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20 Years of Met-Ocean Data Collection on the Northern Norwegian Continental Shelf

L. Lønseth, OCEANOR - Oceanographic Company of Norway ASA, A. Kvitrud, Norwegian Petroleum Directorate

Abstract

The data collection program for the Norwegian Continental Shelf north of 62°N started in 1976 and is still in operation, gathering Met-Ocean measurements at strategic locations. Insitu recorded Met-Ocean data were previously not available from the study area. By this program a long term data base of environmental data is established before development of petroleum resources is initiated. The data form a basis for definition of environmental criteria for design of installations and planning of operations on the shelf. The data also contribute to the data basis for analysis of general climatic trends and regional variations. Access to the data and other results from the project is unrestricted.

Directional and non-directional wave buoys with internal data recording and satellite data telemetry have been used for wave and meteorological data collection at 7 locations, collecting approximately 40 station years of wave data. Ocean current data have been collected by moored single point current meters and Acoustic Doppler Current Profilers at 16 locations, giving 20 years of current profile data. Stationary weather ships have also been employed. Parts of the data are collected in deep water off the Continental Shelf.

Data have been analysed to determine normal and extreme conditions at different locations. Regional differences of wave climate have been studied, indicating that extreme wave and wind conditions are at a maximum at the Vøring area (off Central Norway), with a general reduction of extreme values toward north and east into the Barents Sea. Inter-annual variations of wave conditions have also been studied, with the support of wave hindcast results and long term time series from coastal stations.

Background and organisation

For planning of development and operation of installations in the oil and gas fields off shore, a good knowledge of the physical environmental forces acting on the platforms, pipelines, ships, floating production units and so on, is of vital importance. The main factors which are present in every offshore area are the winds, surface waves and ocean currents. In northern areas factors inherent to a cold climate; drifting ice and icebergs, and icing of constructions from sea spray and precipitation, also play an important role. The relative importance of environmental factors depends on the local conditions, and on the type of installations involved.

Reliable knowledge of the environment depends on long series of observations collected over many years. Therefore the data collection must start many years before the design of installations is finalized.

The development of offshore petroleum resources first started in parts of the North Sea where the ocean is relatively shallow, typically less than 100 m. In this area the environmental conditions were also fairly well known. Gradually the activity expanded north to deeper ocean areas with a more harsh physical environment. Water depths in areas of interest are from around 250 m at Tromsøflaket and in the Barents Sea, to more than 1400 m at the Vøring Plateau.

In 1975-76 NPD engaged several Norwegian institutions to collect and evaluate existing data about waves, currents, wind and temperature on the Norwegian Continental Shelf. It was found that the existing information for the Northern parts of Norway's offshore areas was far from sufficient. One major conclusion was that a major effort for collection of environmental data was needed, and that the data should be collected by means of weather ships.

Based on these conclusions the data collection was started at Tromsøflaket in September 1976 with the intention of achieving a better knowledge of the physics in the ocean, at the sea surface and the atmosphere, data of the ice conditions and better weather predictions

The NPD guidelines on loads and load effects was first issued in 1987, and has had a yearly revision since then. The guidelines have to a large extent been based on the results from our measurements.

The data collection was financed 100% by NPD from 1976 to 1981. In 1981-1983 Statoil contributed financially and in the period 1983-1988 ODAP (Oceanographic Data Acquisition Project) contributed. ODAP was a Met-Ocean program sponsored by the operators in the Northern parts of Norway. An overview of the ODAP data is given by Mathisen and Steinbakke[1]. From 1989 NPD has again covered all the expenses. The total cost of the program has been about 140 million Norwegian kroner or about 21 million US$, annual expenditure is indicated by Fig. 1.

All the data which have been collected by NPD are in the public domain. Meteorological data and wave measurements are stored at the Environmental data base at the Norwegian Environmental Data Centre in Oslo. The same data and the current data are stored at OCEANOR in Trondheim. The data are freely accessible and anybody can get copies of data and reports. Only costs for data retrieval and copying will be charged for delivery of data.

Data collection from platforms

NPD have issued a regulation concerning the collection of meteorological and oceanographic data from platforms on the Norwegian Continental Shelf.

The purpose of the regulations is to obtain:

a) *background* data of the environmental conditions to be used for planning of activities, and for design of the installations. Such data are needed before an activity starts up.
b) continuos collection of environmental data (in real time) to be used in the *day to day* activities on the platform.
c) data to be used for *weather-forecasting*. The data measured are the basis for the meteorological offices to perform accurate weather-forecasting offshore.

In Norway eight platform locations are sending observations to the meteorological office every three hours. The platform locations are evenly distributed along the Norwegian coast to get a good network. Most of them are fixed production platforms, except for three mobile drilling units. These are the three platforms which most frequently are drilling in the northern parts of Norway where no production have started yet. The data also give input to the weather forecast for onshore Norway.

The first regulations concerning collection of environmental data were issued in 1978. The regulations assigned the responsibility to initiate data collection to the Norwegian authorities (NPD). After the introduction of the internal control principle to our offshore business, the data collection program was reorganised. The operators should be responsible for data collection, maintenance, data control and the data reporting.

The operators are now responsible for evaluation of the need for data, the purchasing of instruments, installation, maintenance, data control and reporting. But not to forget, even if the routine responsibility is assigned the operators, NPD still has the right to require data collection where data are needed to get a better national network of stations or when there is a need for continuos data collection for an individual platform.

No offshore earthquake collection programs have so far been required by NPD. At the moment there is a reasonable good data coverage from several onshore networks. As long as these stations are maintained, NPD does not foresee any need to require offshore measurements. The largest onshore network in Norway is actually paid by a joint venture project initiated by the oil companies. A main purpose of this project is to avoid requirements to be made for offshore measurements. Measurements offshore are shown to be more expensive than shore based measurements.

Most of the data which are collected are instrumental data. Some data are also based on observations such as clouds and visibility. Personnel who performs such observations are required to have a one week training seminar at the meteorological office. The personnel who do the observations are usually the radio operator on the platform. For one installation the observations are also performed on a standby vessel. Several persons on each platform must then have this training to maintain a 24 hourly service.

Two sets of data are reported from the platforms. Firstly the data which are sent to the Meteorological office every three hours. Such data are sent by radio, telex, computer link or telefax depending on which is most appropriate for the operator. No control of the data is usually performed offshore except for the radio operators own evaluation. If he suspect the quality of the data to be poor, he will give a warning or delete that data from his report. A daily quality control will be performed by the forecasters at the Meteorological office, when comparing the data with other stations and model results. A possibility to have a direct contact between the observer and the meteorological office is available.

In addition instrumental data are stored on a magnetic tape or on an other computer medium. Once a month the data are send onshore for control. After control of the data, a data control report is issued. Every year a comprehensive report is made.

After the data have been controlled, they are sent to the Meteorological Office together with the data control reports. The data and the reports are then **public** data, and can be used by anyone as researchers and other oil companies. The same principle of public data have been followed as long as data collection have been required in Norway.

The NPD data collection program 1976 - 1996

This program has focused on measurements of waves, both directional and non-directional, and current velocity profiles, mainly using instruments moored at fixed locations. Measurements of wind and other meteorological parameters, water level, and sea temperature and salinity profiles have also been included. Tables 1-3 gives a summary of measurement periods and locations, a map of the measurement stations is included in Fig. 2.

