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This report is a collection of technical reports with data from SKAGEX and presentations from the SKAGEX Workshop in Lysekil, Sweden, in November 1992.

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SKAGEX

The Skagerrak experiment

Lars Føyn
editor

Foreword

This report is a collection of technical reports with data from SKAGEX and presentations from the SKAGEX Workshop in Lysekil, Sweden, in November 1992. It has taken a long time finally to come to this publication. Some of the reasons for this regretful situation are mentioned in the introduction to this report. However, the data and the reports from the Skagerrak Experiment are still and will continue to be of great value for scientist working with this important area.

That SKAGEX was established and successfully accomplished are to a great extent due to the merit of one scientist, Dr. B. I. Dybern, Institute of marine research, Lysekil, Sweden. He was the driving force in the whole exercise. But without the enthusiastic participation from scientists, captains and crews of the research vessels and the support from the involved institutes and countries, it would have been impossible to make SKAGEX to the success it became. Never in the history of ocean sciences has so many research vessels been engaged at the same time in a coordinated synoptic coverage of an area as in SKAGEX I. Probably this will never happen again, and for all of us that took part in SKAGEX it is good to know that we participated in an outstanding experiment.

Finally I will also like to thank my colleagues, Didrik Danielssen and Einar Svendsen, for the work they have put into the preparation of this report. I will also use the opportunity to thank Vibeke Kristiansen, Jorunn Træland and Julio Erices for their support in typing and drawing where this was necessary. Without the support from the Institute of marine research the printing and distribution of this report would not have been possible.

Bergen, November 1999

Lars Føyn

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SKAGEX

THE SKAGERRAK EXPERIMENT

Introduction

by
Lars Føyn

Skagerrak is a particular important area in terms of the water circulation of the North Sea, as a sink for pollutants and as a highly biological productive area. The coastal areas of Skagerrak is also of great recreational value, and in addition a considerable amount of various maritime transports are passing through the area.

Skagerrak is the transitional area between the North Sea and the Baltic. Almost all water entering the North Sea passes through the Skagerrak where it is mixed with water from the Baltic and the Kattegat forming the Norwegian coastal current which transports the water out and northwards from the North Sea.

The importance of Skagerrak both as an area of high biological productivity and of a challenging distribution and mixing of water masses, together with the fact that several marine research institutes are located with easy access to Skagerrak, have led to a considerable amount of written scientific papers about the area. The scientific interests for Skagerrak have tradition back to the last century and the written papers comprise the whole area of the marine sciences from geology through hydrography, biology and fisheries biology to seabirds.

Although the scientific interests have been and still are considerable, most of the research have been and is connected to investigations by one research vessel at a time. In an area where changes take place fast and frequently, investigations by a single research vessel may miss important events, and even fairly regular monitoring may not cover important changes.

Synoptic multi-ship studies over an extended period of time will give a solid basis for interpretation of data obtained by single-ship investigations and for establishing monitoring programmes. However, multi-ship synoptic surveys are both a demanding and a costly performance which need support from a range of institutes and interested scientists as well. It is certainly not something done frequently.

Previous synoptic investigation
In 1966 the ICES Joint Skagerrak Expedition was developed by an *ad hoc* Working group of the then Hydrographical Committee, chaired by Dr G.

Tomczak (FRG). Germany (FRG), Finland, Norway, UK (Scotland) and Sweden took part with the research vessels, "Alkor", "Meteor", "Aranda", "G. M. Dannevig", "G. O. Sars", "Scotia" and "Skagerak". The expedition covered the period from June 20th to July 15th 1966 and worked after a synoptic scheme on 21 sections totalling 233 stations.

The purpose of the 1966 Expedition was to study the distribution of the different water-bodies of the Skagerrak by means of hydro-chemical measurements, i.e.; temperature, salinity, oxygen and phosphate, in some cases also pH and silicate, and current measurements. In addition continuous recordings of the surface-layer temperature between 0 and 70 m were carried out by means of the "Delphin" towing gear used by R/V "Gauss". Current measurements were made at 7 anchor stations, 8 drifting stations, and by 17 self-recording current meters deployed over periods up to 20 days.

The data from the ICES Joint Skagerrak Expedition in 1966 were published in 1969 as "Joint Skagerrak Expedition 1966" Vols 1 - 4, in the series "ICES Oceanographic Data Lists". In 1970, the "Joint Skagerrak Expedition 1966" Vol 5, Atlas was published in the same series.

Present study

In 1988 after an initiative originating from the Danish - Norwegian - Swedish Committee on the Fisheries and Environment in the Skagerrak - Kattegat area, Dr. Bernt I. Dybern, National Fishery Board of Sweden, started the planning of what should become the Skagerrak Experiment, **SKAGEX**. At an initial meeting in Lund, Sweden, in February 1989, with participants from the Nordic and Baltic countries, the idea of a multiship study in Skagerrak was developed. At this meeting it was decided that the ideas of a multiship synoptic Skagerrak experiment should be presented to the International Council for the Exploration of the Sea (ICES).

At the ICES Statutory Meeting in October 1989 the Council adopted the ideas of a joint international investigation in the Skagerrak (Council Resolution 1989 / 4:1). A Study Group on SKAGEX under the chairmanship of Dr. B. I. Dybern was established (Council Resolution 1989 / 2:28) "to plan, coordinate the field work and work up the results".

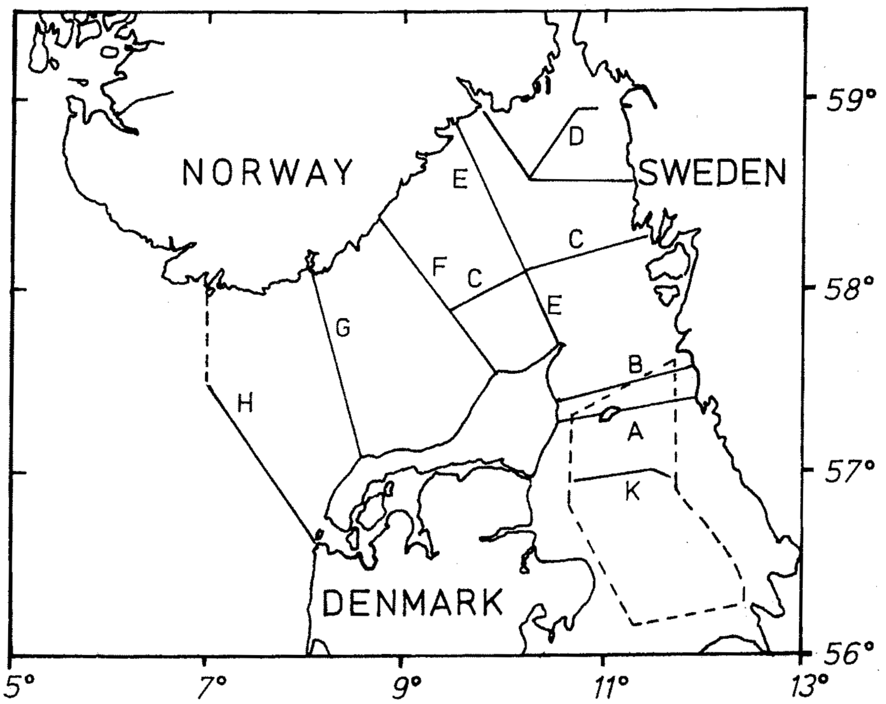
A rather intensive period followed in order to arrange for the first and major multiship investigations of Skagerrak, SKAGEX I, scheduled for May - June 1990. SKAGEX II in September 1990, SKAGEX III in January 1991 and SKAGEX IV in May 1991 followed with fewer participating ships. Following the Lund meeting two more meetings October/November 1989 (Kiel) and March 1990 (Gdynia) were held for detailed planning of SKAGEX.

Representatives from research institutes from the seven participating countries, Denmark, Federal Republic of Germany, German Democratic

Republic, Norway, Poland, Soviet Union and Sweden, took part in the planning process. Considerable financial support from the Nordic Council of Ministers made this broad attendance possible. Since the project took place during the political changes in eastern Europe the participating scientists finally came to represent the following countries: Denmark, Estonia, Germany, Lithuania, Norway, Poland, Russia and Sweden.

In addition to logistics like permissions to enter territorial waters, harbor facilities in Arendal, Norway, (for the mid-term SKAGEX I gathering of the participating research vessels) and allocation of national ship time, the preparation of a SKAGEX Manual, in a fairly short time, was a real challenge for the SKAGEX Study Group and in particular the chair, Dr. Dybern, who had to take most of the burden of the work.

The defined area of investigation and the various cross section are presented in the figure below.



In the main field investigation of the experiment, SKAGEX I, 17 research vessels and about 200 scientists took part. The need for a manual that secured the comparability of data collected by the various research vessels was obvious. Consequently a SKAGEX Manual had to be produced comprising detailed guidelines for:

- current meter moorings;
  position, depths, dates and names of responsible research vessels,
- stations for hydrography and chemical parameters as well as for phyto- and zooplankton sampling;

cross sections, positions, depths, dates, starting points and times for operating the cross sections by the allocated research vessels, procedure for intercalibration of CTDs,

- chemical parameters;
  nutrients to be analyzed and preparation for intercalibration of nutrient analysis,
- phytoplankton measurements;
  in situ fluorescence, chlorophyll *a*, phytoplankton (sampling depths and preservation), primary productivity measurements,
- zooplankton measurements;
  how and where to sample, the use of WP-2 net, handling of samples, preservation and microscopic inspection,
- presentation of data;
  isolines to be drawn and how to draw them.

Forms with the outline of the obligatory cross sections were produced and handed out to the participants prior to the start of SKAGEX I.

In addition remote sensing was also part of the experiment as data obtained from the US polar orbiting weather satellites and LANDSAT measuring the radiance in the visible and infrared electromagnetic bands of the visible radiance were to be calibrated and tested by the Swedish meteorological and hydrological institute, SMHI. LANDSAT 5 passed over the SKAGEX area 15 times during the period 17 May - 29 June and samples were taken, at the announced times for the LANDSAT passings, by the participating research vessels for measuring; the depth of the photic zone (secchi disk depth), chlorophyll, humus and total suspended matter.

SMHI also provided special detailed weather forecasts twice a day covering the three sub-areas of SKAGEX, i.e.; Kattegat, Inner Skagerrak and Outer Skagerrak. The participating vessels observed and sent data 8 times per day to SMHI of wind direction and speed, surface pressure, air temperature, sea surface temperature, waves and total cloud cover.

The synoptic period of SKAGEX I was from May 24 to June 20, 1990, with a mid term gathering for intercalibration in Arendal, Norway, June 6 - 7. The following 13 research vessels participated in the intercalibration exercises in Arendal:

- "Gunnar Thorson" (Denmark),
- "Alexander von Humboldt" (German Democratic Republic),
- "Trygve Braarud", "G. M. Dannevig" and "G. O. Sars" (Norway),
- "Hydromet", "Oceania" and "Professor Siedlecki" (Poland),
- "Argos", "Svanic" and "Arne Tiselius" (Sweden),
- "Lev Titov and "Arnold Veimer" (USSR)

In addition the following research vessels participated in parts of SKAGEX I:

- "Atair" and "Gauss" (Federal Republic of Germany),

- "Haakon Mosby" (Norway),
- "Pluton" and "Shelf" (USSR).

In an introductory chapter it must be allowed to highlight SKAGEX as the outstanding event in the world of ocean sciences. The fact that it was possible to engage 18 research vessels, representing 8 ICES member countries, at the same period of time in a detailed coordinated investigation is in itself remarkable. For most of the participating scientist and crew members as well, the gathering in Arendal harbor of the participating research vessels was a one-time opportunity highly appreciated, to learn and discuss with fellow participants and to see how other research vessels operated.

The considerable effort of this multi-ship investigations in May - June had not been fully justified had it not been followed up with investigations in other periods of the year. Consequently the Study Group of SKAGEX proposed that follow-up studies should take place in September 1990 (SKAGEX II), January 1991 (SKAGEX III and again in May 1991 (SKAGEX IV). This was done but with lesser effort than in SKAGEX I. In SKAGEX II - IV respectively 5, 3 and 6 research vessels took part in the coordinated coverage of the same cross section as in SKAGEX I.

It has also to be mentioned that the accomplishment of SKAGEX depended much on the support from the ICES Secretariat and in particular the Hydrography Adviser, Dr. Harry Dooly. The data collected were sent to the ICES Data Center in accordance with the rules of ICES.

Publication of results
A computerized SKAGEX data handling system, the SKAGEX Atlas, that comprises the hydrographical, hydrochemical and biological data from the multi-ship investigations has been elaborated. A user´s guide to the SKAGEX Atlas was prepared by Marek Ostrowski and published in a TemaNord report, 1994:635, from the Nordic Council of Ministers. A summary of The Skagerrak Experiment is reported by B. I. Dybern, D. S. Danielssen, L. Hernroth and E. Svendsen and published in the same TemaNord 1994:635, report.

A finalizing workshop was held in Lysekil, Sweden, in October 1992. At the workshop it was decided that the various presentations together with other papers concerning SKAGEX should preferably be published as an ICES Cooperative Research Report. It was also a common opinion that those papers that the authors felt valid as a peer review paper should be submitted to the ICES Journal of Marine Science to appear in a special volume designated to SKAGEX.

Unfortunately a joint presentation of peer reviewed SKAGEX reports in a special volume of the ICES Journal of Marine Science was not accepted by the editors. However, interested authors were encouraged to submit papers to the JMS for consideration the usual way.

It was also a common understanding that as many contributions as possible should be presented in the ICES Cooperative Research Report, as it was felt of special importance to include the work of as many of the participating scientists as possible. This meant among others that the deadline set for the contributions had to be postponed several times. This also meant that various presentation forms, like insufficient layout (lack of abstracts and so on) and not so presentable figures and tables, had to be accepted.

Financial problems connected to the printing of ICES Cooperative Research Reports delayed the process of finishing the report. Then finally when the possibility for printing was there, the chair of the ICES Oceanography Committee, who was given the responsibility of accepting the report for printing as a Cooperative Research Report, was of the opinion that in order to be printed as an ICES Cooperative Research Report the contributions had to be given a common layout. As we found this to be an almost impossible task, both as an extra work burden too late in the process and as a possibility to violate the personal contributions, which we did not wanted to do, we had to find another solution for printing the reports. We decided, in understanding with the Chair of the ICES Oceanography Committee, that we had to print it at the Institute of marine research and seek financial support within our institute for this.

The process leading up to the finalizing and distribution of this SKAGEX report has been long. But it is the hope that the contributions, in this report, still will be of importance. Although data and results from the Skagerrak Experiment to a great extent have been used and are in use in referee papers in many various scientific journals, this report contains a well of valuable details that are important as documentation for a better understanding of the dynamics of Skagerrak.

Presentation no 1.

Remote sensing of water mass distribution in the Skagerrak as observed from CZCS imagery from 1979 - 1983.

by

Thorkild Aarup

Remote sensing of watermass distributions in the Skagerrak as observed from CZCS imagery from 1979-1983

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Introduction

The Coastal Zone Color Scanner(CZCS) launched on the Nimbus-7 satellite in 1978 were in operation until 1986. The purpose of the sensor was to provide near-surface maps of phytoplankton pigment and suspended matter by measuring the waterleaving radiance at four visible wavelengths (440, 520, 550 and 670 nm). In ocean areas where the optical properties of the watermass mainly is dominated by phytoplankton and their byproducts [so called case 1 waters, Morel and Prieur (1977)], algorithms have been established that relate the waterleaving radiances to the chlorophyll-a concentration and the vertical attenuation coefficient (Gordon and Morel, 1983). In waters where yellow stuff and suspended sediment also may contribute (so called case 2 waters) to the optical signature of the watermass, the algorithms for estimating the geophysical parameters might be site and/or seasonal specific.

Despite the problems of achieving an exact quantitative interpretation of the CZCS data in coastal areas, previous studies from the North Sea (Holligan et al., 1989) have shown that the CZCS-imagery contain important qualitative information about frontal areas, advection and water mass distributions. Thus for the Skagerrak/Kattegat region the CZCS imagery represent a new largely untapped data source with a fairly good resolution in time and space.

The CZCS imagery are not only interesting as a historical data source in relation to the SKAGEX study but are also of importance in relation to the next satellite ocean color sensor SeaWifs that will be launched by the end of 1993. SeaWifs will have a better spectral resolution than the CZCS, which might enable a more precise determination of the amounts of the various constituents (chlorophyll-a, yellow stuff, suspended sediments) particularly in coastal areas. Optical measurements are however needed for establishing these regional algorithms.

Few CZCS scenes have been worked up for the transition area between the North Sea and the Baltic Sea (Horstman, 1988; Holligan et al., 1989), and little use has been made of optical methods for classifying watermasses (remotely [Pettersson et al., 1989] or by in situ measurements [Højerslev, 1971; Aas et al., 1990; Karabashev, 1992]) in the Skagerrak. [Spectral irradiance, beam attenuation and yellow stuff absorption measurements from 7 cruises, during 1990-1993, with R/V Svanik, along the Danish westcoast, and 2 cruises with R/V Gunnar Thorson, during 1992, in the Skagerrak/Kattegat frontal area and 5 cruises with R/V Martin Knudsen, during 1975-1979, in the Kattegat are currently being worked up (N. Højerslev, pers. communication). The aim of that exercise is to try and identify the watermasses that form the deep water of the Kattegat. The preliminary results indicate that 1) through salinity-yellow stuff analysis Jutland Current water can be identified in the Kattegat and 2) only small amounts of Jutland Current water enter the Kattegat (N. Højerslev, pers. communication)].

In this report some examples of CZCS-images are shown together with matching meteorological and hydrographical data that elucidate particular surface watermass features. It should be noted that the results of this study and the optical measurements in the Skagerrak/Kattegat will be reported in greater detail later in 1993, when the optical data have been worked up.

Materials and methods

Approximately 170 CZCS scenes and 120 matching Advanced Very High Resolution Radiometer (AVHRR) images have been processed (atmospherically and geometricly corrected; details about the processing can be found in

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Holligan et al., 1989) as part of this study. The vast majority of CZCS scenes were gathered during the period 1979-1983 and there exist only a small number (< 15) of cloud free scenes of the Skagerrak in the period 1984-1986 when the CZCS sensor was starting to fail. All the CZCS images of the Skagerrak/Kattegat were gathered in the period February-October. The depth to which the CZCS can "see" is limited to approximately one attenuation length. For the most transparent wavelength that corresponds to a depth of about 5 m [Jerlov coastal water type 1, Jerlov (1976)]. In contrast the AVHRR-sensor only measures the temperature in the upper skin surface which is < 0.1 mm.

Hardly any optical measurements have been carried out in the Skagerrak/Kattegat in the period 1979-1983. Other types of hydrographical data that were gathered in the area over the same period were therefore included to aid the image interpretation.

An extract from the hydrographical database at ICES of temperature and salinity from stations in the area 6°E-16°E, 53°N-60°N were kindly provided by Dr. Harry Dooley. This material consist of approximately 3700 stations. Only a small set of these data were collected during periods with cloud free CZCS scenes, and there are just a few periods, where data have been gathered with a sufficient horizontal resolution, that is of use for interpreting messo-scale phenomena in the imagery.

Hydrographical and meteorological time series from permanent stations (L/V Anholt Knob, Bornø, Flødevigen, Skagen Lighthouse and Baltic sea level observations) as well as data from short term deployed buoys (Jensen and Jonsson, 1987; Shaffer and Djurfeldt, 1983) have also been of use for the image interpretation.

Main results and discussion

1. The CZCS imagery show that the surface water of the Kattegat is relatively homogeneous on a horizontal scale, and the sea surface reflectance does not undergo a large seasonal change, most likely due to high amounts of yellow stuff in this region.

2. Inspection of the CZCS and AVHRR imagery indicate that the front between the Skagerrak and the Kattegat rarely lies within the Kattegat during the period February-October. A typical delineation is Skagen-Marstrand or a bit north of here (see for instance figure 1).

3. The imagery indicate that anticyclonic circulation in the Skagerrak (with an outgoing current along the Danish westcoast) is relatively rare.

4. Previous studies have shown that the wind play an important role for the lateral displacement of the Norwegian coastal current (Aure and Sætre, 1981; Sætre et al., 1988). An extreme case is shown in figure 2 where NCC water can be observed down to the entrance of the Limfjord and stretching in a westerly direction from there (CZCS imagery from April 14, 16 and 20 show a similar southward spreading of NCC water in the North Sea, and figure 2a confirm this particularly for the two western most stations [about 56.6°N,6.3°E] of Thyborøn). A similar observation was made in relation to the SKAGEX experiment (Daniellessen et al., 1991), and it was noted that this phenomena had not previously been observed and reported in the literature.

5. In the Skagerrak highly reflective areas, due to coccolithophore blooms, can be observed in CZCS images, and is typicly seen from the end of June until the end of July (Blooms were observed in the central Skagerrak in four of the years 1979-1983). The CZCS imagery suggest that the coccolithophores are transported to the Skagerrak from the central and northern part of the North Sea (see fig 2 and 3). Hardly any traces are seen of coccolithophores in the surface water of the Kattegat-part of this frontal zone. CZCS summer images from other years do not reveal any high reflectance areas in the Kattegat. From measurements at a permanent mooring in the southern Kattegat it is known that coccolithophores can be found in the Kattegat (H.Thomsen, pers. communication), but little is known about their ecology in the Skagerrak/Kattegat. The extent of coccolithophore blooms in the Skagerrak do not appear to previously have been reported in the literature, and further studies of their ecology in this region would be of interest for an understanding of a) their spatial and temporal variability b) their light reducing impact on sub surface

phytoplankton populations[2] and c)the role coccolithophores play in the carbon budget for the Skagerrak and Kattegat.

6. For the Skagerrak remotely sensed data about ocean color is an important supplement to AVHRR imagery and often reveal more details than found in sea surface temperature maps.

Acknowledgements
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References

Aas, E., T. Andresen, T. Løyning and E. Sørgård (1990) Optiske observasjoner - Overflatevannets kvalitet sett ut fra observationer i overflatelaget. Norwegian Institute for Water Research, report no. 388/90.

Aure, J. and R. Sætre (1981) Wind effects on the Skagerrak outflow. In: The Norwegian Coastal Current, R. Sætre and M. Mork, editors, University of Bergen, pp. 263-293.

Danielssen, D.S, L.Edler, S. Fonselius, L. Hernroth, M. Ostrowski, E. Svendsen and L. Talsepp (1992) Oceanographic variability in Skagerrak/Northern Kattegat, May-June 1990. Report presented at the SKAGEX symposium, Lysekil, Sweden.

Gordon, H.R. and A. Morel (1983) Remote assessment of ocena color for interpretation of satellite visible imagery. Lecture Notes on Coastal and Estuarine Studies. Springer Verlag.

Holligan, P.M., T. Aarup and S.B. Groom (1989) The North Sea: Satellite Colour Atlas. Continental Shelf Research, 8, 667-765.

Horstman, U., H. van der Pieppen and K.W. Barrot (1986) The influence of river water on the Southeastern Baltic Sea as observed by Nimbus-7/CZCS imagery. AMBIO, 15, 286-289.

Højerslev, N.K. (1971) Tyndall and fluorescence measurements in Danish and Norwegian waters related to dynamical features. Institute for Physical Oceanography, University of Copenhagen, Report no. 6.

Jensen, T.G. and S. Jonsson (1987) Measurements and analysis of currents along the Danish west coast. Deutsche Hydrographische Zeitschrift, 40, 192-213.

Jerlov, N.G. (1976) Marine optics. Elsevier Oceanographic Series, 14.

Karabashev, G.S. (1992) On the influence of dissolved organic matter on remote sensing of chlorophyll in the Straits of Skagerrak and Kattegat. Oceanolgica Acta, 15, 255-259.

Morel, A. and L. Prieur (1977) Analysis of variations in ocean color. Limnology and Oceanography, 22, 709-722.

Pettersson, L.H., O. Frette, O.M. Johannessen, K. Sørensen, E. Svendsen, E. Dahl, G. Borstad, R. Kerr and J.F.R. Gower (1990) NORSMAP'89, Technical Report no. 28, The Nansen Remote Sensing Center, Bergen, Norway.

Shaffer.G. and L/ Djurfeldt (1983) On the low-frequency fluctuations in the eastern Skagerrak and in Gullmaren,

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[2] Due to high amounts of yellow stuff in the Kattegat/Skagerrak light may be attenuated to an even greater extent because of the combined effects of coccolithophore backscattering and yellow stuff absorption, than found in coccolithophore blooms in open ocean areas.

Journal of Physical Oceanography, 13, 1321-1340.

Sætre, R., J. Aure and R. Ljøen (1988) Wind effects on the lateral extension of the Norwegian Coastal Current. Continental Shelf Research, 8, 239-253.

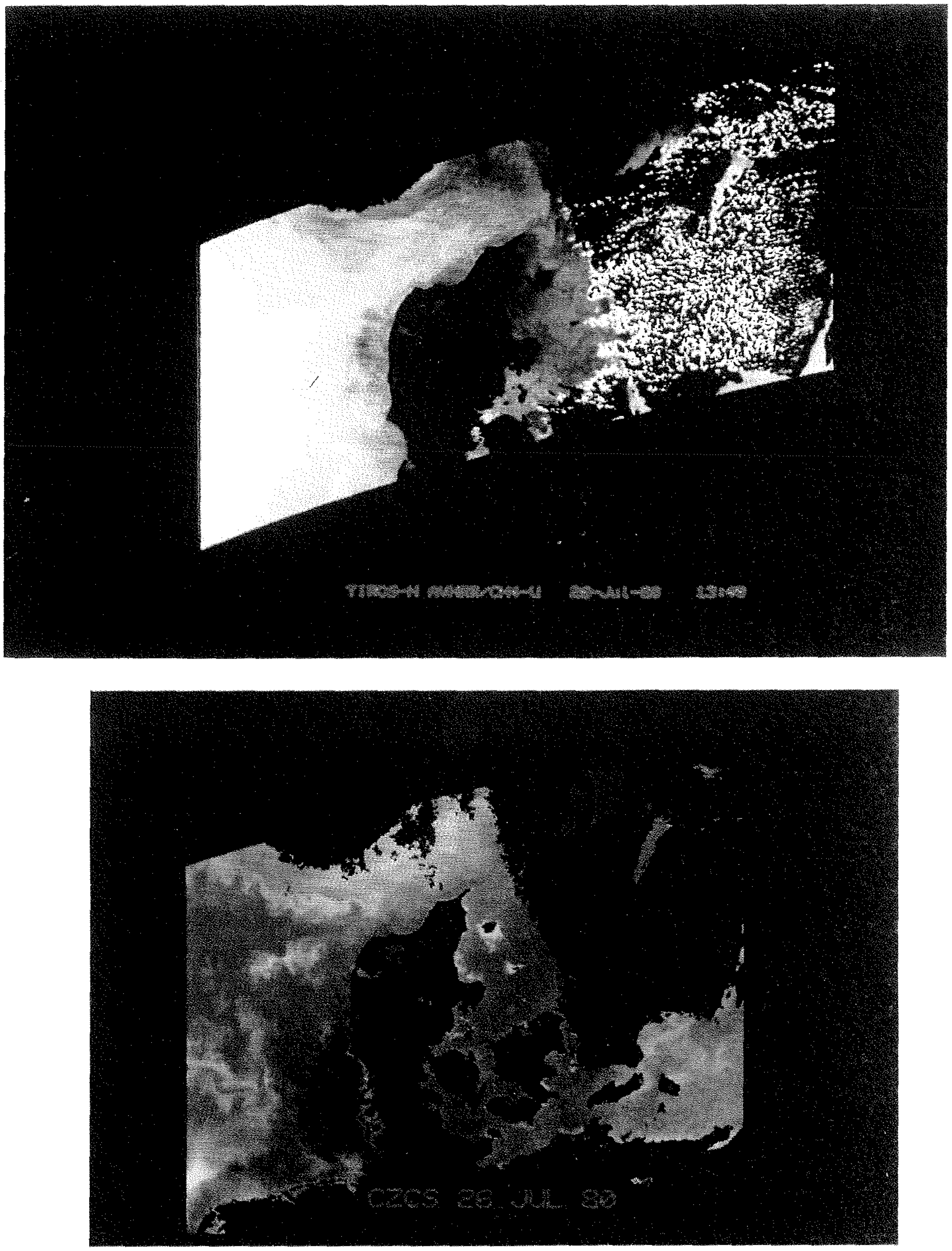

Figure 1. a) AVHRR channel 4 image. The color scale goes from white (low temperature) to black (high temperature). The image has been stretched in order to enhance the features in the Skagerrak. b) Color composite of atmospherically corrected CZCS channels 1, 2 and 3. Channels 1 (443 nm), 2 (520 nm) and 3 (550 nm) have been assigned to the blue, green and red colors in the image display system, thereby giving a semi natural color image (i.e without the intervening atmosphere). Dark areas are indicative of strongly absorbing substances (yellow stuff or chlorophyll-a/phaeopigments), yellow and reddish colors signify high reflectance due to suspended matter while blue-green colors are representative for clear water. The combined effects of the backscattering and absorption of the different water constituents gives rise to intermediate colors, thereby preserving all the information from CZCS bands 1, 2 and 3 (in contrast to CZCS chlorophyll that are calculated based on the ratio of two bands). Cloud and land areas are masked black. Erroneous colors on the right hand side of clouds and land can occasionally occur in a band

a few pixels wide due to sensor saturation. Noticeable features are the narrow outflow from the Kattegat and the high reflectance areas in the North Sea due to coccolithophores. Weak westerly winds prevailed in the previous period and then changed to easterly/north-easterly winds around July 26. A weak Baltic outflow took place from about July 15 until July 25 with a total discharge of approximately 50 km^3.

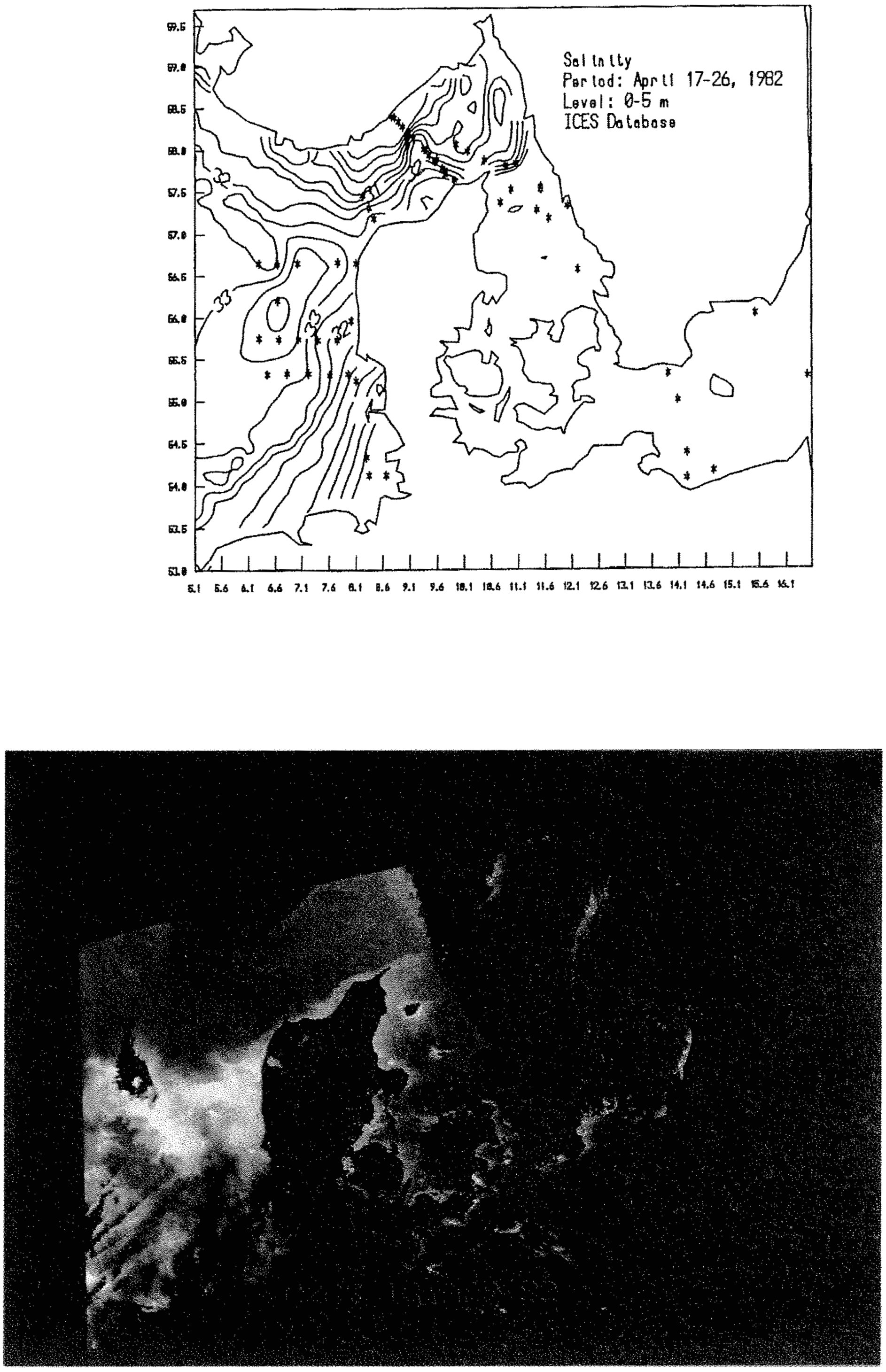

Figure 2. a) Contour plot of the sea surface salinity based on samples (stars) taken during the period April 17-26, 1982 b) CZCS color composite image from April 18, 1982. Strong north westerly winds prevailed in the period prior to the date of the image. A strong upwelling is observed along the Swedish west coast in the Skagerrak. [The hydrographic data (not shown) from Bornø also demonstrated this]. A weak Baltic outflow started around April 12.

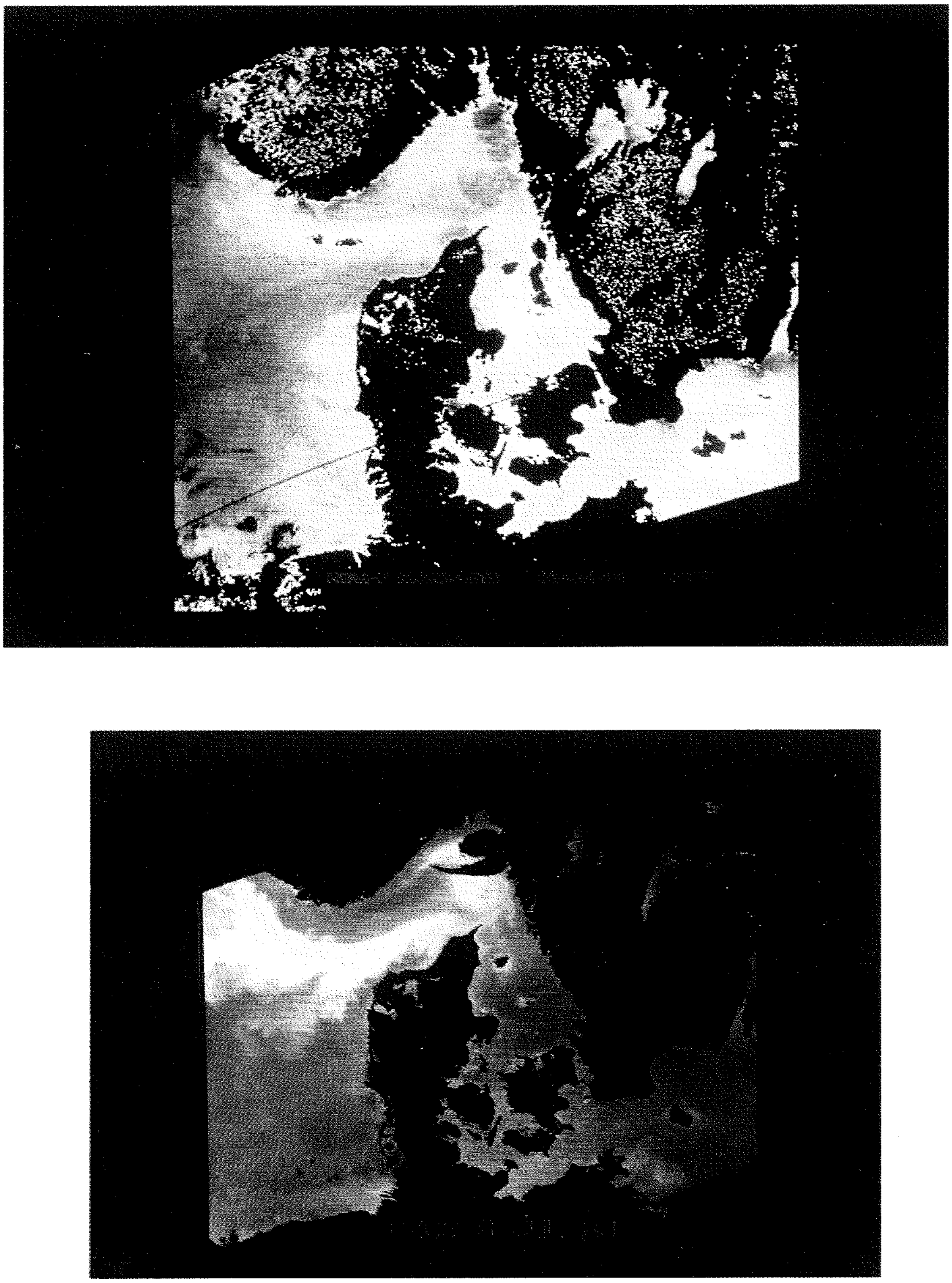

Figure 3. a) AVHRR temperature image b) CZCS color composite image. The image shows a large coccolithophore bloom, that cover most of the northern part of the North Sea and stretches into the Skagerrak. The cyclonic circulation in the central part of the Skagerrak is clearly seen. The wind was mainly south westerly in the period prior to the image, with weak winds on July 6. A weak outflow to the Baltic took place from June 25 until July 6.

Presentation no 2.

On the relationship between concentration and fluorescence of chlorophyll in waters of the Skagerrak and the Kattegat.

By

V. V. Andrjuschenko, G. S. Karabashev and P. Kavolite

ON THE RELATIONSHIP BETWEEN CONCENTRATION AND FLUORESCENCE OF CHLOROPHYLL IN WATERS OF THE SKAGERRAK AND THE KATTEGAT

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INTRODUCTION

The use of *in situ* fuiorometry in marine ecological studies depends on good knowledge of the concentration dependence of chlorophyll fluorescence in the actual water masses. This is particulary important in the straits where waters of different origin are mixed. But just here the age of algae and species diversity, abundance of nutrients, available light and other factors influencing the dependence are highly variable. Their influence is insufficiently studied and can be locally specific. Therefore it is desirable to estimate combined effects of the factors in the straits using simultaneous measurements of the concentration and fluorescence of chlorophyll in sea water. This approach has been taken to data collected in the Skagerrak-Kattegat area during SKAGEX field activities in 1990-1991. The aim of the present paper is to assess possible errors of chlorophyll determinations by means of *in situ* fluorometry in waters of the Skagerrak and Kattegat.

DATA COLLECTION AND HANDLING.

