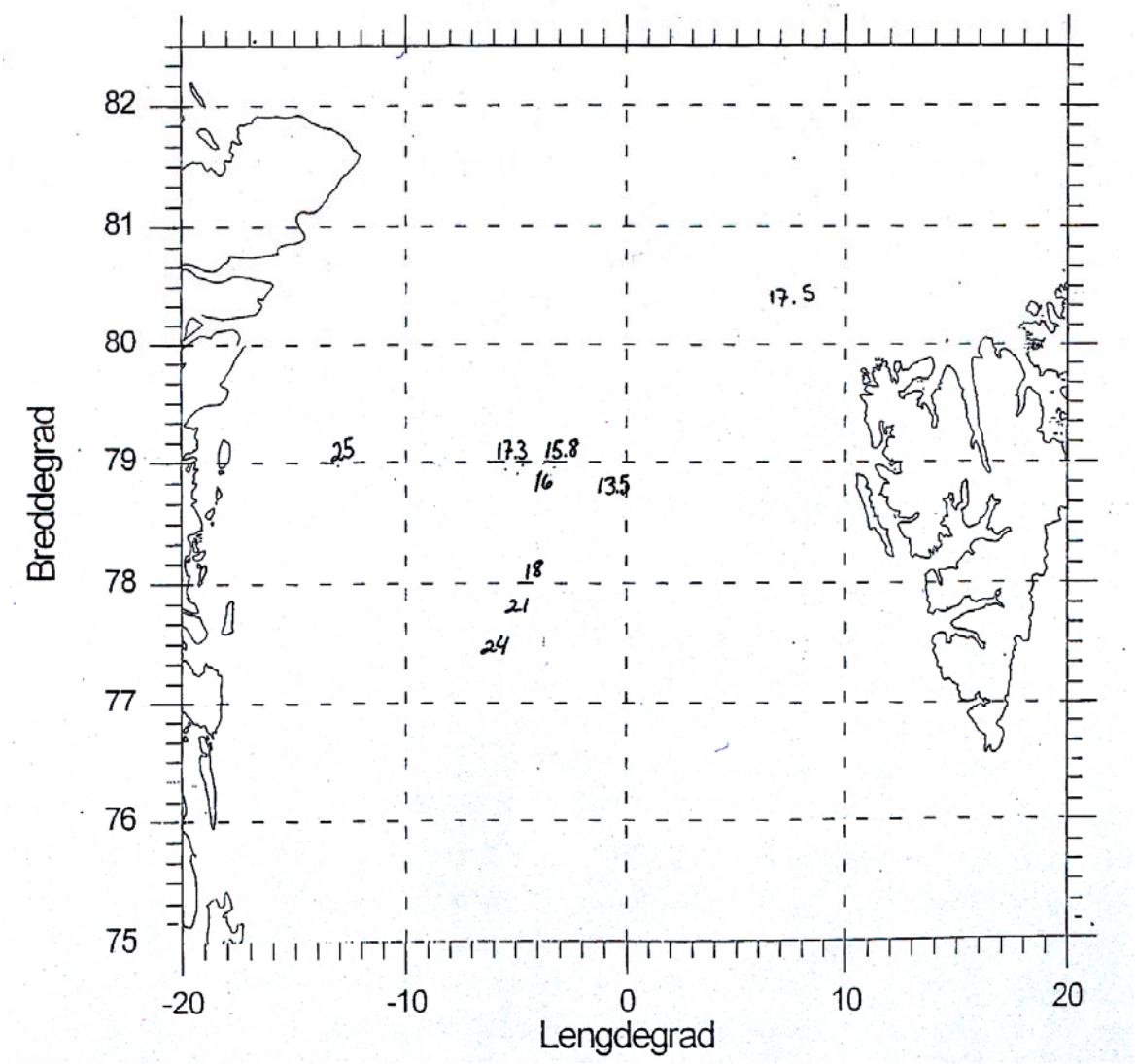
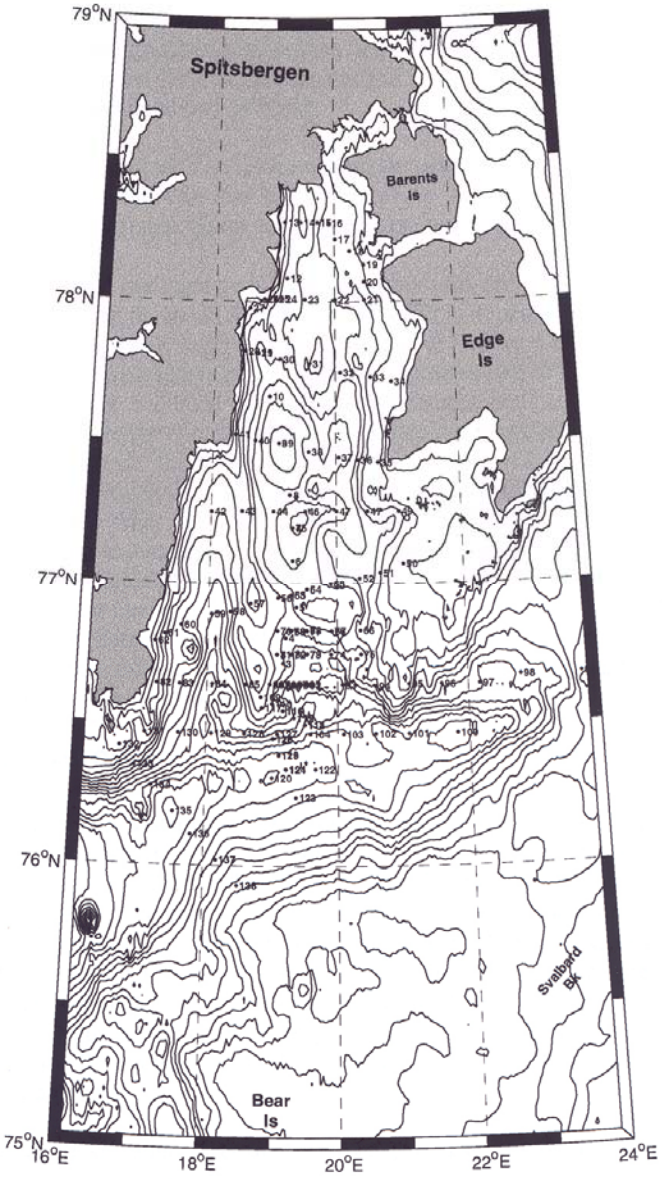