Tromsøflaket. The data collection started in September 1976 when the weather ship "Ami" first occupied the position 71° 30' N, 19° 00' E, where the water depth was 230 m. With the exception of the monthly trips to Tromsø for change of crew etc., the ship remained stationary in this location until the end of 1984. Regular meteorological observations were made from the ship and telegraphed to The Norwegian Meteorological Institute (DNMI) where the data were used in the regular weather service. Alongside the ship moored oceanographic instrumentation was deployed:

The wave height was measured by a Datawell waverider, the data were transmitted from the buoy to a recorder onboard the "Ami".

The current velocity profile was measured by a string of Aanderaa RCM-4 current meters at 25, 50, 100, 175 and 225 m depth.

In January 1985 the "Ami" was replaced by a Tobis buoy, an oceanographic data buoy incorporating the Waverider, a current meter and meteorological sensors. The measurements with the Tobis buoy continued until the end of 1986.

Wave measurements were also carried out at Tromsøflaket from May 1993 to April 1995. A directional Waverider was used during parts of this period. Measurements of wave height started again in October 1996 and will continue throughout 1997.

The Barents Sea. From the end of 1983 the data collection program was focused on the areas further north and east in the Barents Sea: the Bear Island, the Central Bank and the North Cape Bank.

The Central Bank. The wave and current measurements at the Central Bank started in December 1983. A discus buoy was used for collection of directional wave data and meteorological data. Current was measured by moored current meters at 6 depths.

From 1985 the research vessel "Endre Dyrøy" was stationed at the Central Bank in the position 71° 31'N, 30° 55'E. The vessel was stationary at this location for 3 weeks at a time. The 4th week of the month was used for change of crew, instrument service etc. During this 4th week the ship followed a fixed route, collecting hydrographic data (temperature and salinity profiles) along straight lines between Fugløya, Bear Island, the Central Bank and Vardø. The vessel made regular meteorological observations, serviced the wave buoy and the current meters, and functioned as platform for other types of research projects. "Endre Dyrøy" was stationed at the Central Bank until April 1988.

In February 1987 the directional wave buoy was moved to a location near the Bear Island, and the current measurements were terminated. Measurements of wave height continued until the end of 1989.

In the period November 1987 - June 1988 moored current meters were deployed under the ice at 5 locations on a line from the Central Bank toward the South Cape (Spitsbergen), using 3 - 6 current meters at each location.

Bear Island. Measurements have been made at several positions south-east of the Bear Island. Waves were measured from January 1985 to December 1989, including wave direction from February 1987 to May 1989. Current was measured at 1-3 locations (labeled A, B and C in Table 2) along a line from the Bear Island to the North Cape from April 1987 to May 1988, using 3 - 4 current meters at each location.

The North Cape Bank. The wave measurements in this location started in April 1988 and continued until December 1993. During the first two years directional data were collected, later mainly non-directional data were collected. Current data were collected by 6 current meters at the North Cape Bank from April 1988 to June 1989.

The Norwegian Sea. From 1989 the program has also included measurements in the offshore areas of the Norwegian Sea, where the ocean depths are considerably greater than in the Barents Sea.

The Vøring Plateau is located at water depths of 1000 - 1600 m between the Norwegian continental shelf and the deep central regions of the Norwegian Sea. Directional wave data were collected by a discus buoy in the position 67° 16'N, 5° 35'E, water depth 1440 m, from the end of March 1989 until July 1991. Current profiles were measured from July 1989 until July 1990. The profile in the upper 300 m was measured by a 150 kHz RD-ADCP, while the deeper parts of the water column was covered by 3 Aanderaa current meters.

From June 1995 until July 1996 current was measured at a location further south, 65° 00'N, 5° 00'E, in the slope between the Vøring Plateau and the Halten Bank. This area is now named Helland-Hansen. The 150 kHz ADCP was used to profile the upper 300 m, and 4 RCM-7 current meters covered the rest of the profile to 780 m depth.

Vesterål's Bank. A directional wave buoy was deployed off Vesterålen at a water depth of 430 m in March 1992. Later the buoy was moved further off shore to a depth of 1000 m. The measurements continued until October 1996.

The current profile in the upper 300 m was measured by an ADCP from June 1992 until May 1992, with an additional current meter at 430 m depth.

Instrumentation

A detailed description of the oceanographic instrumentation used is not within the scope of this paper, but a brief overview is given. During the 20 years there has been considerable development in oceanographic measurement technology, and this has been reflected in the instrumentation used in this project.

Waves. The Datawell waverider has been used for measurement of wave height since the measurements started at Tromsøflaket in 1976, and this buoy type is still being used. The vertical acceleration of the buoy is sensed by an accelerometer and transformed into vertical displacement, which in turn is interpreted as surface elevation. Data were transmitted to the nearby weather ship and recorded on tape. Later improved versions of the buoys have had the capability of transmitting compressed data via an Argos satellite transmitter, and storing all raw data internally on data loggers employing tapes or hard disks.

For directional wave measurements both the NORWAVE buoy and the Seatex WAVESCAN buoy have been used. These are discus buoys with heave, pitch and roll sensors. They are also equipped with meteorological sensors and sea surface temperature sensors. Data have been transmitted via Argos satellite, while the raw data have been recorded on tape for subsequent analysis. Lately the Datawell Directional waverider has become available, and has been used at Tromsøflaket.

Typical mooring configurations for wave measurements are shown in Fig. 3.

Currents. Aanderaa current meters have been used extensively in this project. From the beginning of the project the RCM-4 current meter was used. This instrument type has the obvious weakness of over-speeding in oscillatory current associated with the Savonius rotor, which cause recorded current speeds to be too high close to the surface. This problem is small at 50 m depth, and negligible at depths of 100 m and more.

Later the RCM-4s was introduced, eliminating the over-speeding associated with the rotor, but still having the weakness of direction being a single instantaneous value. In later years the RCM-7 has been used. This instrument is a true vector averaging current meter and is found to give good results even close to the surface.

For near surface current measurements we have occasionally used ultrasonic current meters, Simrad UCM-30, and the dual propeller vector measuring current meter VMCM made by EG&G.

Since 1989 the RD Instruments 150 kHz Acoustic Doppler Current Profiler (ADCP) has been used frequently for profiling of the current from 300 m depth to near surface. This instrument has proven reliable and given good results to about 50 m depth. During the latest measurements at Helland-Hansen the ADCP data from 200 m depth have been compared to the data from an Aanderaa RCM-7 at the same depth, showing excellent agreement between the two instruments. A typical mooring configuration using the ADCP and the RCM-7 is shown in Fig. 4.

Water level. Aanderaa water level recorders have occasionally been mounted near the anchor of the current meter moorings to record the water pressure near the sea bed.

Results

The data have been analyzed to determine the normal and extreme conditions at the measurement locations. The data give some basis for evaluation of regional differences and climatic tends, although the lack of simultaneous measurements at all locations creates an obvious need for additional data sources. For such analyses long term hindcast modeling of waves is a valuable tool. One such study is presented by Barstow et al.[2]. Extended hindcast wave data are available covering the years up to 1995.