The chlorophyll fluorescence was recorded with a submersible MZF fluorometer (Karabashev and Khanaev, 1988) aboard r/v «Shelf» in 1990 and «Lev Titov» in 1991. The chlorophyll concentration was determined in sea water sampled with water bottles at standard depths. In 1991 tha water sampling was completed at each station not later than 20 min after the fluorometer cast. The pairs of values of fluorescence intensity and concentration of chlorophyll measured at a station at one and the same depth aboard «Lev Titov» formed the 2nd data samples totalling 124 pairs. There was no water sampling aboard «Shelf». Some other ships sampled water at the transects where «Shelf» deployed fluorometer. It was decided to use their chlorophyll data if the time gap between water sampling and fluorescence recording did not exceed 2 days. The chlorophyll determination aboard r/v «Arnold Veimer» on 02.06.90 at transect F in the Skagerrak and aboard r/v «A. Thiselius» on 08.06.09, 17.06.90 and 12.09.90 at transect B in the Kattegat complied with the decision. The fluorescence measurements were conducted on 04.06.90, 09.06.90, 17.06.90 and 12.09.90. The pairs of chlorophyll-fluorescence values for the same depths and stations represents thefirst data sample set of 117 "comparable" pairs.

It was known in advance that time gap of 2 days between fluorometry and water sampling may be tolerable in a stable state of ecosystem. This is hardly possible in the Kattegat/Skagerrak area. Usually a synoptic variability of chlorophyll fluorescence is highest at depths of its maxima (Karabashev, 1987). Just here the large time gap between fluorescence and chlorophyll determination corrupts their interdependence to a considerable extent. For this reasons the data pairs for fluorescence maxima have been excluded from its sample diminishing the first data set to 96 elements. The 2nd sample set contained data collected mainly at transect C, E and B in the transitional area between the Skagerrak and the Kattegat. Only few outliers have been excluded from this sample set. Of importance for the use of this 2nd sample set is that the and data collecting took less than a week. The first sample set consists of data collected at different locations (transects F and B in June 1990) and during different seasons (transect B in June and September 1990). We therfore consider the 2nd sample as the main data set of sufficiently good quality and the first as auxiliary material.

RESULT AND DISCUSSION.

Statistical characteristics in Table 1 provided evidence that the chlorophyll concentration and fluorescence intensity were higher and varied in wider limits for the 2nd sample set in comparison to the first one. The correlation and linear regression between chlorophyll and fluorescence have been computed to assess their relationship. The computations have been conducted for the 2nd sample set as well as for the first subsample set. Some results of the computations are given in Table 2. The correlation coefficients in Table 2 reveal strong positive stochastic connection between concentration and fluorescence of chlorophyll in waters of the transitional Skagerrak-Kattegat area regardless of criteria for data selection in the subsamples. The only exception represents subsample No 2. But it comprises data for waters of low chlorophyll concentration were the contribution of measurements errors to the variability of measured quantities increases and may diminish estimates of their covariability.

The estimates of correlation coefficient for the complete samples 1 and 2 made up 0.80 and 0.89, correspondingly. They did not distinguish from each other or from the estimates in Table 2 (except subsample 2). The scatter plot in Fig. 1 confirms similarity of data distributions in both samples. The estimates of the parameters in a regression of chlorophyll concentration C on fluorescence intensity F:

$$C = kF + m \qquad (1)$$

made up k = 0.00182, m = 0.19 for the first sample set and k = 0.00192, m = -0.24 for the 2nd sample set having no significant differencies.

Regression (1) may be used to estimate the chlorophyll concentration from measured fluorescence intensity. The first sample was used to test this. The parameters of regression (1) for the 2nd sample set and fluorescence from the first sample set were used to compute chlorophyll concentration C1. Then the mean of the absolute differences in chlorophyll between C1 and the values in the first sample set has been calculated. This average has made up 0.4 mg m^{-3} and may be regarded as possible error of chlorophyll determination with submersible fluorometer in the Skagerrak-Kattegat area. The error is slightly overestimated because of poor quality of the first sample set.

CONCLUSIONS

1. The dependence between the *in situ* fluorescence measurements and the measured chlorophyll concentration in the Skagerrak and the Kattegat was fairly stable during SKAGEX studies in 1990- 1991 and may be expressed with one and the same linear regression for different water layersand locations.

2. The regression has demonstrated that the error in *in situ* chlorophyll fluorometric determination is not greater than 0.4 mg m^{-3}. This error amounts to about 10 % of the highest values for chlorophyll concentration in the Kattegat/Skagerrak. And it is sufficiently low to enable visualization of a coarse scale structure of chlorophyll distribution in the straits by means of rapid *in situ* fluorometry.

REFERENCES

Karabashev G.S. 1987. Fluorescence in the ocean. Gidrometeoizdat, Leningrad, 200 p. (in Russian).

Karabashev G.S., S.A. Khanaev. 1988. A submersible multichannel fluorometer for marine studies. Zhurnal Prikladnoy Spektroskopii, v.249, 515-518 (in Russian).

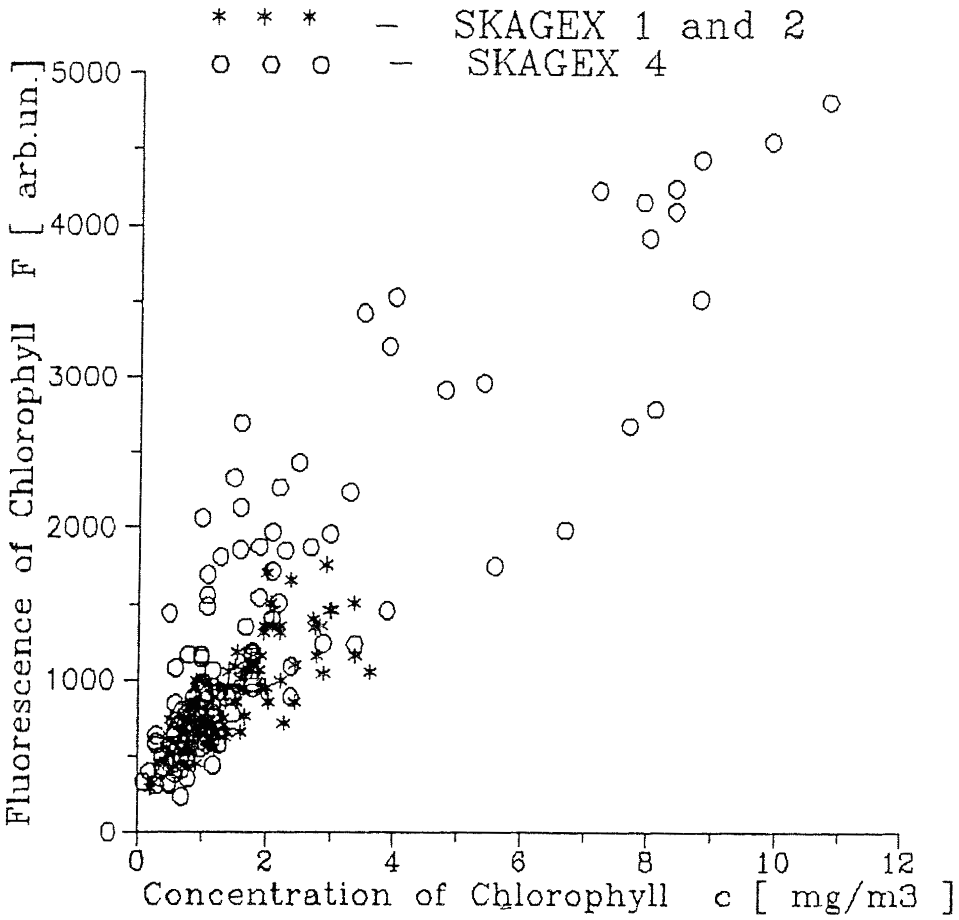
Table 1. The statistical characteristics of fluorescence F [alb. un.] and chlorophyll concentration C [mg m^{-3}] for the 1st and the 2nd samples.

	The 1st, size 96		The 2nd, size 117	
	C	F	C	F
Minimum	0.24	140	0.10	94
Maximum	3.43	1600	10.8	4675
Average	1.56	753	2.05	1200
Coefficient of variation %	47	42	113	90

Table 2. The correlation coefficients between fluorescence F and concentration of chlorophyll C for subsamples of the 2nd samples.

No	Corr.Coeff.	Size	Criteria for data selection
1	0.81	45	C > 1.5 mg m-3
2	0.50	80	C < 1.5 mg m-3
3	0.70	42	Stations C2-E12, 13.05.91
4	0.88	42	Stations C2-E12, 17.05.91
5	0.91	41	Stations L0-N5
6	0.87	34	Depth 5 m
7	0.89	33	Depth 10 m
8	0.95	12	Depth 11-18 m
9	0.80	30	Depth 20 m
10	0.82	12	Depth 30 m

Fig. 1. The scatter plot for data from the 1st sample (SKAGEX 1 and 2) and from the 2nd one (SKAGEX 4).



Presentation no 3.

On the exchange of water masses between Kattegat and Skagerrak during the SKAGEX I, 1990.

by

E. Andrulewicz, S. Fonselius and W. Slaczka

ON THE EXCHANGE OF WATER MASSES BETWEEN KATTEGAT AND SKAGERRAK DURING THE SKAGEX I, 1990

by

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ABSTRACT

The results of the SKAGEX-I programme of the HYDROMET from the Institute of Marine Meteorology and Water Management in Gdynia are described. The meteorological conditions in the area are described. Current measurements and salinity results from the B and K sections in the Kattegat are discussed. The results are compared with the satellite images of the NOAA-AVHRR from the Skagerrak-Kattegat area available from this period. Biological results are briefly discussed. The main conclusions of the results are presented. Very small exchange of water between the Kattegat and the Skagerrak seems to have occurred between the 24th May and the 9th June 1990.

1. INTRODUCTION

During the SKAGEX-90 a hydrographical section between Göteborg and Frederikshavn was worked in order to study the contribution of the Kattegat to the hydrographical conditions in the Skagerrak. The section was run by the R/V HYDROMET, from the Polish Institute of Meteorology and Water Management from the 24th of May to the 5th of June and by the R/V ARNE TISELIUS from the Kristineberg Marine Biological Laboratory from the 8th of June to the 17th of June.

The HYDROMET carried out 5 hydrological and hydrochemical sections along the profile B between Göteborg and Fredrikshavn and 4 sections along the profile K from Helsingør to Göteborg (fig. 1). Hydrographical and chemical analyses were performed using methods recommended for the Baltic Monitoring Programme (HELCOM 1988).

Current measurements were carried out with an ADCP current profiler. During the current measurements the ship was anchored with a bow anchor. The results were registered by a computer (IBM PC AT) coupled to the current meter through FSK. The results were recorded as mean values of 500 impulses in order to minimize the effect of the ships movements. The results of current and wind measurements on section B are presented as figures depicting directions and speed variability during the experiment.

2. METEOROLOGICAL CONDITIONS

From the 23rd to 24th May the Kattegat and the Danish Sounds were covered by a low pressure centre. The weather was dominated by considerable overcast, continuous rain and W to WNW winds of force 14.5 m/s. The air temperature was between 10 and 13° C. From the 25th May an almost stationary low pressure stayed over central Sweden and an expanding high pressure from the Norwegian Sea to the British Islands was observed. This resulted in an increasing wind force causing a sea state of 4-5°B, which forced the HYDROMET to a temporary break of the measurements on the profile K the 27th May. From the 28th May to the 1st June the weather improved, but it changed later during the 2nd June to considerable overcast. The air temperature increased to 15°C. On the 24th May strong easterly winds were blowing almost parallel with the profile. The 28th the wind had shifted to SSE. The 30th May the winds were weak and variable. The 2nd June the wind had shifted to W-NNW. On the 5th June the wind was SSE to SE.

3. RESULTS

3.1. Results of section B

3.1.1. Currents at section B

Wind speed and direction during the investigations in the Kattegat were probably the main driving force for the movement of water masses. The variability of wind and current along the profile B is presented in the figures 2a-e. The 24th May strong easterly winds were blowing almost parallel with the section forcing the surface water away from the Swedish coast. The water in the surface layer moved towards the Danish coast, where it turned to the north joining the outgoing current from the Læsö Channel.

Upwelling of water may have occurred close to the Swedish coast. In the Deep Channel (st. B1) the bottom water moved to the north (fig. 2). The 28th the wind shifted to SSE. At stations B2-B5 the surface water was still moving towards the Danish coast, but at stations B1 and B2 the current at 5 and 10 m depth had changed to S-ESE. The bottom currents were directed towards N-NE (fig. 2b). The 30th May the winds were weak and variable. At stations 2 and 3 the surface currents were strong, coming from the north. At station B5 the water was moving out towards the Skagerrak. In the Deep Channel (st. B1) the deep water was flowing out towards the Skagerrak (fig 2c). The 2nd June the wind had shifted to WNW-NW. The surface water at stations B1 and B2 was moving towards W, but at stations 3 and 4 the current was going towards S and at station B5 the current moved in the opposite direction, towards NW-NE. In the Deep Channel only a very weak south current could be detected (fig. 2d). The 5th May the wind was SSE to SE. At station B3 a strong SW current could be observed. Below the halocline the current was SSE to SE and at station B1 from 10 m downward S to SE. At station B4 the current was strong WNW above the halocline. At station B5 the current was very weak and NE to SE. Below the halocline it was also weak and NW to NE (Fig. 2e).

Figs 3a-e show the currents of the surface layer on surface maps of the Kattegat (0, 5 and 10 m). As a conclusion we may say that during 24th and 30s May and the 5th June, there seems to have been a gyro moving clockwise north of the section.

3.1.2. Salinity and nutrients at section B

The salinity in the surface water supports the current observations (Fig. 4a-e). The 24th May we find a salinity minimum with salinities below17 PSU at stations B3 and B4, which indicates inflow of water from Skagerrak at the Swedish coast and outflow at the Danish coast. The 28th May the lowest surface salinities were found on the Danish side indicating westward movement of the surface water. The 30th May we find rather high salinities (above 30 PSU) on the Swedish side and low salinities on the Danish side, showing that Skagerrak water was moving in on the east side and Kattegat water out on the west side. The 2nd June the Baltic current was strong at the Swedish coast. At station B3 Skagerrak water was flowing in and at stations B4, B5 and B6 Kattegat water was flowing out. The 5th June the Baltic current again was found at the Swedish coast. At station B3 Skagerrak water was moving in to the Kattegat, at station B4 we found a salinity minimum and an outgoing strong surface current. At the Danish coast the currents were weak and variable and the salinity was rather high, 24-26 PSU indicating intrusion of Skagerrak water.

Fig. 5 shows a time diagram for the surface salinity at 0 m in the B section from 24th May to the 9th June. We can see that the salinity was rather low until the 28th indicating water of the Baltic current especially on the Swedish side. The layer was thinner, less than 10 m, on the Danish side, but was very distinct and thick on the Swedish side. In the middle of the period higher saline water has entered from the Skagerrak. At the 0 m level we can see some intrusion of less saline water on station 5. At the end of the period we again find low saline Baltic current water at the Swedish coast.

Silicate may here represent nutrients. A plot of the silicate concentration at 0 m (Fig. 6) shows the same picture with higher silicate concentrations at the beginning and end of the period indicating Baltic water and lower values in the middle of the period indicating Skagerrak water.

3.2. Results of section K

3.2.1. Currents at section K

Fig. 7a-d shows the currents on the section K, Göteborg-Öresund. The current directions are however rather confusing.

The Baltic current enters the Kattegat through the Öresund and the Great Belt. The water is already stratified in the whole Belt sea area with high saline Skagerrak water close to the bottom and Baltic water above it. At the beginning of the program the surface currents at station K 8 show a weak southerly direction, which indicates that the outflow of Baltic water from the Öresund has ceased or it may have been forced towards the Danish side due to the easterly winds.

3.2.2. Salinity and nutrients at section K

The surface salinity at station K8 (Fig. 8a) varied from the 25th May to the 3d June between 14.1 and 15.4 PSU, but decreased the 9th June to 11.0 PSU indicating that stronger outflow of Baltic water begun. At station K7 (Fig. 8b) the variations in the surface salinity were small, between 15.3 and 16.8 PSU, which shows that hardly any changes occurred in the southern Kattegat during the measuring period. From fig. 8e we can see that Skagerrak surface water with a salinity of 27-28 was present at station BK1 from the 28th-31st May. At all other occasions the surface salinity was between 17 and 19 PSU. Also at stations K6 and K7 elevated salinities could be found the 31st May. From the salinities we can conclude that no remarcable changes happened in the Kattegat deep water during the period 24th May to 9th June (Fig. 8a-e). The salinities varied between 33.5 to 34 PSU at K8 and 33.5 to 34.9 PSU at K1. This water is obviously Skagerrak deep water. The halocline is generally located between 10m and 15m at the entrance to the Öresund and between 5 m and 20m at BK1.

The 25th May the surface currents were rather strong inside the Kattegat with a southwesterly direction (Fig. 7a). As can be expected during the spring the nutrient concentrations were very low in the surface water due to the spring plankton bloom. Below the halocline the nutrient concentrations were high. Because the silicate concentration is very high in the Baltic water, it may be used as an indication of outflow through the Öresund. The only stronger outflow during the period occurred at the end of the program, the 9th June (Figs 7d and 8e). The concentration of silicate in the surface water at station K8 exceeded then 6 µgat/l.

3.3. Satellite images

The satellite image taken on 25th May indicates an upwelling along the Swedish coast, though this event went unnoticed on board the HYDROMET due to considerable distance of station BK1 from land. The current measurement that day displayed a surface current with a velocity of 40 cm/s directed away from the Swedish coast, although the wind direction was strictly opposite and the current vectors in deeper layers were directed towards land (north to northeast). This discrepancy supports and explains the upwelling observed from the satellite image, and reveals the complex dynamics of the Kattegat water. The NOOA-AVHRR satellite picture from 28th May was rather difficult to interpret as regards temperature distribution. A comparison of the satellite image and the measured surface temperatures along the B profile that day explains the horizontal distribution of water masses in the region. Satellite results show an systematic difference of 0.5 °C in comparison to the in situ measurements, which is a comparatively good agreement.

3.4. Biology

Extremely low concentrations of phosphate and nitrate above the halocline are in good correlation with the phytoplankton bloom observed during this period. *Diatoma* were in bloom in the surface layer and below the thermocline *Dinoflagellata* predominated (Edler, pers. comm.). Zooplankton observations revealed predominance of *Copepodae* (Hernroth, pers. comm.)

4. CONCLUSIONS

The main result of the expedition with the HYDROMET is that very little Kattegat surface water was transported to the Skagerrak along the Swedish coast and that only small amounts were transported through the Læsö Channel. Thus the Skagerrak was very little influenced by inflow of Baltic water between the 24th of May and the 9th of June. Fig 9 shows the silicate variations from the 23d May to the 20th June at station B1 (Danielssen et al. 1992). As can be seen, no important variations could be observed in the silicate concentration during the first part of the programme, when the HYDROMET was working at the station. Fig. 10 shows the currents at the st.ation BK1 from the 24th May to 5th June. We can see that there was hardly any outflow of surface water to the Skagerrak before the 31st May. The inflow the 24th and 25th May brought in Skagerrak water. Fig. 11 shows an example of a gyro in the area (Danielssen et al. 1992). Such a gyro may have caused the circulation of the surface water at section B, described in chapter 2.1.

5. ACKNOWLEDGEMENT

The authors wish to thank Eng. Zbigniew Lauer, Institute of Meteorology and Water Management - Maritime Branch, Gdynia, for his valuable contribution to this work.

6. REFERENCES

Danielssen, D.S., L. Davidsson, L. Edler, E. Fogelqvist, S. Fonselius, L. Føyn, L. Hernroth, B. Håkansson, I. Olsson and E. Svens 1991. SKAGEX: Some preliminary results. ICES C.M. 1991/C:2 Hydrography Comm. Ref: E.

Danielssen, D.S., L. Edler, S. Fonselius, L. Hernroth, M. Ostrowski, E. Svendsen and L. Talpsepp 1992. Oceanographic variability in Skagerrak/Northern Kattegat, May-June 1990. Report from meeting at Flødevigen, Norway, 31 August - 4 September 1992. Mimeo. 12 pp and 21 figures. (To be published by ICES).

Edler, Lars (1991). Personal communication.

Hernroth, Lars (1991). Personal communication.

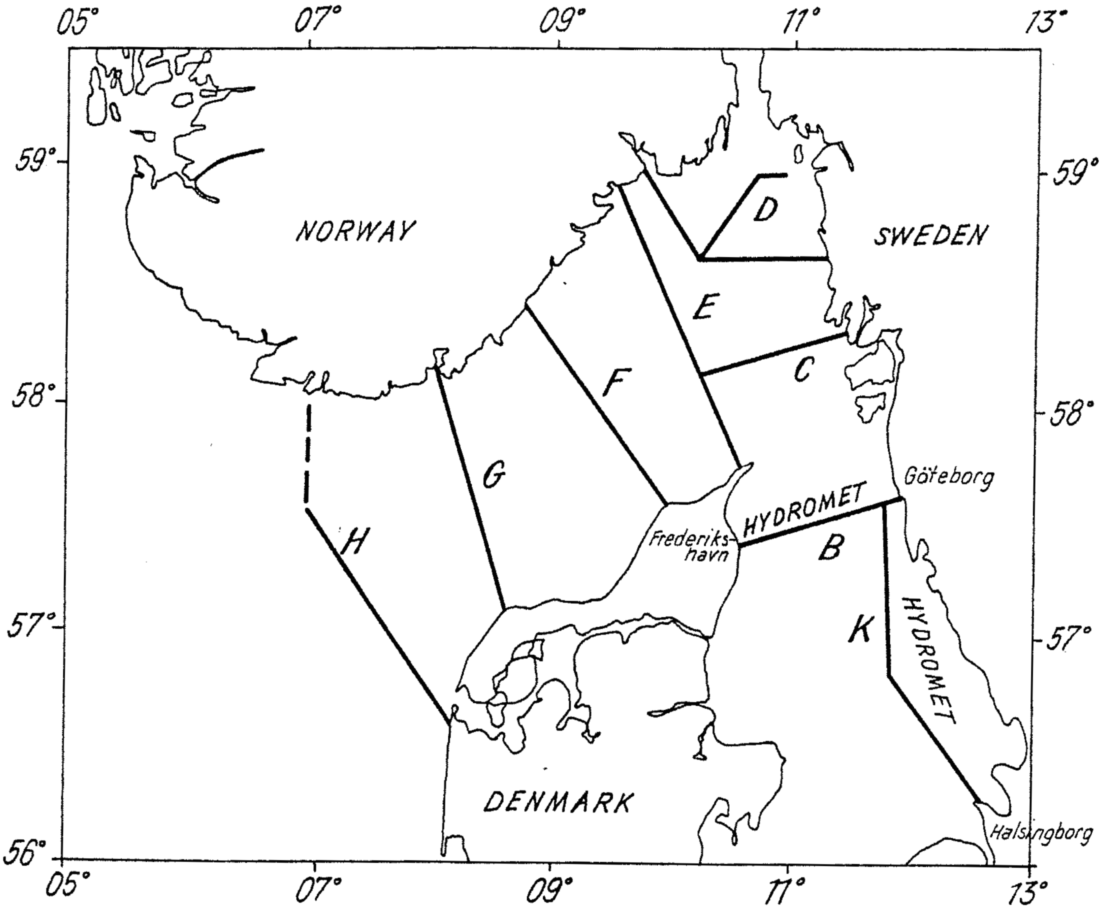


Fig. 1 Sections taken by r/v Hydromet during SKAGEX 1
(24th May - 5th June)

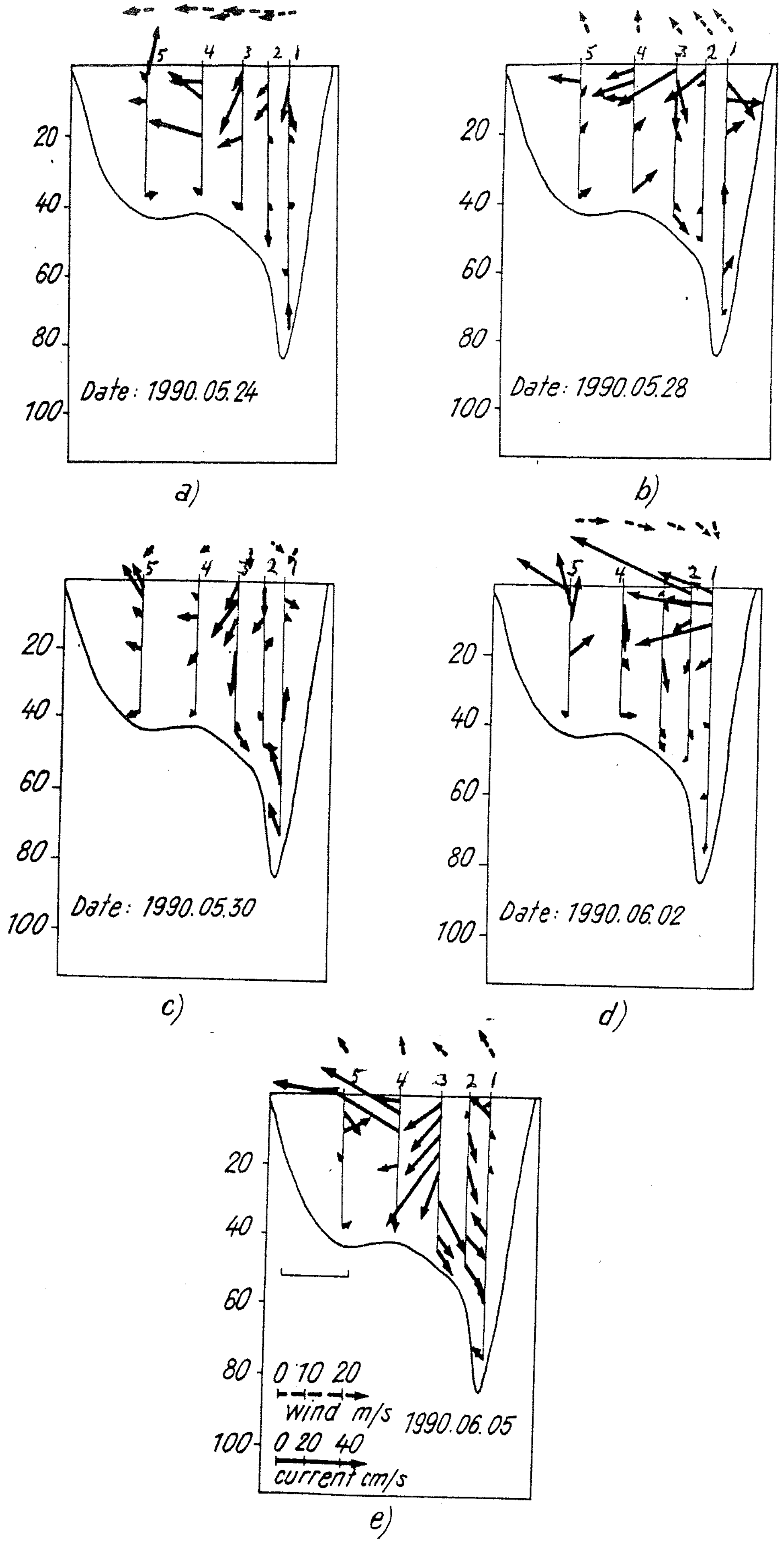
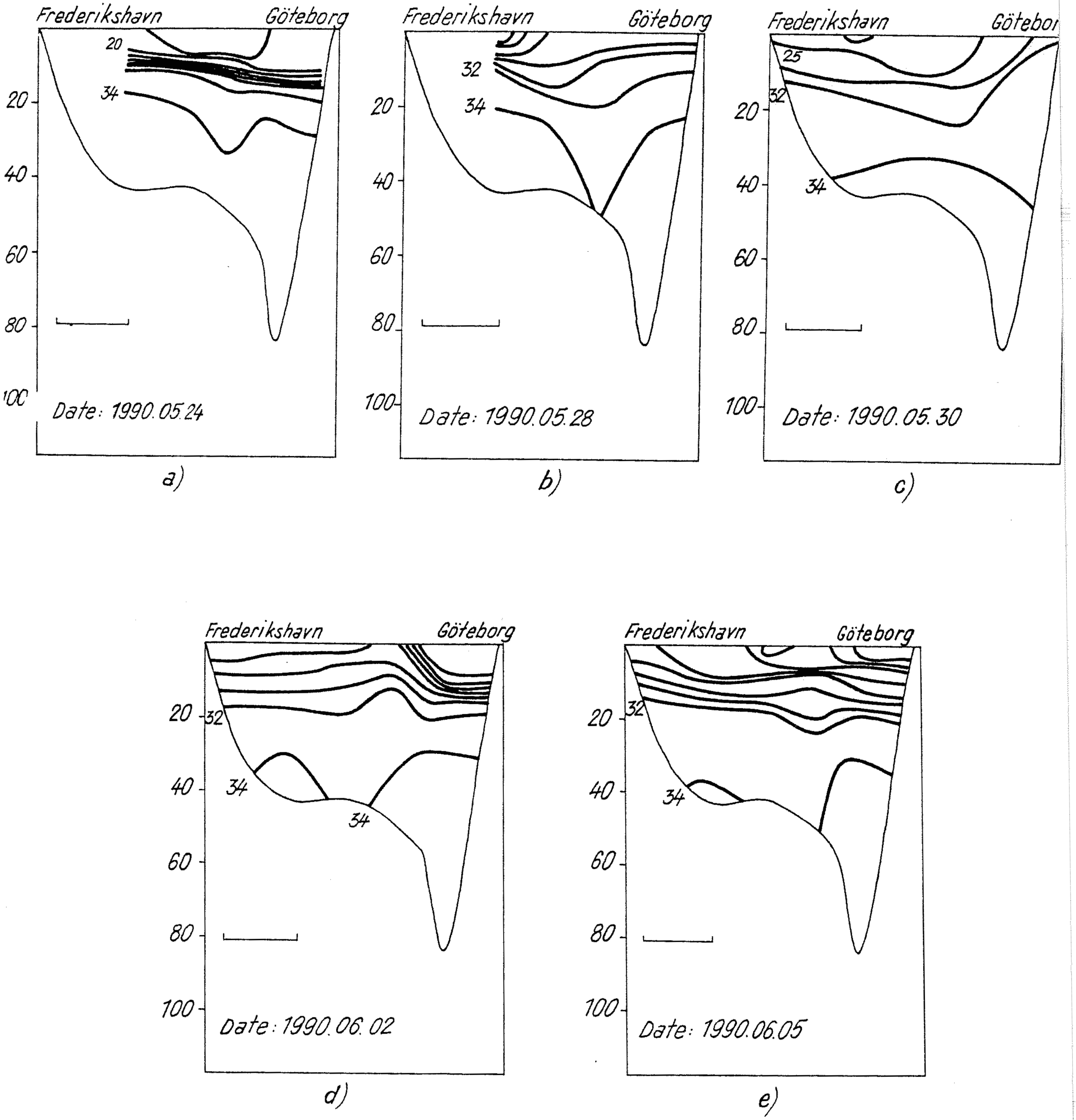


Fig. 2 The variability of wind and currents along the profile B.

Fig.3 Currents of the Kattegat surface layer at section B.



a) b) c)

d) e)

Fig. 4 Salinity of surface water along the section B.

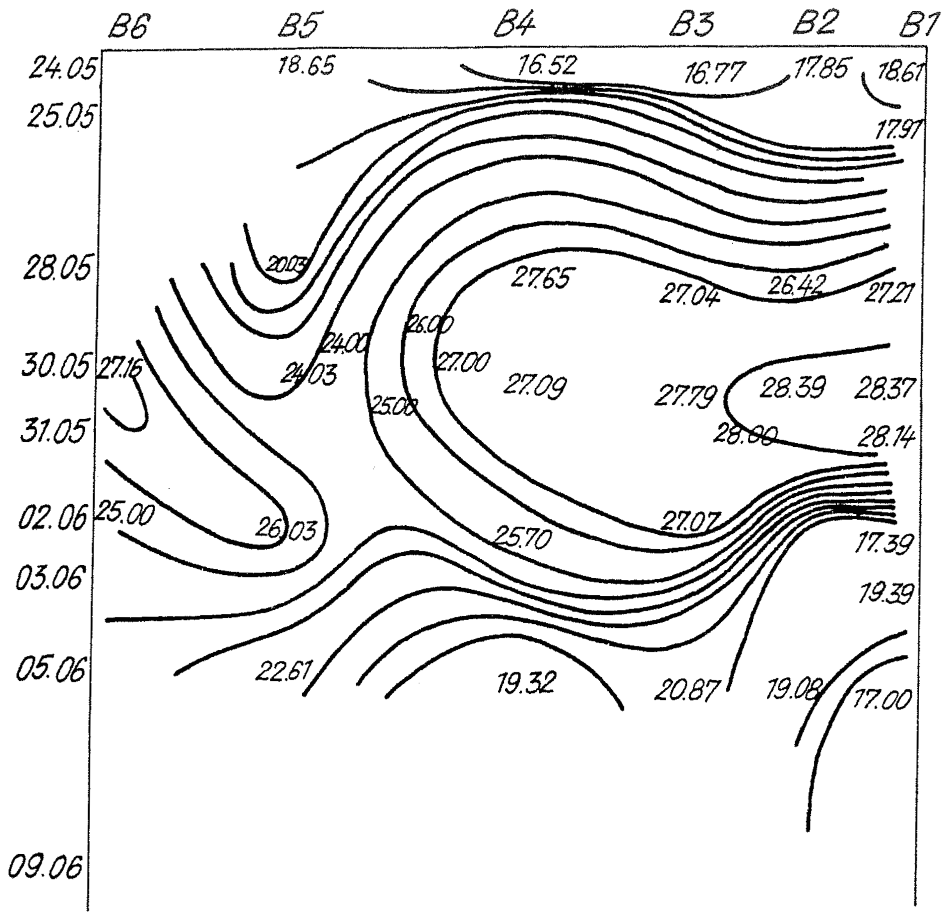


Fig. 5 Salinity of surface water along the section B

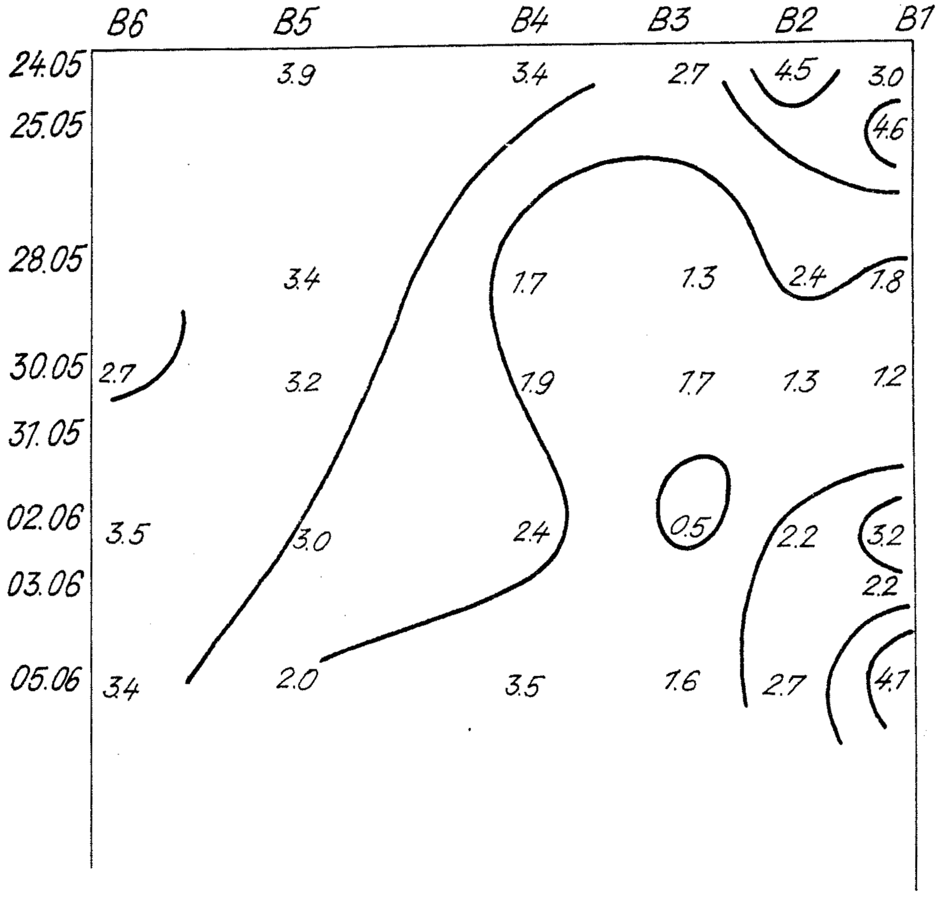


Fig. 6 Surface silicate concentration along the section B

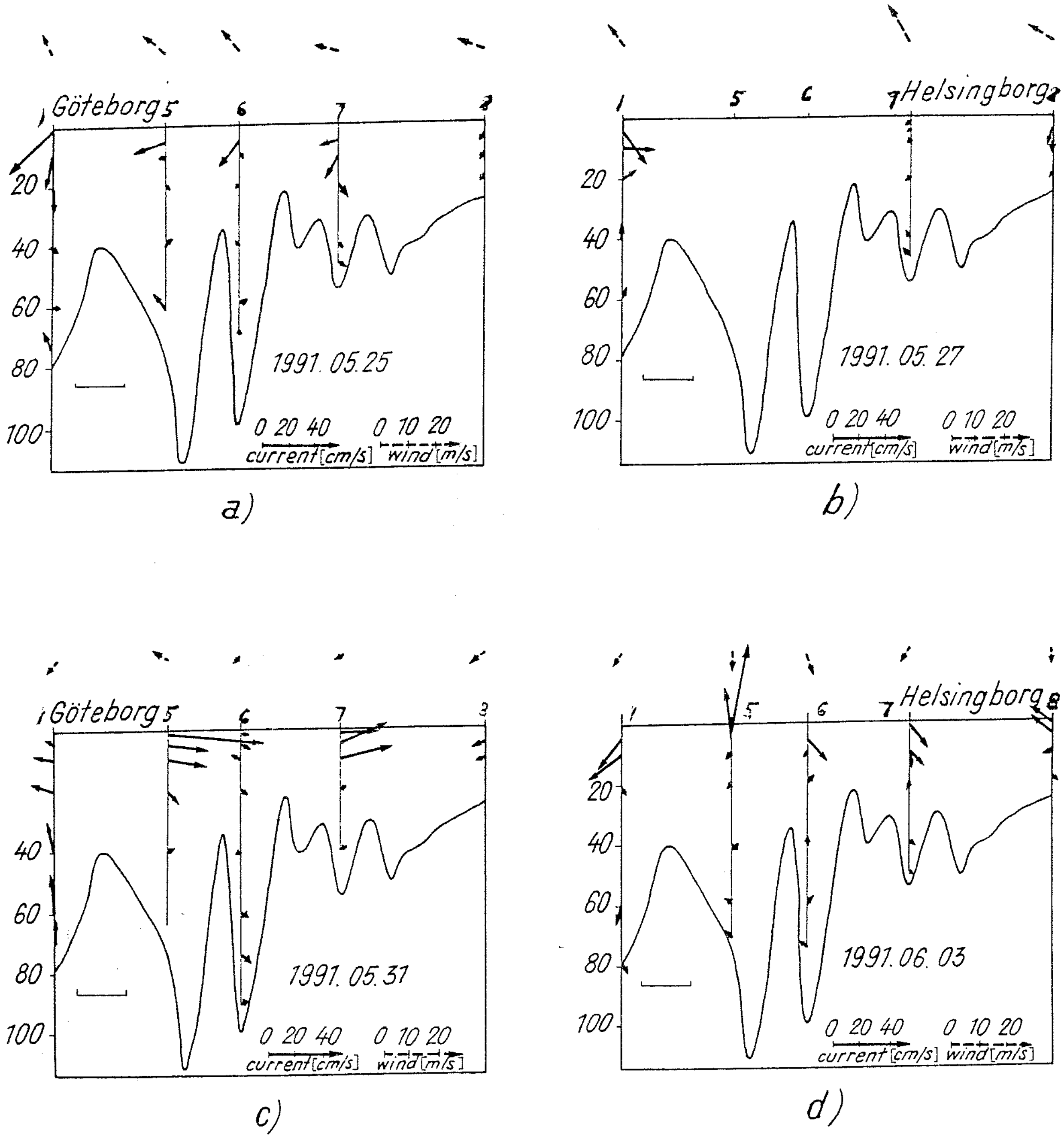


Fig. 7 Currents along the section K (Öresund - Göteborg)

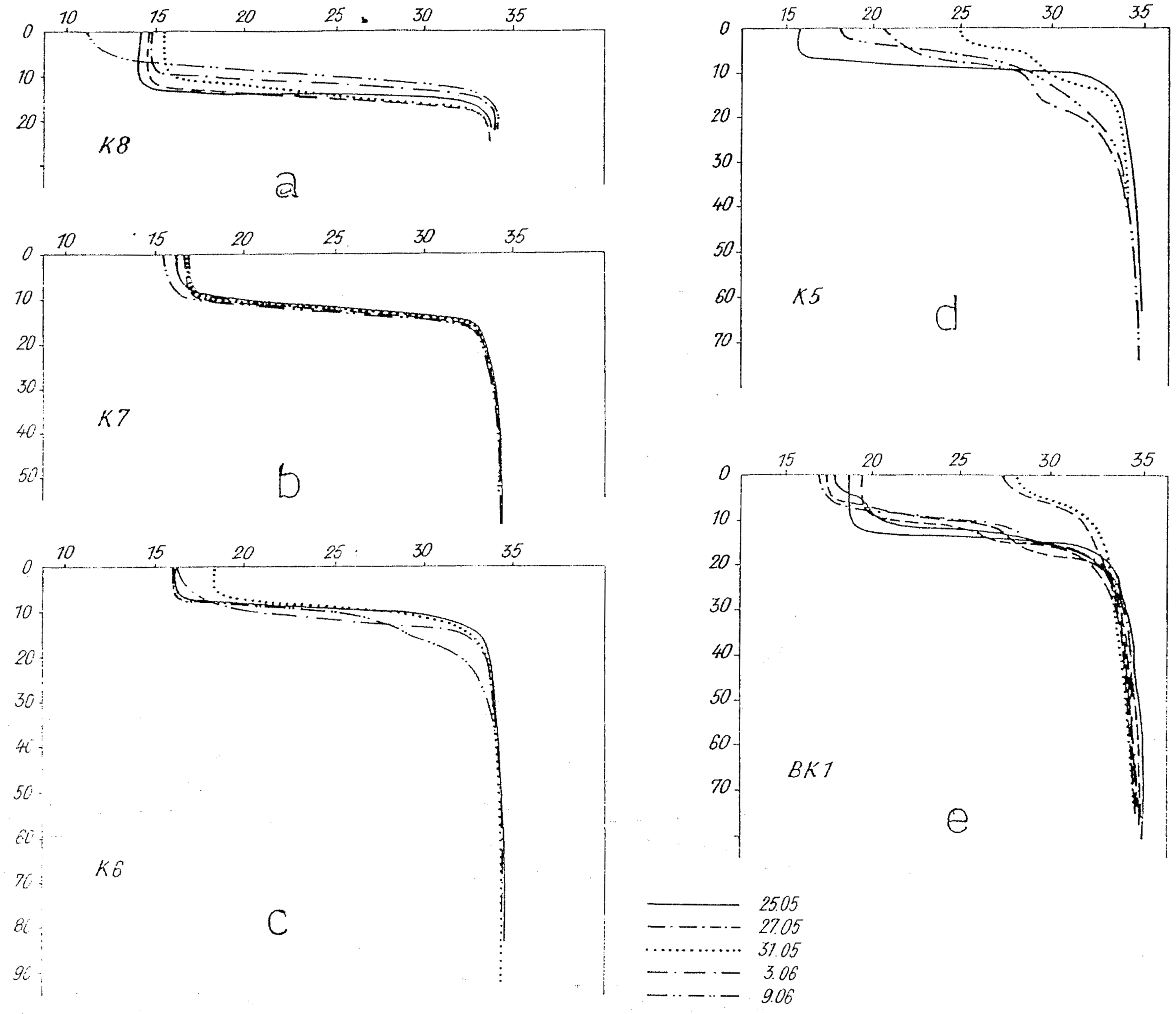


Fig. 8 Salinity variations during 24 th May - 5 th June along profile K.