Fig. 10. *RV Lance* (http://npolar.no/lance/).

Fig. 11. Ingerid Fossum.

Fig. 12 (above). Cruise leader Ragnheid Skogseth and Ingerid Fossum at Longyearbyen, Svalbard. Note the rifle, which is obligatory equipment.

Fig. 13 (right). Locations of the stations in Storfjorden, 2001.



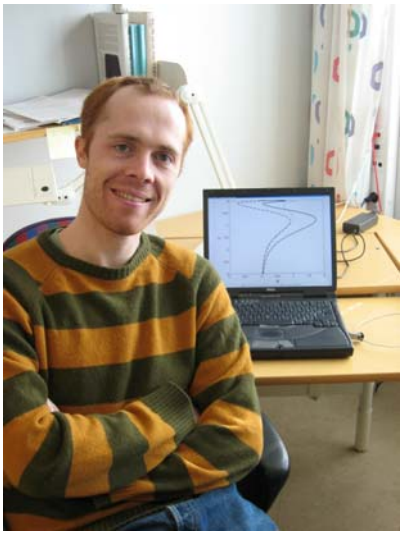


Fig. 14 (left). Kai Håkon Christensen.

Fig. 15. Jan Mayen (photo H. Hanken).

Fig. 16. Trond Kristiansen at Alkevika, Jan Mayen. Note the volcanic formations.