During the project results have been presented continuously in data reports and summary reports. The main summary reports presenting detailed accumulated statistics are Schjølberg et al.[3], Schjølberg and Barstow[4], Schjølberg and Lønseth[5], and Lønseth[6,7].

Here we will present some general results concerning wave climate, current conditions and water level.

Waves. The long term variation in the sea state can be described by the joint probability distribution for significant wave height (Hm0) and peak period (Tp), $f_{Hm0Tp}(h,t)$. This function is estimated from the joint frequency tables for Hm0 and Tp, and for this purpose it is conveniently written

$$f_{Hm0,Tp}(h,t) = f_{Hm0}(h)\, f_{Tp|Hm0}(t|h).$$

$f_{Hm0}(h)$ and $f_{Tp|Hm0}(t|h)$ are fitted to the observations separately We have modeled the marginal distribution of Hm0, $f_{Hm0}(h)$, by the 3 parameter Weibull distribution

$$f_{Hm0}(h) = \frac{\gamma}{\theta}\left(\frac{h-\varepsilon}{\theta}\right)^{\gamma-1} \exp\left[-\left(\frac{h-\varepsilon}{\theta}\right)^{\gamma}\right]$$

The analysis of wave data from 6 stations in this program indicates that the model distribution fits the data very well. The model distributions have been used to estimate the 100 year extreme value, i.e. the value which is exceeded once every 100 years, for each location. The resulting estimates are given in Table 4.

The highest value is found at Vøring Plateau, while there are decreasing values going east into the Barents Sea. The values for Vøring agrees well with results from the Halten Bank (65°N, 5°E) obtained in the ODAP project.

The conditional distribution of Tp given Hm0 is estimated by the log normal distribution:

$$f_{Tp|Hm0}(t|h) = \frac{1}{\sqrt{2\pi\phi^2}} \exp\left[-\frac{(\ln t - \mu)^2}{2\phi^2}\right]$$

where $\mu = Avg(\ln Tp)$ and $\phi^2 = Var(\ln Tp)$. Based on this model, Bjerke and Torsethaugen[8] found that for high sea states the mean value of Tp can be approximated by

$$Tp = k\, Hm0^{1/3}.$$

Assuming that the factor k is the same at all locations, the regression line has been estimated from the total data set for Hm0 > 6 m. This gives $k = 6.9$. The regression line is compared to the observed mean Tp as a function of Hm0 in Fig. 5.

Modeling the short term distribution of individual waves by a 2 parameter Weibull distribution, and the long term distribution of Hm0 by a 3 parameter Weibull distribution, Krogstad[9] and Barstow and Krogstad[10] states that

$$E(Hmax_{100}) = 1.92\, Hm0_{100,3\,h}$$

where $E(Hmax_{100})$ is the expected highest individual wave during the 100 year extreme situation, and $Hm0_{100,3\,h}$ is the extreme Hm0 for 100 years and 3 hours duration of exceedance.

In a directional analysis the 100 year extreme value is estimated from a fitted Weibull distribution for each 30° sector. The results of the above mentioned analyses are summarized by Fig. 6 for Hm0 and Hmax, and in Fig. 7 for Tp.

Currents. There are quite large variations in current conditions within the study area. Among other things the current is influenced by the presence of topographic features such as slopes and banks, and inflow of water masses from the North Atlantic and from the ice covered Arctic Ocean.

The tidal component of the current has been evaluated at each location by harmonic analysis. The results shows great variations in the tidal current, which is illustrated by Fig. 8 showing the resulting ellipses of the dominating semidiurnal tidal constituent M_2. The tidal current is seen to be particularly strong in the relatively shallow area north-east of the Bear Island. On the other hand it is at a minimum (~1 cm/s) in the deep water location off Vesterålen, then increasing slightly going south in the Norwegian Sea, where we find an M_2 amplitude of 6 cm/s at Helland-Hansen.

Considerable variations are also found in the estimated extreme total currents between our measurement locations. Strong currents are found in the Norwegian Sea along the Norwegian Coast and in the slope along the edge of the Norwegian Continental Shelf. Strong currents in this area are mainly associated with (1) the North Atlantic Current, bringing relatively warm and saline water into the Norwegian Sea through the Faroe-Shetland Trench, and (2) the Norwegian Coastal current, generated from the southern North Sea and the Baltic, bringing less saline water with seasonally variable temperature northward along the coast. At the western entrance to the Barents Sea, the north going current splits into two branches, one continuing east into the Barents Sea, and the other going north along the continental slope west of Spitsbergen. In the Barents Sea the Atlantic and Coastal current water meets the very cold Arctic Water flowing into the Barents Sea between Novaja Semlja and Franz Josef's Land.

The extreme current velocity with return period of 100 years has been estimated by fitting the Weibull distribution to the initial distribution of measured current velocity at each measurement depth and location. The results for 9 locations in the Norwegian and Barents Sea are shown as extreme current profiles in Figs. 9 and 10. These results give an indication of the relative difference between the measurement locations, although the differences may in part be due to temporal variations, since the measurements are not made at the same time.

The extreme values of the Norwegian Sea locations (Fig. 10) are consistent with the deep north going Atlantic Current. The strong current events observed in this area are generally deep, reaching down to the deep ocean pycnocline at 300-500 m depth, and at Helland-Hansen even the bottom current meter observed a maximum value of 0.6 m/s.

Of the 6 measurement locations shown in the Barents Sea, Fig. 9, Tromsøflaket has the lowest extreme value estimates. This location is on the top of a bank which is encircled by the main current in a clockwise motion. With 7 years of measurements the description of the current climate is fairly accurate.

The highest extreme values are found at the North Cape Bank, with 1.5 years of measurements. The profile is peculiar with its maximum at 50 m depth. This illustrates the randomness involved in extreme value estimation from short time series, where the extremes are rare events compared to the span of observations. In this case the high extreme value at 50 m depth is due to data from one event in February 1989, at a time when current data from the current meters near the surface and at 100 m depth are missing. This event is described by Schjølberg et al.[11]. The current was measured simultaneously at 50, 276 and 323 m depth, Fig. 11 shows the time series for the period 5-13 February. The maximum velocity at 50 m depth was 1.0 m/s toward north, while the maximum of 0.7 m/s at 276 m depth was recorded 2 days earlier. At 50 m depth the background current was increasing from the 7^{th} to the 9^{th} and slowly turning from NE to N, with overlying semidiurnal inertial oscillations. In the same period the non-tidal water level increased to about 25 cm. The wind was mainly westerly with speeds of 10-15 m/s. Development of a small scale low over the North Cape Bank may be contributing to the strong inertial oscillations. On the 10^{th} the residual current turned W and decreased, while the amplitude of the inertial oscillations increased both at 50 and 276 m depth. This event shows that the maximum current is not necessarily connected to strong winds and powerful lows.