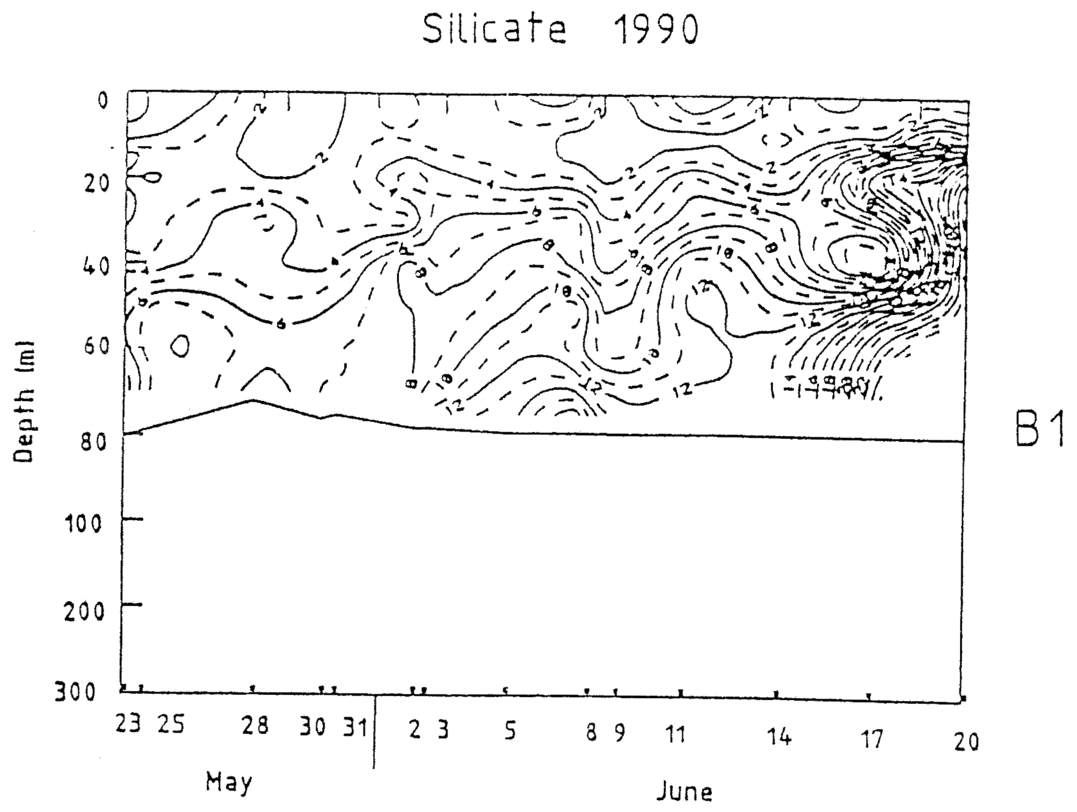


Fig. 9 Time series of silicate at station B1 during SKAGEX 1 [Danielsen D. S. et al]

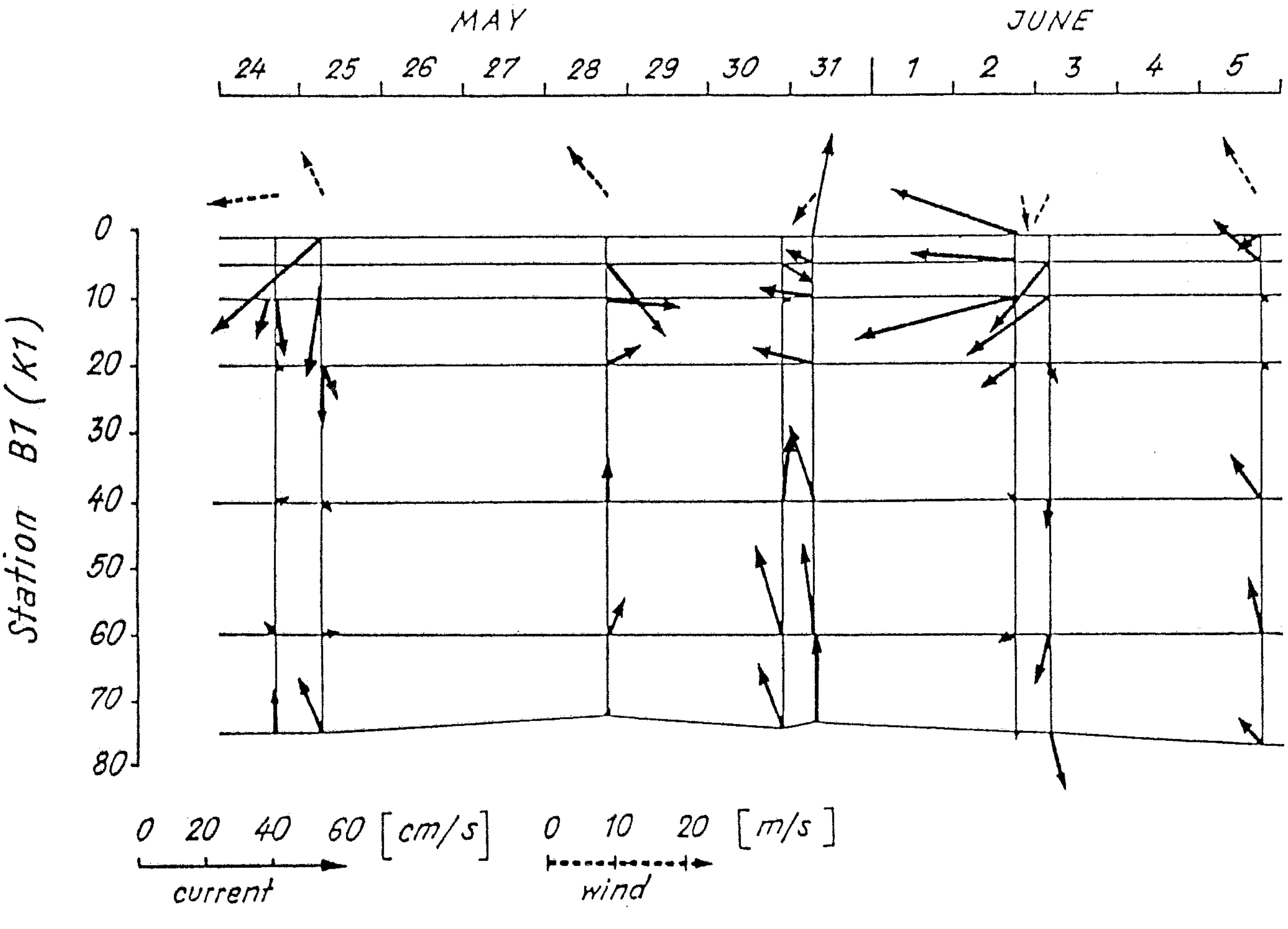


Fig. 10 Currents at station B1 K1 (near Göteborg) from 24th May to 5th June.

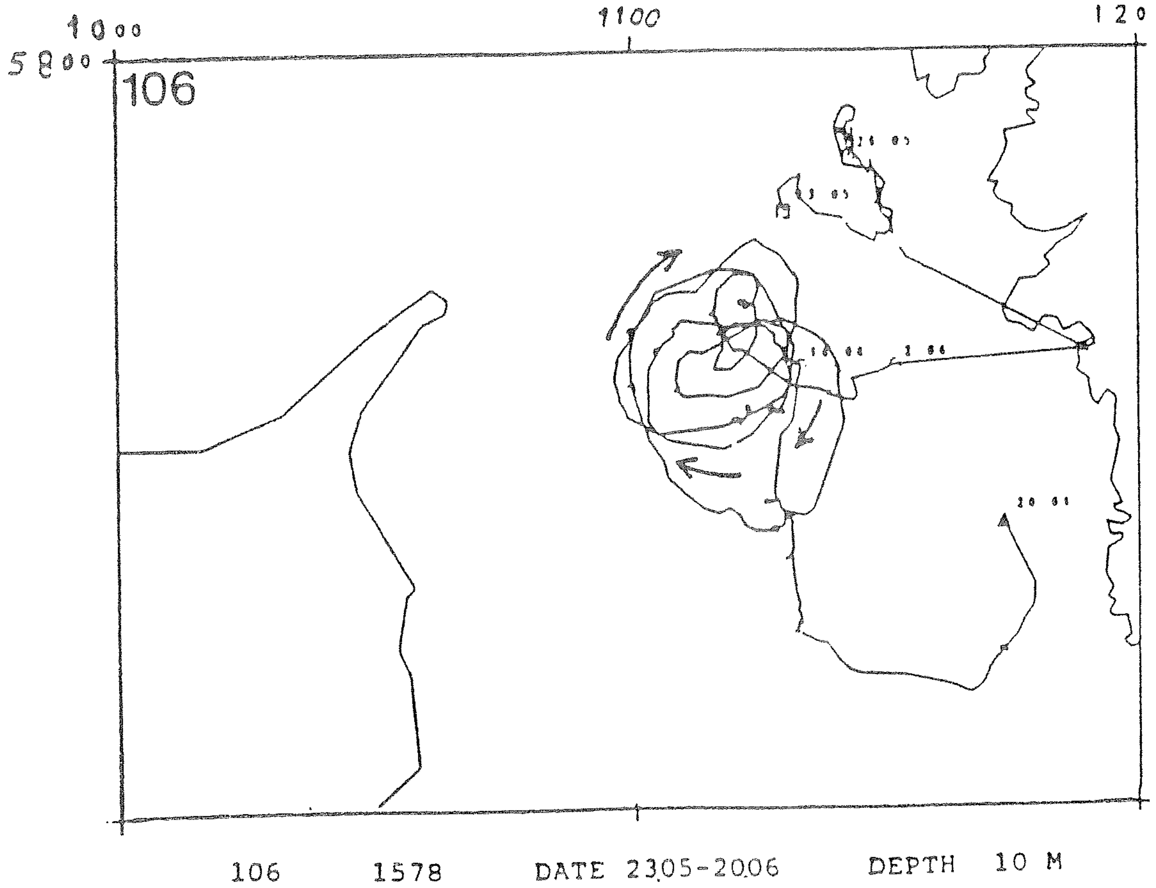


Fig. 11 Argos drifter tracks in the northern Kattegat during SKAGEX 1 [Danielsen D.S. et al, 1992]

Presentation no 4.

SKAGEX: some preliminary results.

by

D. S. Danielssen, L. Davidsson, L. Edler, E. Fogelqvist,
S. Fonselius, L. Føyn, L. Hernroth, B. Håkansson,
I. Olsson and E. Svendsen

Not to be cited without prior reference to the authors

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Exploration of the Sea

C.M. 1991/C:2
Hydrography Comm.
Ref: E

SKAGEX: SOME PRELIMINARY RESULTS

by

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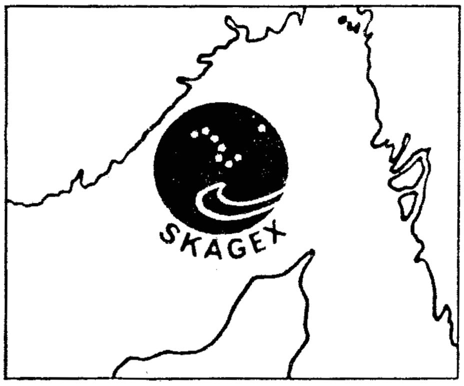

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1. Abstract

A series of synoptic hydrographic and biological investigations were carried out in the Skagerrak area in May-June and September 1990 and in January and May 1991 (Skagerrak Experiment or SKAGEX).

The hydrographic conditions in the area have been demonstrated to be very complicated and dynamic. Six different water masses of importance have been identified. These water masses constitute or merge into different current systems. Nitrate rich water outside the west coast of Jutland (Jutland Coastal Water, JCW) seems only sporadically to reach the Skagen and northern Kattegat area.

Typical transports of water into or out from the western Skagerrak have been estimated to be 0.5-1.5 Sverdrup in the upper 100 m with significant fluxes also below this level. The main transport of water from the Kattegat to the Skagerrak seems to take place to the west of the island of Läsö.

Blocking of surface water in the Skagerrak seems to be a frequent phenomenon. During SKAGEX I strong NW winds forced a significant upwelling of nutrient rich water at the Norwegian coast and almost 90 km offshore. Also surface water from the central and southern Skagerrak was found far south and west of Hanstholm at the southern border to the North Sea. These surface transports blocked the Norwegian coastal water to leave the Skagerrak and the Jutland coastal water to enter it.

Several eddy-like features were observed during SKAGEX I both at hydrographic measurements and with drifting buoys. Persistent eddies were found with drifting buoys in the northern Kattegatt performing for several days an anti-cyclonic and a cyclonic circulation, respectively.

Nitrite maxima were found at all larger Skagerrak sections in the core of the inflowing Atlantic water. At section G, where ammonia was also measured, a separate ammonia maximum was found. These nitrite and ammonia maxima indicate a diversified nitrification process in the water.

Over large areas of the Skagerrak and in the northern Kattegat, the maximum chlorophyll-a concentrations were recorded in subsurface layers. **In situ** primary production measurements in the northern Kattegat showed high rates of production in subsurface phytoplankton populations.

Secondary production, measured as copepod egg production, reached its highest values in the shallow areas north of Skagen. Occasionally, high rates were also found at nearshore stations west of Jutland and in the eastern Skagerrak close to the Swedish coast.

2. Introduction

2.1. Background

The Skagerrak may be regarded as a part of the transitional area between the Baltic and the North Sea. It is a very productive sea area with a production of fish of 70 kg/hectare/year, almost double that of the North Sea. The Skagerrak is thus of great economical importance to the surrounding countries. It has been stated that the major part of the continental, coastal water of the southern North Sea makes a turn into the Skagerrak before being exported from the North Sea. The Skagerrak is also a nursery and feeding area for about two thirds of the North Sea herring (Böhle, 1989). Today, the Skagerrak area is threatened by pollution from different sources, and since the hydrobiological conditions of the area are very complex and dynamic, many features are poorly known.
At the SKAGEX meeting in Moscow (C.M. 1991/C:1) it was decided that a preliminary report on the scientific results of SKAGEX should be presented at the coming ICES statutory meeting. The report should merely give a hint of what was achieved during SKAGEX (the Skagerrak Experiment). The presentation should also be of some guidance for further contributions.
The main topography, the obligatory transects investigated (A-H) and main entering water masses of the Skagerrak are indicated in Fig. 1a and b.

This paper was mainly produced at an informal meeting in August 1991 at the Institute of Marine Research, Flödevigen Marine Station, Norway, where pleasant and comfortable meeting facilities were provided.

2.2. Synoptic investigations

The planning of the ICES project SKAGEX commenced in 1988 under the leadership of Dr Bernt I Dybern, Sweden, and continued in 1989 and early 1990. During this period several meetings took place between scientists from the interested countries. The field work commenced with SKAGEX-I in May-June 1990 with a participation of 17 research vessels from 7 states around the Baltic Sea and the Skagerrak-Kattegatt area. The primary aim was to cover the sea area with synoptic measurements of key parameters at a number of transects in order to obtain data for the mapping of the hydrographical and biological conditions and to compile information on the transport mechanisms (mainly currents) and general dynamics.

The participating vessels mainly worked every third day at obligatory stations along the obligatory transects. The following obligatory parameters have been investigated: salinity, temperature, density, nutrients, oxygen, fluorescence, chlorophyll, phytoplankton, primary productivity and zooplankton. Currents have been measured by use of registrating current meters at the A- and G-sections and by use of ADCP on various sections. Satellite images have been used for the interpretation of hydrographical and biological data, and meteorological observations have been carried out.

For further details of objectives, parameters, methods used etc. the reader is referred to the "Report of the Study Group on Skagex" (C.M. 1990/C:31).

During SKAGEX-I an intercalibration exercise was carried out in Arendal, Norway, the preliminary results of which were presented at the 78th ICES Statutory Meeting (Föyn, 1990).
At an early planning stage it had been decided that three minor additional expeditions, SKAGEX-II-IV, should be carried out during 1990 and 1991 in order to cover

different seasons. Five ships took part in SKAGEX-II between September 10-15, 1990 and three ships in SKAGEX III between January 12-18, 1991. During these two expeditions the most important transects were covered. The final expedition, SKAGEX-IV, took place between May 13-17, 1991, with participation of 6 vessels. On the basis of different results obtained during this final expedition was carried out in a somewhat different manner in order to get a more complete picture of the water areas between the main transects (cf ICES C.M. 1991/C:1).

The information presented in this paper is based on uncorrected data. IT should be regarded as preliminary. A very large number of SKAGEX data are still to be analyzed, especially from SKAGEX II - IV, and eventually corrected

3. Water masses

A differentiation/distinction between water masses entering the Skagerrak from the North sea and low salinity water entering Kattegat from the Baltic will be of help in understanding the circulation and the biological processes in the Skagerrak and the Kattegat. An approximate division between entering water masses is shown in Fig. 1b. In Fig. 2 a and b, the Temperature - Salinity (T - S) and Nitrate - Salinity (N - S) relations of these waters are presented.

During SKAGEX I six water masses were distinguished in the Skagerrak, and they are presented in Table 1.

Table 1. Main water masses during SKAGEX I

Water mass	**Salinity**	**Temperature**	**Comments**
SW, surface water	15 - 32	10 -15	Low nutrients, outgrown; thickness 5 - 20 m
JCW, Jutland Coastal	32 - 34	10 - 15	High nitrate, low phosphate; thickness 35 m
SNSW, Southern North Sea Water	34.8-34.9	8 - 9	Low nitrate, (0 - 1 μmol/l)
CNSW, Central North Sea Water	34.8-35.0	8 - 9	Subsurface nitrate (2 - 5 μmol/l)
AW^h, Atlantic Water high	35.0-35.15	8 - 10	Nitrate (0 - 7 μmol/l), nutrients increasing with depth
AW^l, Atlantic Water low	35.18-35.32	7.2- 8	Nitrate (10 -15 μmol/l)

Baltic Water (BW), salinity about 8, enters Kattegat at about 56° N, is mixed fairly rapidly to an approximately 10 m thick surface layer, with salinities between 15 and 20 north of 57^c N. This water can enter Skagerrak both east and west of Läsö (Rydberg and and Andersson, 1989), and continues generally along the Swedish coast to the border of Norway where it turns westward as the Norwegian Coastal Water (NCW). On this route it gradually mixes (both horizontally and vertically) with water of higher salinity, and leaves the Skagerrak with salinities between 25 and 32 in the upper 10 - 20 metres.

Due to northerly to westerly winds, meandering and eddies, the BW often spreads out over large areas of the Skagerrak surface. Since the above water masses are all roughly restricted to the upper 20 m and connected to the inflow of Baltic water (BW), we define it all just as Surface Water, SW. The common features of the waters composing the SW are the gradual increase in temperature from about 10 - 15 C during the time of the experiment (SKAGEX I), and the very low content of nutrients during the whole period, due to primary production.

The picture of the water masses entering Skagerrak from the North Sea is much more complex (Fig 1b). The most dominating inflow during SKAGEX consisted of Atlantic Water (AW), with a core salinity of around 35.3, and high nitrate, phosphate and silicate concentrations closely corresponding to the Redfield ratio of deep ocean water. This water follows the Norwegian Trench from the north, and when entering Skagerrak it is found mainly between the 100 and 300 m bottom contours on the Danish side of the trench. Svendsen and Magnusson (1991) have demonstrated large year to year fluctuations in this flow, whereas the SKAGEX focus was on the short time variability.

Atlantic water is generally defined as water with a salinity above 35.0. It has been found convenient to separate the Atlantic water in a "high" (shallow), AW^h, and a "low" (deep), AW^l, part, Fig. 1b. The AW^h is especially interesting with respect to biology, because it may contain high amounts of nutrients available for primary production. Typically it was found that parts of the AW^h was directed somewhat south of the Norwegian trench while entering Skagerrak.

The AW^l was typically found at variable depths from 200 to 500 m. The distribution of nitrite and ammonia in the upper part of this water mass indicates age differences as their maxima are separated.

South of the in flowing AW^h it was also observed inflow of water from the central North Sea, Central North Sea Water (CNSW), and from the southern North Sea, Southern North Sea Water (SNSW). These water masses are separable in the nitrate - salinity diagram, Fig. 2b,in which the SNSW below the photic zone is characterized by its lack of nitrate. The reason for this, as suggested by Föyn (pers. comm.), is the difference in origin (i.e. English Channel water), with the transport route from the English Channel flowing north eastwards mainly <u>south</u> of the Dogger bank where these relatively shallow areas have a high production even during winter, consuming nutrients originally transported into the area from the Channel. During SKAGEX it was, however, found that some phosphate was left in the water mass concerned.

The CNSW (Central North Sea Water) is water of north Atlantic origin mixed with Scottish coastal water transported eastwards over a wide area north of the Dogger Bank. This water has an increasing nutrient content with depth, similar to the AW^h.

An additional water mass entering Skagerrak from the North Sea is the Jutland Coastal Water (JCW), (Fig 1b and 2). This water originates in the German Bight and is a mixture of continental river water and SNSW. The river water has a high nutrient load and depending on seasons and rainfall the discharge of nitrate is in large excess over phosphate, giving JCW a characteristic feature of extremely high nitrate and low phosphate values (in relation to the Redfield ratio).

The JCW flows northwards close to the western Danish coast, parallel with the the SNSW, gradually increasing its salinity due to horizontal mixing. As the JCW enters Skagerrak close to Hanstholmen it typically has salinities between 32 and 34 probably also due to an additional mixing with CNSW and AW^h. Due to tidal mixing and bottom friction JCW is vertically homogeneous and generally spreading over the shallow area at depths less than 35 meter.

From Fig. 2b it is clear that in principle it should be relatively easy to locate the JCW in Skagerrak and Kattegat. However, at the beginning of the experiment, due to strong north westerly winds, large amounts of Surface Water (SW) were transported south to the western coast of Denmark, and it was strongly interacting with and changing the typical signature of the JCW.

As seen in Fig. 1b, all the different water masses from the North Sea are entering the Skagerrak in a narrow area of about 50 km, and clearly, a mixing between all of them (in addition to the surface water) can occur in this region.

The bottom water, below 500 m, of the Skagerrak (SBW) is partly formed by AW^l and other Atlantic winter water cooled in the northern central part of the North Sea and sank into the deepest parts of Skagerrak (Ljöen 1981 , Magnusson 1985, and Svendsen et al. 1991). As this water is only occasionnally renewed it acts like a sink for organic matter. Elevated nutrient concentrations are found demonstrated by high silicate values (10 - 14 µmol/l).

4. Some results on the water circulation

A moored current meter section located between Hanstholm and Kristiansand in the western area of the Skagerrak (Fig. 1b, Section G), and some Argos drifting buoys as well as shipborne ADCP (Acoustic Doppler Current Meter) were used to study the inflow and the circulation in the Skagerrak. The results from the current meter section clearly show a large-scale cyclonic circulation taking place at the entrance of the Skagerrak. Inflow (of which the surface part is referred to as the Jutland Current in the literature) takes place along the southern side of the Skagerrak from the surface layer to the bottom, and outflow along the northern part also extending from the surface layer to the bottom. The flow at transect G is changing direction along a vertical section above down to vicinity of the 400 m isobath. In Fig. 3 the velocity distribution is shown as the mean from three consecutive days. The total time series covers a period of 30 days (May 21 to June 20) and demonstrates that the above given circulation is indeed persistent. During the same period of time ADCP measurements along the transect from Tyborön and 70 nm northwest (Section H), exhibits similar current characteristics as those found at transect G.

Preliminary estimates from the ADCP measurements indicate a total volume transport in the upper 100 m of about 1 SV (1 SV = 10^6 m^3/s) varying with +/- 0.5 SV during the first part of the SKAGEX I. However, while studying the individual inflowing water masses in relation to the observed currents, clearly a variability of more than 100 % occurred. Significant variability in the currents appears at a typical-time scale of 1 to 2 days. For example, the JCW pulsated into Skagerrak on May 23 to 25, June 4 to 6, 11 and 20, to some extent correlated with winds from S to W. However, this water was never observed east of section F (Fig 1b) during SKAGEX I. Similar pulsating behaviour of the JCW was found during the other SKAGEX missions.

As seen in Fig. 3, there often seems to be a clear core of maximum velocities into the Skagerrak located along the area approximately between and above the 35-80 bottom depth on the Danish side. This bottom depth range represents most of the southern and central North Sea, and the drastic focussing on especially this topographic range at the entrance to the Skagerrak can easily explain the maximum velocities. However, the most interesting findings are the shifts in water masses which this flow represents. By combining the currents with the salinity and the nitrate observations (below the surface layer) from May 20 until June 1 mainly the AW^h (partly mixed with CNSW at the beginning) was represented in this core. From June 1 to June 3 the inflow of AW^h was reduced and replaced by SNSW. For the rest of the experiment it seems that it is mainly this SNSW with nearly no nitrate, which is entering the Skagerrak in this area with the exception of the end of the experiment on June 20, when the SNSW is again replaced by the AW^h.

As stated above the deeper and the main parts of the Atlantic Water was in general flowing into the Skagerrak on the southern side. This flow, however, seems to have turned into a week outflow during the period June 6-13, although the current meter observations are sparse (Fig. 3, June 8 and 11).

The surface layer in the Skagerrak (SW) extended to the halocline, which in general was found at 20 m depth. It covered the whole inner part of the Skagerrak area with low salinity water (<31). Below the halocline the nutrient distribution (nitrate) shows weak vertical but strong transversal gradients with maximum values around the zero velocity zone (cf Fig. 14). This feature dominated all the transversal transects in the Skagerrak during SKAGEX I. An example of the nitrate distribution at 50 m depth is shown in Fig. 4. The largest nitrate concentrations are found in the central parts of the Skagerrak, extending from transect H towards the inner parts. A similar nitrate and chlorophyll distribution in the Skagerrak has been found, among others, by Pingre et al (1982). In a review paper by Richardsson (1989) it was suggested that these characteristic distributions involved both biological, chemical and physical processes. Regarding the SKAGEX I study, and at the present stage, it is assumed that this nutrient distribution may be intensified by an upward transport of deep water, which is driven by an Ekman pumping forced by the large-scale transversal geostrophic velocity shear (cf Fig. 3). This more or less continuous pumping of nutrients towards the euphotic zone may be the feeding mechanism for the high biological productivity generally observed here (cf. Fig. 12,15,17).

Fig. 4 also indicates an enhanced lifting of the nutrients in the eastern Skagerrak. This might be caused by a similar process, but probably intensified in this area due to topographically steered recirculation around the deepest parts in the Skagerrak. This feature is often referred to in the literature as the "dome", but the SKAGEX data indicate that this "dome" is highly variable and at times not present. Fig. 4 also indicates some mesoscale upwelling features in the salinity distribution, which will be discussed later on.

Several drifting Argos buoys were deployed with draughs at 10 m depth in order to study the drift currents in the surface layer of the Skagerrak. Some drift tracks are shown in Fig. 5. In general the surface drift is in accordance with what is expected from earlier investigations and thus conforms to the cyclonic circulation in Skagerrak. Several of the Argos drifters coming from north of Skagen go straight east towards the Swedish coast and either turn northward along with the coastal water, or south into the Kattegatt following the bottom topography (trench). Just to the north of Skagen the eastward transport is converging along the coast, resulting in a high velocity jet stream strongly interacting with the northward outflow of the lighter KSW (Kattegatt Surface Water). This interaction between currents of more or less different directions and of varying strengths, implies that this might be an area for the initiation of meanders and eddies (discussed below). There are also indications that this jet stream is so strong that it totally may block the outflow from the Kattegatt.

5. Some specific features

5.1 The blocking event on May 24 to 29

Blocking events of the Skagerrak surface water during strong westerly winds are well known. It causes piled up water in the inner Skagerrak, which after the wind has ceased penetrates along the Norwegian coast as a coastal rotating gravity current (Mork and Saetre, 1980, Mork, 1981, Johannesen et al, 1989 and Håkansson et al, 1990). However, less attention has been focused on the blocking event itself and its implications on other currents and water masses in the area (i.e. Saetre et al, 1988 and Håkansson, 1990), like the winddriven upwelling, occurring along the Norwegian coast as well as the spread of the surface water in Skagerrak .

During May 24 to 27 a strong upwelling driven by winds from NW was observed both with **in situ** and remote sensing data. The wind event lasted for 4 days with speeds from 5 to 15 m/s. An example of the wind distribution, calculated by using an objective analysis technique is shown in Fig. 6. The wind driven Ekman transport forces surface water offshore along the southwestern part of the Norwegian coast, which for continuity reasons are replaced by cold upwelling water. The upper satellite image in Fig. 7, showing the sea surface brightness temperature, is indicating the time evolution of the upwelling as well as the size of the area. The horizontal distribution of the surface water salinity and nitrate are shown in Fig. 8. These maps have been elaborated on the basis of data from ship measurements on May 27, demonstrating that the upwelling area is also characterized by high surface water salinity (>33) and nitrate (>5 umol/l). The upwelling continues for three days, whereafter the warm surface water in the Skagerrak is spreading above the upwelled water along the coast (cf. Fig. 8 and the lower image from May 28, 1990). The upwelled area is probably limited in the alongshore direction by the curvature of the coast, since the upwelling is most effective when the wind direction is parallell with the coastline. The offshore extent should depend on the strength of the wind impulse as well as the thickness of the surface layer.

During the same event the northwesterly winds also transported SW, generally found along the Norwegian coast of the inner Skagerrak, as far south as to the Danish coast at Hanstholm. This is most clearly indicated in the satellite image from May 25 and in the maps of surface salinity and nitrate distribution shown in Fig. 7 and 8, respectively. Note also, that the currents close to the shoreline is heading south on May 27 (Fig. 3), indicating that the JCW is blocked during this event. According to the satellite images from May 25 and 28 warm SW can also be found far west of Hanstholm in the North Sea. This water mass is also of low salinity and nitrate according to Fig. 8. It thus appears that northwesterly winds can spread the surface water of Skagerrak to a large extent and in manner which is not previously well documented.
It should also be noted that upwelling was observed along the Swedish coast in the northern Kattegatt during May 28 and 29, and during May 3 and 4 along the Norwegian coast in the inner part of Skagerrak.

5.2 Mesoscale features

The well known topographically steered subsurface transport southward in the Kattegatt is during SKAGEX also clearly seen (by several Argos drifters) to affect the near surface current. At 10 m depth, the southward flow seems to stop close to 57°20'N. Clearly much of the outflow of the KSW/BW to Skagerrak is to be found on the Danish side and this might be caused by a barotropic effect caused by the southward flow along the trench on the Swedish side. This tendency for an anticyclonic velocity shear can produce an anticyclonic eddy as indicated in Fig. 9, showing an Argos drifter rotating for more than two weeks (June 2-18) on a scale of about 20 kilometer.

As mentioned earlier it is assumed that the eastward jet stream from Skagen interacting at varying strength with the KSW might produce meanders or eddies. Johannessen **et al.** (1989) described a similar process on the west coast of Norway where the AW interacting with the NWC produced a strong eddy downstream in the NCW. Fig. 10 showing the horisontal salinity distribution obtained May 23-25,demonstrates such a cyclonic eddy at about 58°10' (downstream relative to the outflowing KSW) with a scale of about 50 km, and a cyclonic eddy was observed in this region several times during SKAGEX I. The typical upwelling in the center of the eddy in this region is clearly shown in the salinity distribution in Fig. 4 (June 15-17), and historical data from the Inst. of Mar. Res., Norway, indicate that such an upwelling is present here most af the time (Danielssen, pers. com.). In addition to what can be recognized in several of the horizontal distribution maps, this eddy was also tracked by a buoy from 10-17 June. In the western part of the eddy the southward movement of the water was rather slow, while in the eastern part the northward velocities were about 50-60 cm.

From the biological measurements it is evident that this area to the north of Skagen exhibited the highest values of secondary production (of the areas studied), and it is assumed that this fact is related to the convergence of the water and that the eddy is bringing out (westwards) a stable thin surface layer with high nutrient contents etc. favouring a high biological production.

A similar upwelling phenomenon can be seen in the north eastern area of the Skagerrak (cf. lower image in Fig. 7), indicating the presence of a strong eddy feature bringing NCW far south from the coast. Due to the bottom topography, this eddy can be caused by a similar process as described above, this time by the AW flowing northwards towards the Norwegian coast, punching into and initiating a meandering process here.

Another mesoscale feature west of Hanstholmen at about 57° N (earlier discussed by Aure **et al.**, 1990) is as an example seen in the salinity distribution of May 23-25 (Fig. 10). Here a fraction of the watermasses from the North Sea (either CNSW and/or AW^{h}) flowing towards the Skagerrak, turns southwards due to topographical steering. Such a tendency of a southward flux will tend to block a possible inflow of JCW. This blocking mechanism is clearly different from the above described directly winddriven SW meeting the JCW, and the SKAGEX data confirm that the pulsation of the AW^{h}/CNSW might be important for the steering of the inflow of the JCW.

5.3 Nitrification processes

In the SKAGEX I experiment, elevated concentrations of nitrite (and ammonia, which was measured in the G section only) were observed in the water below the halocline outside the Danish as well as the Norwegian coast lines, generally at depths of 30 m to the bottom at 100-400 m throughout the whole period in the sections C, E, F, G and H.

In the following, these features will be described by choosing a representative transect from the SKAGEX I experiment (May-June 1990), when current measurements were carried out. It should be pointed out, that all through SKAGEX II (September 1990) and IV (May 1991) similar results were obtained. In the winter experiment, SKAGEX III (January 1991), such maxima were not observed.

In a section close to section G, a series of recording current meters were anchored, and the results (averaged over three days, 26-28 May) are presented in Fig. 3 (May 27). For comparison, the distribution of salinity, nitrate, ammonia and nitrite in section G on May 27 are shown in Figures 11 a-d.

The nitrate distribution (Fig. 11 c) shows that the highest concentrations were found close to the centre of the section between stations 4 and 6, which coincides with the zero velocity zone in the current section (Fig. 3). South of the zero-line, in the inflowing Atlantic Water (salinity > 35.0, Fig. 11 a), the ammonia distribution shows a maximum (station 8-9 in Fig. 11 c), extending down to the bottom.Nitrite also shows a maximum, but somewhat closer to the centre of the section (at station 7 in Fig. 11 d). Both ammonia and nitrite maxima coincide with an increasing nitrate gradient towards the centre of the transect.

North of the zero velocity zone (Fig. 3), at the Norwegian coast, there is a similar situation. Both ammonia and nitrite show elevated concentrations down to the bottom at about 300 m, and, again, the nitrate shows an increasing gradient towards the centre or the current zero-line.

A study of the current section shows that the ammonia maximum was located in the core of the inflowing Atlantic Water, where the current velocity was higher than 30 cm/s. The nitrite maximum appeared north of the core and at lower velocities, 15-20 cm/s. At the Norwegian coast, both ammonia and nitrite maxima were found in the outflowing water with the highest velocities.

It is known, that when organic material is degrading, the amines from proteins form ammonia. Eventually, ammonia may be oxidized to nitrate in a process called nitrification. This process is carried out in two steps, first to nitrite and then further to nitrate, by two different kinds of nitrifying bacteria. Based on the experiences from SKAGEX I and II, it was decided that the nitrification potential should be measured during SKAGEX IV (May 1991) by means of incubation of water samples with nitrogen-15. Samples were collected all over the SKAGEX area at various depths and prepared for this purpose. They are still to be analyzed.