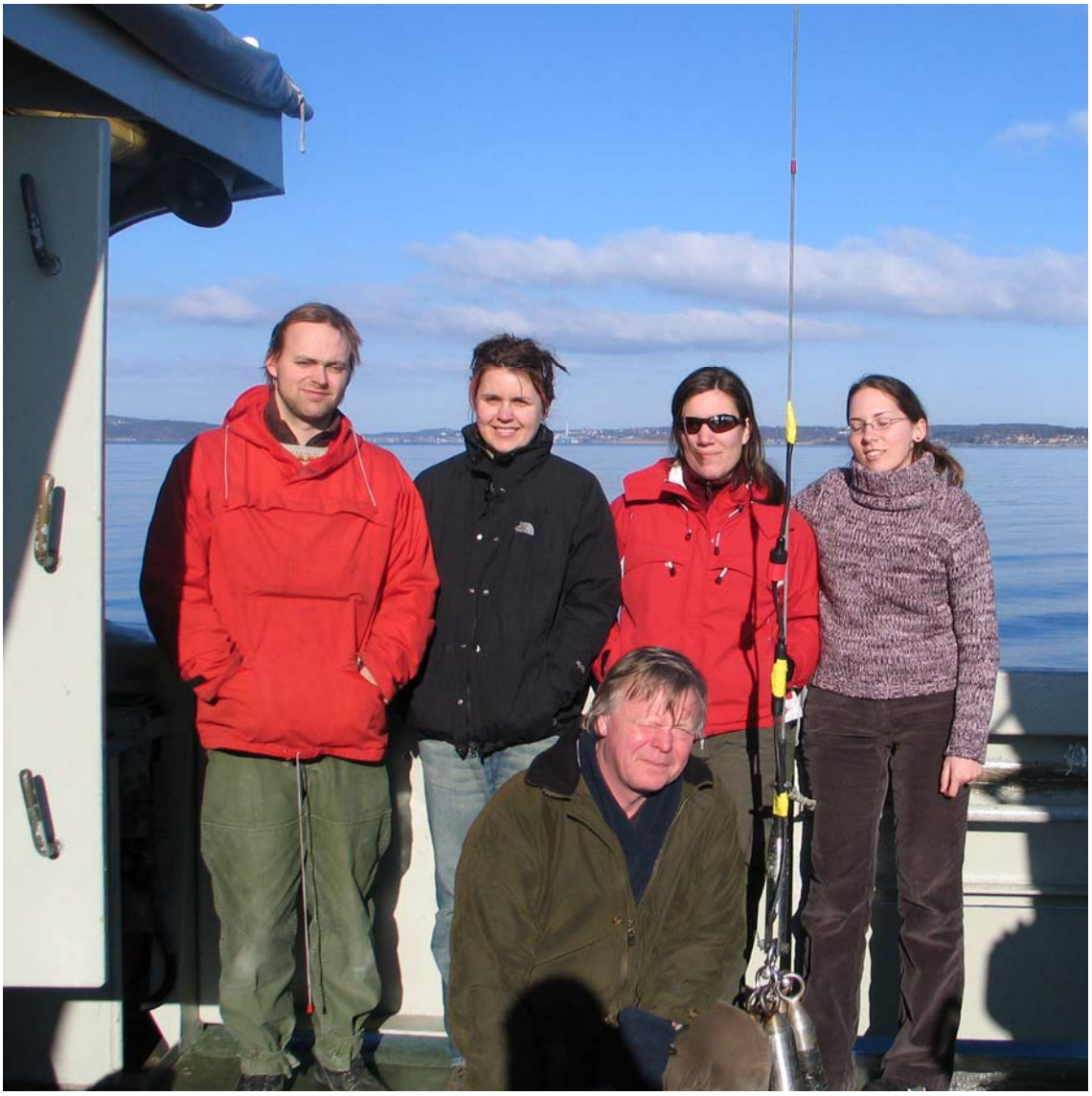


Fig. 17. André Staalstrøm, Karina Thill, Paula Moreno Sanz, Michaela Ferbar and Anders Åman (in front).

Fig. 18. The new *RV G. O. Sars* (http://www.imr.no/english/about_imr/vessels/g.o._sars).