Long term trends in the wave climate

One main goal of our data collection has been to establish long homogenous data series. The basis has been to have ten years of measurements from Tromsøflaket and five years from each of the other stations. In a climatic perspective, even 20 years of data collection is a short time, but really long homogeneous observation series are hard to come by in this region, even from coastal weather stations. An example of a long data series is shown in Fig. 12, indicating the number of "storm days", i.e. days when the wind force was Bf 9 or more, at the stations Fruholmen (on the north coast of Norway, 24° E) and the Bear Island. The Fruholmen data are probably representative of the conditions at both Tromsøflaket and the North Cape Bank, and indicate that the period covered by measurements at Tromsøflaket is slightly less severe than the average, while the period of measurements at the North Cape Bank had less than half of the "normal" number of storm days.

The case for relatively severity in the Norwegian Sea will be different from the Barents Sea, depending on the predominant track followed by low pressures crossing the Norwegian Sea. If lows move toward mid Norway, this gives strong SW winds and severe wave conditions in the Vøring area. If lows go further north, entering the Barents Sea off the Norwegian North coast, conditions will be more severe at Tromsøflaket and further east.

On the Norwegian Coast from Møre to Troms both the number of storms and severity of storms appears to have increased after 1988, and several severe storms have caused widespread damages on the Norwegian coast. From a study of data from several sources, both buoy measurements and satellite altimeter measurements, Barstow and Krogstad[10] concluded that winter wave heights after 1989 were significantly higher than during the previous 15 years. The shift appears to have occurred rather quickly, within 1-2 years, and has affected all areas of the Norwegian Shelf from the North Sea to the Barents Sea.

By themselves, our measurements do not describe the climatic trends on a scale of 10-20 years, due to the lack of continuous measurements at one place. However, reasonably good coverage is achieved at Tromsøflaket, with measurements covering the periods Sep 1976 - Dec 1986 and May 1993 - April 1995. The annual average significant wave heights for the winter half year (October-March), as shown by Fig. 13, indicate an increasing trend over the measurement period. However, to achieve more reliable results, the measurements should be bound together by use of long continuous data series, such as long term wind and wave hindcast model simulations, and satellite altimeter measurements. Such data sources also provide good spatial coverage, and may help to resolve the issue of differences between the various parts of the study area.

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Table 1–Locations and periods of wave measurements

Location	Position	Begin	End	Dir.
Torsvåg	70°26'N 19°33'E	79-11-01	85-12-31	N
Tromsøflaket	71°30'N 19°00'E	76-09-01	84-12-31	N
Bear Island	73°50'N 19°52'E 73°30'N 20°00'E 73°30'N 20°00'E	85-01-28 85-12-01 87-02-27	85-11-30 87-02-27 87-10-15	N N Y
Bear Island (B)	73°30'N 21°30'E 73°30'N 21°30'E	87-11-09 89-06-19	89-06-01 89-12-31	Y N
Central Bank	74°30'N 31°00'E 74°30'N 31°00'E	83-12-16 87-03-02	87-02-19 89-12-31	Y N
Tromsøflaket	71°42'N 20°37'E	85-01-26	87-03-15	Y/N
North Cape Bank	72°00'N 31°00'E 72°00'N 31°00'E	88-04-28 90-05-24	90-05-01 93-12-31	Y Y/N
Vøring Plateau	67°16'N 05°35'E	89-03-30	91-07-08	Y
Vesterål's Bank	69°00'N 13°30'E	92-03-21	96-10-31	Y
Tromsøflaket	71°30'N 19°00'E	93-05-02 96-11-01	95-04-30 Cont.	Y/N N

Table 2—Locations and periods of current measurements

Location	Position	Begin	End	No. of depths
Central Bank	74°30N' 31°00'E	85-02-21	87-02-21	5
Bear Island	73°50'N 19°52'E	85-01-26	85-04-03	5
North Cape Bank	72°00'N 31°00'E	88-04-25	89-06-20	6
Tromsøflaket	71°30'N 19°00'E	76-09-01	84-12-31	5
Tromsøflaket	71°42'N 20°39'E	85-01-26	85-04-03	6
Under ice, 5 pos. in cross section	75°40'N 21°57'E 74°51'N 28°43'E	87-11-01	88-07-31	3 - 6
A	73°50'N 20°00'E	87-04-24	87-09-06	4
B	73°30'N 21°30'E	87-04-02	88-03-24	3
C	72°20'N 24°20'E	87-05-22	88-06-02	3
Vøring Plateau	67°16'N 05°35'E	89-03-30	90-06-30	3+ADCP
Vesterål's Bank	69°00'N 13°30'E	92-03-21	93-05-05	1+ADCP
Helland-Hansen	65°00'N 05°00'E	95-05-30	96-07-09	4+ADCP

Table 3—Location and period of water level measurements

Location	Position	Begin	End
Bear Island	73°50'N 20°00'E	87-04-24	87-08-07
Tromsøflaket	71°30'N 19°00'E	77-04-01 78-09-01	78-01-01 78-09-30
Central Bank	74°30'N 31°00'E	85-01-26	87-02-21
North Cape Bank	72°00'N 31°00'E	88-04-25	89-06-20
A	73°50'N 20°00'E	87-04-24	87-09-06

Table 4—Estimated 100 year extreme values of HmO with corresponding Tp

Location	Period	HmO_{100} [m]	Tp_{100} [s]
Vøring Plateau	Dec 83 - Dec 89	16.3	17.5
Vesterål's Bank	Mar 92 - Oct 96	13.7	16.5
Tromsøflaket	Sep 76 - Dec 86 + May 93 - Apr 95	13.9	16.6
Bear Island	Jan 85 - Dec 89	13.1	16.3
North Cape Bank	Apr 88 - Dec 93	14.2	16.7
Central Bank	Dec 83 - Dec 89	12.8	16.1

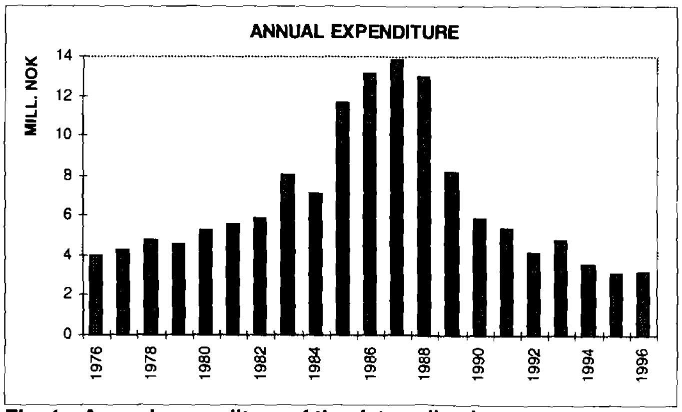

Fig. 1—Annual expenditure of the data collection program.