One hypothesis is, that the ammonia in the inflowing water emanates from algal production and subsequent algal degradation in surface water before it enters the Skagerrak as a subsurface current. The Atlantic Water (AW in Fig. 1b) originates in an area west of Norway with a very high productivity (Föyn, pers. comm.). The formation of ammonia, appears to be under way in the core of the Atlantic Water with the highest velocity. This is the youngest water in the sense that it most recently was at the surface, in the photic layer of the Northern North Sea.

In the Skagerrak, the current velocity decreases on the northern side of the core and at the same time it is forced to the left (see Chapter 4). Meanwhile, the ammonia is oxidized to nitrite, and the nitrite maximum appears in water with higher age. The final step is the formation of nitrate, and consequently, an increasing nitrate gradient towards the centre of Skagerrak.

The deep water in the Skagerrak is turning to the north outside the Swedish coast and is flowing back westward along the Norwegian coast (see Chapter 4). Similar nitrite maxima could be observed in the C transect (Fig. 1b) (ammonia was not measured) and along the Norwegian coast. Separation of the nitrification substrate (ammonia) and products (nitrite and nitrate) into different water masses was also found there, even if the frequency (in space) of sampling points does not make it obvious in all sections.

Another explanation to the separated ammonia and nitrite maxima may be that water with ammonia and nitrite maxima have different origins in the North Sea (cf. Chapter 3) and, therefore, do not coincide. Because, on some occasions, (not shown in Fig. 11) high ammonia concentrations were found in SNSW, which was low in nitrate. In those cases, the ammonia could be the degradation product from an earlier algal production in the Southern North Sea.

The winter experiment, SKAGEX III, did not show any ammonia and nitrite maxima in the Atlantic Water, which could be explained by low productivity during the winter season.

5.4 Subsurface chlorophyll-a and primary productivity maxima

A pronounced feature during the cruises in May and September 1990 and in May 1991 was the large concentrations of phytoplankton found at subsurface levels over large areas in the Skagerrak and northern Kattegatt (Fig. 12). The vertical profiles of fluorescence and chlorophyll-a exhibited single or multiple peaks at levels from approximately 10 m down to more than 30 m depth. Such high subsurface concentrations of chlorophyll-a has earlier been reported from this area by Dahl and Danielssen (1981), Pingree **et al.** (1982) and Dahl **et al.** (1987).

In September, during SKAGEX II, maxima were at times found as deep as 40-50 m depth (Fig. 13) in the border between the upper nutrient-poor water (SW) and the nutrient-rich Atlantic water (AWh) (Fig. 14). During this period, more than 4 ug/l chlorophyll-a was recorded (Fig. 14) and up to 370 000 cells/l of **Gyrodinium aureolum** were found at transect F. In a previous study carried out during the same time of the year, Dahl **et al.** (1987) also found that the subsurface maximum consisted mainly of **G. aureolum**. The authors stated that **Gyrodinium** may have utilized nitrogen down to at least 50 m depth. This statement is supported by the findings of Paasche **et al.** (1984) and Richardson and Kullenberg (1987), which indicate that **G. aureolum** is able to assimilate nitrogen at low light intensities.

When multiple peaks appeared, they were often separated by only one or a few metres. The species composition usually differed in the different peaks. At the transect in northern Kattegat (B) in May-June 1990 for instance, the upper peaks of fluorescence were generally dominated by diatoms and the lower peaks by dinoflagellates.

The subsurface chlorophyll maxima were generally found in stratified water bodies, below the pycnocline. The phenomenon in May, June and September can, however, be considered to general, occurring over wide areas, in water bodies of qiute different charateristics. It was thus found in the northwestern Kattegatt, in the central Skagerrak and along parts of the western coast of Jutland. It was conspicuous, however, that the Southern North Sea Water (SNSW) entering the Skagerrak, contained very low chlorohyll-a concentrations throughout the May-June cruises (Fig. 12).

The high concentrations in the central Skagerrak seem to be sustained over long periods of time due to a more or less continuous supply of nutrients found in the border area between the surface water and the nutrient-rich Atlantic water. This border area appears as a "ridge" in the central Skagerrak and the nutrients are through upwelling spread along the sides of this "ridge" (Fig. 14).

High concentrations of phytoplankton in the surface layers also occur (Fig. 15). They may be found along the coasts during situations of upwelling, and in the nitrate-rich Jutland Coastal Water (JCW), which originates from the German Bight. The resulting high lightsaturated primary productivity in this water mass was clearly recognized at transect H.

Although the subsurface chlorophyll maxima were observed on many occasions and over substantial periods during SKAGEX I, no **in situ** primary production measurements were made to quantify the activity of these phytoplankton populations and their contribution to the total water column productivity. During SKAGEX IV, however, in situ primary production measurements were introduced at a station in north west Kattegat where a pronounced chlorophyll maximum was found in a high salinity (33.6) water body close to the bottom (Fig. 16). These measurements, which were run over a period of three days, showed that the primary production maxima throughout the period coincided with the chlorophyll maxima (which was located in the nutricline). The nutricline was initially at a depth of 13 metres, the next day at 15 metres and day three at 18 metres. The primary productivity remained high as the depth of the nutricline increased and the productivity rates were very high, even when compared with rates generally found in surface layers.

Secondary production

During SKAGEX I in May-June 1990, a group of planktologists were engaged in measurements of copepod egg production (Tiselius **et al.** 1991). This was performed on six transects ranging from northern Kattegat to western Skagerrak. These studies showed that the shallow areas north of Skagen were the most productive overall. However, large variations in egg production over short distances were observed in this area (Fig. 17). This is also clearly illustrated in measurements of lightsaturated primary production in the area.

Relatively high and stable values were recorded in northern Kattegat during the period 8-20 June. This corresponds to the relatively stable hydrographical conditions in the area where only minor water exchange with Skagerrak could be observed.

In the coastal water along western Jutland, high levels of secondary production were recorded during the period June 14-17. During the same period, high rates of primary production were also recorded in that area.

6. Concluding remark

The significant and variable inflows from the North Sea of different water masses found during SKAGEX, clearly indicate that many of the physical, chemical and biological processes in the Skagerrak are strongly affected by processes outside, especially processes in the North Sea. In relation to nutrient budget and biological productivity speculations it must be important to recognize the mechanisms of the rapid shifts between the different inflowing water masses and their individual variability with time. It is assumed that ongoing efforts in running full 3-dimensional, baroclinic, numerical models for the North Sea and the Skagerrak/Kattegatt will be of great help to study these mechanisms, and the SKAGEX data-sets are probably one of the best, ever obtained to evaluate such regional models.

7. Acknowledgements

The authors want to express their sincere thanks to Dr M. Windsor, Edinburgh, for his kind linguistic revision of the manuscript.

8. References

Aure J., Svendsen E., Frey F.and H. R. Skjoldal (1990): The Jutland Current: Nutrients and Physical Oceanographic Conditions in Late Autumn 1989, ICES, C.M. 1990/C:35.

Böhle B. (1989): Ressurser av fisk, krebsdyr og sel i Skagerrak. Flödevigen Meldinger, nr 3 - 1989, pp. 1-115.

Dahl E. and D.S Danielssen (1981): Hydrography, nutrients and phytoplankton in the Skagerrak along the section Torungen-Hirtshals, January-June 1980. In: Saetre R. and M. Mork (eds): The Norwegian coastal current. University of Bergen , pp. 294-310.

Dahl E., Danielssen D.S., Semb A. and K. Tangen (1987): Precipitation and run-off as a fertilizer to a *Gyrodinium aureolum* Hulburt bloom. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 187, pp. 66-73.

Föyn L. (1990): SKAGEX 1990. Preliminary results from the nutrient calibration. ICES. C.M. 1990/C:44. Ref.E.

Håkansson, B. (1990): Remotely sensed water mass distribution and large scale surface circulation in the Skagerrak. ICES, C.M. 1990/C:15, Sess. P.

Håkansson B., Mork M., Sjöberg B. and E. Evjen (1990): A comparative analytical, numerical and experimental study of buoyant flows. Kungl. Vetenskaps- och Vitterhets- samhället i Göteborg, Acta Geophysica (ed .P. Lundberg), pp. 20-39.

Johannessen J.A., Svendsen E., Sandven S., Johannesen O.M. and K. Lygre (1989): Three dimensional structure of mesoscale eddies in the Norwegian coastal current. J. Phys. Oceanogr., 19, pp.3-19.

Ljöen R. (1981): On the exchange of deep waters in the Skagerrak basin. In: Saetre R. and M Mork. (eds): The Norwegian Coastal Current. The University of Bergen, pp. 340-356.

Magnusson A.K. (1985): Plume model for bottom water renewal in the Skagerrak. Thesis (in Norwegian) in physical oceanography, Geophysical Institute, University of Bergen.

Mork M. (1981): Circulation phenomena and frontal dynamics of the Norwegian coastal current. Royal Soc. London, Philosophical tranactions, Serv. A, mathematical and physical sciences, 302(1472), pp. 635-647.

Mork M. and R. Saetre (1980): The Norwegian coastal current. Proceedings from Norwegian coastal symposium, Geilo, vol. 1+2.

Paasche E., Bryceson I. and K. Tangen (1984): Interspecific variation in dark nitrogen uptake by dinoflagellates, J. Phycol., 20, pp. 394-401.

Pingree R., Holligan P., Mardell G. and R. Harris (1982): Vertical distribution of plankton in the Skagerrak in relation to doming of the seasonal thermocline. Cont. Shelf Res., 1, pp. 209-219.

Richardsson K. (1989): Phytoplankton distribution activity in the Skagerrak: a review. ICES C.M. 1989/L:24, Sess Q.

Richardsson K. and G. Kullenberg (1987): Physical and biological interactions leading to plankton blooms: A review of *Gyrodinium aureolum* blooms in Scandinavian waters. Rapp. P.-v. Réun. Cons. Int. Explor. Mer,187, pp. 19-26.

Rydberg L. and L. Andersson (1989): Measurements of Velocities, Hydrography and Nutrients in the Northern Kattegatt during 1984-1989: Data report. Report No 49, Department of Oceanography, University of Göteborg, Sweden.

Svendsen E. and A.K. Magnusson (1991): Climatic Variability in the North Sea. ICES Variability Symposium, No. 10, Session 1.

Svendsen E., Saetre R. and M. Mork (1991): Features of the northern North Sea Circulation. Continental Shelf Research, 11(5), pp. 493-508.

Saetre R., Aure J. and R. Ljöen (1988): Wind effects on the lateral extension of the Norwegian Coastal Water. Continental Shelf Research 8(3), pp. 239-253.

Tiselius P., Nielsen T.G., Breuel G., Jaanus A., Korshenko A. and Z.Witek (1991): Copepod egg production in the Skagerrak during SKAGEX, May-June 1990. Mar. Biol. (in press).

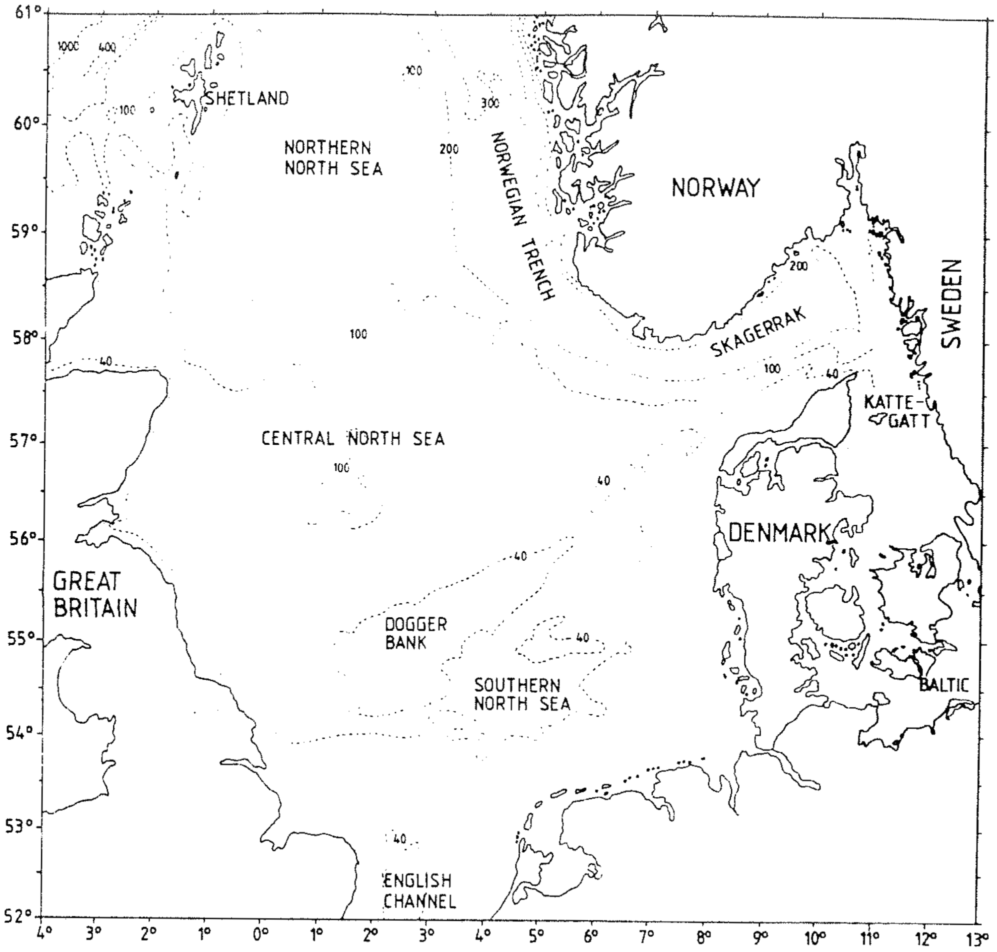


Fig. 1a. Skagerrak, topography and adjacent water areas.

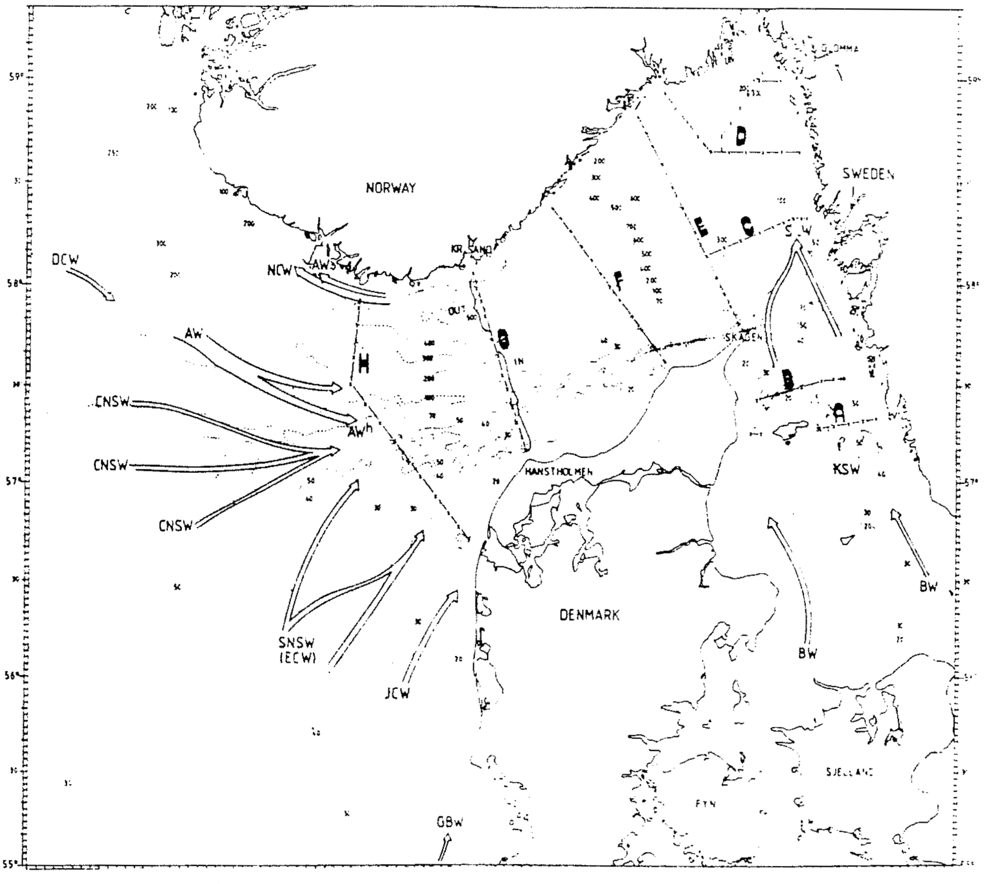


Fig. 1b. Skagerrak, main transects (A-H) and relevant water masses. (AW= Atlantic water, AW^h= Atlantic water high (shallow), AW^l= Atlantic water low (deep), BW= Baltic water, CNSW= Central North Sea water, DCW= Dooley Current water, ECW= English Channel water, GBW= German Bight water, JCW= Jutland coastal water, KSW= Kattegatt surface water, NCW= Norwegian coastal water, SNSW= Southern North Sea water, SW= Surface water).

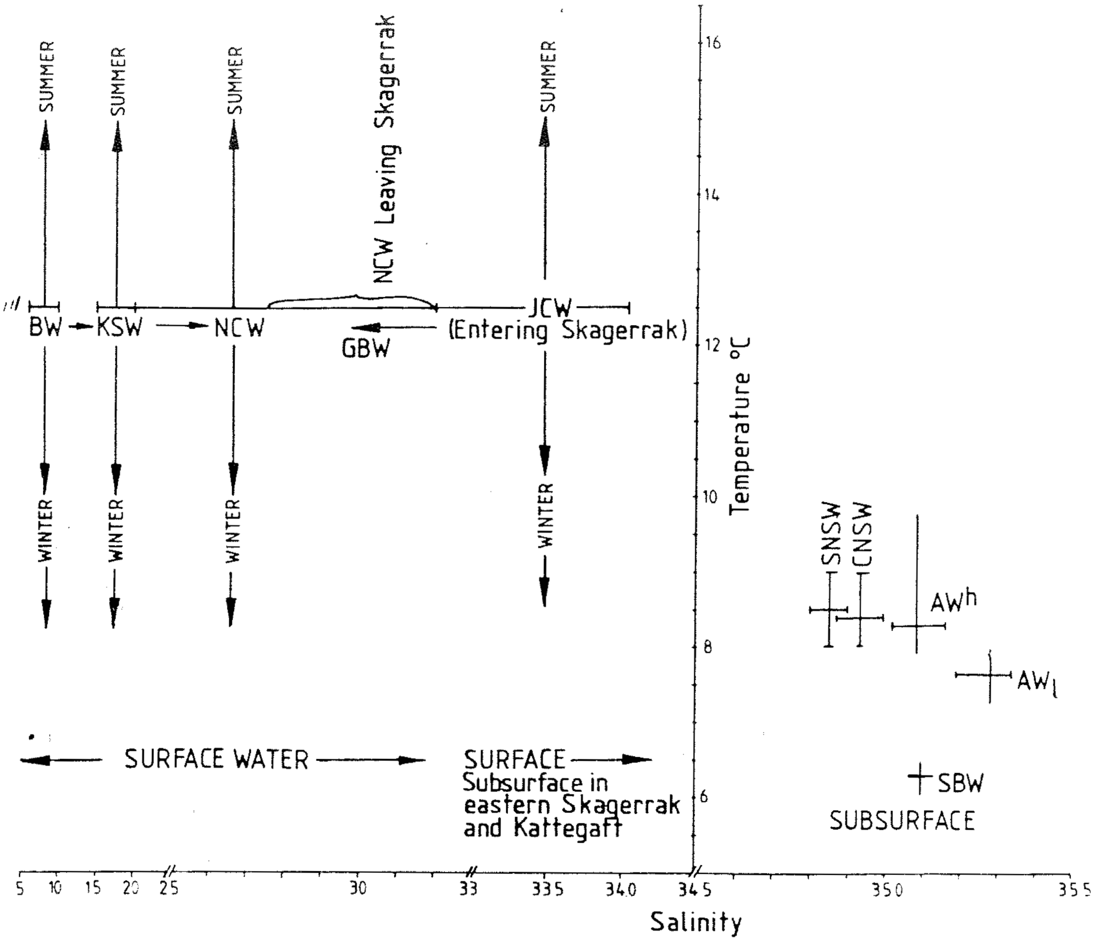


Fig. 2a. Temperature-salinity (T-S) relations between different water masses (SBW= Skagerrak bottom water, other abbreviations, see text and Fig. 1b).

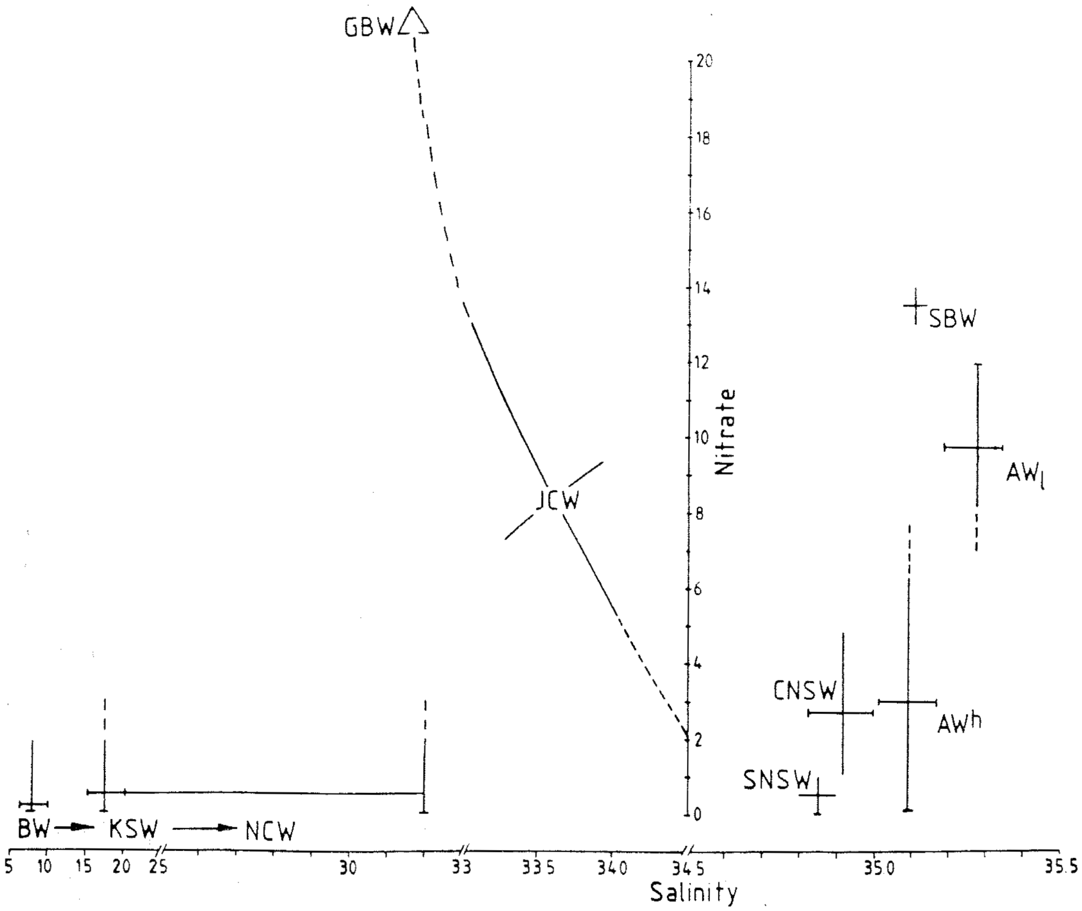


Fig. 2b. Nitrate-salinity (N-S) relations between different water masses (abbreviations, see text and Fig. 1b).

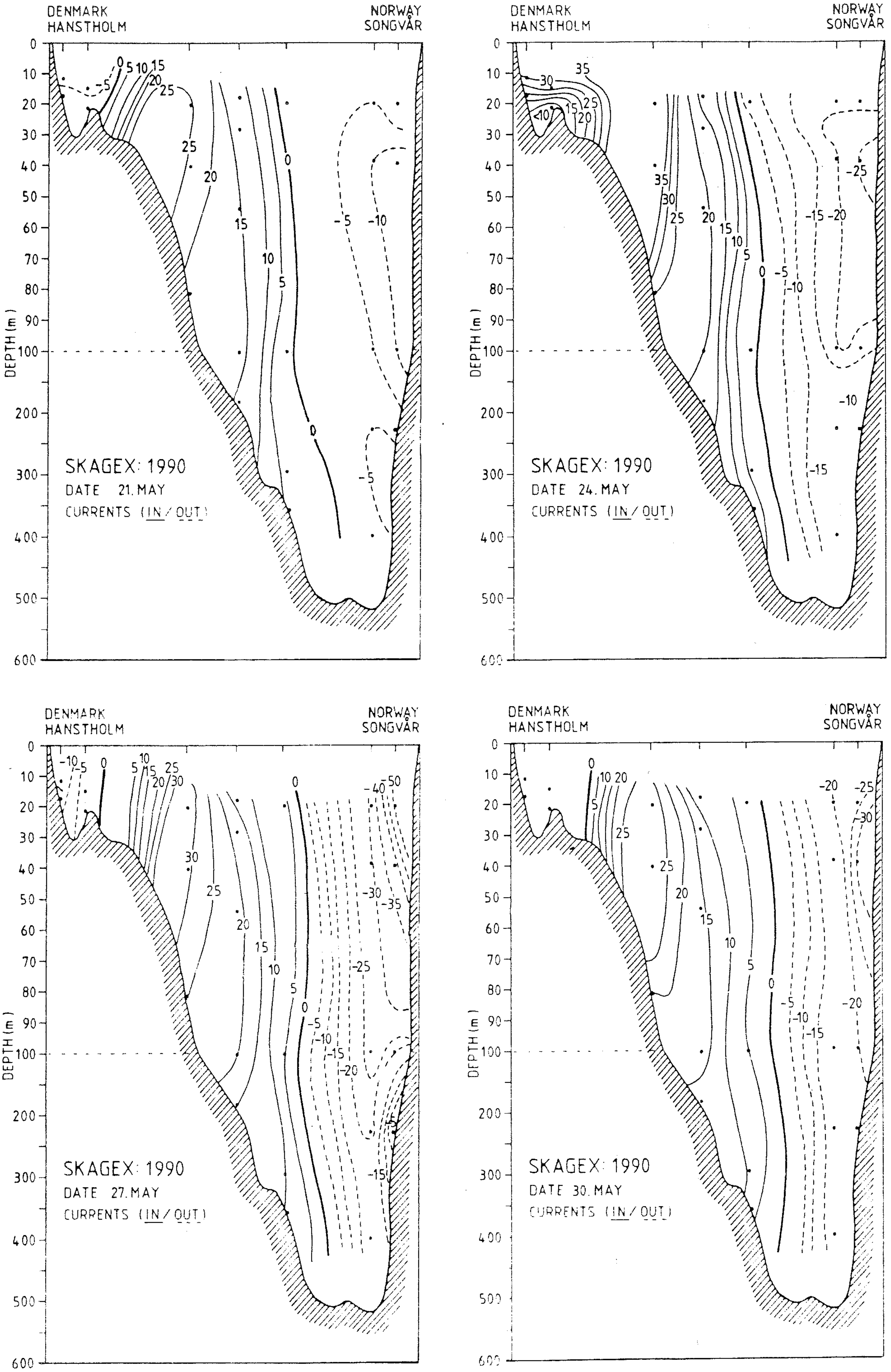


Fig.3 Three day mean in/out flow velocities along the transect G between Hanstholm and Kristiansand from May 21 to June 20, 1990 (21 May, mean flow velocity for May 20-22, May 24, mean flow velocity for May 23-25 etc).

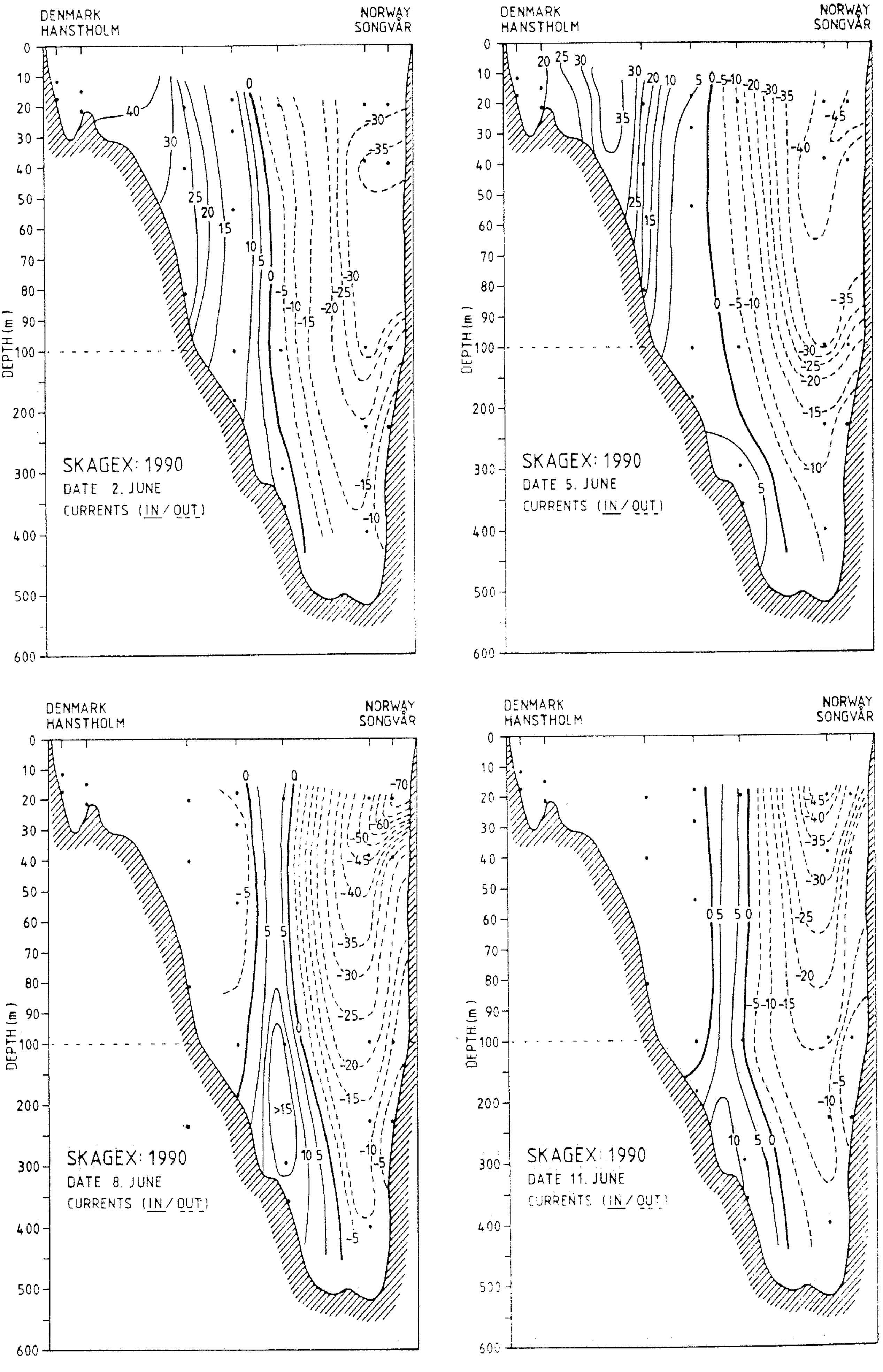
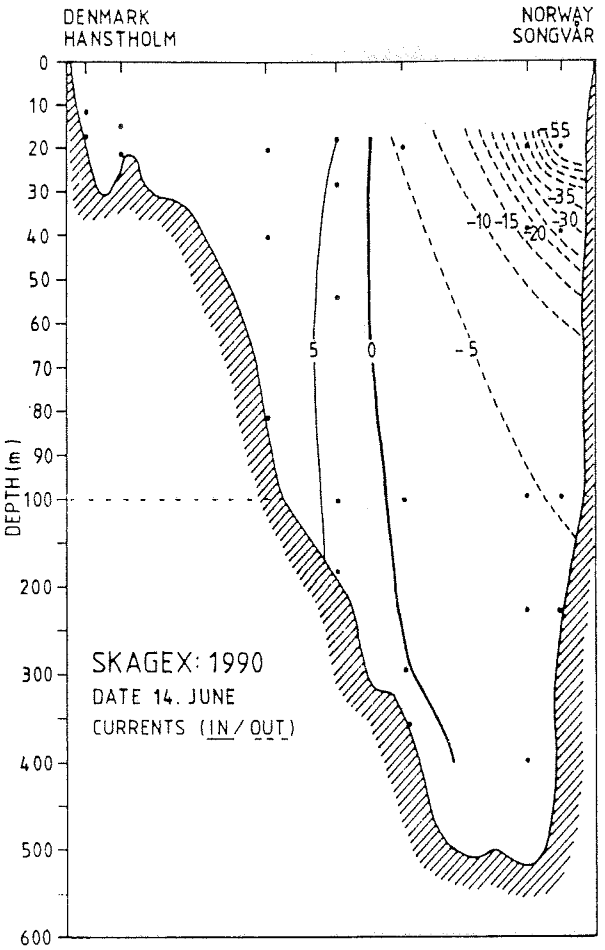

DENMARK
HANSTHOLM
NORWAY
SONGVÅR
DEPTH (m)
0
10
20
30
40
50
60
70
80
90
100
200
300
400
500
600
SKAGEX: 1990
DATE 2. JUNE
CURRENTS (IN / OUT)
40
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
SKAGEX: 1990
DATE 5. JUNE
CURRENTS (IN / OUT)
-40
-45
SKAGEX: 1990
DATE 8. JUNE
CURRENTS (IN / OUT)
>15
-50
-60
-70
SKAGEX: 1990
DATE 11. JUNE
CURRENTS (IN / OUT)

Fig. 3. (cont.)


DENMARK
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DEPTH (m)
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-10
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5
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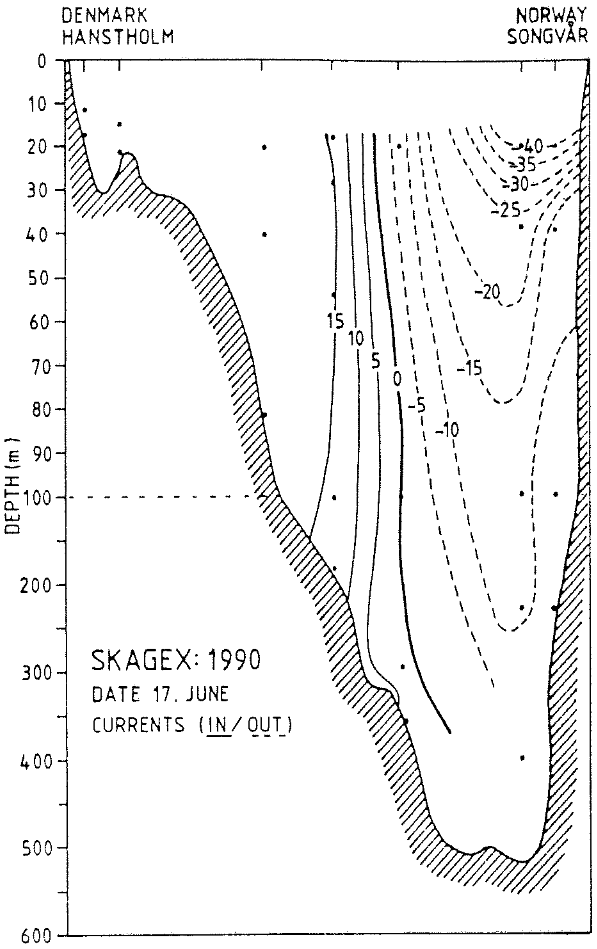
SKAGEX: 1990
DATE 14. JUNE
CURRENTS (IN / OUT)


DENMARK
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600
DEPTH (m)
-40
-35
-30
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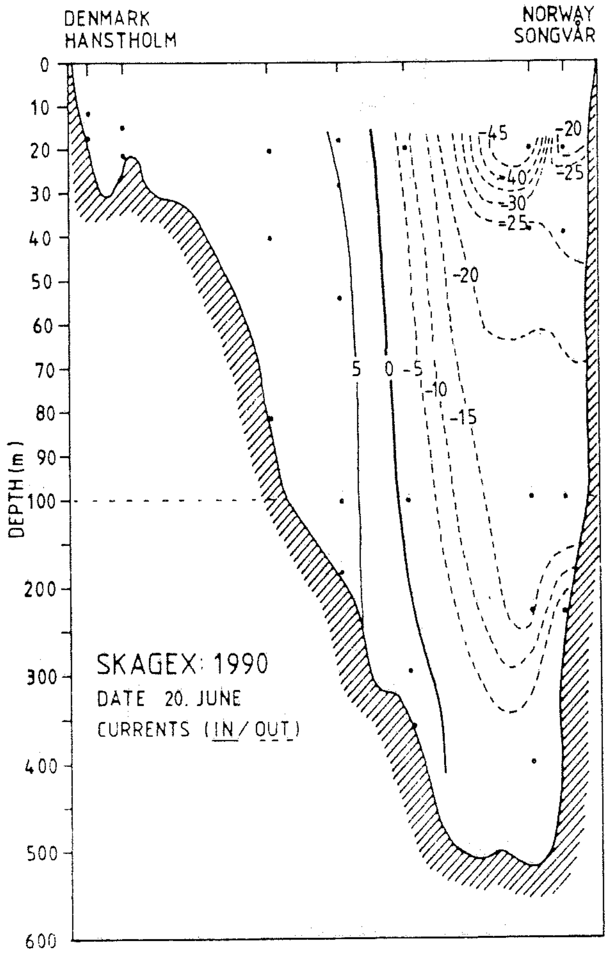
-10
SKAGEX: 1990
DATE 17. JUNE
CURRENTS (IN / OUT)


DENMARK
HANSTHOLM
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DEPTH (m)
-45
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-15
SKAGEX: 1990
DATE 20. JUNE
CURRENTS (IN / OUT)

Fig. 3. (cont.)