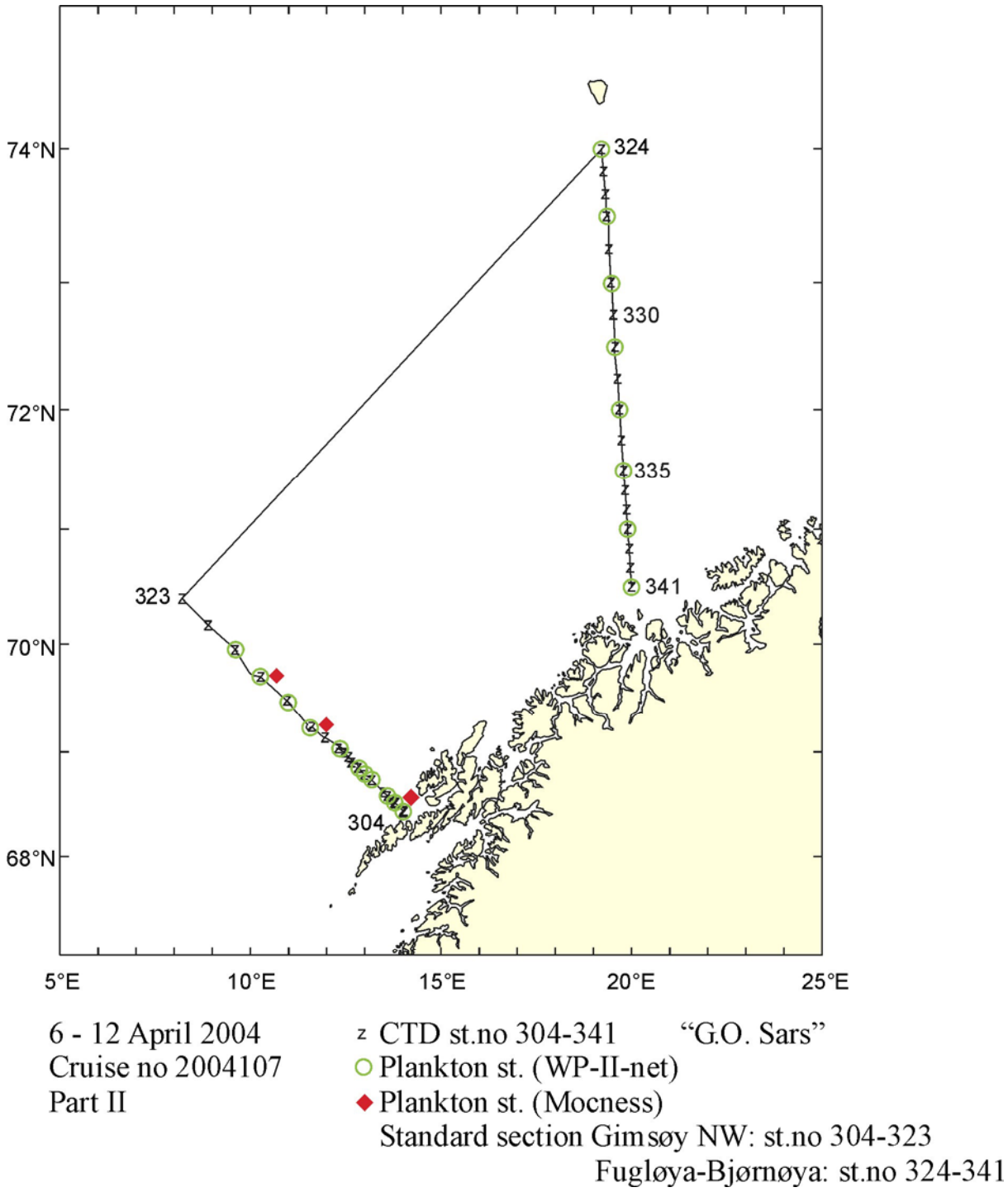


Fig. 19. Cruise track 2004 (H. Loeng, pers. comm.)

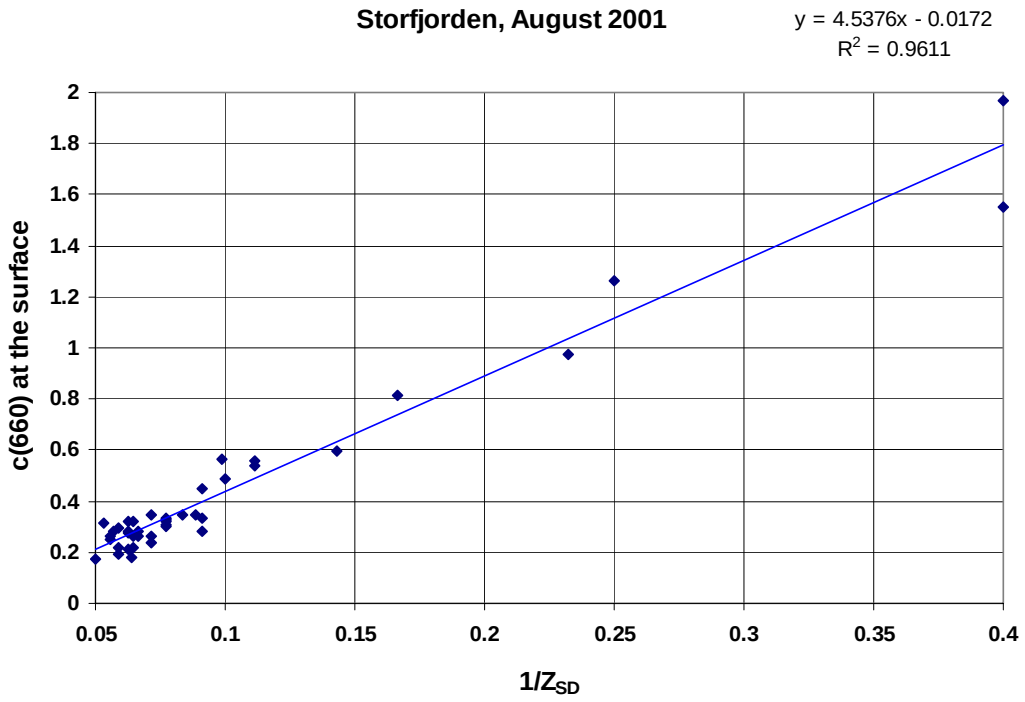


Fig. 20. The particle content in Storfjorden, expressed by the coefficient of beam attenuation at 660 nm (red light), as a linear function of the inverse Secchi disk depth $1/Z_{SD}$.