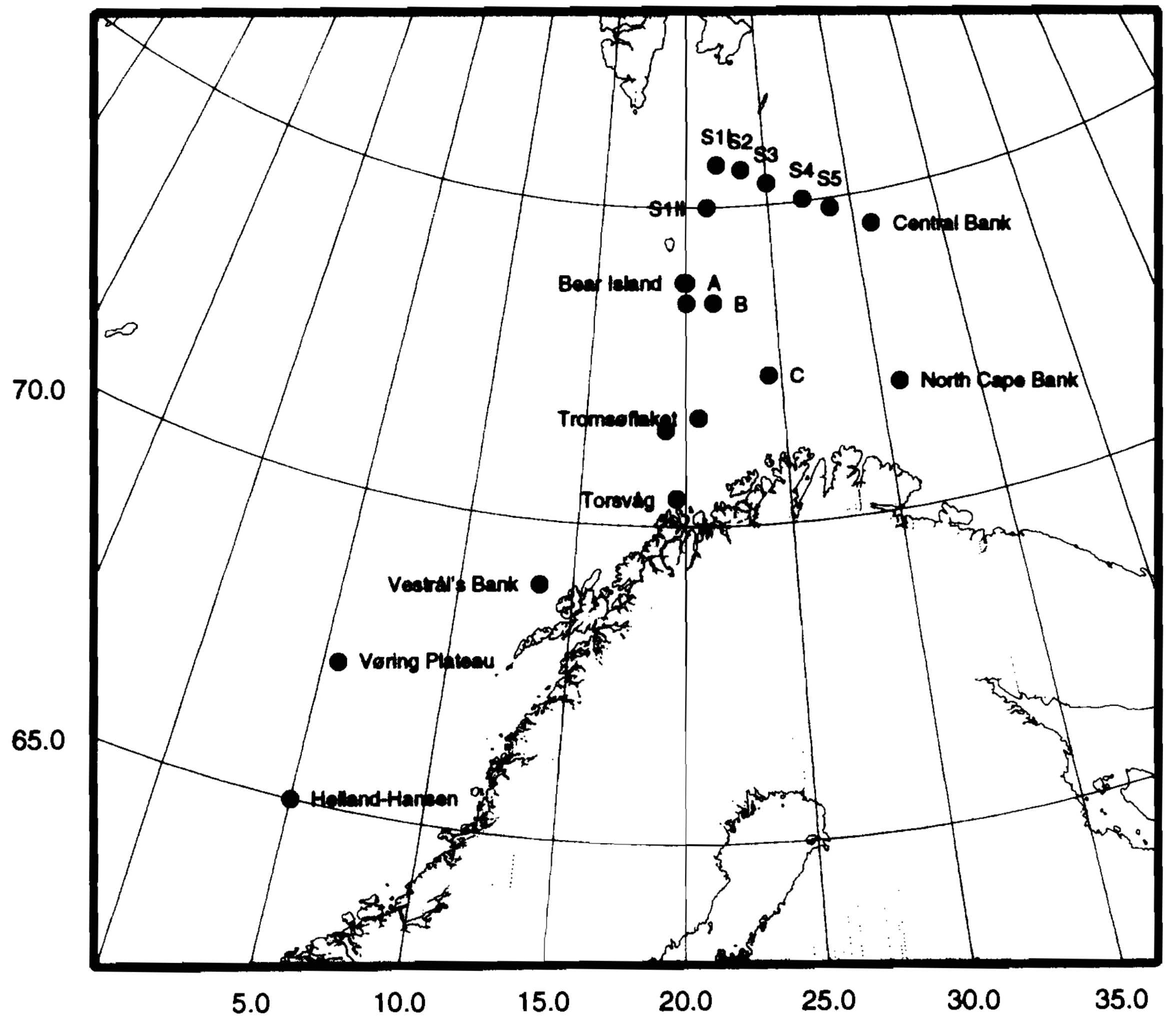

Fig. 2—Measurement locations in the NPD data collection program.

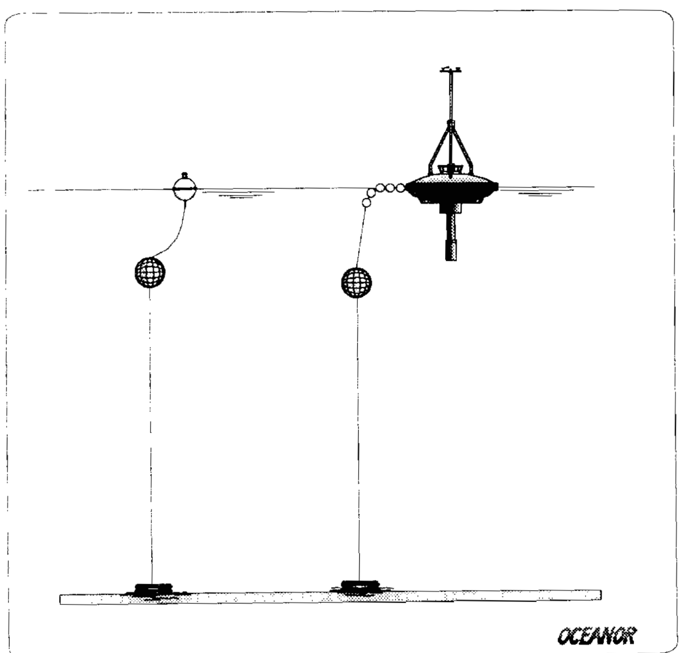

Fig. 3—Typical mooring configuration of wave measuring buoys.

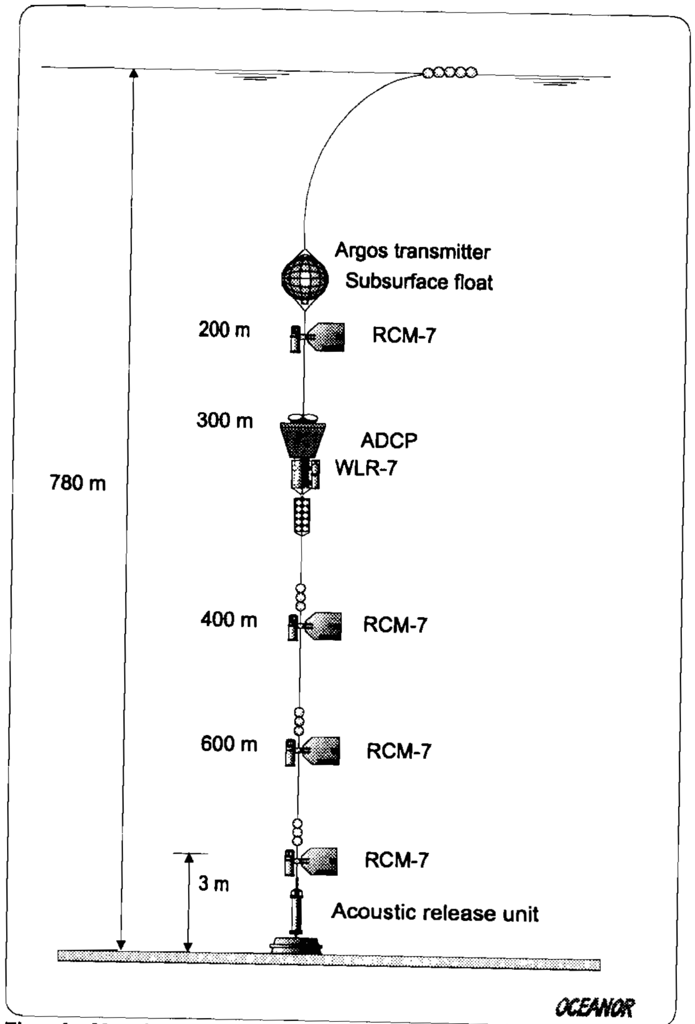

Fig. 4—Mooring configuration of current meters at Helland-Hansen 1995-96.