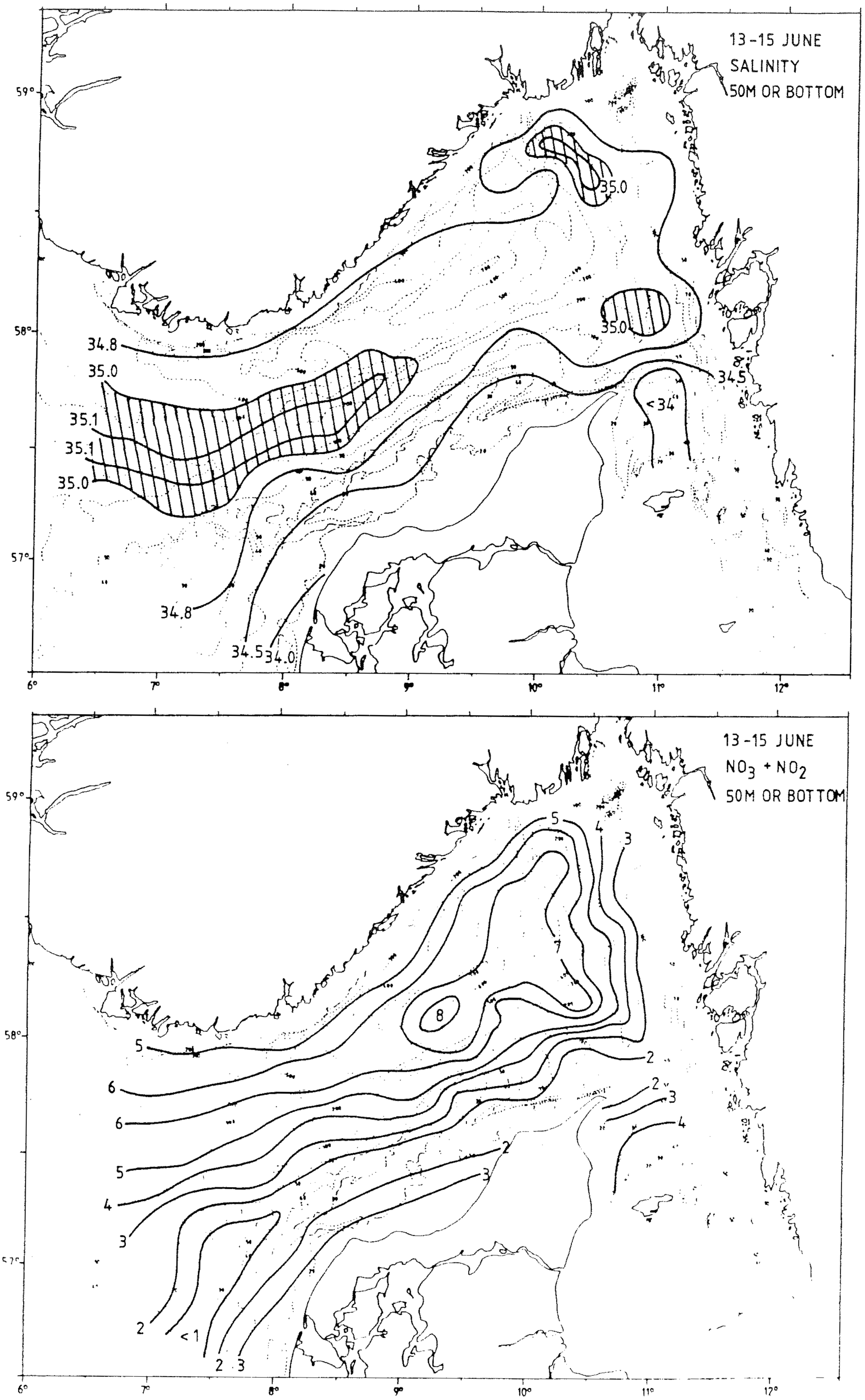


Fig. 4. Horizontal distribution of nitrate and salinity at 50 m depth or at the bottom during June 13 to 15, 1990.

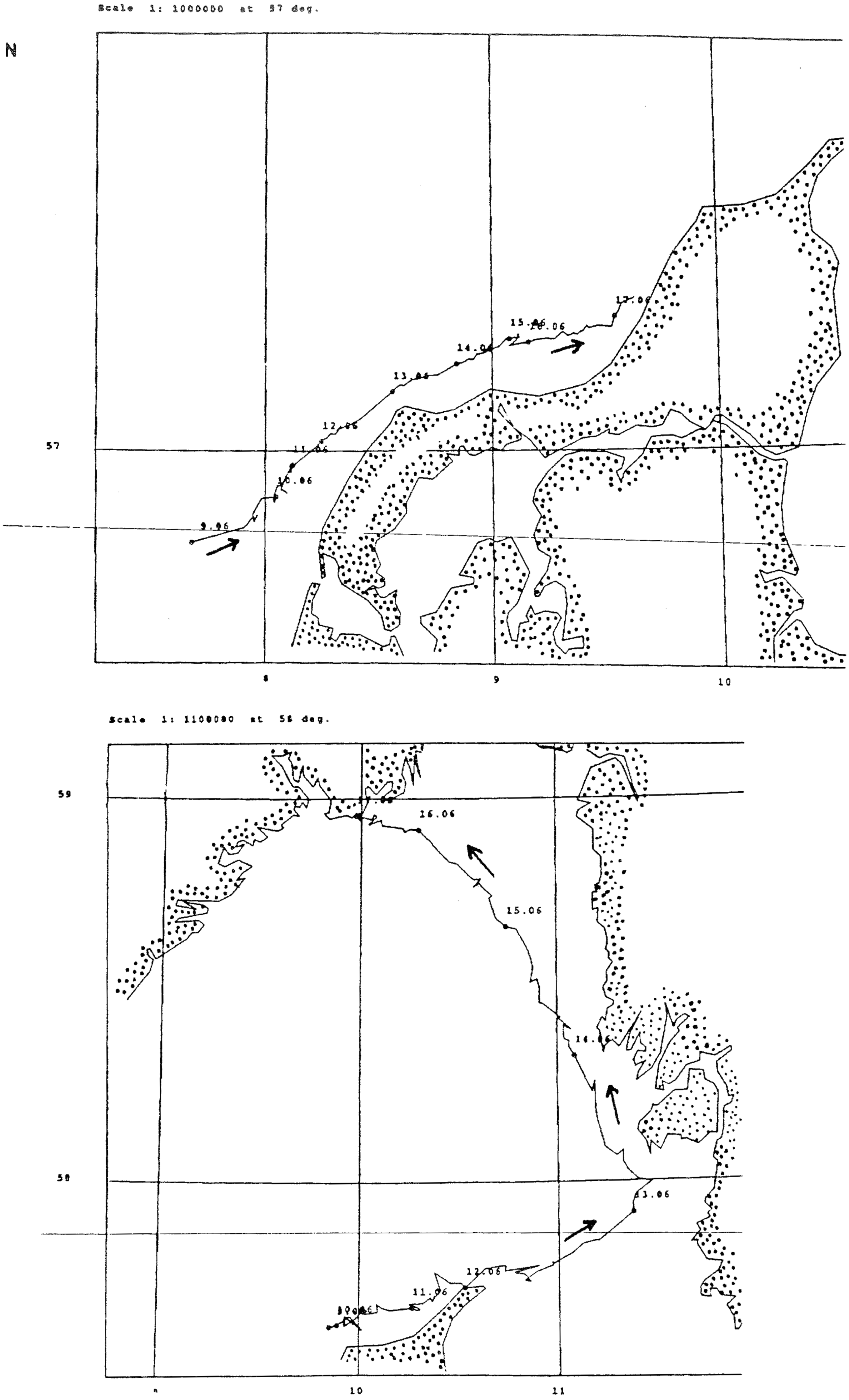


Fig. 5. Some drifter tracks during SKAGEX I.

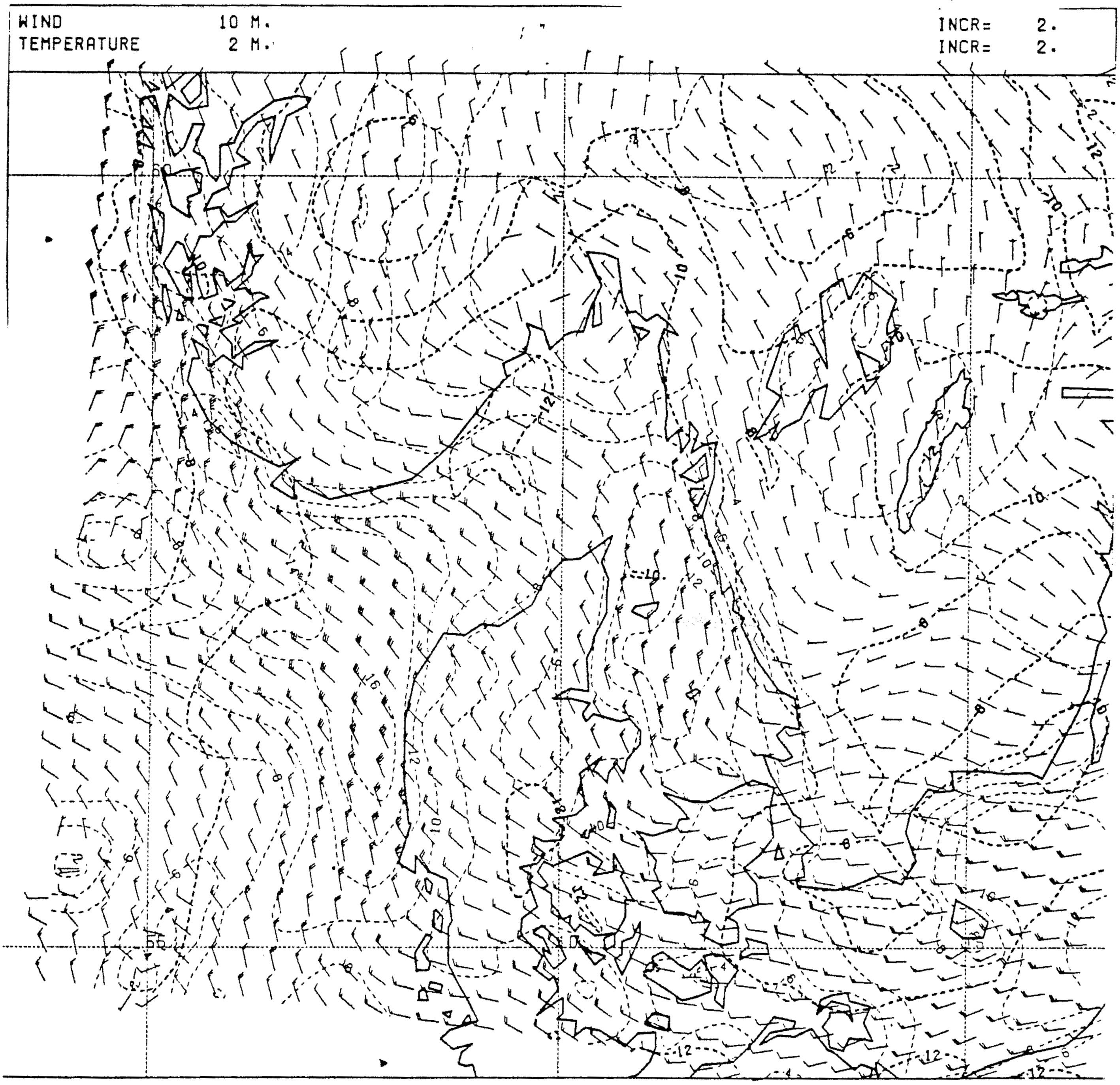


Fig. 6. Winds at 10 m height and air temperature at 2 m height from May 27, 1990, 12^{00} utc.

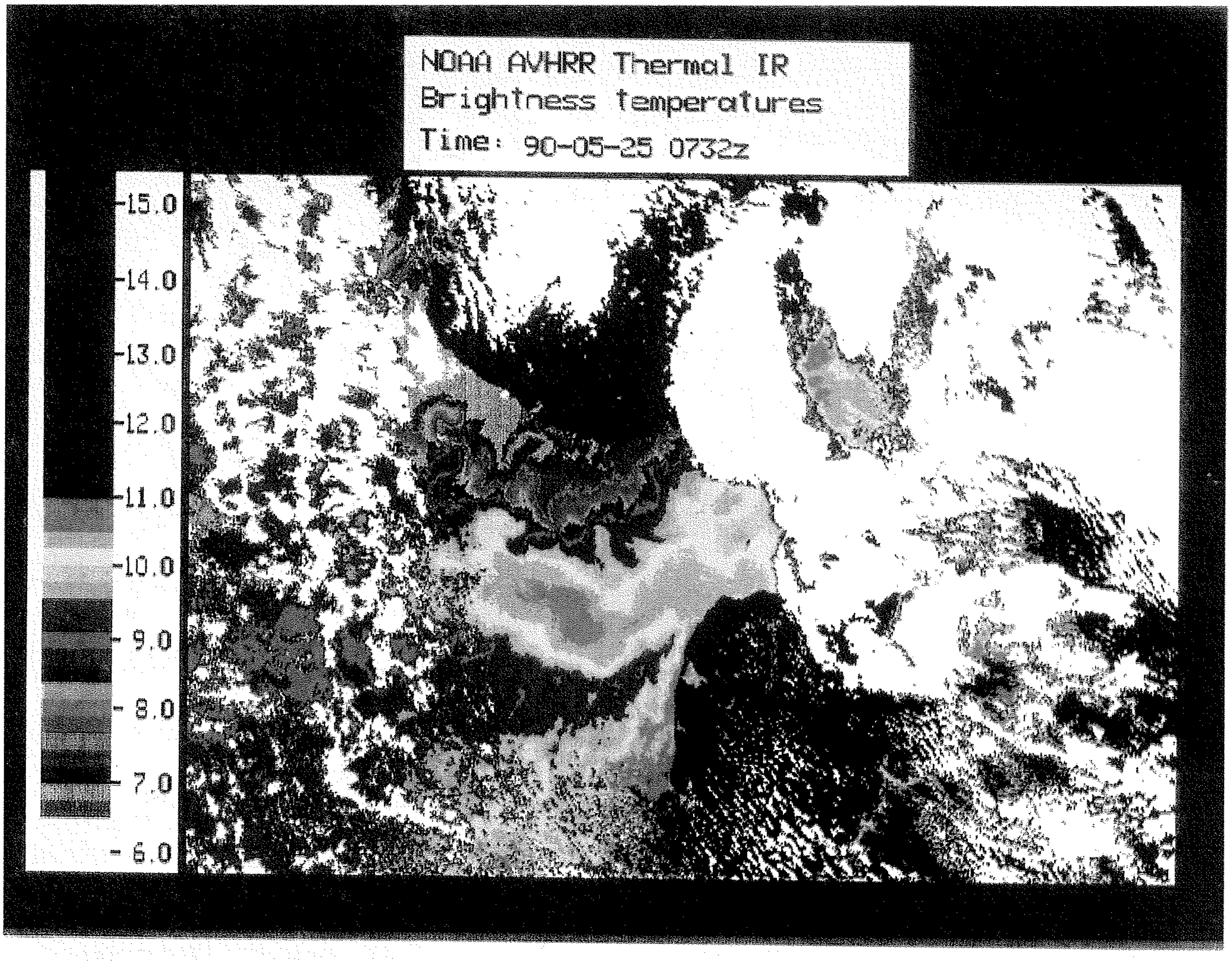
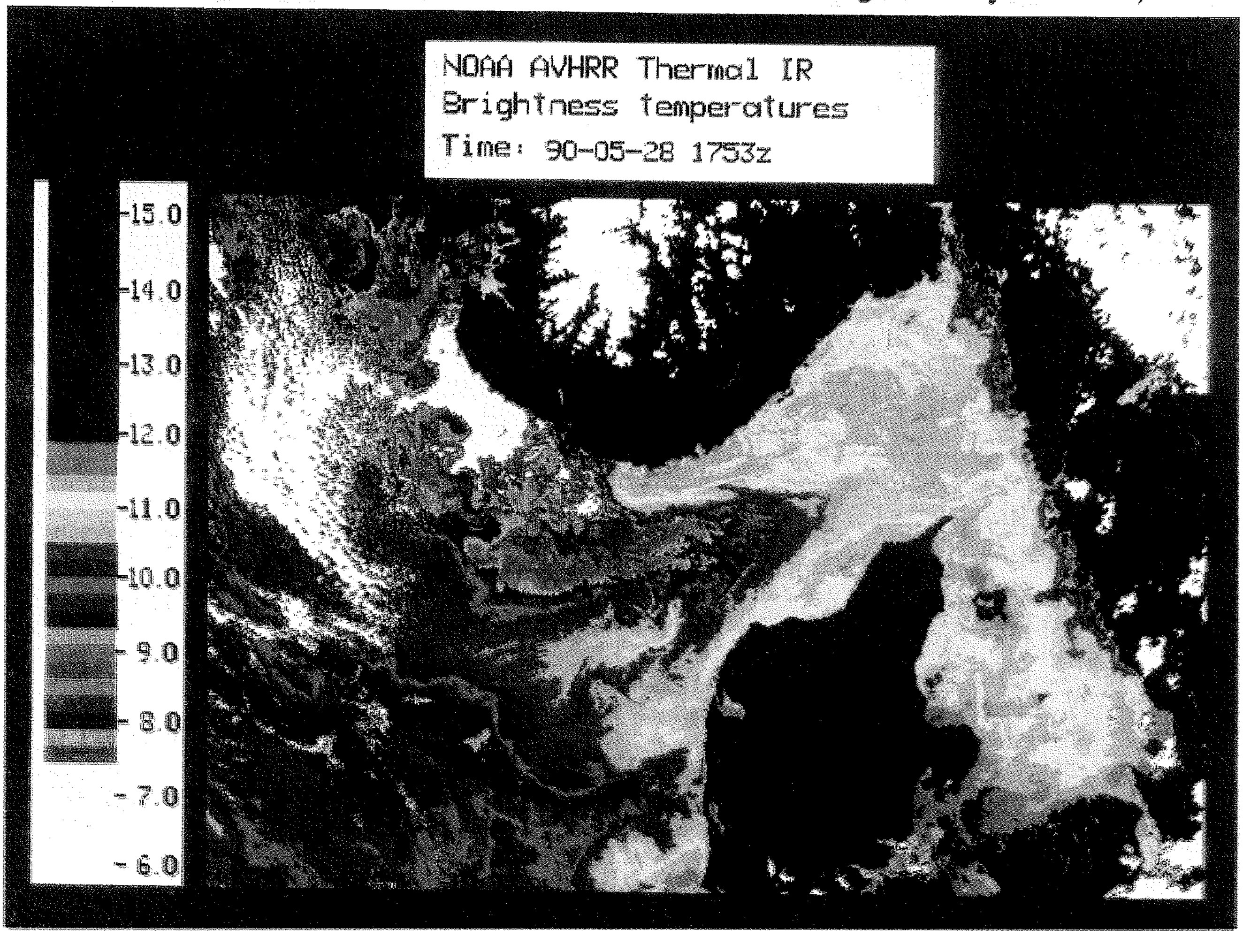


Fig. 7 Sea surface brightness temperature from NOAA-AVHRR images on May 25 and 28, 1990.



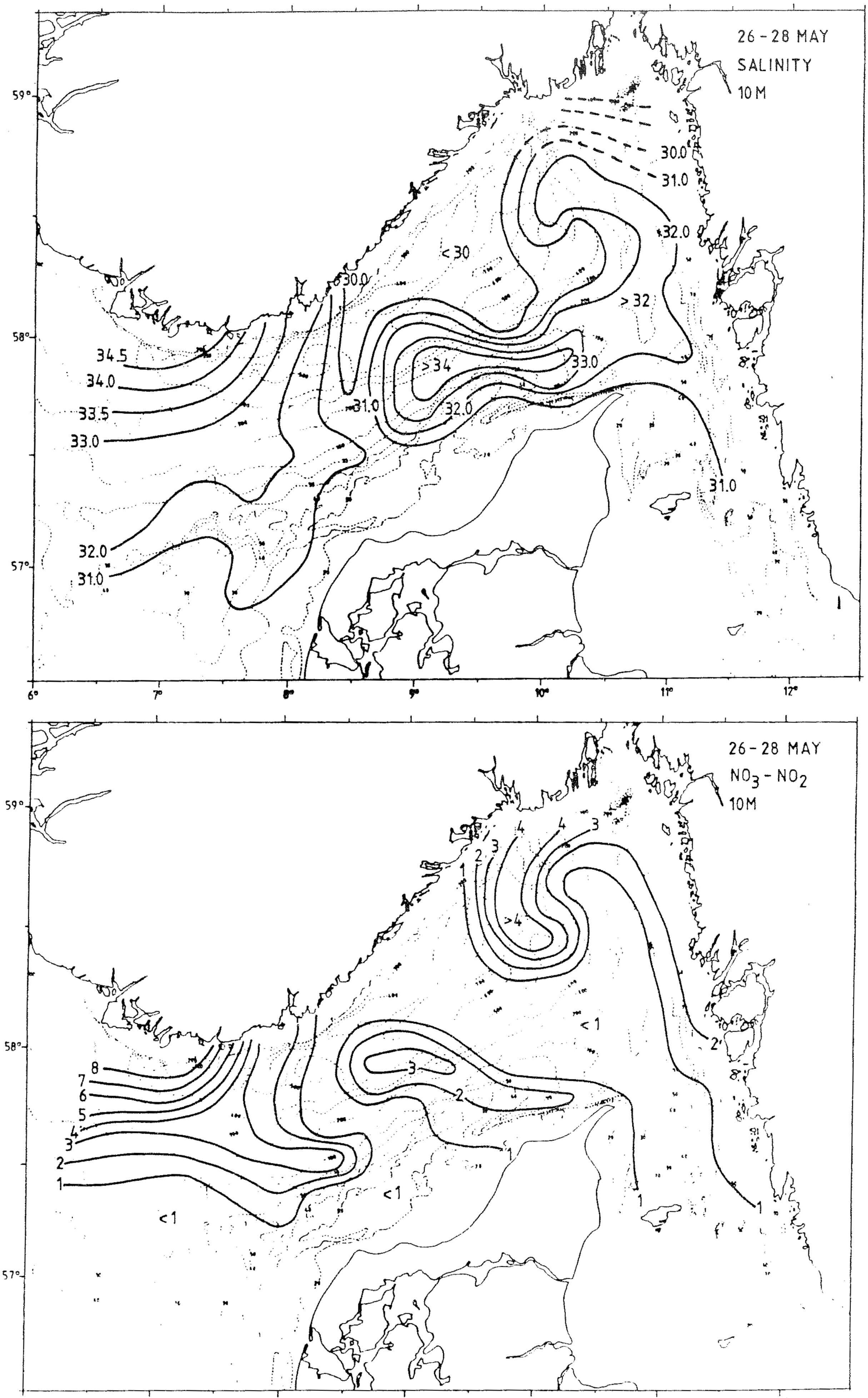


Fig. 8. Horizontal plot of salinity and nitrate from 10 m depth , May 27, 1990.

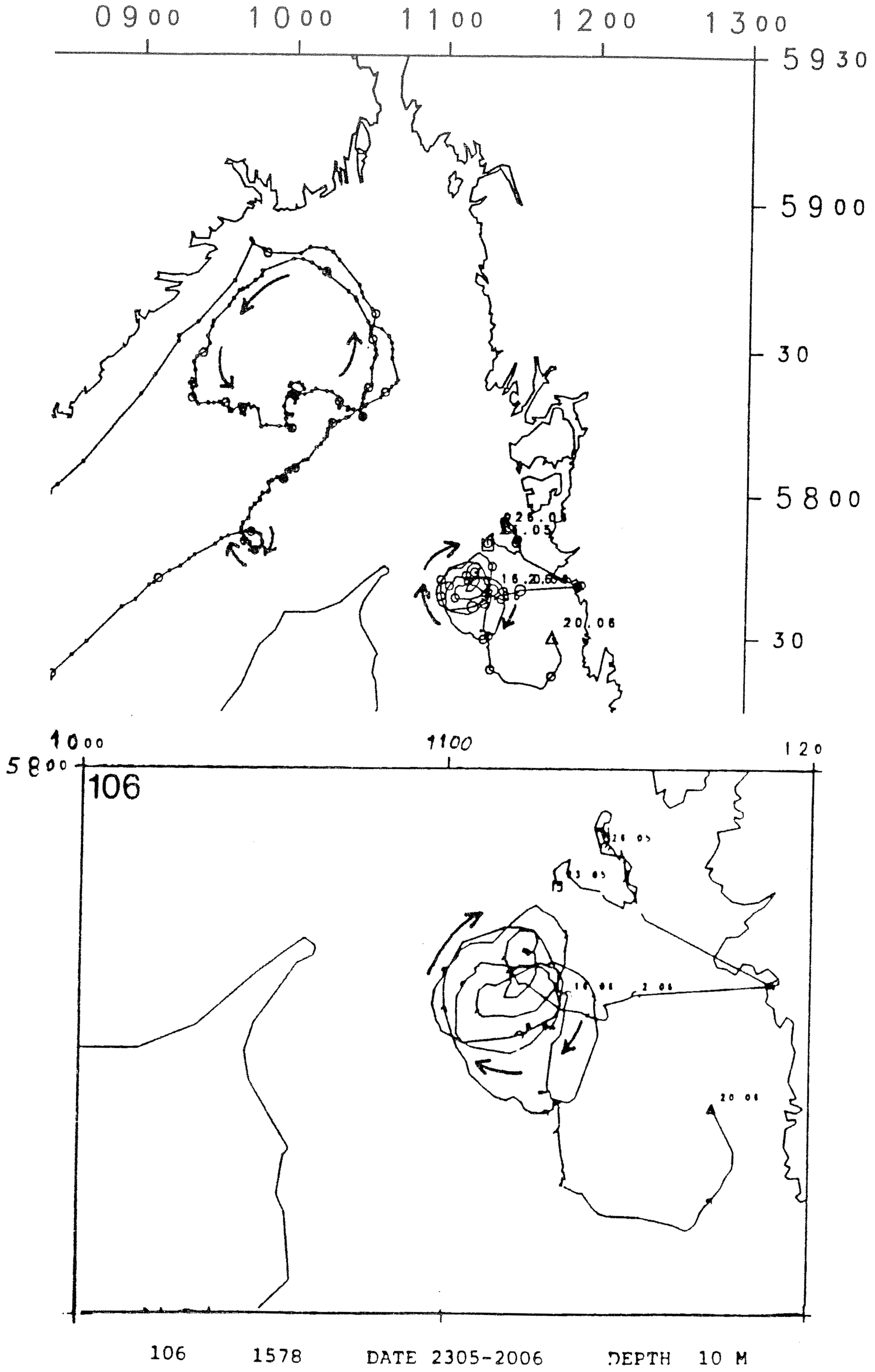


Fig. 9. Argos drifter tracks in the northern Kattegatt during SKAGEX I.

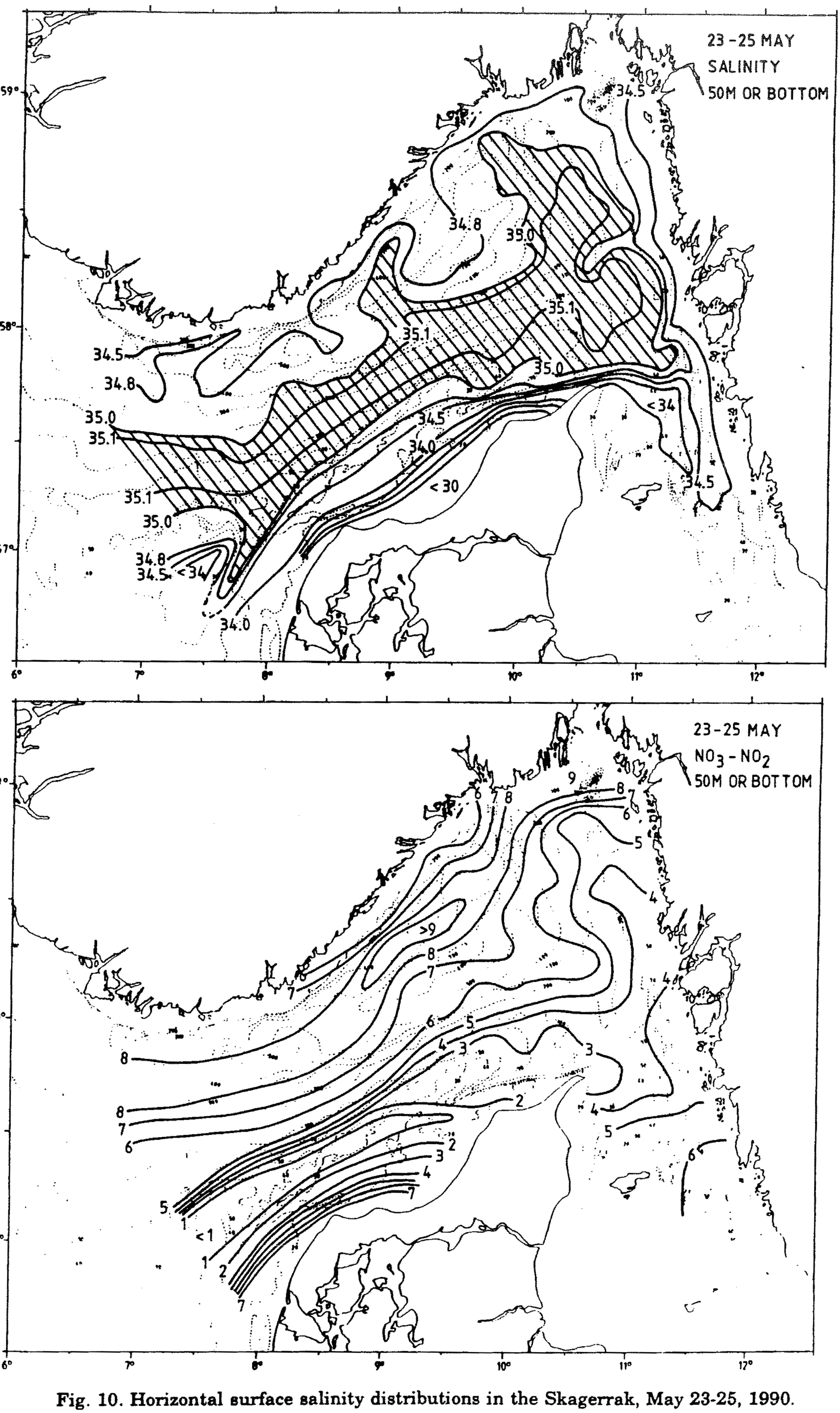


Fig. 10. Horizontal surface salinity distributions in the Skagerrak, May 23-25, 1990.

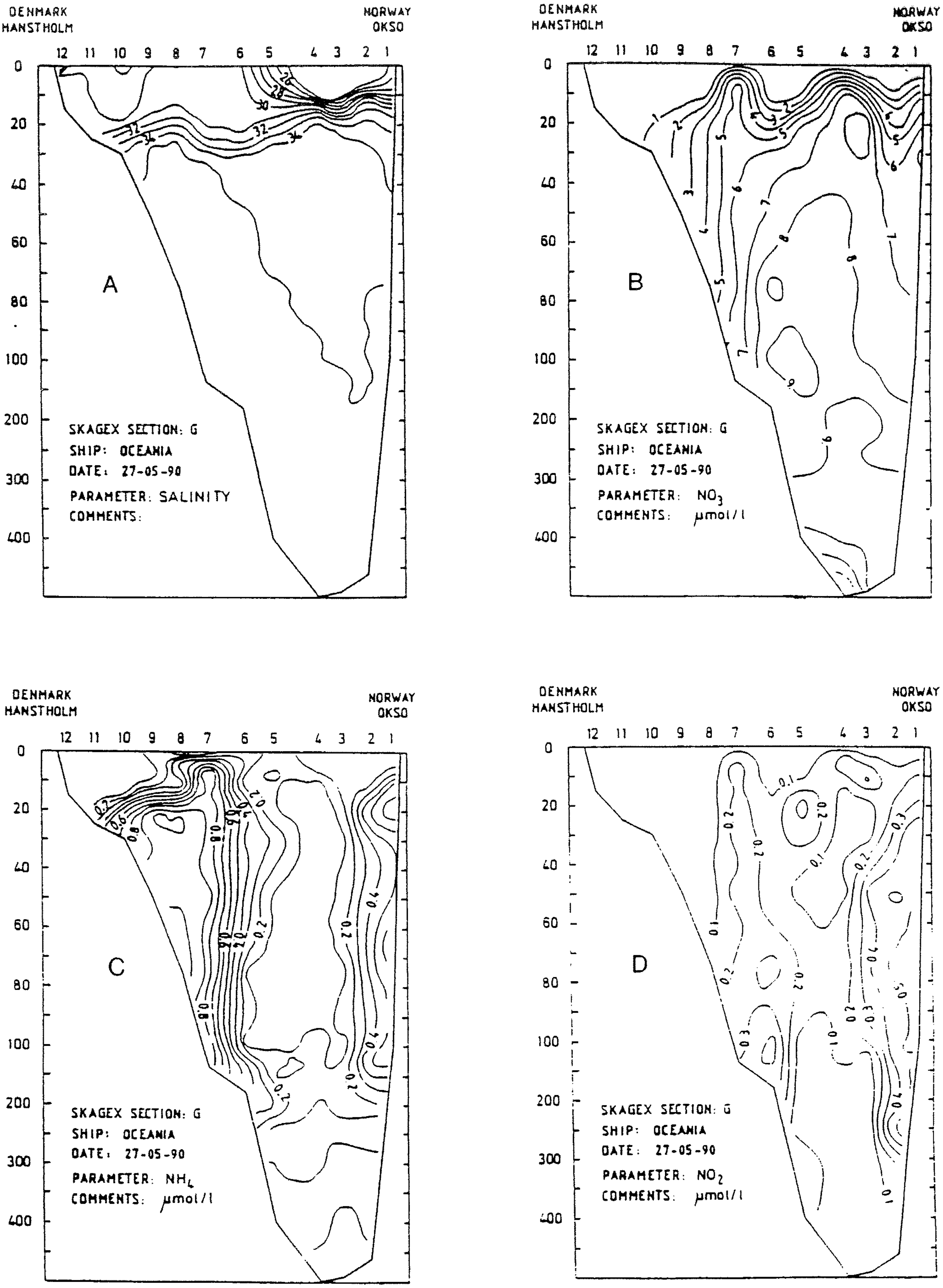


Fig. 11 Distribution of salinity (A), nitrate (B), ammonia (C) and nitrite (D) in section G on May 27, 1990.

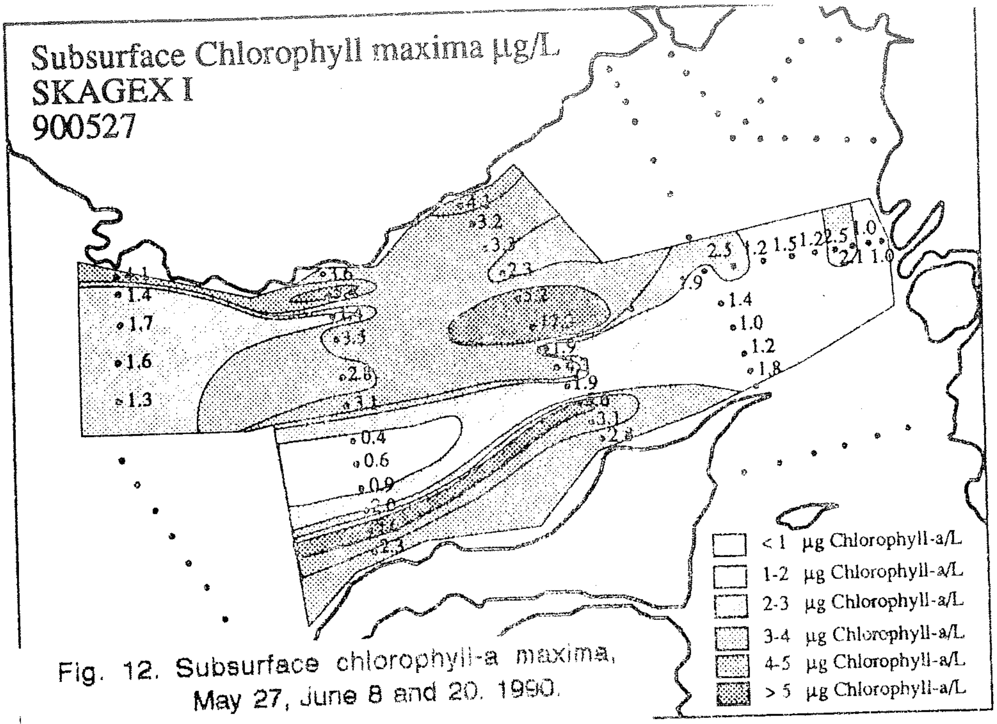
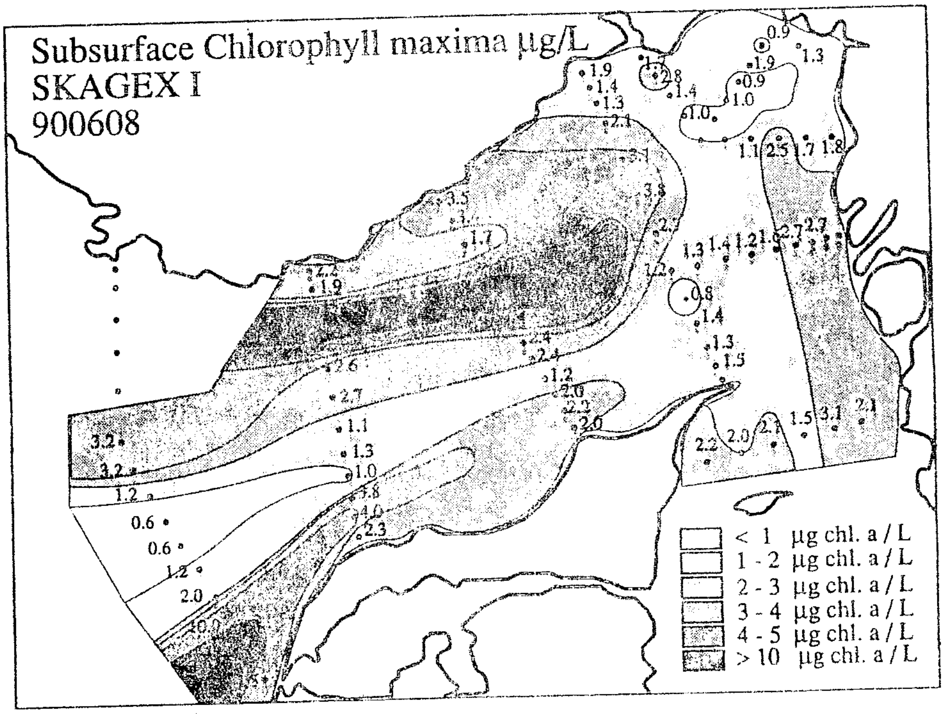
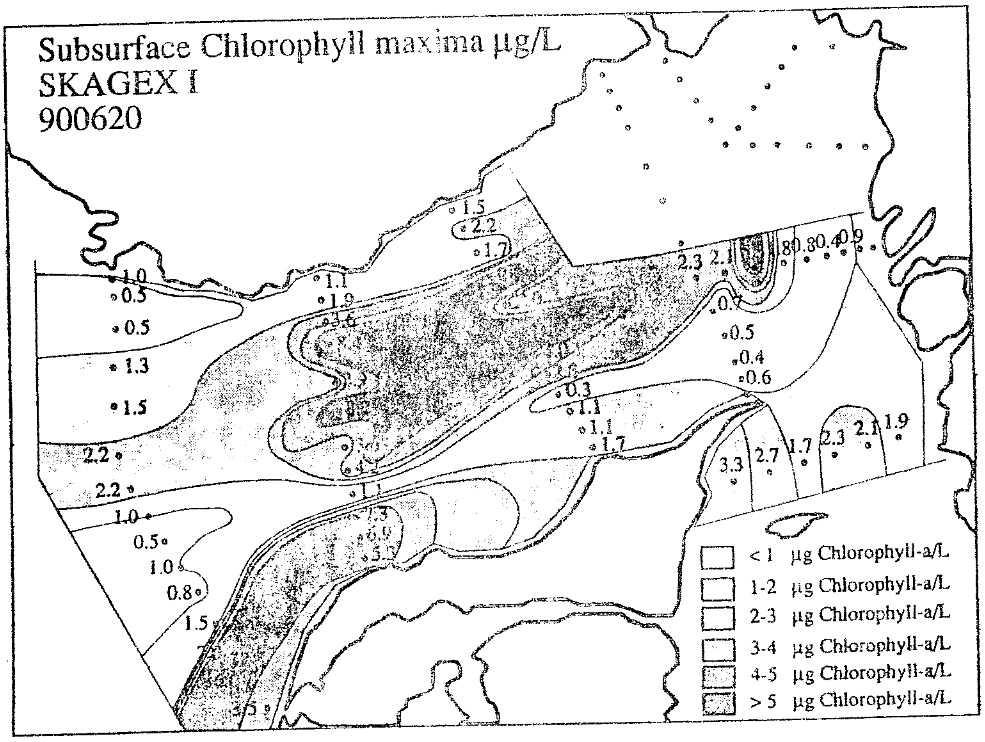


Fig. 12. Subsurface chlorophyll-a maxima, May 27, June 8 and 20. 1990.