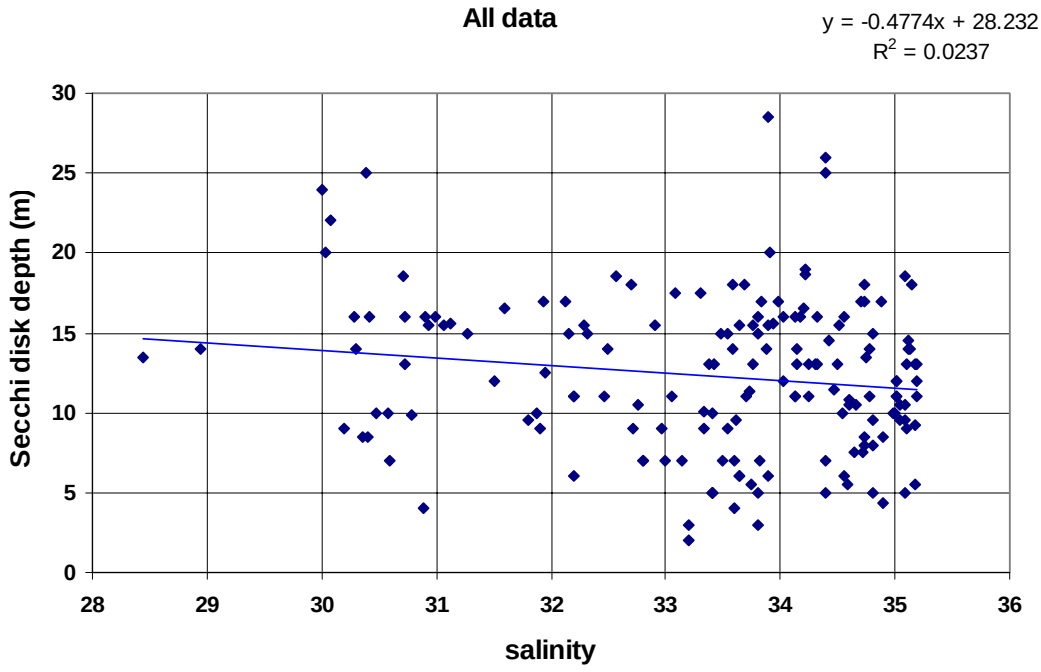


Fig. 21. All observations of the Secchi disk depth as a function of the surface salinity.