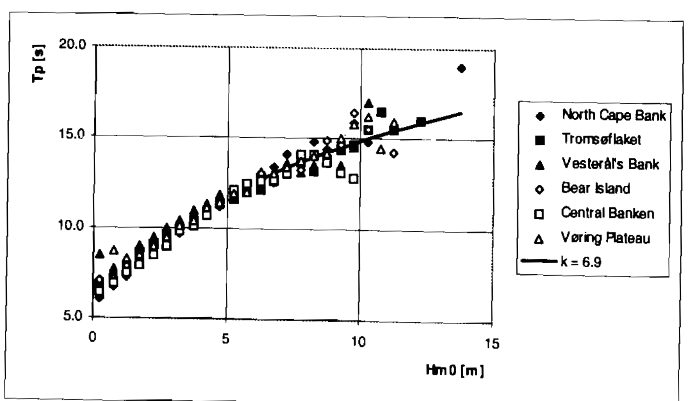

Fig. 5—Average Tp as function of Hm0 for 6 locations in the Norwegian Sea and the Barents Sea. Thick line: $Tp = 6.9\ Hm0^{1/3}$.

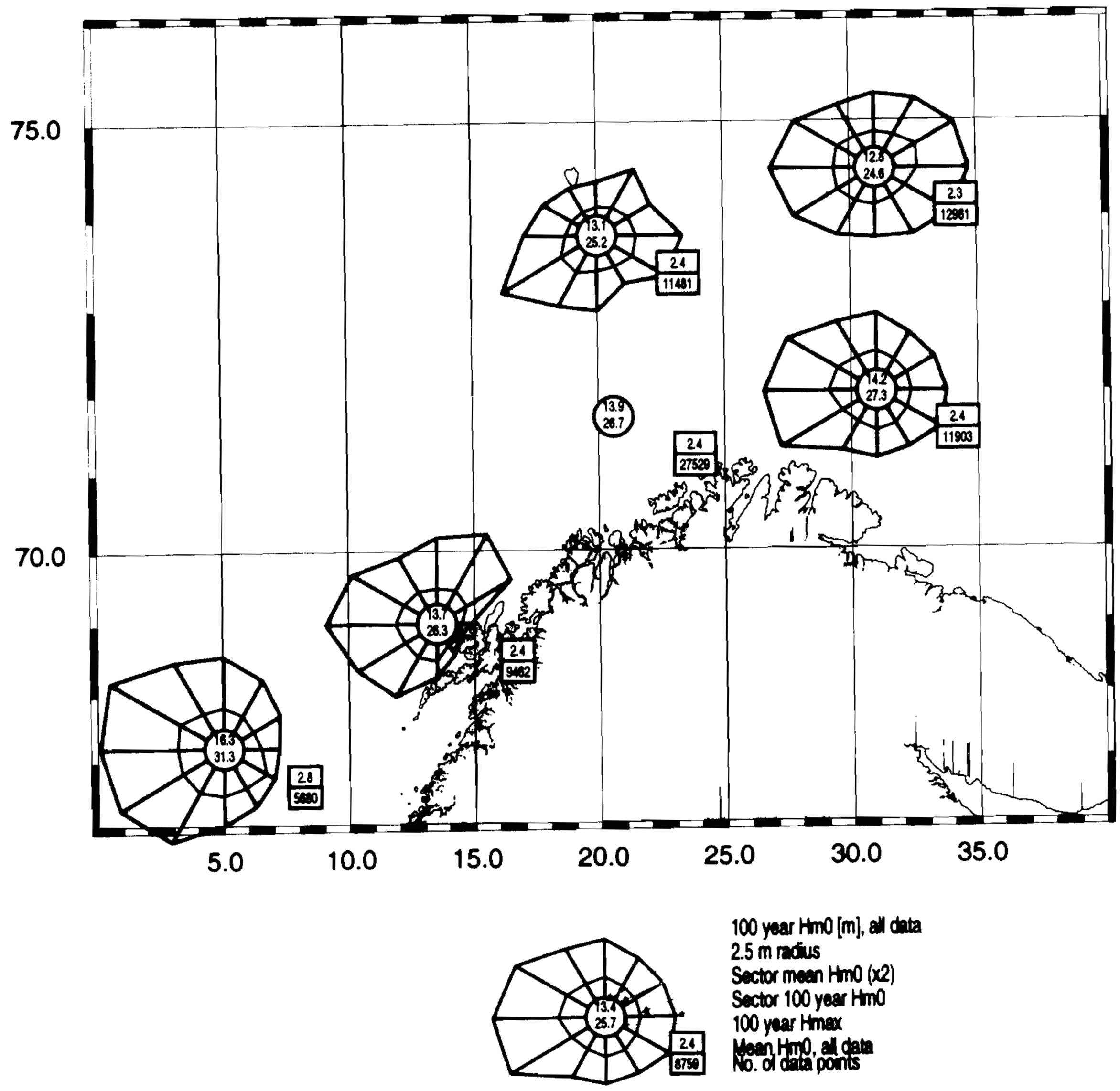

Fig. 6—Summary of wave height (Hm0 and Hmax) statistics for the Norwegian and Barents Sea.