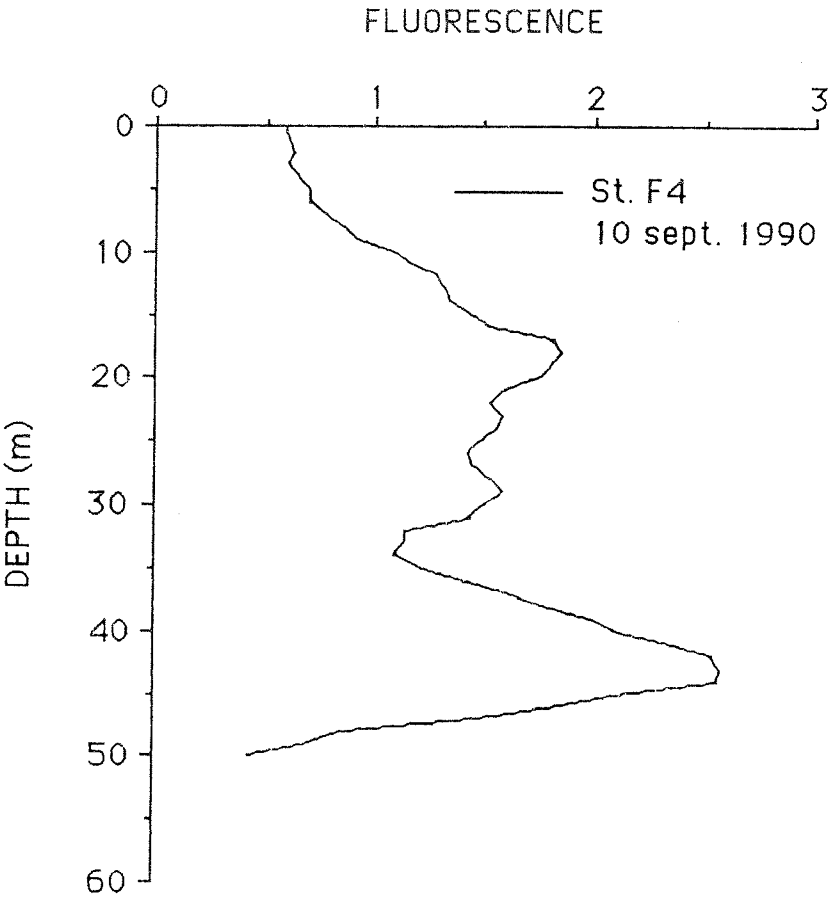


Fig. 13. Fluorescence (arb. units) at station F4, September 10, 1990.

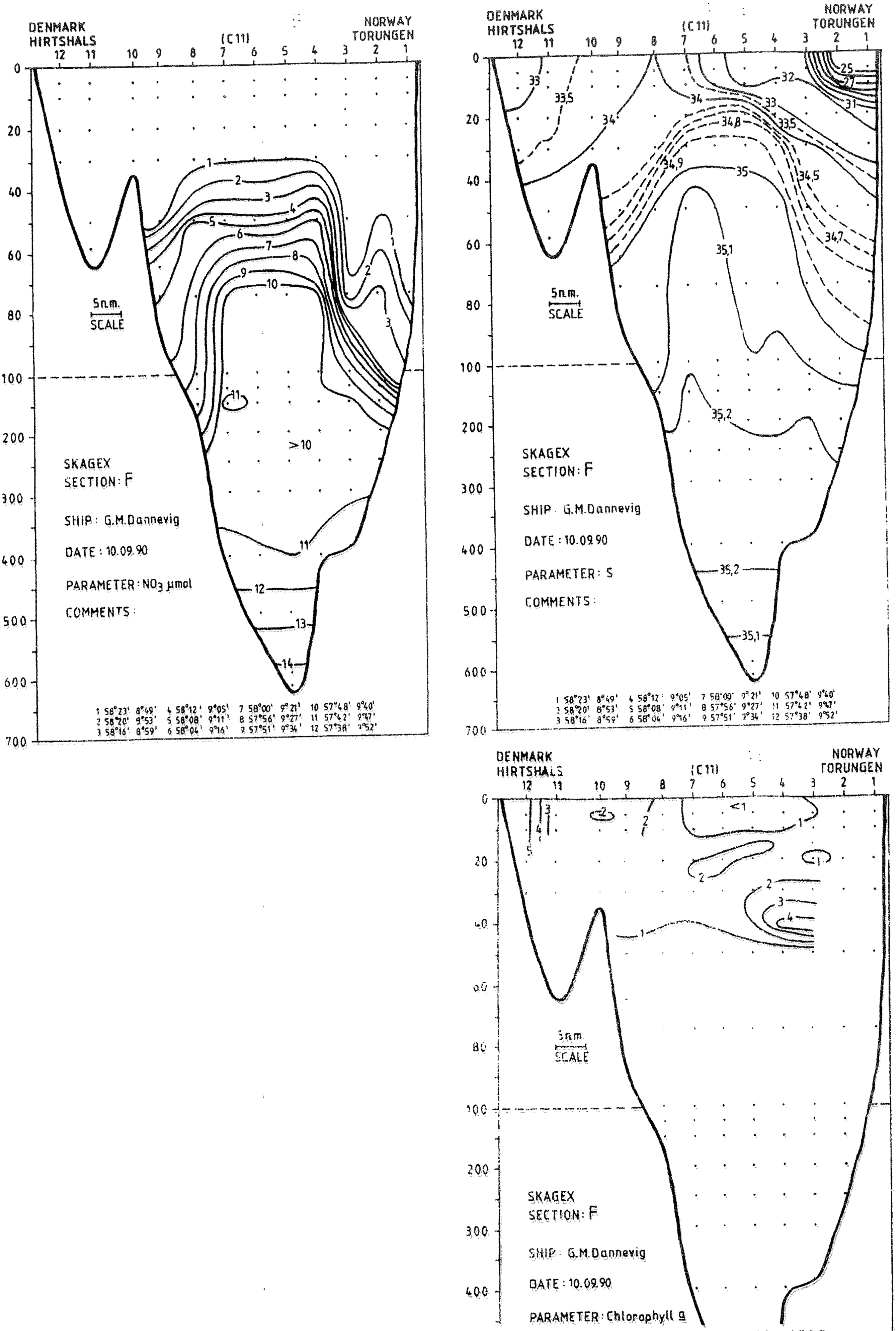


Fig. 14. Nitrate (NO_3 umol/l), salinity and chlorophyll a at Transect F, September 10, 1990.

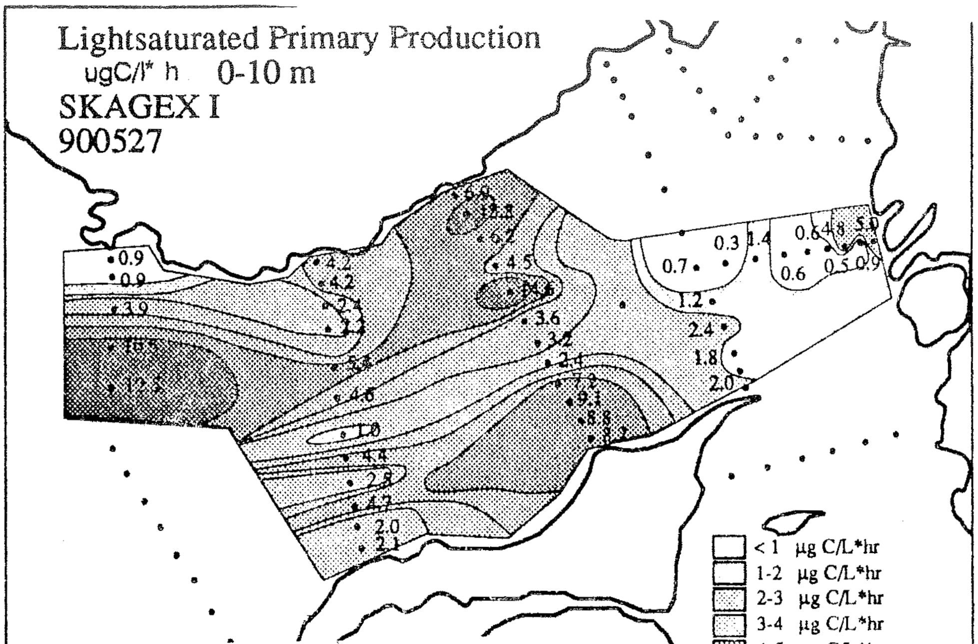
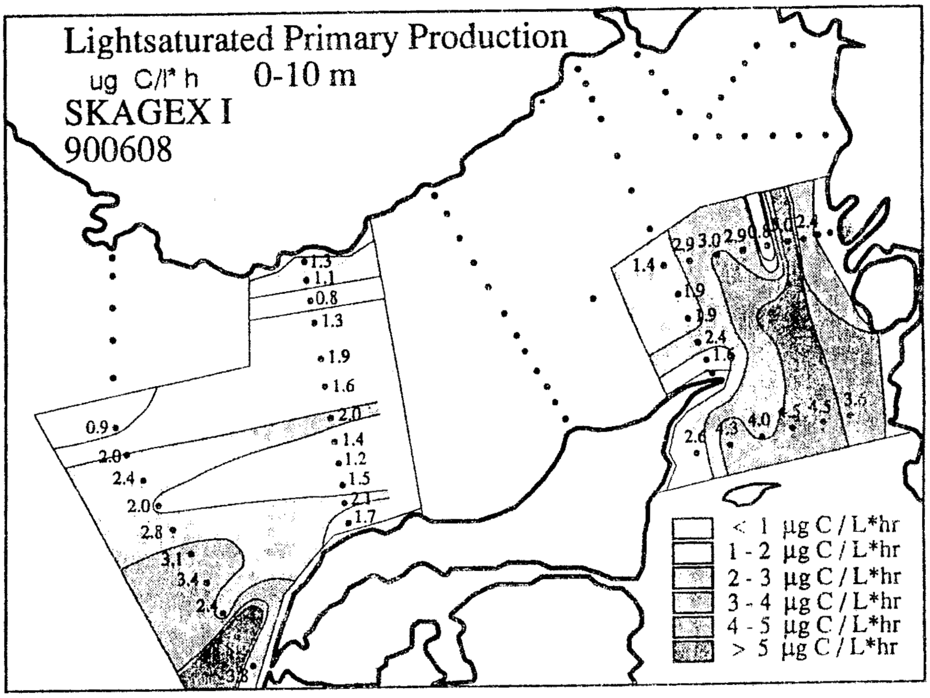
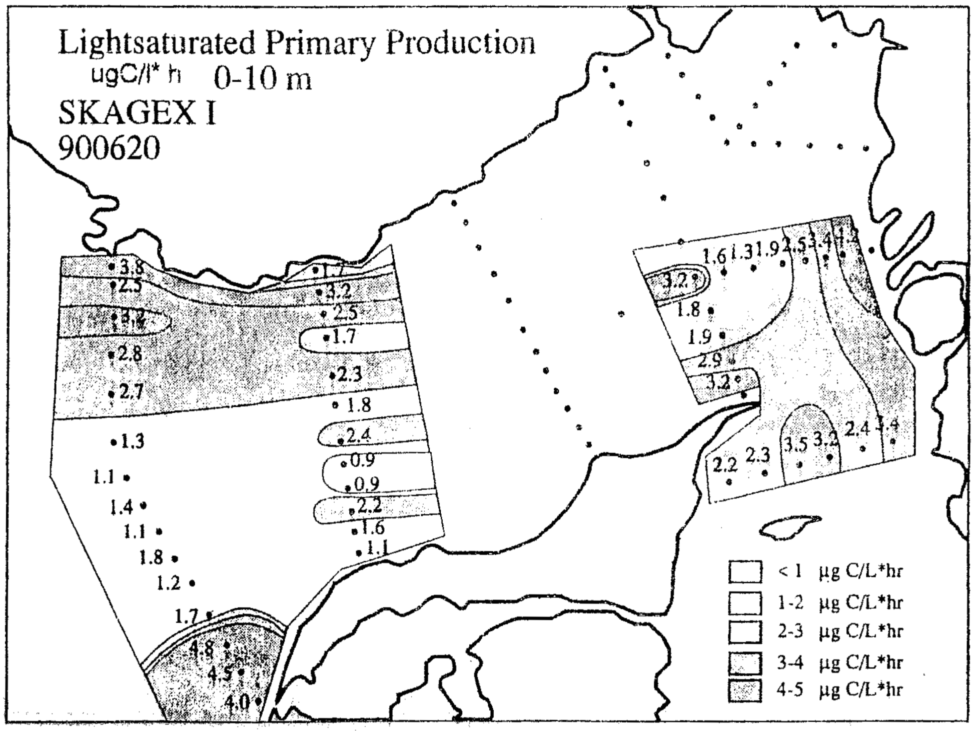


Fig. 15. Lightsaturated primary production (ug l^{-1} h^{-1}), 0-10 m.





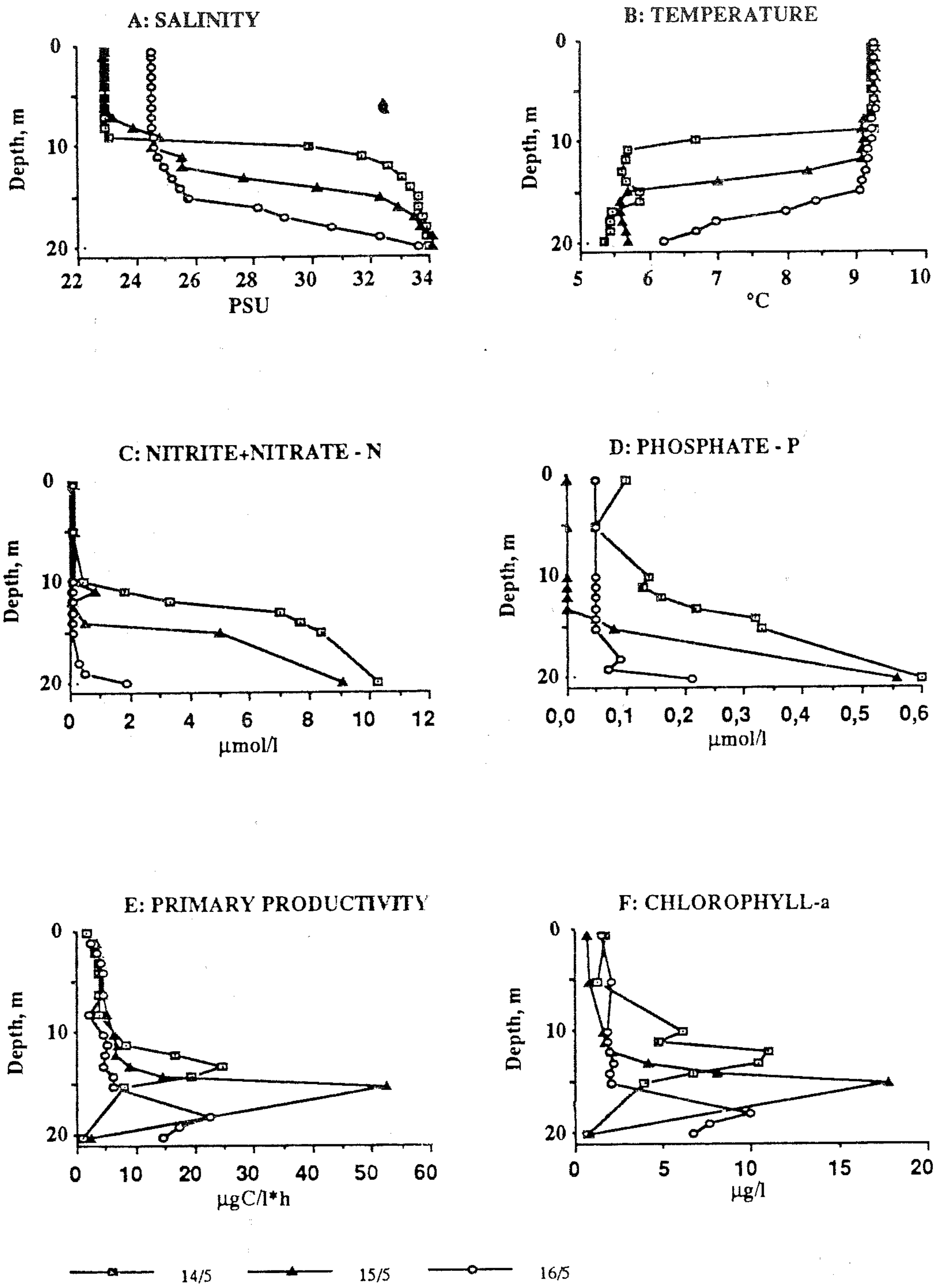


Fig. 16. Hydrography, chlorophyll-a and in **in situ** primary production at station Y1 (57°38,0' N, 10°45,0' E), May 14-16, 1991.

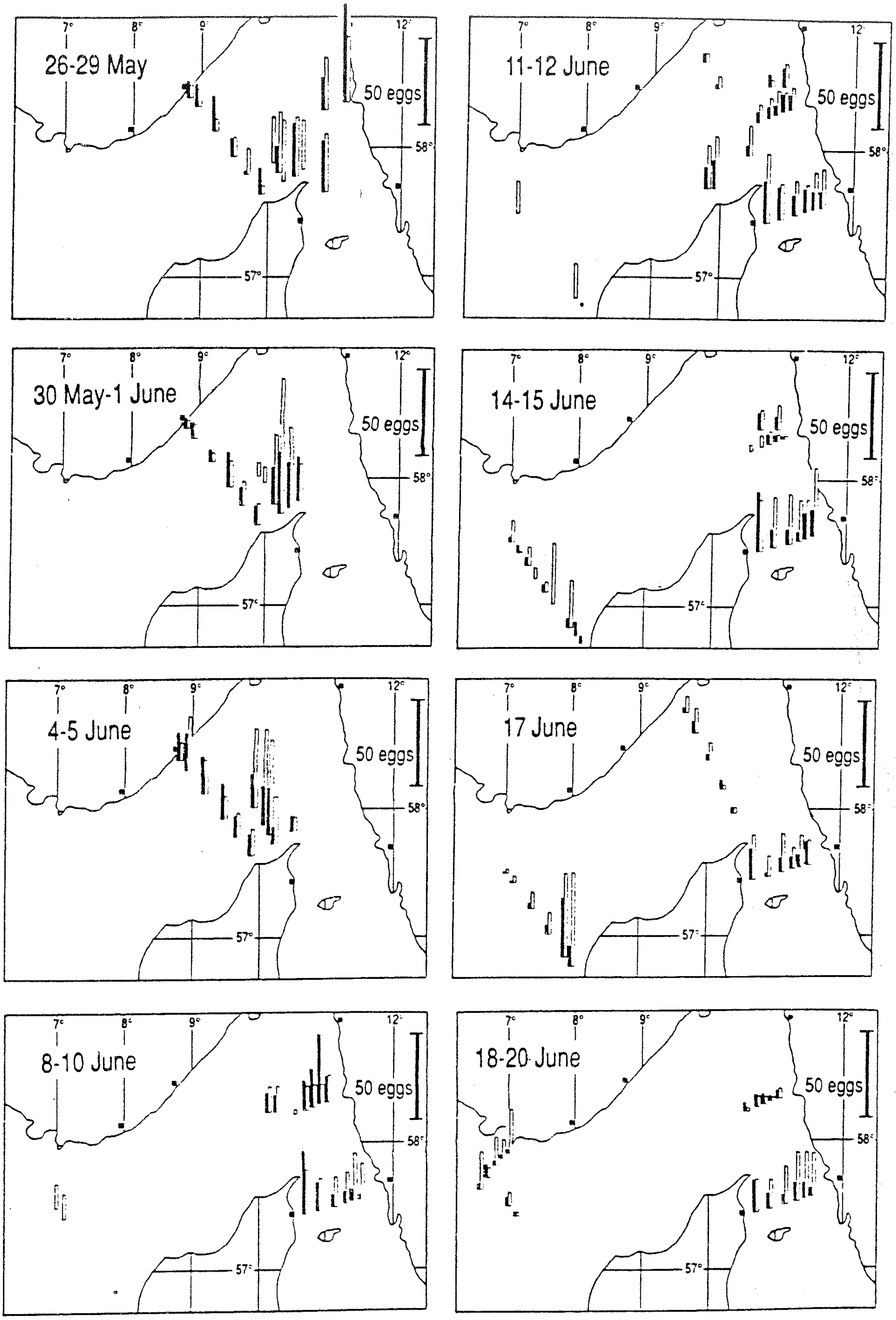


Fig. 17. Average egg production (eggs female $^{-1}$ day^{-1}) for *Acartia clausi* (solid columns) and *Centropages hamatus* (open columns) May 26 - June 20, 1990.

Presentation no 5.

Chlorophyll vs AVHRR satellite data during SKAGEX experiment.

by

M. Darecki, P. Kowalczuk, S. Sagan and A. Krezel

CHLOROPHYLL VS AVHRR SATELLITE DATA DURING SKAGEX EXPERIMENT

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INTRODUCTION

The development of satellite technology has opened quite new perspectives in oceanological investigations even in relatively easy accesible coastal areas. The primary oceanographic application of the Advanced Very High Resolution Radiometer (AVHRR), carried aboard NOAA polar-orbiting satellites, is estimation of sea surface temperature on the basis of signal sensed in its three infrared channels. Its visible bands (red and near-IR) have low sensitivity and practically work only in situations where the water backscattering is much larger than normal oceanic one. Such a situations take place in the coastal regions which are under influence of turbid land waters.

Relatively low cost and accessibility of the AVHRR data as well as the high sampling frequency causes expanding interest in using them in new oceanographic applications.

The aim of this work is an attempt to apply the AVHRR data to study some oceanographic characteristics of surface water in moderately turbid waters of the Skagerrak region.

METHODS

Stumpf and Tyler (1988) and Stumpf and Pennock (1989) have proposed a method of estimation of chlorophyll and suspended sediments in turbid estuarine water using the data sensed by AVHRR from the satellite level. According to their idea, it should be significant dependence of chlorophyll content in the surface layer of estuary on "water color" defined as

$$C_{ij}=\frac{R_2}{R_1} \tag{1}$$

where R is the irradiant reflectance of the sea surface in red (1) and near-IR (2) bands, and suspended sediment on total reflectance defined as

$$R_T=\frac{Q[L_w(1)+L_w(2)]}{[E_d(1)+E_d(2)]} \tag{2}$$

where L_w(ch) and E_d(ch) are the water-leaving radiances and downwelling irradiances in AVHRR's channels 1 and 2 respectively. Assuming Lambertian reflectance of the sea surface, Q can be considered a constant and equal to π. The values of E_d(ch) can be calculated using one of the models of solar radiation transmission in the atmosphere. Here we have used the model proposed by Bird and Riordan (1986).

Much more serious problem is to obtain reliable values of upwelling radiances on the basis of satellite sensed signal. Radiance, leaving water surface (in AVHRR's channel 1, i.e. band, 0.58 - 0.68 μm) is very small (up to about 30 $Wm^{-2}\mu m^{-1}sr^{-1}$). It is the same order as atmospheric path radiance in this spectral band.

According to Gordon *et al*. (1983), ignoring direct sun glint and assuming that the sea surface is flat, the sensor radiance $L_*(\lambda)$ can be expressed by

$$L_*(\lambda)=L_r(\lambda)+L_a(\lambda)+t(\lambda)L_w(\lambda) \tag{3}$$

where $L_r(\lambda)$ and $L_a(\lambda)$ are the Rayleigh and aerosol path radiances respectively; $t(\lambda)L_w(\lambda)$ is the water-leaving radiance diffusely transmitted to the top of the atmosphere.

In clearer oceanic waters, the path radiance (i.e. $L_r(\lambda)+L_a(\lambda)$) can be approximated as $L_*(\lambda)$. It is because $L_w(\lambda)$ in red and near-IR bands is negligible small (Gordon, 1978). On the basis of this assumption, it is possible to simplify significantly the atmospheric correction of the signal in AVHRR's channels 1 and 2. The method has the name of "clearwater subtraction technique", and the only condition which must be fulfilled is the presence of clear water within the area with the same atmospheric conditions as in the area of interest. If the nearest clearwater is far from this area, the proper value of clearwater (i.e. path) radiance, L_{cw}, can be corrected using

$$L_{cw}(i) = L_{cw}\frac{\cos\vartheta_{cw}}{\cos\vartheta(i)} \tag{4}$$

where ϑ_{cw} and $\vartheta(i)$ are the viewing angle to clearwater and to the pixel of interest, respectively (Stumpf, 1987).

Because of strong linear dependence of optical depth, t, on aerosol path radiance, and practically constant Rayleigh optical depth, it is possible to approximate its value in relatively simple way. Stumpf (1987) quotes such approximation in terms of path radiance as

$$t_{ch}=a_{ch}+b_{ch}[L_{cw}(ch)-c_{ch}] \tag{5}$$

where ch denotes number of AVHRR's channel, and a, b and c equal 0.09, 0.03, 0.8 and 0.05, 0.04, 0.2 for channel 1 and 2, respectively.

MATERIAL

Basing on the above mentioned assumptions and solutions, the values of R_t and C_{ij} have been calculated for Skagerrak using NOAA-11 AVHRR data from the period since May 24 to June 13 1990. The raw satellite data were obtained from Institute of Meteorology and Water Management HRPT receiving station in Kraków, Poland. 8 near-noon images (May 24th and 27th and June 5th, 9th to 13th) of the area have been processed in Institute of Oceanology of Polish Academy of Sciences and Institute of Oceanography of Gdańsk University.

Coincidently, the Skagex 90 experiment with participation of 10 research vessels took place. The chlorophyll *a* concentration and Secchi depth were measured simultaneously among other parameters on 5 transects (Fig. 1). Beam attenuation coefficient c(655 nm), diffusive coefficient for downwelling irradiance $K_d(525)$ and color index were measured incidentally. All these measurements we tried to compare with the satellite data.

RESULTS

Chlorophyll

The chlorophyll data, that were collected on standard levels of 1, 5, 10, 15, 20 and so on meters, were preprocessed to obtain the C_s value representative for optical penetration depth. The method proposed by Gordon and Clark (1980) was used. It was assumed that the value of K_d was constant in the surface layer and that there was linear change of chlorophyll concentration between measuring levels. With diffuse attenuation coefficients, $K_d(535)$ of 0.1-0.3 m^{-1}, the penetration depth in channel 1 equals approximately from 2 to 4 m. It means that the satellite couldn't see the layer of maximal chlorophyll concentration which was about 20 m, and that the vertical profile of chlorophyll had only small importance for the remote sensing in AVHRR's channels 1 and 2 in the area.

Taking into account a basic reflectance equation (Gordon *et al.*, 1975)

$$R_k=\frac{0.33b_{bk}}{a_k+b_{bk}} \tag{6}$$

where a is the absorption coefficient, b_b - the backscatter coefficient and the subscript k denotes wavelength or band k, Stumpf and Tyler (1988) prove that, in turbid waters, it should be linear dependence between C_{ij} and chlorophyll concentration.

Unfortunately, the chlorophyll concentrations in the Skagerrak appear to be outside the range of values valid for Stumpf's model. For this reason we were looking for the appropriate dependence between linear (for turbid estuarine waters) and multiplicative (for clear oceanic waters) one. The final result is shown in Fig. 2. As we expected, the regression analysis gave much better results for the form

$$C_s=\exp(A+B*C_{ij}) \tag{7}$$

where A and B are constants of regression, then for the linear one.

On the basis of obtained relationship we have processed the AVHRR data. The results are shown in Figs. 3 and 4. All the values of chlorophyll *a* are in [mg/m^3]. Comparing these distributions with the ones obtained on the basis of undersatellite measurements (Fig. 5) one can see that

- there is a general agreement between them; for example: the Skagerrak receives a chlorophyll from the North Sea (a tongue of higher values in the south-western part of the scene),
- the absolute values of chlorophyll *a* measured *in situ* and calculated on the basis of the AVHRR data are in close coincidence.

Beam attenuation coefficient c(655)

The value of c(655) coefficient in sea water depends strongly on suspended matter. Using (2) for processing the AVHRR data and *in situ* measurements of c(655) we have obtained the regression relationship shown in Fig. 6. The shape of expression has a physical meaning if backscatter from the suspended matter is much greater then backscatter from the water (Stumpf and Pennock, 1989). Because of limited number of paired data it is only a tentative relationship for a range of R_t shown in Fig. 6.

Nevertheless, comparing the spatial distribution of chlorophyll *a* in Fig. 4 with the calculated distribution of c(655) in the same day (Fig. 7) one can see very good agreement. It seems that it is due to the fact that the organic contents in suspended matter exceed 50% in the Skagerrak (Eisma and Kalf, 1987).

Similar results obtained with two different methods confirms the validity of assumed relationships. It is, in particular, because of ascertained strong dependence of chlorophyll on c(655) in the area of interest.

CONCLUDING REMARKS

In spite of lack of theoretical basis for using the AVHRR's channels 1 and 2 for detection of optical parameters of comparatively clear sea waters ($C_s<5$ mg/m^3, susp.mat.<3 mg/dm^3), obtained results show that, at least qualitative description of some spatial structures is possible. So, it seems substantial to us, that further development of processing algorithms is promissing.

REFERENCES

1. Austin R.W., 1974, *The remote sensing of spectral radiance from below the ocean*, in "Optical Aspects of Oceanography", Academic Press, London, New York, 317-343,
2. Bird R.E., Riordan C., 1986, *Simple Solar Spectral Model for Direct and Diffuse Irradiance on Horizontal and Tilted Planes at the Earth's Surface for Cloudless Atmospheres,* J.Clim.Appl.Met., Vol 25, No. 1, 87-97,
3. Eisma D., Kalf J., 1987, *Distribution, Organic Content and Particle Size of Suspended Matter in the North Sea*, Neth. Journ. of Sea Research, 21(4), 265-285,
4. Gordon H.R., 1978, *Removal of atmospheric effects from satellite imagery of the oceans*, Appl.Opt., 17, 1631-1636,
5. Gordon H.R., Brown O.B., Jacobs M.M., 1975, *Computed relationships between the inherent and apparent optical properties of a flat homogeneous ocean*, Appl.Opt., 14, 417-427,
6. Gordon H.R., Clark D.K., 1980, *Remote sensing optical properties of a stratified ocean: an improved interpreta tion,* Appl.Opt. 19, No. 20, 3428-3430,
7. Gordon H.R., Clark D.K., Brown J.W., Brown O.B., Evans R.H. and Broenkow W.W., 1983, *Phytoplankton pigment concentrations in the Middle Atlantic Bight: comparison of ship determinations and CZCS estimates*, Appl.Opt., 22, 20-33,
8. Stumpf R.P., 1987, *Application of AVHRR satellite data to the study of sediment and chlorophyll in turbid coastal water*, Tech.Memo. NESDIS AISC 7, 50 pp., Natl.Environ.Satell. Data, and Inf.Serv., NOAA, Washington D.C.,
9. Stumpf R.P., Pennock J.R., 1989, *Calibration of a General Optical Equation for Remote Sensing of Suspended Sediments in a Moderately Turbid Estuary*, J.Geoph.Res., Vol. 94, No. C10, 14,363-14,371,
10. Stumpf R.P., Tyler M.A., 1988, *Satellite Detection of Bloom and Pigment Distributions in Estuaries*, Remote Sens. Environ., 24,

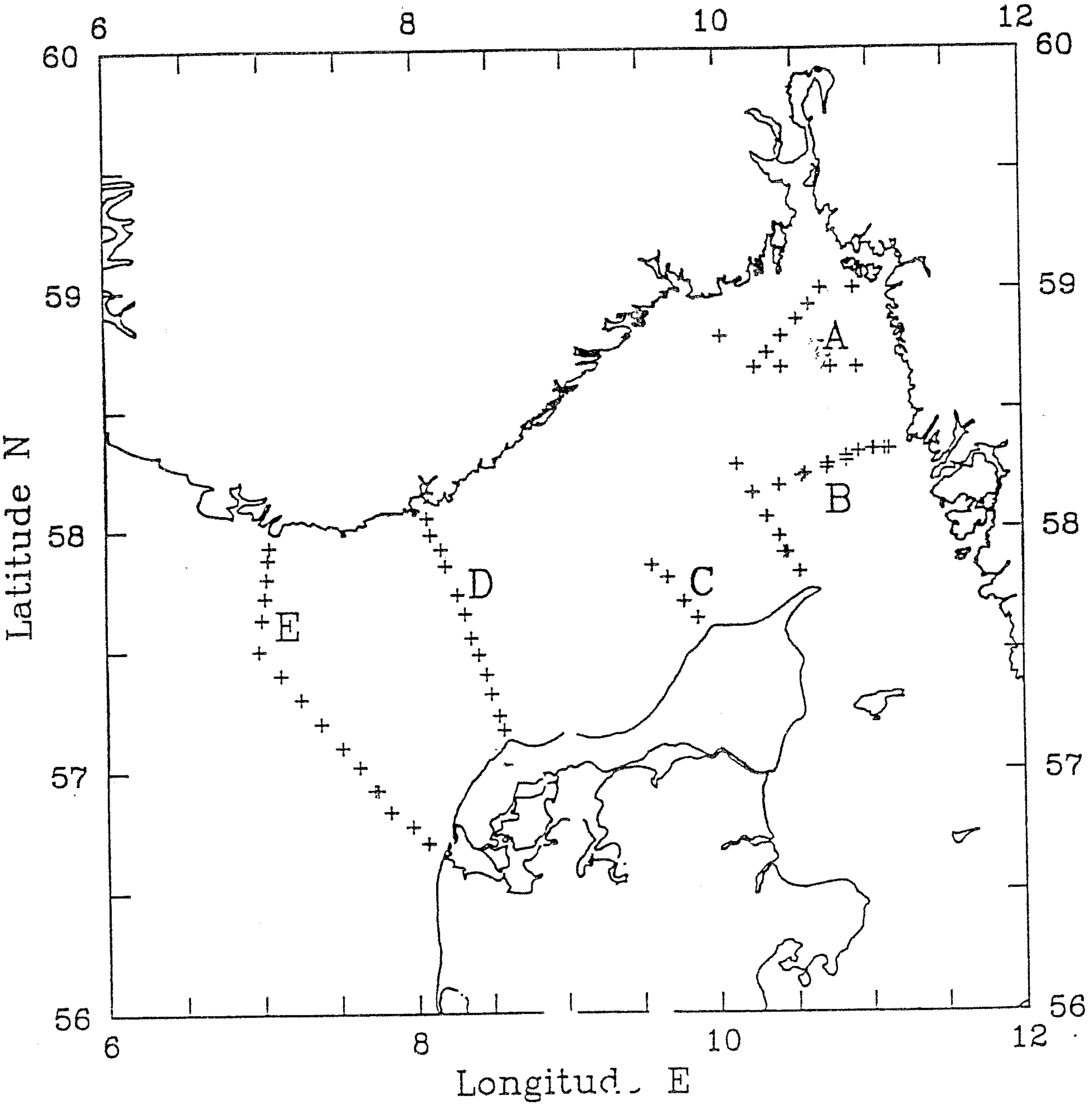

Fig. 1. Loctions of sampling stations in Skagerrak (May 24 - June 13, 1990.

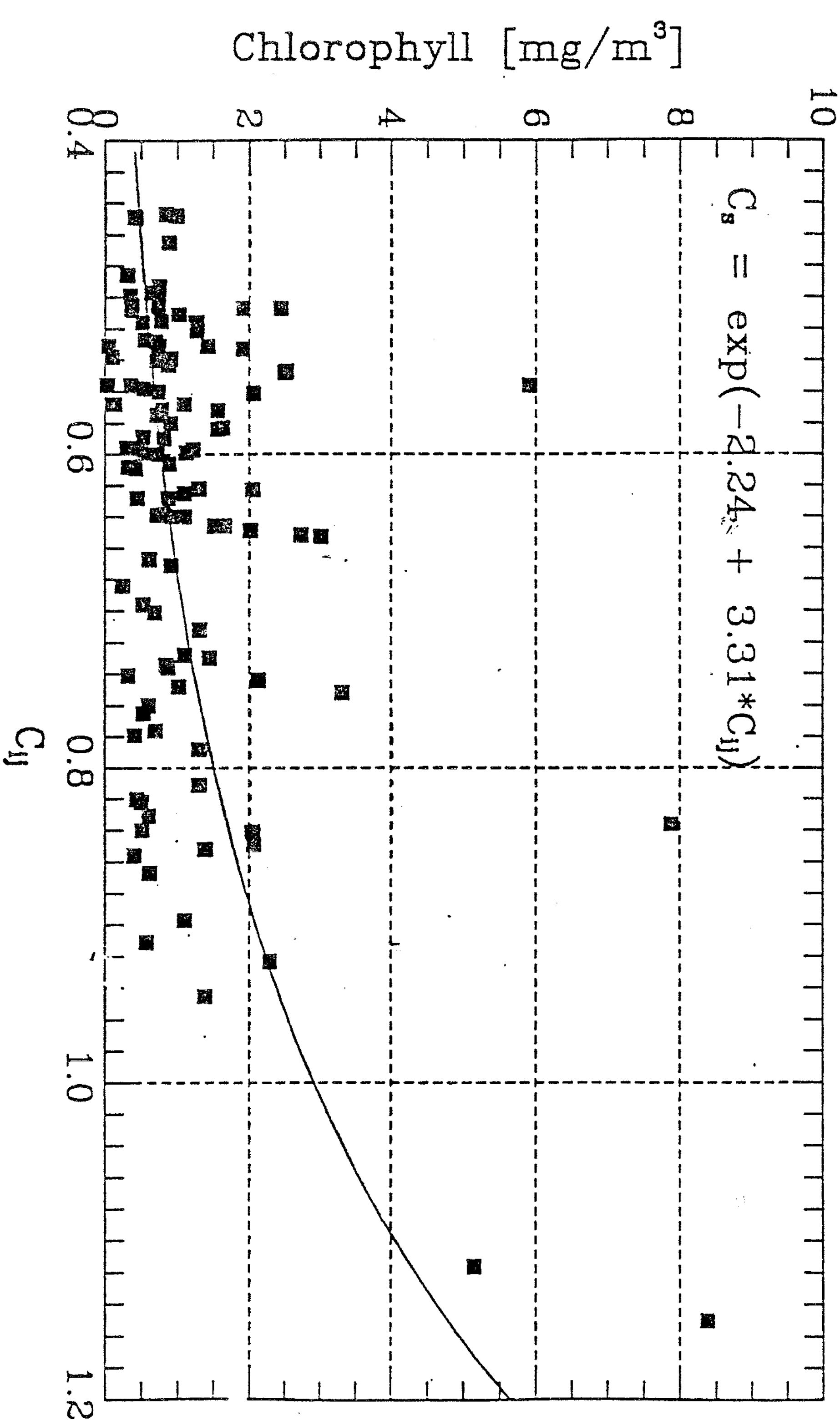

Fig. 2. Chlorophyll data vs. 'water colour' coefficient C_{ij} in Skagerrak. Data sources: *in situ* measurements of chlorophyll collected within optical penetration depth since May 24 to June 13, 1990; NOAA-11 AVHRR images for near-noon local times in the same period.