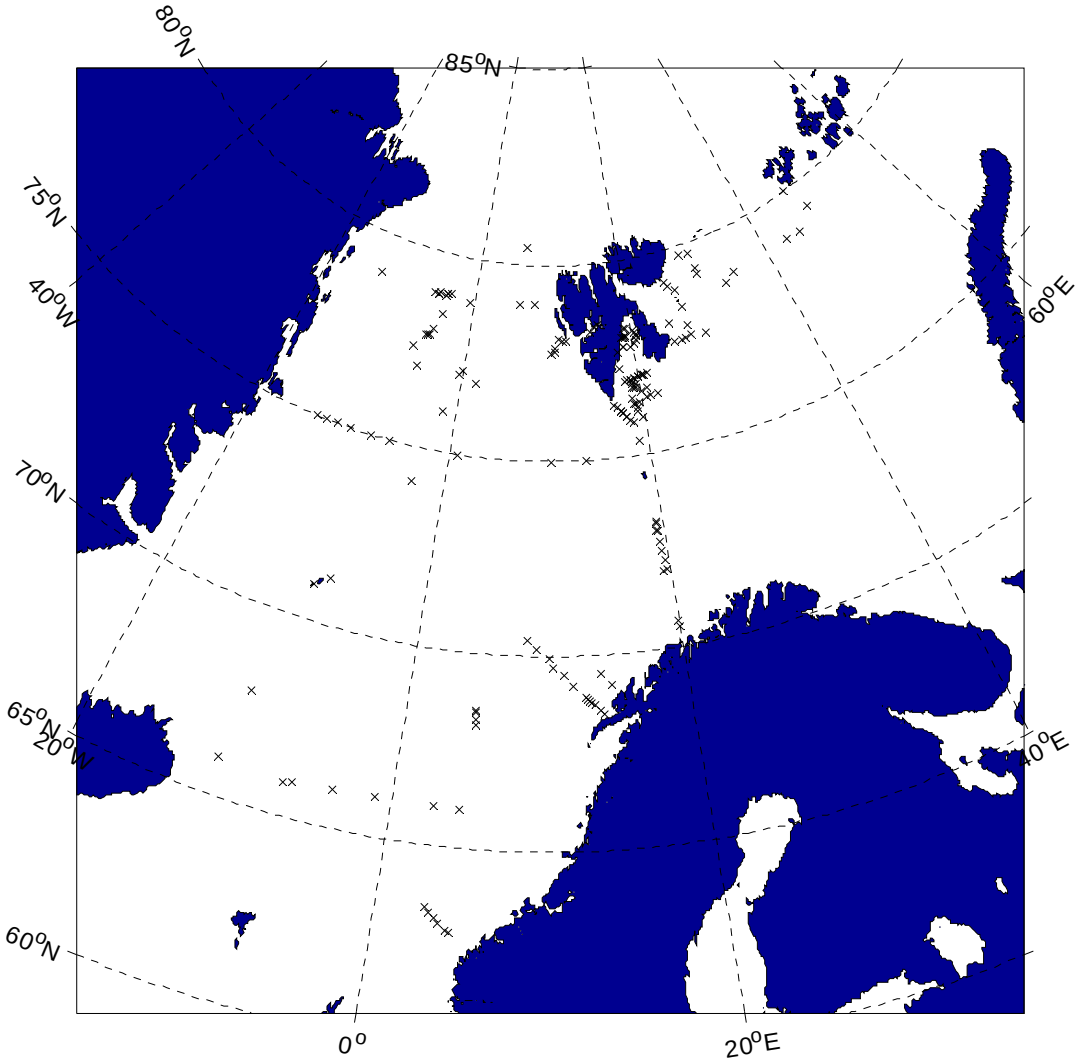
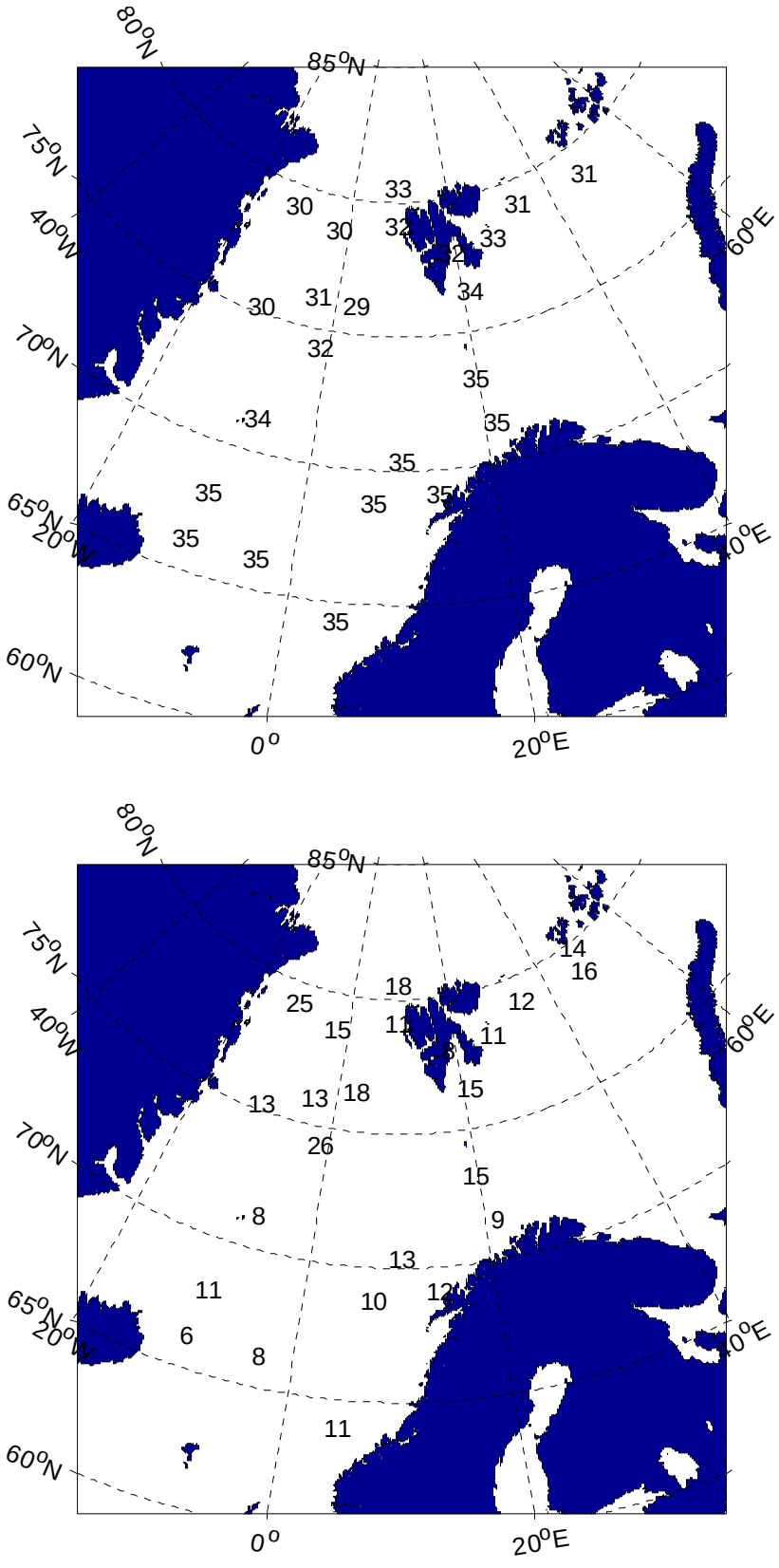