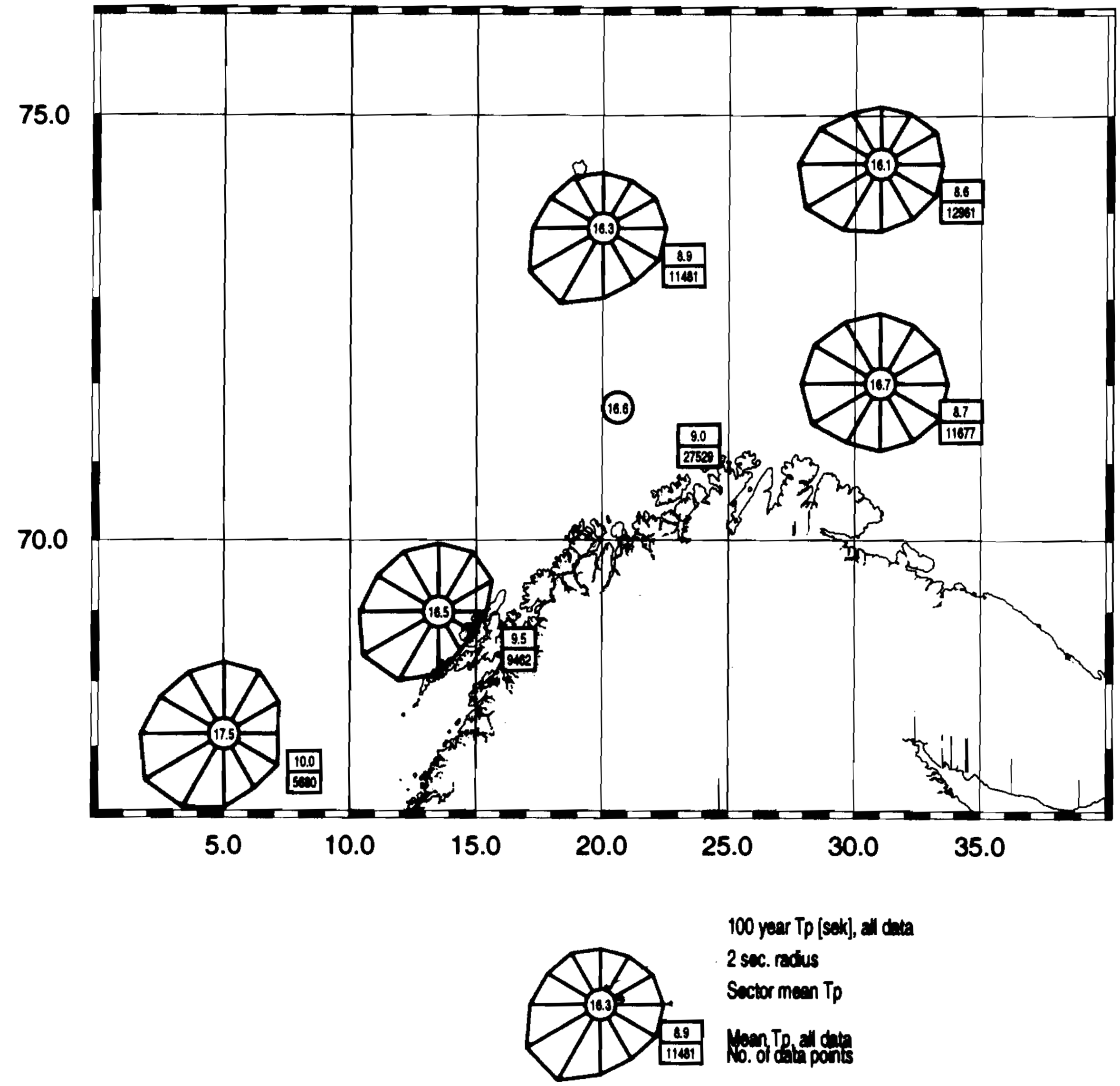

Fig. 7—Summary of wave period (Tp) statistics for the Norwegian and Barents Sea.

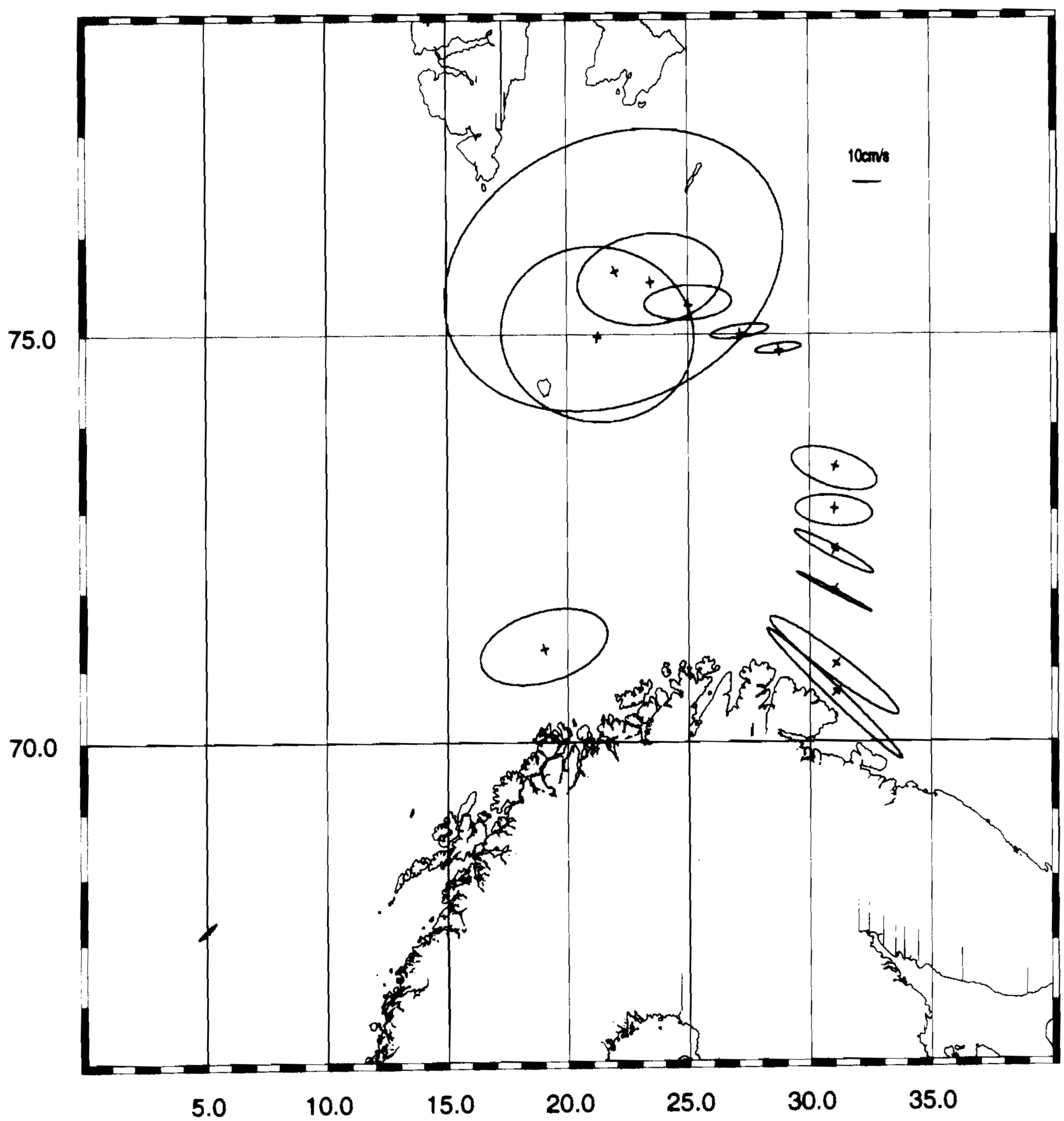

Fig. 8—Ellipses of the M_2 tidal current observed in the Norwegian and Barents Sea.

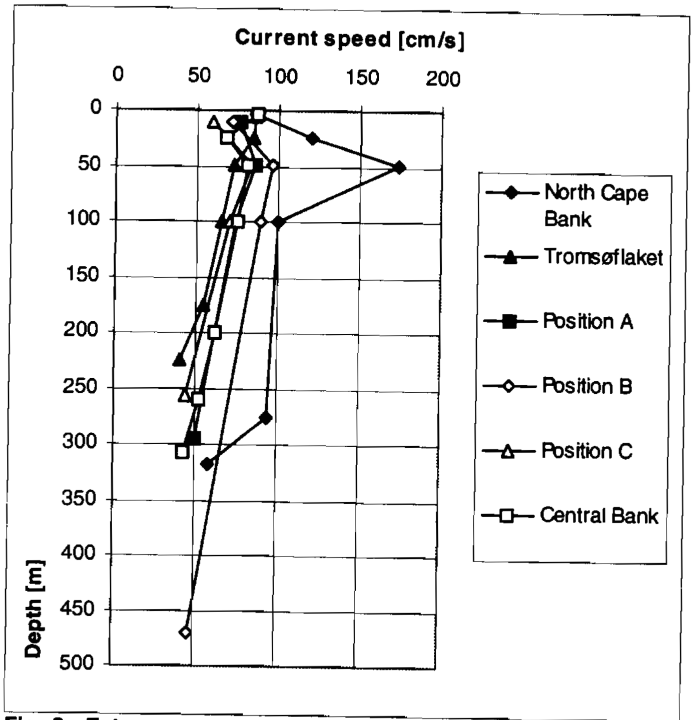

Fig. 9—Extreme current velocity profiles for 100 year return period at 6 locations in the Barents Sea.