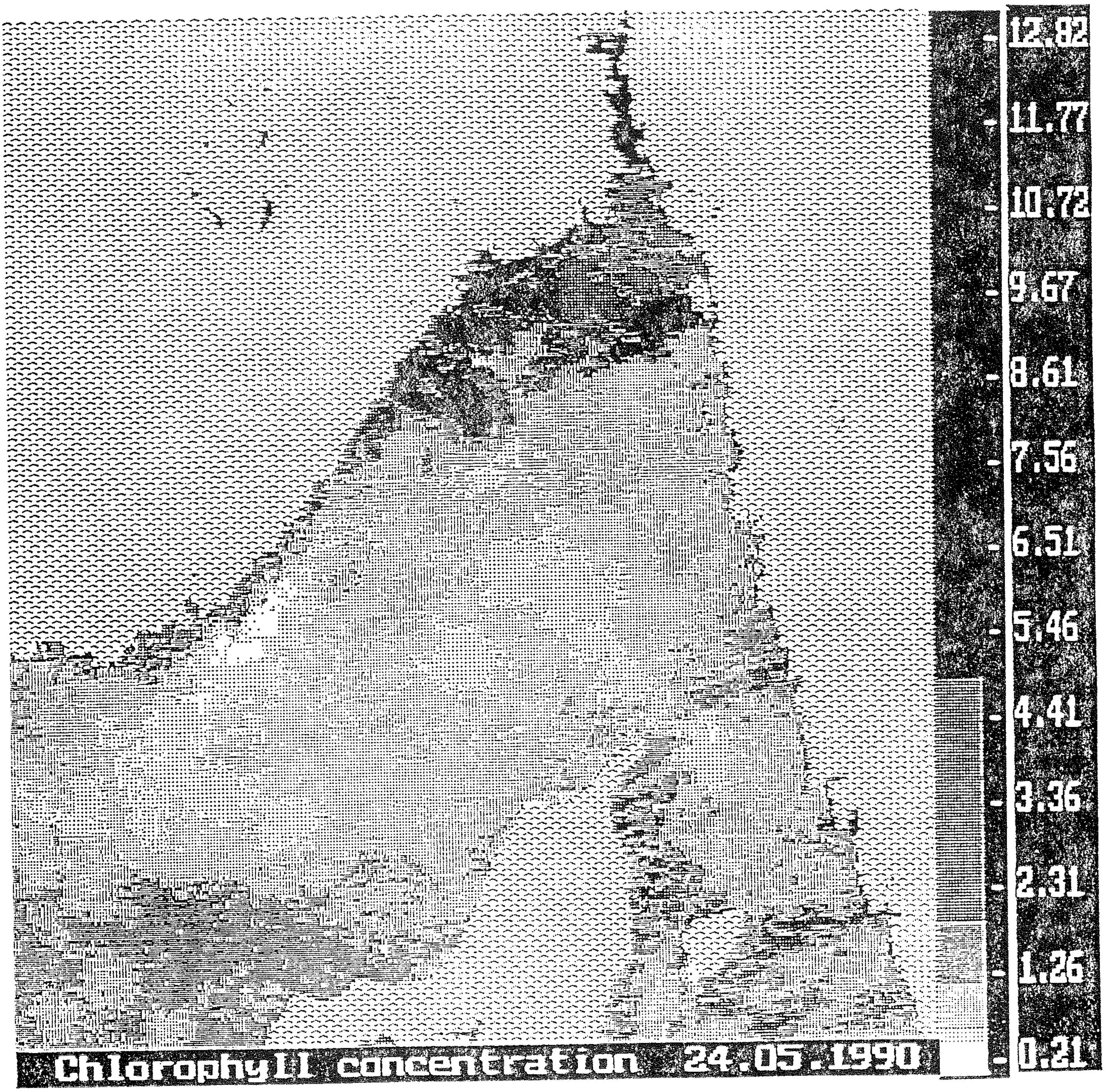

Fig. 3. Chlorophyll concentration in the Skagerrak surface layer as seen from NOAA satellite in May 24, 1990.

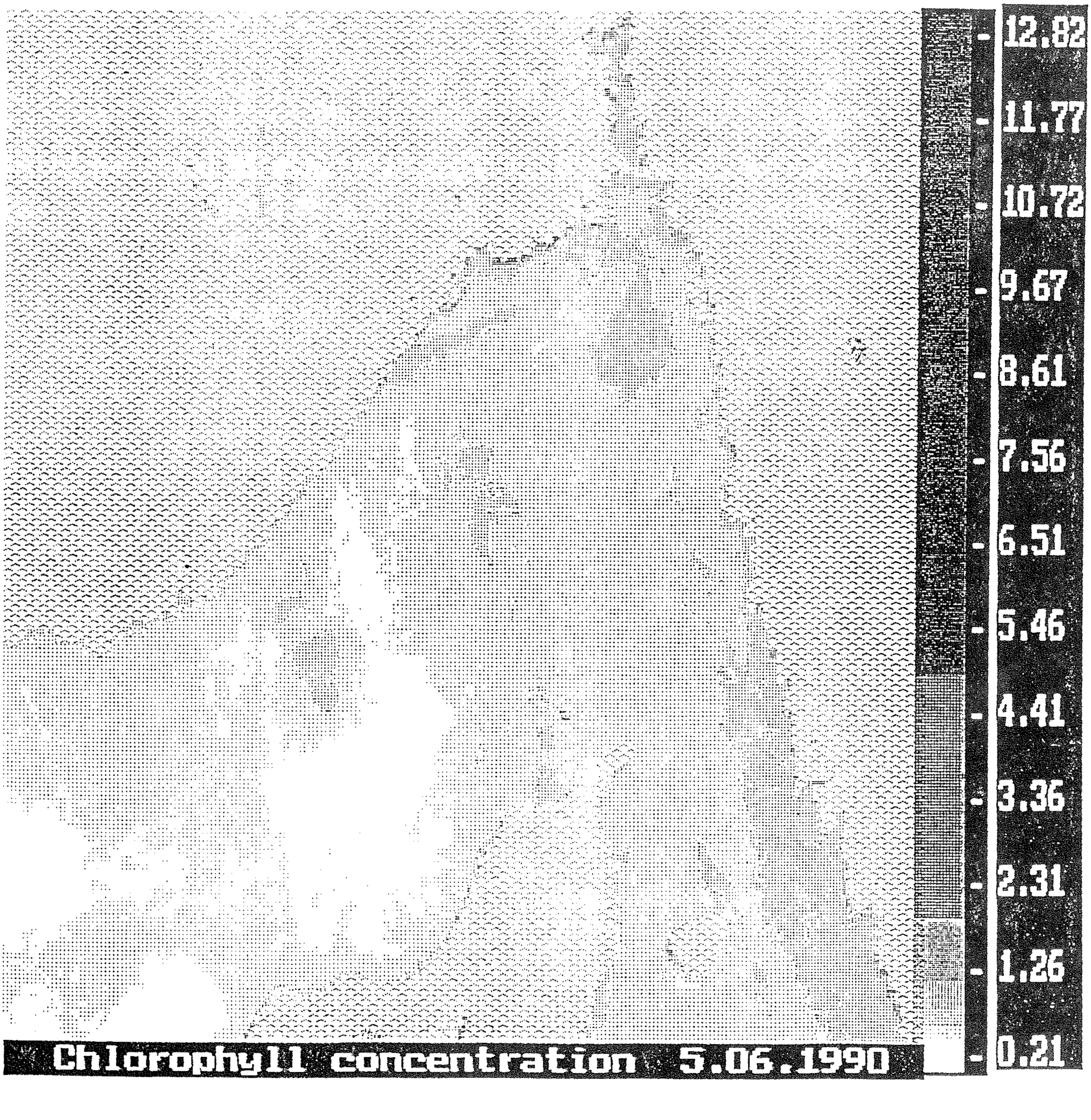

Fig. 4. Chlorophyll concentration in the Skagerrak surface layer as seen from NOAA satellite in June 6, 1990.

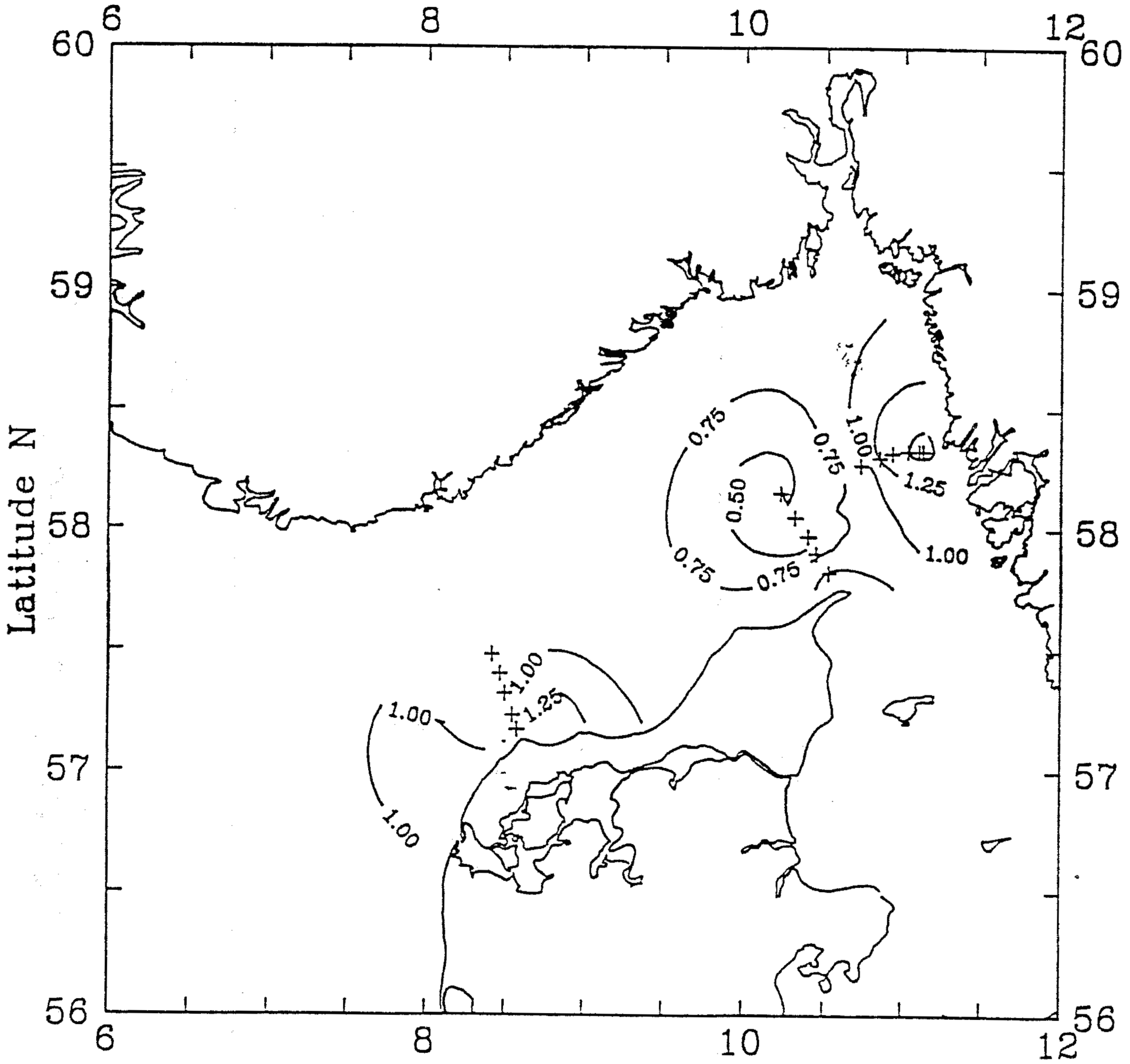

Fig. 5. Surface distribution of chlorophyll concentration in Skagerrak on the basis of *in situ* measurements.

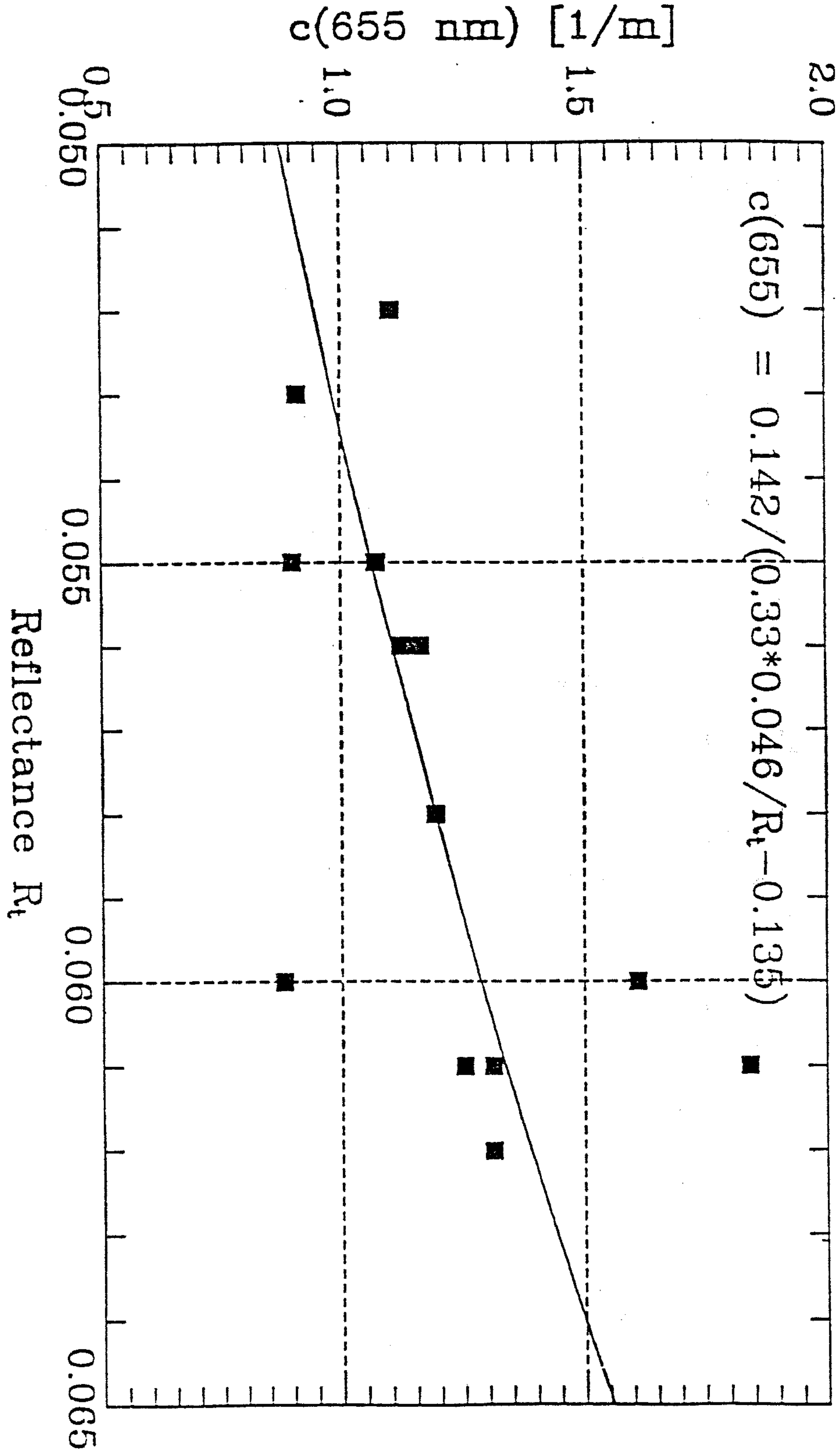

Fig. 6. Beam attenuation coefficient c(655) vs. R_t reflectance in Skagerrak. Data sources: *in situ* measurements of c(655) collected from r/v OCEANIA on transect D in June 5, 1990; NOAA-11 AVHRR image for noon (12^{16} local time) on the same day.

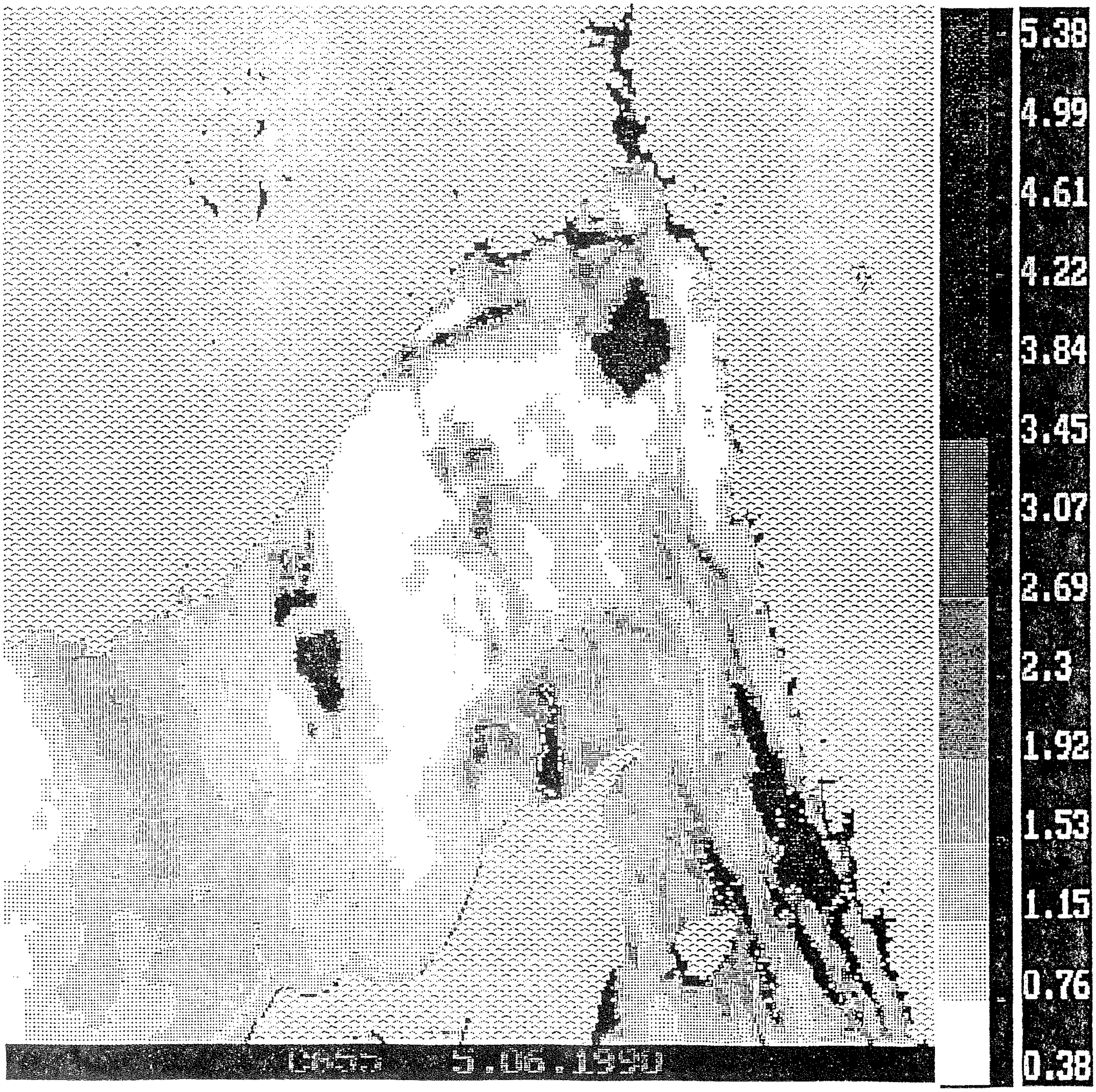

Fig. 7. c(655) coefficient distribution in Skagerrak calculated on the basis of AVHRR channels 1 and 2 data; June 5, 1990; NOAA-11 image for noon (12^{16} local time).

Presentation no 6.

Nitrogen speciation and nitrification potential in the Skagerrak area during the SKAGEX IV experiment.

by

V. Enoksson, E. Fogelqvist and S. Fonselius

NITROGEN SPECIATION AND NITRIFICATION POTENTIAL IN THE SKAGERRAK AREA DURING THE SKAGEX IV EXPERIMENT

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ABSTRACT

The potential for nitrification has been studied in relation to the inorganic nitrogen species ammonium, nitrite and nitrate in the Skagerrak in May 1991 during the SKAGEX IV expedition. Results on ammonium, nitrite and nitrate, together with basic hydrographic parameters, collected at four north-south transects, are presented together with the potential rate of nitrification (nitrification potential, NP, measured with excess ammonium) from two of the transects. A core of highly saline and ammonium rich Atlantic/North Sea water was sinking into the Skagerrak along the Danish slope. The inflowing water gradually mixed with the "old" and relatively stagnant Skagerrak water with high nitrate concentrations but very low ammonium concentrations. The zone of mixing was characterised by high concentrations of nitrite, which accumulated because there was a lag period between the bacterial oxidations of ammonium and nitrite. The NP was at its maximum in or near the zone with high nitrite concentrations. It is postulated that nitrification was stimulated in the mixed water, where ammonium was provided from the inflowing water and an inoculum of nitrifying bacteria from the "old" Skagerrak water.

INTRODUCTION

Nitrification is the oxidation of ammonium to nitrite by *Nitrosomonas*-like bacteria and the further oxidation of the nitrite to nitrate by *Nitrobacter*-like bacteria. These bacteria are very specialised and they can not grow on organic substrate. They grow slowly and the rates measured in most marine pelagic samples are low compared to processes like nitrogen uptake by phytoplankton or ammonification. Typically, the reported rates are negligible in the upper mixed layer or in old deep water (Ward 1986; Enoksson 1986; Enoksson et al., 1990). The bacteria are inhibited more or less permanently by the sunlight (Olson, 1981a; b) and/or possibly by some not yet identified, surface related factor. Water from the upper mixed layer in the Baltic sea was incubated for three months in glass bottles with glass stoppers (CS_2 in rubber kills the nitrifying bacteria) during which time virtually no production of nitrite or nitrate was demonstrated, even though all the substrates (ammonium, oxygen and carbon dioxide) were abundant (Enoksson 1980). It is suggested that water, after being irradiated at the surface, must be inoculated with active nitrifiers before ammonium can be converted to nitrite and nitrate. It is also postulated that water that has been at the surface recently or that has not yet received an inoculum of nitrifiers, may be recognised by its lack of nitrification potential (NP).

Inorganic nitrogen, i.e. nitrite, nitrate and ammonium, was measured in the Skagerrak water during the international programme SKAGEX. The experiment extended over a period of one year and comprised four multi-ship expeditions. During the SKAGEX I expedition in May-June 1990, some striking features were observed in the distributions of ammonium and nitrite during the ten crossings (five by R/V Argos and five by R/V Oceania) of the Skagerrak at the G section, the only section where ammonium was measured (Danielssen et al., 1991). Both ammonium and nitrite showed pronounced maxima in the deep water along the slopes of the Skagerrak, on the Danish side as well as along the Norwegian coast. Maximum concentrations of both these nutrients were found at depth, either in the same water masses or ammonium maxima were found closer to the coasts than the nitrite maxima. Elevated concentrations of ammonium and nitrate were also found in patches near the pycnocline at 20-40 m in the central and northern part of the section. Nitrate appeared at its highest concentrations in the central and deep part, in the ridge of older "stagnant" water described by Danielssen et al. (1991; 1992), in which ammonium and nitrite concentrations were comparatively low. These features prevailed during the five weeks expedition, and also during the shorter expedition SKAGEX II, which lasted for one week in September the same year. The third cruise in January 1991, SKAGEX III, showed a different picture, probably due to winter conditions and low biological activity. There were no pronounced maxima of either ammonium or nitrite in the water flowing in from the west, and nitrate was present all through the water column. Contrary to other seasons, a nitrate minimum was observed in the ridge of older water where ammonium and nitrite were comparatively high (Fonselius, 1993).

In order to explain the distributions of ammonium and nitrite in the Skagerrak as observed in 1990, measurements of the nitrification potential (NP) was included in the SKAGEX IV expedition in May 1991. The NP was measured at the E and G sections (Fig. 1b in Danielssen et al., 1991). Another aim was to investigate the usefulness of NP for elucidating the history of the water masses in the Skagerrak, otherwise not easily distinguished by conservative parameters due to the vigorous mixing of incoming and older "stagnant" water of like salinities.

MATERIALS AND METHODS

Sampling and basic hydrography

The data from transects E, F, G and H (Fig. 1b in Danielssen et al. 1991), that this work are based upon, were collected during three days, 14-16 May 1991, onboard the Swedish *R/V Argos*. Samples were taken at a total of 48 stations.

Water samples were collected in 1.8 l water samplers (TPN, Hydro-Bios) mounted on a wire and taken at the standard depths selected for the entire SKAGEX experiment. Temperature for calculating density was read from reversing thermometers. Salinity was measured manually with a Minisal 2100 Salinometer (AGE Instruments Inc., Canada) and calibrated against standard seawater (Ocean Scientific, England).

Inorganic nitrogen species and oxygen

A computer-controlled ALPKEM RFA/2 analytical system was employed for nitrite and nitrate measurements onboard the ship, essentially according to Whitledge et al. (1986). Ammonium was determined manually according to the indophenol blue method (Koroleff, 1983). Oxygen was measured by Winkler titration as described by Grasshoff (1983).

Nitrification Potential

Samples for NP were taken at sections E and G from the hydrography casts at the depths indicated in Fig. 2 and 4. The water was collected in amber 0.5 l medicine bottles with plastic screw caps which were immediately placed in water baths at *in situ* temperature. After a few hours, ^{15}N-ammonium was added to a final concentration of approximately 9 μM (expected to be saturating for the bacteria). Unlabelled nitrate was added to final concentrations of at least 5 μM. The bottles were then incubated for approximately 13 hours after which time 100 ml aliquots were taken for ^{15}N-nitrate determinations. Nitrate was reduced to nitrite which was captured into an azo dye according to Schell (1978). Upon return to the land-based laboratory, the azo dye was transferred quantitatively to a glass fibre filter and purified (Enoksson, 1993). The further treatment of the filter for determination of $^{15}N/^{14}N$ by emission spectrometry was described by Kristiansen & Paasche (1982). When calculating the amounts of ^{15}N-nitrate + ^{15}N-nitrite that had been produced, correction was made for the contamination with unlabelled nitrogen (ca 0.1 μmol per filter), which was determined with surface and deep water from the Kattegat (May 1991). Aliquots for ammonium, nitrite and nitrate determinations (Technicon AAII autoanalyzer) were taken from the incubation bottles before and after ammonium and nitrate additions and at the end of the incubation. The detection limit for NP was approximated to 2 nmol $l^{-1}d^{-1}$.

RESULTS

Distribution of density, oxygen and nutrients

In Figures 1-4, the distributions of density (sigma-t), nitrite (NO_2^-), nitrate (NO_3^-) and ammonium (NH_4^+) are presented. In Figs. 2 and 4, showing the G and E sections (the two sections where NP was measured), also distributions of oxygen saturation are illustrated.

Density:
The area was covered by a layer of low density water due to influence from outflowing brackish Baltic Sea and Norwegian coastal water. This was most pronounced in the inner parts of the Skagerrak as illustrated by its sharp pycnocline near Denmark (Fig. 4). Figs 1-4 illustrate a core of high density water on the southern slope stretching all the way from the North Sea border (Fig. 1, section H) to the inner part of the Skagerrak (Fig. 4, section E). According to the classification made by Danielssen et al. (1991), this water came from the Atlantic Ocean and from the central part of the North Sea. The flow turned to the north along the Swedish coast and subsequently returned to the west along the Norwegian cost. On its way, it was entrained by the surrounding water as indicated by the sigma-t values at depth in the inner part of the Skagerrak, sections F and E, which were higher than at sections H and G. Close to the Norwegian coast, an upwelling of dense water was taking place at the H and G sections.

Ammonium:
The density and the ammonium plots have certain things in common. At all four sections, maximum ammonium concentrations coincided with the density maxima along the Danish slope; in the outer parts of the Skagerrak at depths below 30 m, in the inner parts below 100 m. This is consistent with high ammonium concentrations in the entering Atlantic/North Sea water, but along its path to the inner parts of the Skagerrak and along the Norwegian coast the ammonium maxima became less pronounced. Relatively high concentrations also appeared in the lowest part of the photic zone or just below it, at 20-50 m depth, in the central part of the Skagerrak, where also the pycnocline was positioned.

Nitrite:
The nitrite distributions in the inflowing Atlantic water showed maxima that seemed to be associated with the ammonium maxima, although closer to the centre of the Skagerrak. At section H, nitrite was highest at station H7, whereas ammonium was highest at station H8. Likewise, nitrite was highest at station G6 and ammonium at G7 etc. The conditions on the Norwegian side were more difficult to interpret, both parameters showing elevated concentrations in about the same water masses. Also, there was a layer in the lower part of, and just below, the photic zone which was rich in both ammonium and nitrite.

Nitrate:
The nitrate pattern was different from those of other nitrogen species. The highest concentrations appeared in the ridge of old "stagnant" water (50 to 100 m and down to the bottom) stretching from the North Sea through the deepest central part to the north-east part of the Skagerrak as described by Danielssen et al. (1991; 1992). Elevated nitrate concentrations were also found in the area where upwelling was observed close to the Norwegian coast at sections H and G.

Oxygen:
The oxygen supersaturated (>100%) surface layer generally coincided with the water mass that had a sigma-t value of <27 and a nitrate concentration of <4 μmol l^{-1} (Figures 2 and 4). The inflowing Atlantic/North Sea water, which stretched down to the deepest parts of the Skagerrak on the Danish side, also showed relatively high saturation values. On the other hand, the water with the lowest oxygen saturation values was found in the upper parts of the ridge of older "stagnant" water.

Nitrification potential

The nitrification potential ranged between 0 and 60 nmol $l^{-1}d^{-1}$. At the Danish side of the G-section (Fig. 2, stations 6-12), there was no NP in the upper 15 m and rates were low in almost all samples down to the bottom (stations 7-12), even at 125 m at station 7. Exceptions were, however, somewhat elevated rates at station 9. Low, but clearly detectable NP rates were found near the surface (5m) at the Norwegian side, in the nitrate-rich upwelling water.

There was a thick layer with insignificant NP rates on the Danish side also at the E-section (Fig. 4), reaching down to 40 m at the two inner stations. Upwelling was not evident at the E-section and NP rates were low or undetectable in almost all samples from 0 to 20 m. Near-surface NP was detected at stations 5 and 9, however, both of which showed elevated salinities.

Below the photic zone, NP maxima were found at both sections. Maximum rates were measured at 30-75 m at the E-section and at 30-100 m at the G-section. The vertical fluctuations of NP near the photic zone reflected to some extent the salinity but there was a more obvious connection to oxygen saturation; high saturation values excluding NP. The NP maximum was found below the maxima of ammonium and nitrite. This layer contained about 8 $\mu mol^{-1}$of nitrate, still higher nitrate concentrations, however, appearing at greater depths.

At the G-section (Fig. 2), there was a lateral maximum at station 6 with NP rates higher than 30 nmol $l^{-1}d^{-1}$. This was significantly different from the rates of 4-7 nmol $l^{-1}d^{-1}$ at similar depths at station 7 where the highest ammonium concentrations and the highest salinities were found. In the bottom water sample from the deepest station, the NP rate was even higher. NP rates were lower than 30 nmol $l^{-1}d^{-1}$ in both the deep "stagnant" Skagerrak water and in the outflowing water along the Norwegian coast. A vertical maximum at station 6 appeared in water with low or moderate ammonium concentrations, with high or maximum nitrite concentrations, and with high but not maximum nitrate concentrations. The negative correlation between NP and oxygen saturation was evident. In general, at oxygen saturation values of >94%, the NP was <20 nmol $l^{-1}d^{-1}$, while oxygen saturation values of <92% coincided with NP values of >40 nmol $l^{-1}d^{-1}$.

Rates of NP were much higher at the E-section (Fig. 4), in general >30 nmol $l^{-1}d^{-1}$, and the distribution was more complicated. The negative correlation with oxygen saturation was, however, similar to that found at the G section, except for the deep water along the Norwegian coast, where both oxygen saturation and NP rates were high. Two small maxima in NP rates were measured at stations 8 and 10 on each side of a local nitrate maximum. This indicates that a portion of the old water in the ridge had been cut off from the ridge and pushed southward by the intruding Atlantic/North Sea water. Significantly lower rates, 20-40 nmol $l^{-1}d^{-1}$, predominated at stations 7-4, where the water characteristics resembled those of the "stagnant" ridge water. In the northernmost portion of the deep water, higher NP rates were again obtained. As for the G-section, maxima in NP rates appeared where ammonium concentrations were low or moderate, where nitrite concentrations were high (although rarely at maximum) and where nitrate concentrations were high but not the highest.

DISCUSSION

The rates of nitrification potential (NP) in Skagerrak were within the ranges of NP and *in situ* nitrification rates in various pelagic waters (Ward 1986, Enoksson 1986, Miazaki et al. 1973) but less than in the deep water of Kattegat (Enoksson et al. 1990).

The pycnocline constitutes a zone of mixing in which, at least during the productive seasons, nitrite maxima are often found. Possibly, this is because nitrite oxidisers are more severely inhibited than ammonium oxidisers (e.g. by light) causing the accumulation of nitrite in the mixing layer. Slightly higher up, both types of bacteria are inhibited, and ammonium accumulates. Deeper down, the ammonium, which is formed when planktonic algae are degraded, will not only be oxidised to nitrite but also further to nitrate. These phenomena, which have been observed in various oceans (Ward, 1986; Olson, 1981a; b), explain the depth distribution of ammonium, nitrite, nitrate and NP rates that were observed below the photic zone.

In Skagerrak, similar maxima were observed also at great depths, but these were vertically or diagonally oriented. We here give a simple explanation for these maxima of ammonium and nitrite as well as maximum rates of NP in waters where none of the three, ammonium, nitrite and nitrate, was at its peak. Salinities were also intermediate where NP was at its maximum and it is postulated that, as discussed for the maxima associated with the photic zone, the NP maxima were formed in the mixing zone between inflowing Atlantic/North Sea water and the "stagnant" ridge water. The mixing of waters continued, and when the outflowing water was observed after its turn in eastern Skagerrak (north part of section E, Fig. 4), high NP rates and nitrite concentrations still prevailed.

In the older water in the ridge, nitrification had proceeded to the point when ammonium has become limiting and the bacteria have decreased in numbers and/or activity. In the inflowing water, nitrifiers were more or less permanently inhibited but ammonium was abundant. The densities (sigma-t) differed only slightly between the two water masses and the high current rates facilitated the mixing where they met. In the mixing zone, the prerequisites for nitrification were available, both the nitrifying bacteria and the ammonium. Nitrite accumulated during the initial period and, therefore, high nitrite concentrations were found in recently formed mixtures of inflowing and old ridge water. There were examples where all three maxima, ammonium, nitrite and NP maxima, were spatially separated, but probably the distance between stations was mostly too large to demonstrate separation between the nitrite and NP maxima, if any. The present data suggest that nitrite maxima are good indicators of the zone of mixing between inflowing Atlantic/North Sea water and older central Skagerrak water. It also appears to show the approximate location of maximum NP rates. This needs, however, to be confirmed for other seasons, especially in the winter.

The organic material is the source of ammonium, but NP is not expected to be high in water with high organic nitrogen because this is associated with light via primary production even more closely than ammonium. Also, the lowest concentrations of organic N is not expected to support active nitrification because mineralization and ammonium replenishment has then ceased. In fact, the highest NP rates were generally found where the concentrations of organic N were in the range of 5-8 μmol l^{-1} (not shown) which excludes both the photic zone (> 8 μmol l^{-1}) and the stagnant deep water (<5 μmol l^{-1}).

ACKNOWLEDGEMENTS

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REFERENCES

Danielssen, D.S., L. Davidsson, L. Edler, E. Fogelqvist, S. Fonselius, L. Føyn, L. Hernroth, B. Håkansson, I. Olsson and E. Svendsen. 1991. SKAGEX: Some preliminary results. ICES C.M. 1991/C:2 Hydrography Comm. Ref: E.

Danielssen, D.S., L. Edler, S. Fonselius, L. Hernroth, M. Ostrowski, E. Svendsen, L. Talpsepp. 1992. Oceanographic variability in Skagerrak/Northern Kattegat, May-June 1990. Report from a meeting at Flødevigen, Norway, 31 August - 4 September 1992, 12 pp. To be published.

Enoksson, V. 1980. Nitrifikation i marina ekosystem. I: Rosswall (red.) Processer i kvävets kretslopp. SNV PM 1213, sid. 157-166

Enoksson, V. 1986. Nitrification rates in the Baltic Sea: Comparison of three isotope techniques. Appl. Environ. Microbiol. 51: 244-250

Enoksson, V., F. Sörensson, W. Granéli. 1990. Nitrogen trasformations in the Kattegat. Ambio. 19: 159-166

Enoksson, V. 1993. Simple extraction of azo-dye bound nitrite for ^{15}N-determination exemplified by nitrification potential in river and sea water. Manuscript.

Fonselius, S. 1993. Nutrient measurements by R/V Argos at section G during the winter expedition SKAGEX III in January 1991. Submitted.

Grasshoff, K. 1983. Determination of oxygen. In: Methods of Seawater Analysis, Second, Revised and Extended Edition. Ed. K. Grasshoff, M. Erhardt and K. Kremling. Verlag Chemie, Weinheim, Germany, 61-72.

Koroleff, F. 1983. Determination of ammonia. In: Methods of Seawater Analysis, Second, Revised and Extended Edition. Ed. K. Grasshoff, M. Erhardt and K. Kremling. Verlag Chemie, Weinheim, Germany, 150-157.

Kristiansen, S.E., E. Paasche. 1982. Preparation of ^{15}N-labeled phytoplankton samples for optical emission spectrometry. Limnol. Oceanogr. 27: 373-375

Miyazaki, T., E.Wada, A. Hattori. 1973. Capacities of shallow water of Sagami Bay for oxidation and reduction of inorganic nitrogen. Deep.-Sea Res. 20: 571-577

Olson, R.J. 1981a. ^{15}N Tracer studies of the primary nitrite maximum. J. Mar. Res. 39: 203-226.

Olson, R.J. 1981b. Differential photoinhibition of marine nitrifying bacteria: a possible mechanism for the formation of the primary nitrite maximum. J. Mar. Res. 39: 227-238.

Schell, D.M. 1978. Chemical and isotopic methods in nitrification studies. In: D. Schlessinger (ed.) Microbiology. Am. Soc. Microbiol. Washington D.C., p. 292-295

Ward, B.B. 1986. Nitrification in marine environments. In: J.I. Proccer (ed.) Nitrification. Special publication of the Soc. Gen. Microbiol. IRL Press oxford, 20: 157-184

Whitledge, T., D. Veidt, S. Malloy, C. Patton and C. Wirick. 1986. Automated nutrient analysis. Technical Report. BNL 38990. Oceanographic Science Division, Brookhaven National Laboratory, Associated Universities INC. 231 pp.