Fig. 22. Locations of all stations during the period 1991-2004.



Figs. 23-24. Salinity (upper fig.) and Secchi disk depth (lower fig.) averaged over a grid size of 10º longitude and 2.5º latitude

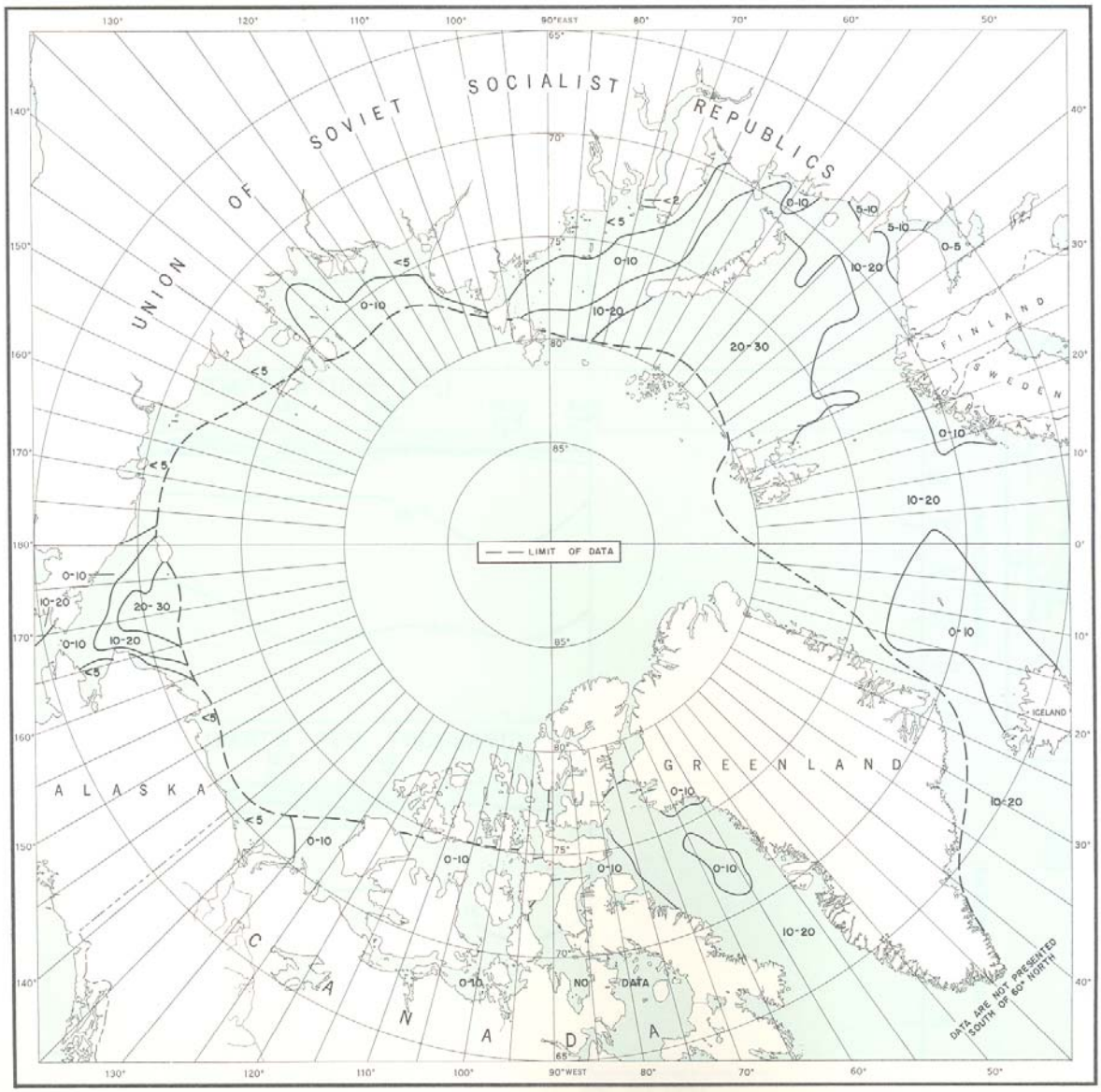


Fig. 25. Average range of Secchi disk depth in meters of open water (US Naval Hydrographic Office, 1958).