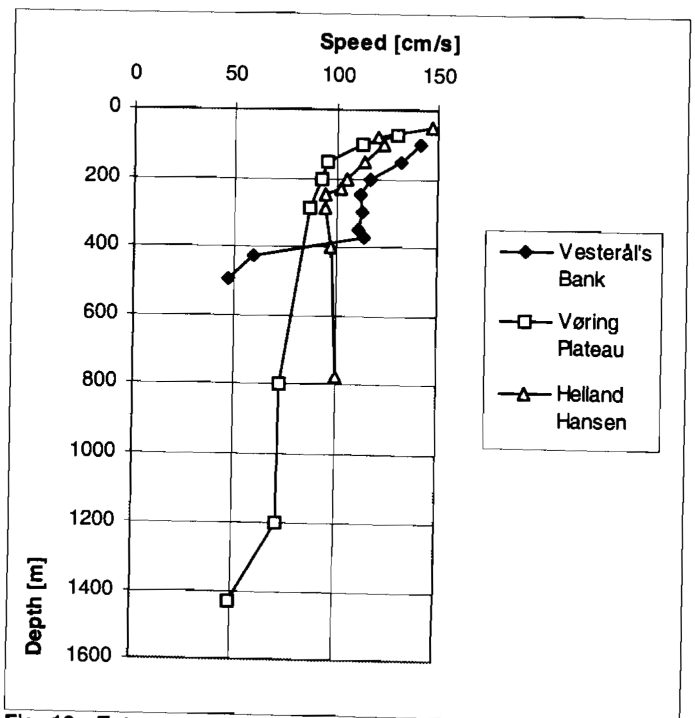

Fig. 10—Extreme current velocity profiles for 100 year return period at 3 locations in the Norwegian Sea.

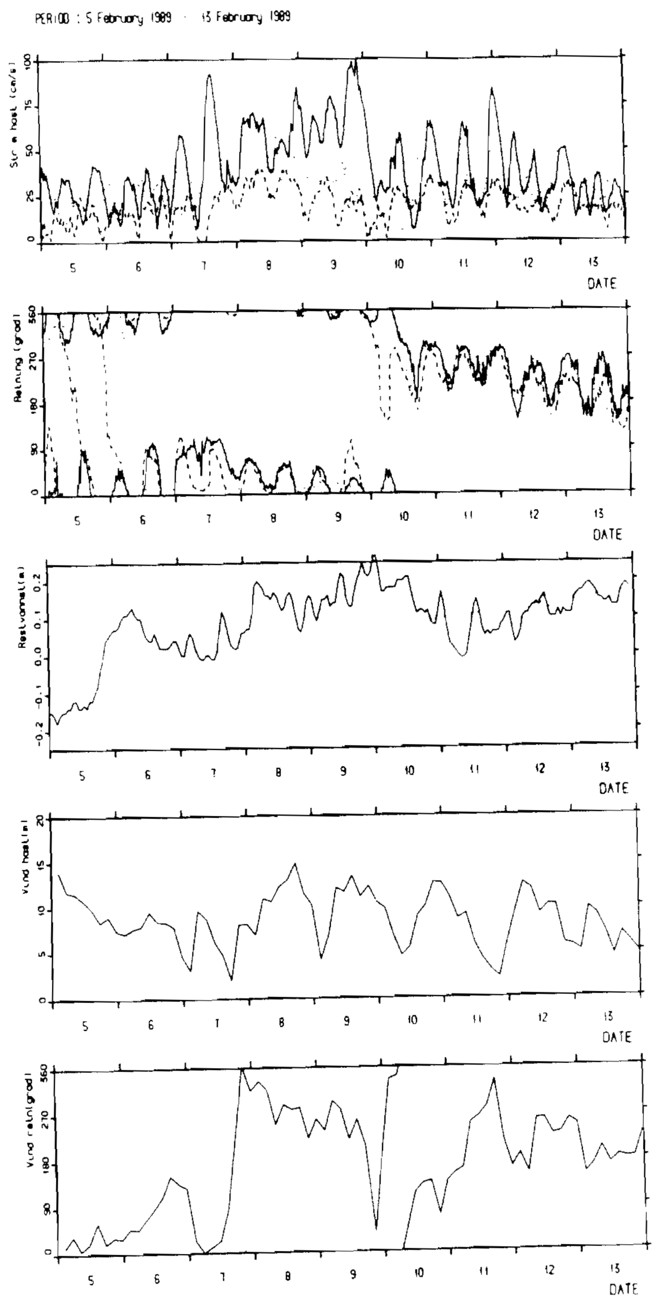

Fig. 11—Time series from the North Cape Bank, 5-13 February 1989; current speed and direction (50 m: full line, 276 m: dotted, 323 m: dashed), residual water level, wind speed and direction.

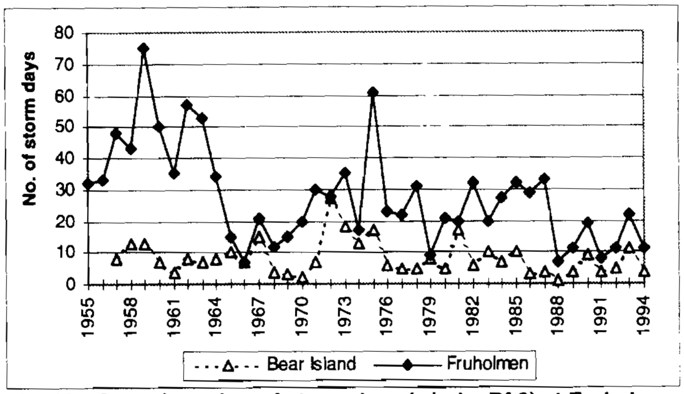

Fig. 12—Annual number of storm days (wind ≥ Bf 9) at Fruholmen (71° 10' N, 24° E) and the Bear Island, 1955-94.

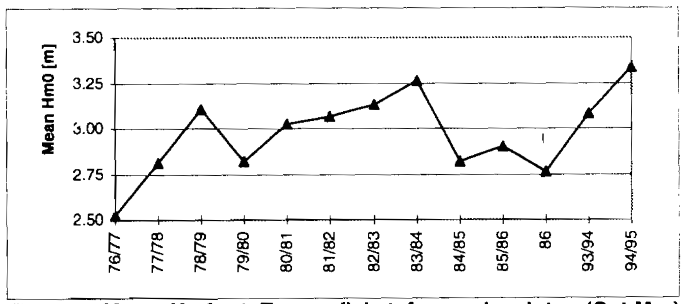

Fig. 13—Mean Hm0 at Tromsøflaket for each winter (Oct-Mar) during the measurement period.