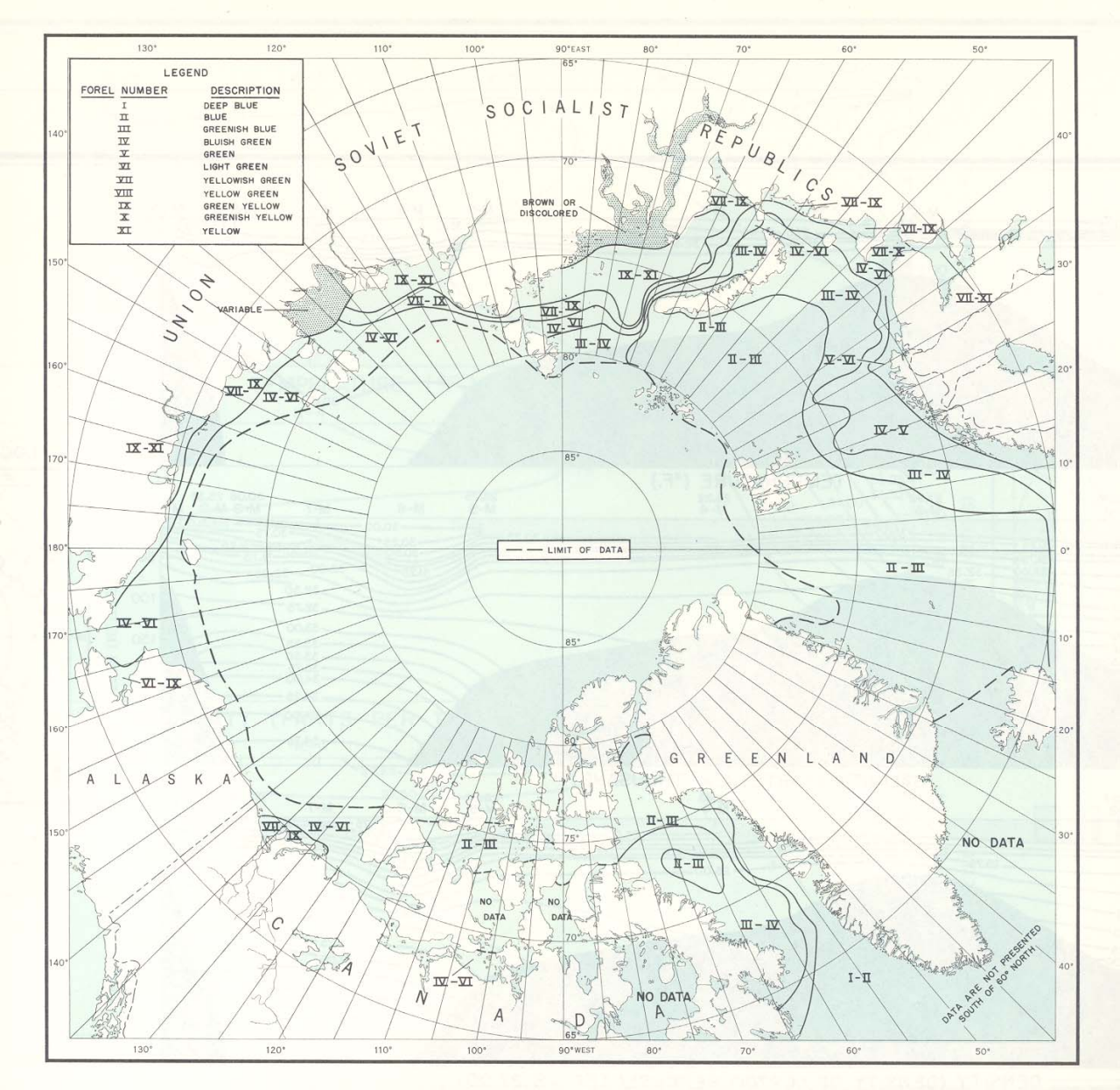


Fig. 26. Average range of water colour of open water (US Naval Hydrographic Office, 1958).