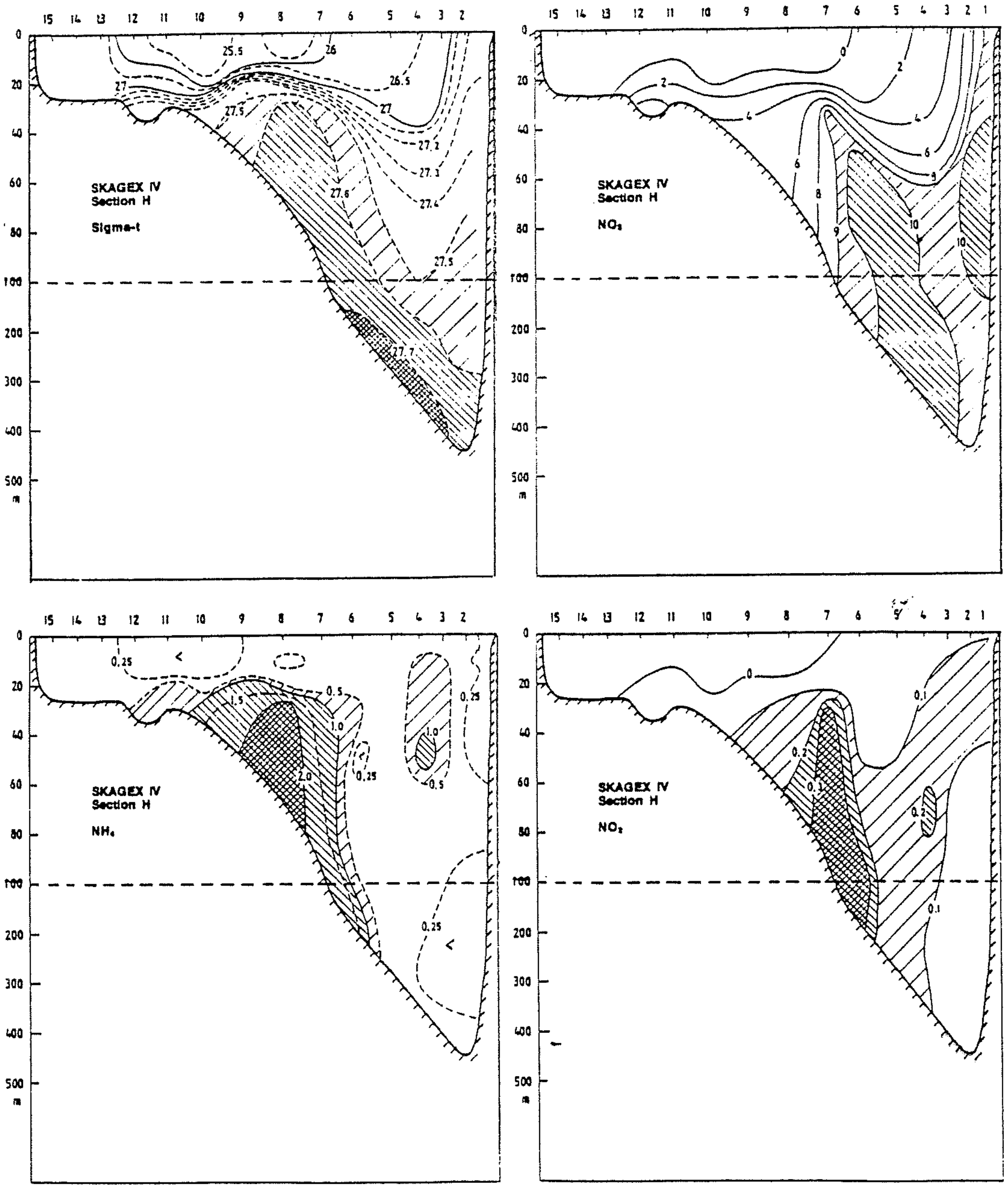

Fig. 1.

Isoplete diagrams showing density (sigma-t, above left), nitrate (NO_3^-, µmol l^{-1}, above right), ammonium (NH_4^+, µmol l^{-1}, below left) and nitrite (NO_2^-, µmol l^{-1}, below right) along the H section from Tyborön in Denmark (left) to Lindesnes in Norway (right).

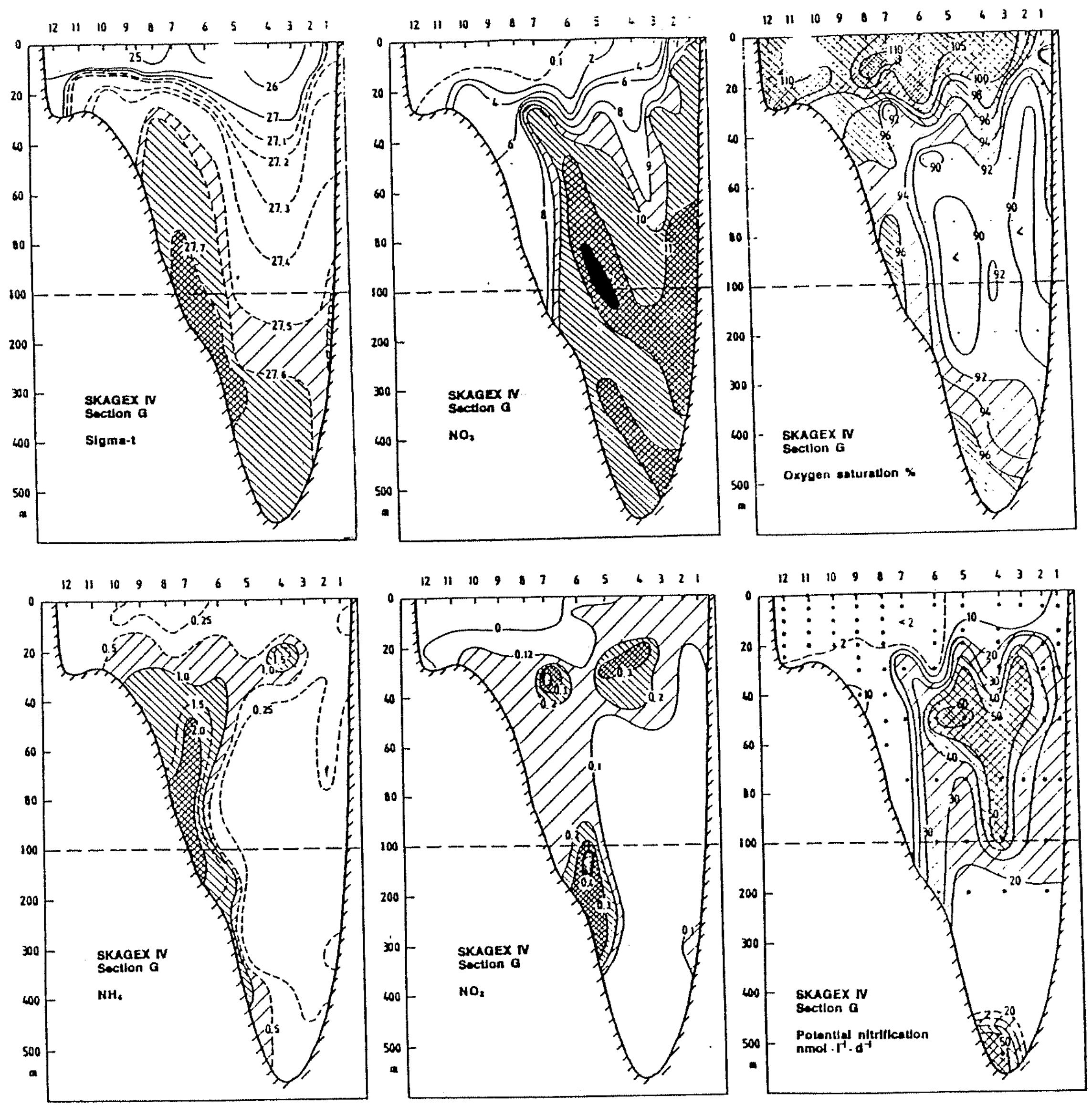

Fig. 2.

Isoplete diagrams showing density (sigma-t, above left), nitrate (NO_3^-, µmol l^{-1}, above centre), oxygen saturation value (%, above right), ammonium (NH_4^+, µmol l^{-1}, below left) and nitrite (NO_2^-, µmol l^{-1}, below centre) and nitrification potential (NP, nmol $l^{-1}d^{-1}$, below right) along the G section from Hanstholm in Denmark (left) to Oksø in Norway (right).

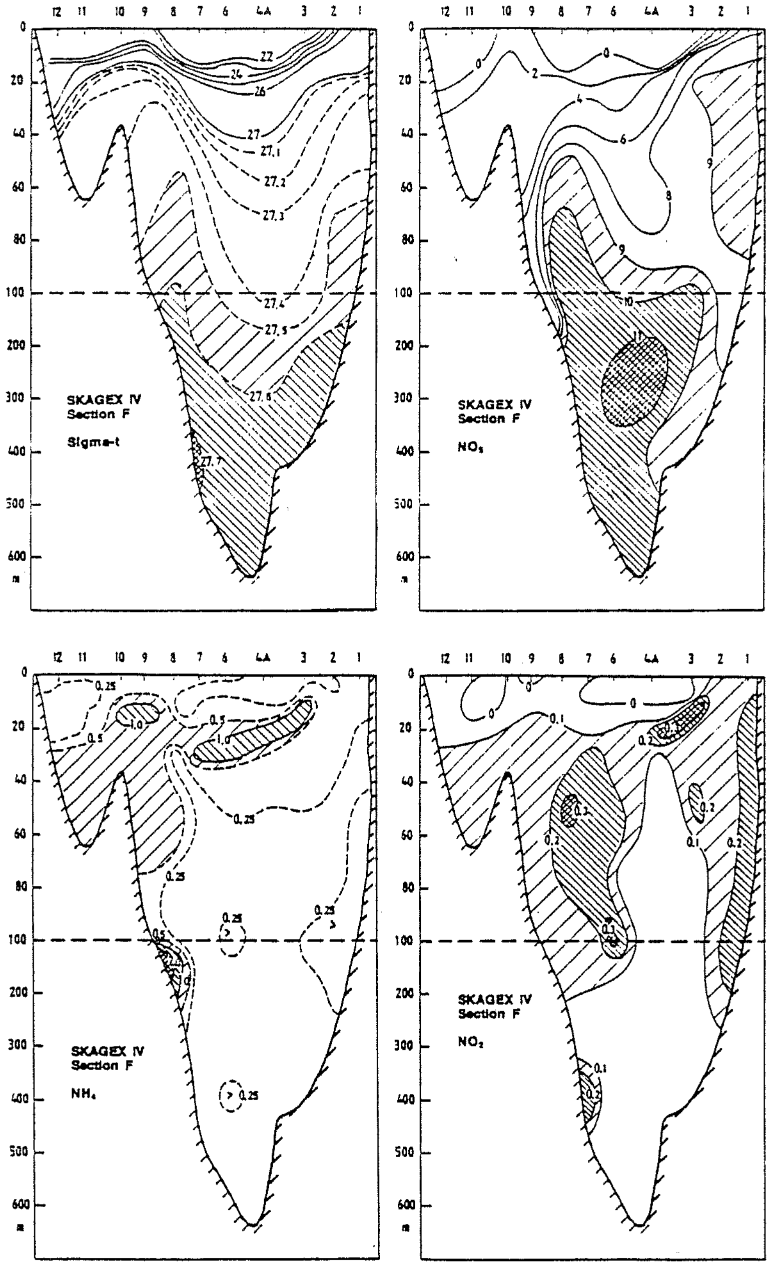

Fig. 3.

Isoplete diagrams showing density (sigma-t, above left), nitrate (NO_3^-, µmol l^{-1}, above right), ammonium (NH_4^+, µmol l^{-1}, below left) and nitrite (NO_2^-, µmol l^{-1}, below right) along the F section from Hirtshals in Denmark (left) to Torungen in Norway (right).

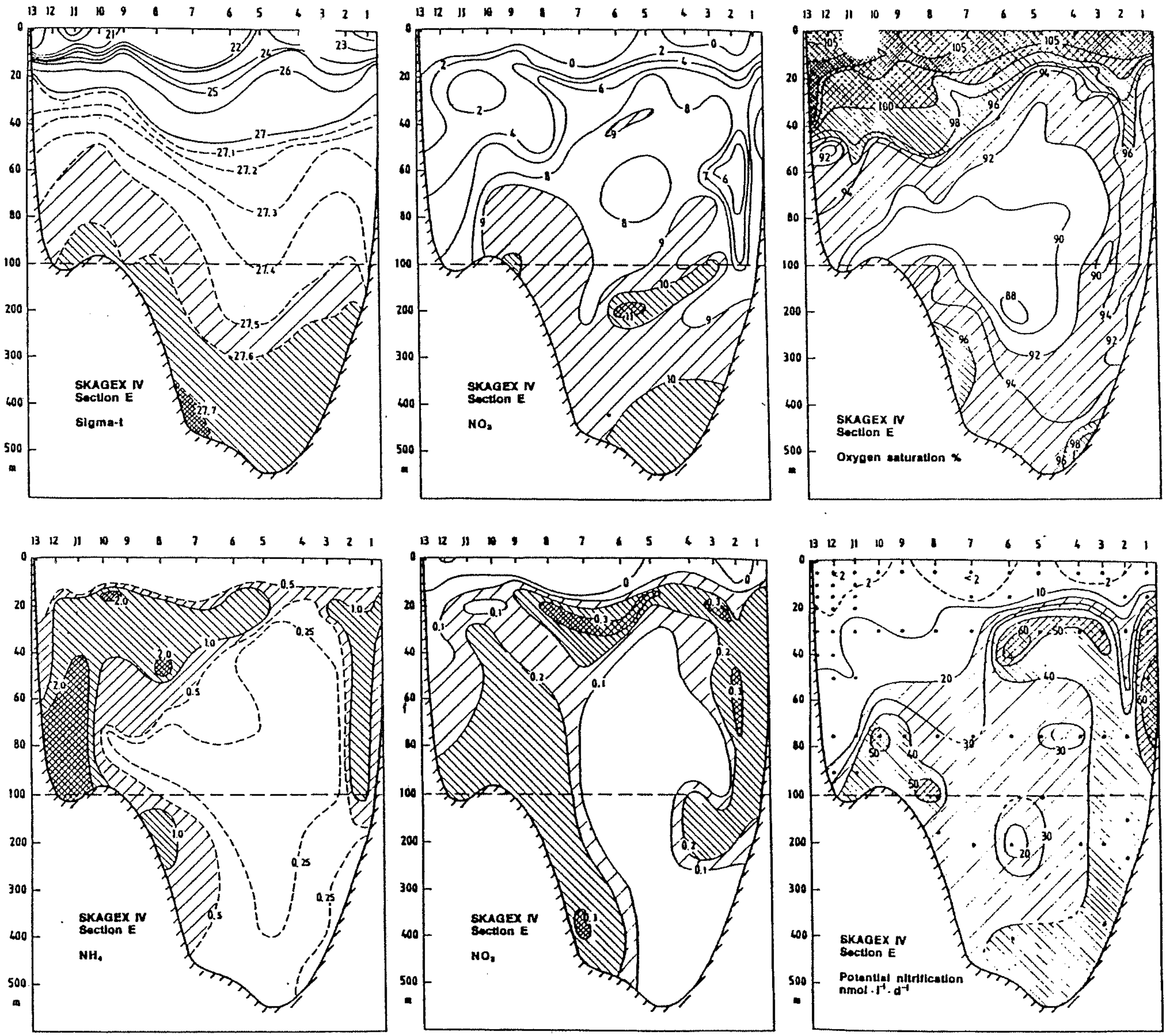

Fig. 4.

Isoplete diagrams showing density (sigma-t, above left), nitrate (NO_3^-, µmol l^{-1}, above centre), oxygen saturation value (%, above right), ammonium (NH_4^+, µmol l^{-1}, below left) and nitrite (NO_2^-, µmol l^{-1}, below centre) and nitrification potential (NP, nmol $l^{-1}d^{-1}$, below right) along the E section from Skagen in Denmark (left) to Jomfruland in Norway (right).

Presentation no 7.

On correction of nutrient data based on the intercomparison exercises during the SKAGEX I and IV experiments.

by

E. Fogelqvist, L. Føyn, H. P. Hansen and D. Danielssen

On correction of nutrient data based on the intercomparison exercises during the SKAGEX I and IV experiments

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INTRODUCTION

The SKAGEX experiment, during which data were collected simultaneously from a large number of ships and from all parts of the Skagerrak, included intercomparisons on nutrient measurements and CTD data as an important part. In the middle of the SKAGEX I expeditions, in June 1990, an extensive intercomparison exercise was arranged, where three chemical parameters were selected for the intercomparison; nitrate, phosphate and silicate.

During the SKAGEX IV period, the intercomparison was arranged through exchange of water samples any time two ships met at sea. The parameters covered by these intercomparisons were nitrate, nitrite, phosphate and silicate.

SKAGEX I

All ships reporting chemical data during the SKAGEX I experiment participated in the exercise which took place in Arendal, Norway, in the middle of the five weeks cruise period. A total of thirteen ships participated in the intercomparison, which was arranged in a way which as much as possible resembles a normal situation during field work. The samples were collected onboard *G.O. Sars* the day before arrival in Arendal at six stations along one of the SKAGEX transects and at standard depths. Subsamples were distributed among the different ships and immediately analyzed. The samples were treated by the various chemists according to normal procedures during the entire SKAGEX I cruise.

SKAGEX IV

A total of six ships participated in the SKAGEX IV experiment in May 1991. As *Argos* was one of the ships covering the whole Skagerrak area, a rendez-vous was arranged with four of the other ships (all except *A. Tiselius*) at one of the standard stations where the cruise tracs crossed each other. Water samples collected onboard *Argos* were split for analysis on both of the two ships involved immediately after sampling, and the analytical procedures followed the individual routines of each ship. Also, whenever an opportunity occurred, the other ships exchanged water samples with *G.M. Dannevig* for comparison of nutrient results. Thereby all ships involved in SKAGEX IV were intercompared, either with *Argos* or with *G.M. Dannevig*.

RESULTS

SKAGEX I

The performance of the SKAGEX I exercise, all the data and preliminary conclusions have been presented in an earlier report (Føyn, L., ICES, C.M. 1990/C:44, 1990). A further treatment of the results from the intercomparison was discussed within the chemical subgroup of the ICES Study Group on SKAGEX during its meeting in Gdynia, Poland, November 4-8, 1991. The inspection of the data led to the following conclusions:

a) Most of the vessels exhibit a reasonably good precision in their measurements over a large concentration range. In nearly all cases linear regressions with coefficients of determination >0.95 permit the correction of the individual measurements with respect to the median of the intercomparison.

b) The preparation of standards and the quality of water used for reagents may have caused certain deviations between ships noticed in the exercise. As some of the reagents are freshly prepared every or every second day, it is impossible to say if correlation factors calculated on the basis of the intercomparison would be valid over the SKAGEX I period (certainly not over the entire SKAGEX year).

c) Any application of correction factors means that new errors will be introduced.

d) The users of the data are encouraged to apply other statistical methods directly on the field data in order to assess the quality of them, and thereafter normalize the data for the purpose of their own interest.

Based on the arguments mentioned above it was decided that:

1. No data sets, that might be regarded as outliers, should be excluded from the data bank.

2. No correction factors should be applied to the SKAGEX data stored in the ICES data bank.

3. For those who want to use the data for a synoptic view of the conditions in the Skagerrak during SKAGEX I, despite the decisions under 1. and 2. above, correlation of the data to the median of the intercomparison, and thereby means for normalization of data, should be made available to the chief scientists and the ICES Data Center.

NOTE: It should be underlined that the field data from the first part of the SKAGEX I experiment reported by *Lev Titov* were analyzed by the chemist from *G.M. Dannevig*. This means that the intercomparison results from *G.M. Dannevig* should be used in evaluating the *Lev Titov* data from the first part of SKAGEX I and not the *Lev Titov* intercomparison results.

SKAGEX IV

In the SKAGEX IV exercise, only individual intercomparisons between two ships at a time are meaningful due to the fact that different sets of samples were used in each case. For those who intend to make a synoptic view of the Skagerrak area, the nutrient concentrations might be normalized to one scale by adjusting the data to the measurements made by *Argos*, the ship which participated in comparisons with all but one ship, *A. Tiselius*. Further information was obtained by the intercomparison between *G.M. Dannevig* and three of the ships. Thereby all the ships were directly or indirectly intercompared.

PROCEDURES APPLIED FOR CORRELATION OF DATA

In the SKAGEX I intercomparison, each nutrient determination was correlated to the median of all reported data for that analyte in the same water sample. The median was chosen as the estimated true value in order to eliminate biases from possible outliers. The results of the correlations are presented in the plots in Fig. 1 (nitrate), Fig. 2 (phosphate) and Fig. 3 (silicate), one plot for each parameter and each ship. The linear correlation lines applied to the data are also shown in the plots together with their slope (a) and intercept (b) values together with coefficients of determination (r^2). Furthermore, all the slopes, intercepts and coefficients of determination are listed in Tables I, II and III, for nitrate, phosphate and silicate, respectively.

The way the axes are oriented with the individual (dependant) data on the vertical and the median (independant) values on the horizontal axes, the interpretation of the correlation will be as follows:

Both a and b are together a measure of the accuracy of the measurements.
a is the slope of the line obtained through comparison of the ship in question with the estimated true value, and should ideally be 1.000. Any other value of a means a deviation in the determinations which is proportional to the concentration as, for example, when the stock standard solution has not been properly prepared.

b is the deviation, from the origin, of the intercept along the vertical axis. The value of b is the laboratory's blank value at zero concentration. It could depend on impurities in the reagents or the water from the pure water supply used for preparation of standards and reagents. If mixed standards are used, it could also be an impurity in one of the standard compounds, other than the one used for the quantification of this parameter. If b is negative, which might happen when a flow-through cuvette, e.g. in an autoanalyzer, is used, the reason is usually contamination of the wash solution.

To compensate for these deviations, firstly, all determinations should be reduced by b and, secondly, the rest should be divided by a.

In other words, the correction is made according to the following formula

$$C_{corr} = (C_{meas} - b)/a$$

where C_{corr} is the corrected and C_{meas} is the measured concentration.

The coefficient of determination, r^2, is a measure of the precision of the determination, all the way from sampling to the analytical measurement. It tells how much of the total variation of the measurements is due to the correlation ($100r^2$ %), the rest is attributed to random variation and other causes. The highest and ideal value is 1.000. The square root, r, the coefficient of correlation, has also an ideal value of 1.000, and $(1 - r)$ describes the degree of variation of the data points around the correlation line in about the same way as a relative standard deviation does for a mean value.

The data from SKAGEX IV have to be treated slightly different. The results presented in Fig. 4 (nitrate), Fig. 5 (nitrite), Fig. 6 (phosphate) and Fig. 7 (silicate) and the Tables 4-7 will, if treated the same way as described for the SKAGEX I exercise above, normalize the measurements to a scale represented by the *Argos* data. Figures 8-10 as well as Tables 8-10 show the intercomparison results between ships others than *Argos*, and give complementary information on nitrate, phosphate and silicate intercomparisons.

As *A. Tiselius* in the SKAGEX IV exercise did not intercompare directly with *Argos* but with *G.M. Dannevig* the data will have to be treated with great care. Even if it is possible to adjust the data to an "*Argos scale*" by a two step procedure, it should be kept in mind that the uncertainties introduced will increase, represented by the accuracy (a and b) and precision (r^2) values.

FINAL REMARKS

The experiences of the exercise and the problems encountered in the interpretation of the results have led to a strong recommendation for future experiments involving several separate laboratories. An ***intercomparison*** of nutrient determinations, like the one described here, should be followed by a proper ***intercalibration*** of the techniques employed by the different laboratories. A mutual exchange of reagents and standards followed by a fine-tuning of the methodologies and analytical instruments before the field experiment commenced could have made any correction of data unnecessary.

REFERENCE

Føyn, L., SKAGEX 1990. Preliminary results from the nutrient intercalibration. ICES, C.M. 1990/C:44, 1990.

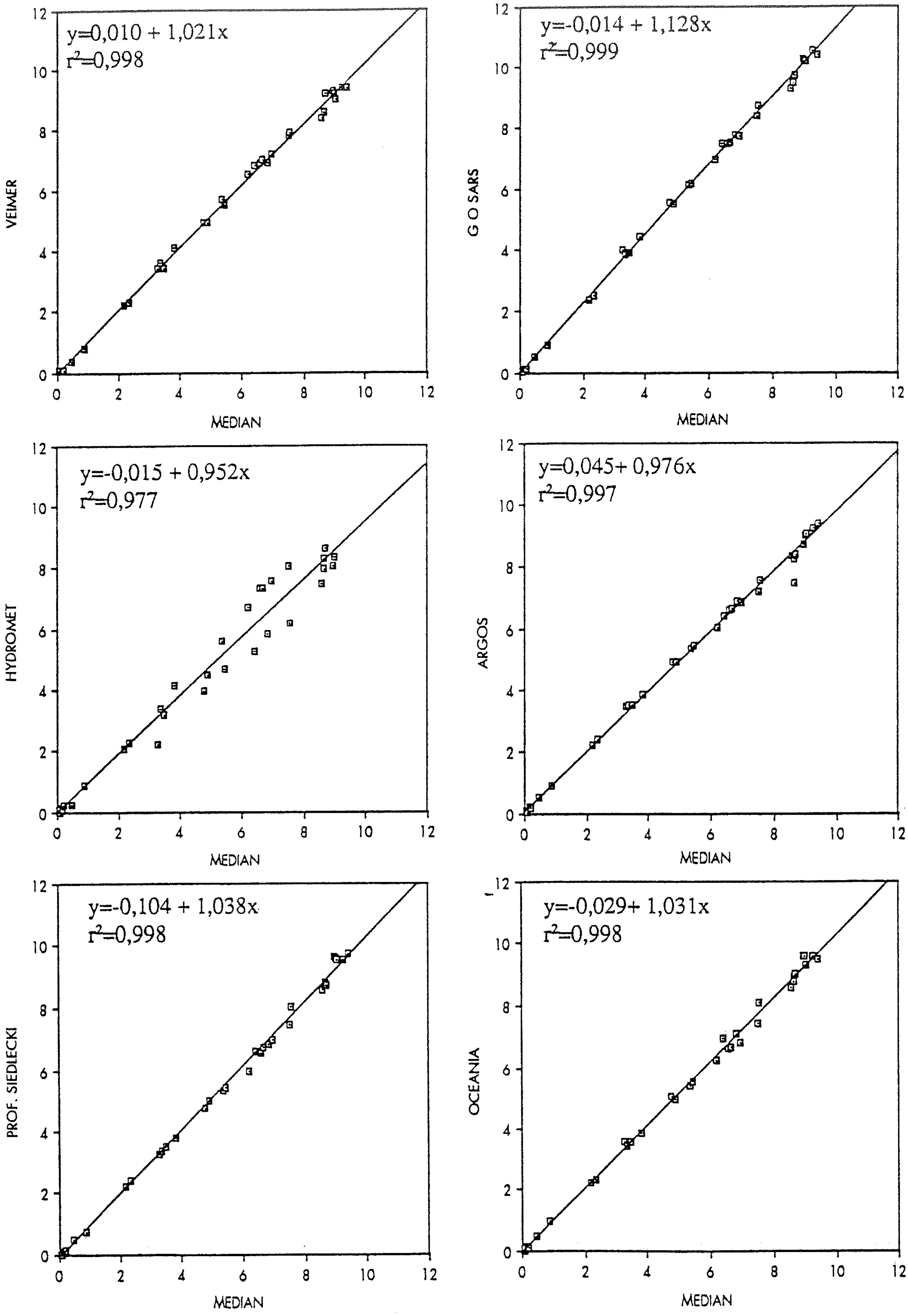
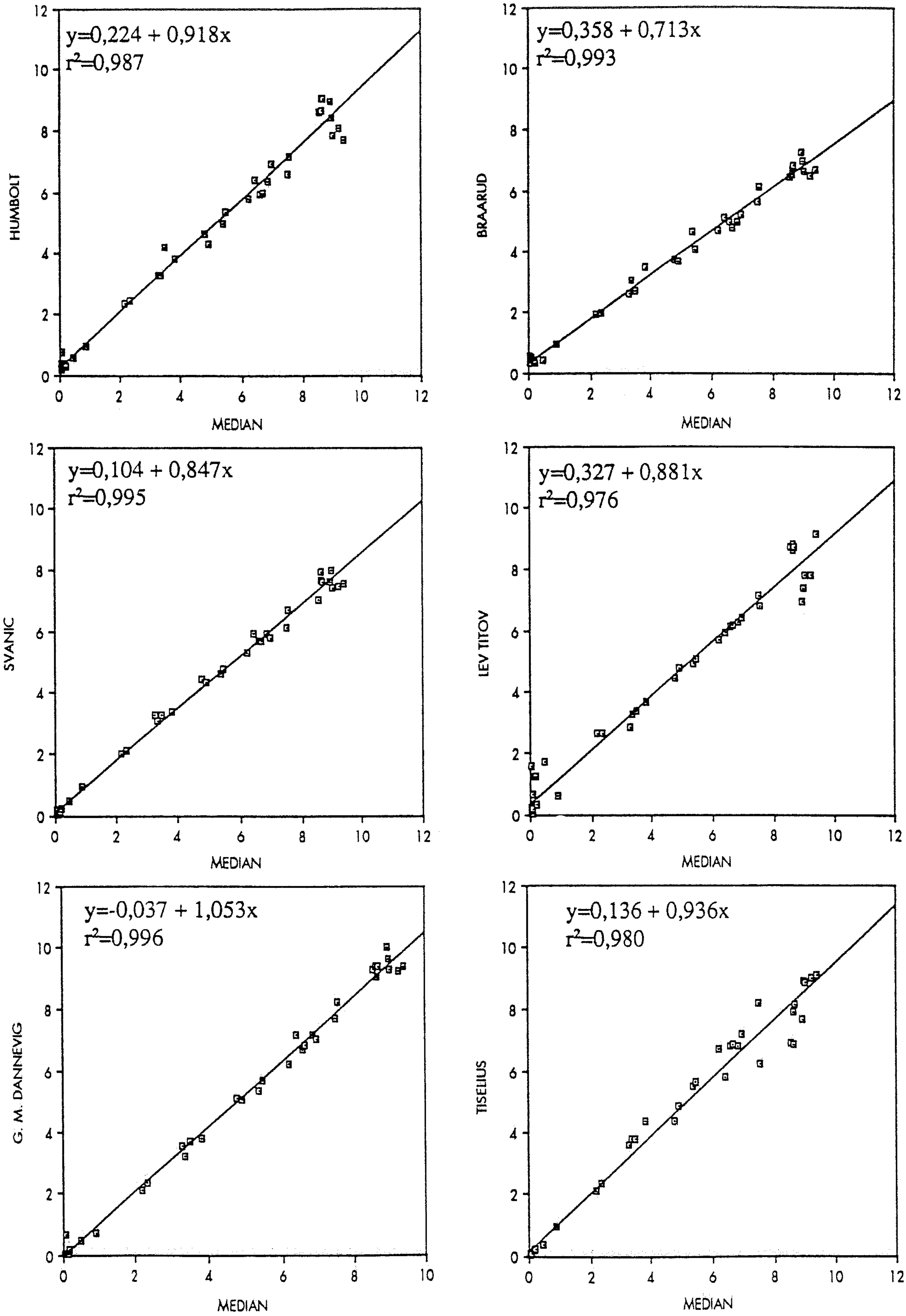


Figure 1: NITRATE, SKAGEX I
Each point represents an individual ship's measurement of nitrate (vertical axis) plotted against the median (horizontal axis) of all reported determinations of the same water sample. The correlation line is drawn and the equation is given together with the coefficient of determination.



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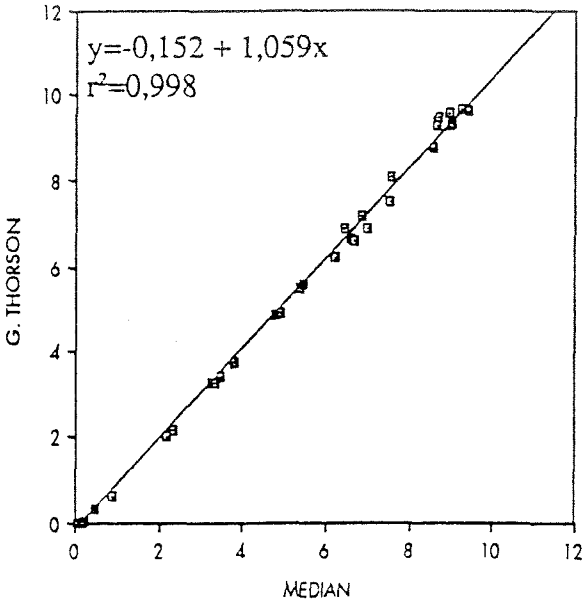


Figure 1: Cont.

Table I: NITRATE, SKAGEX I. Quantities for correction of nitrate determinations. The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff.(r^2)
A. VEIMER	1.021	0.010	0.998
G. O. SARS	1.128	-0.014	0.999
HYDROMET	0.952	-0.015	0.977
ARGOS	0.976	0.045	0.997
PROF. SIEDLECKI	1.038	-0.104	0.998
OCEANIA	1.031	-0.029	0.998
A. V. HUMBOLT	0.918	0.224	0.987
T. BRAARUD	0.713	0.358	0.993
SVANIC	0.847	0.104	0.995
LEV TITOV	0.881	0.327	0.976
G. M. DANNEVIG	1.053	-0.037	0.996
A. TISELIUS	0.936	0.136	0.980
G. THORSON	1.059	-0.152	0.998

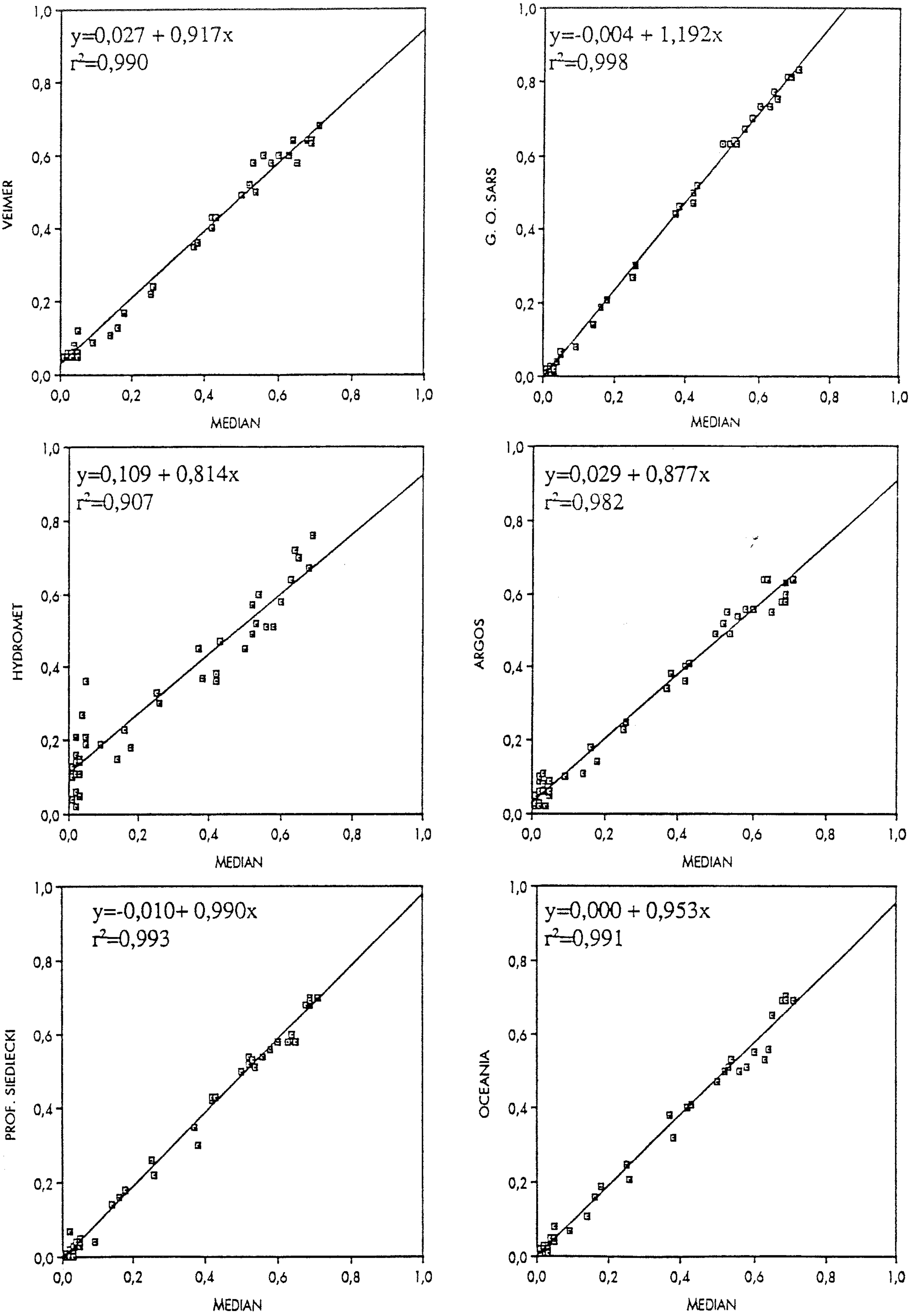
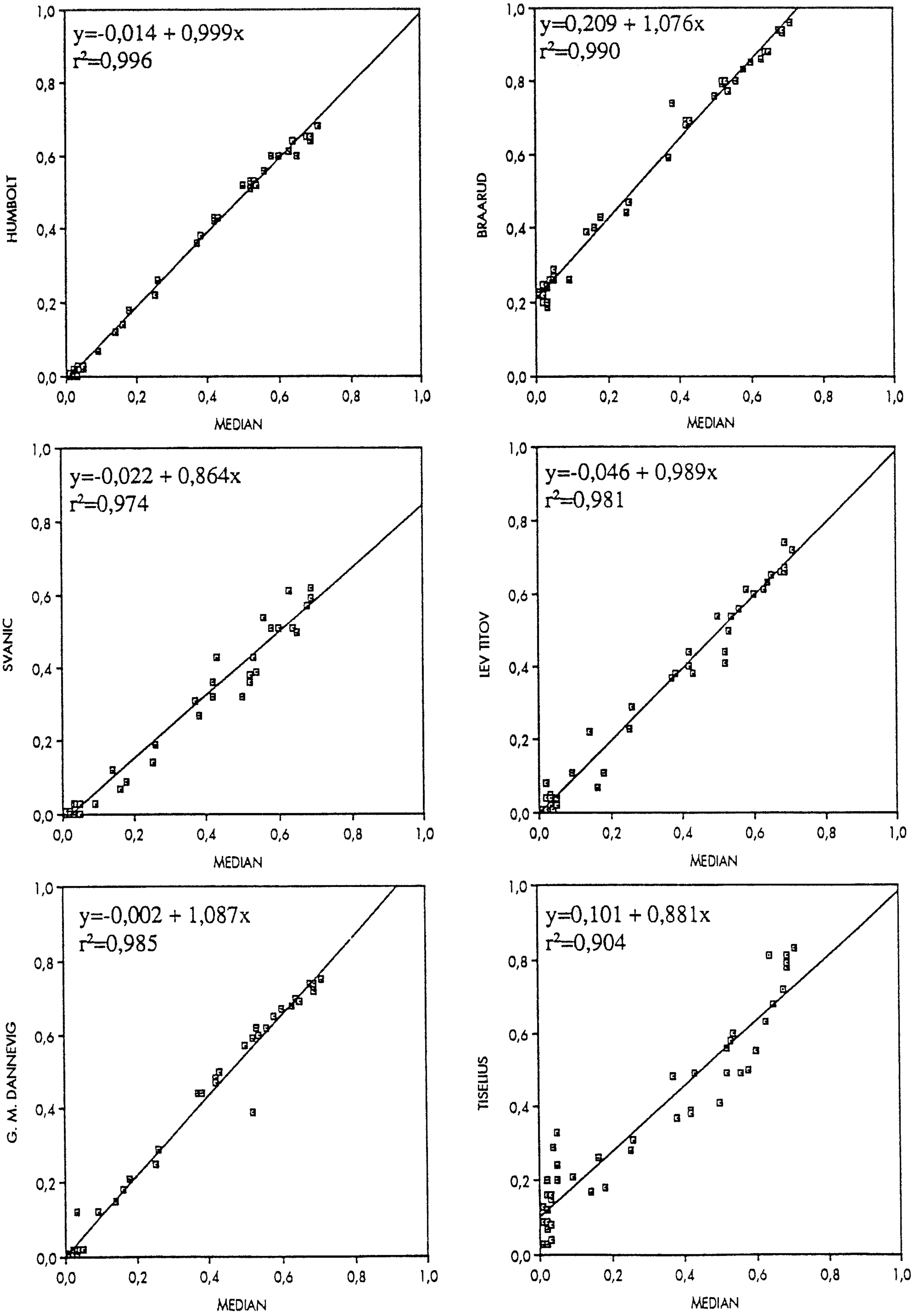


Figure 2: PHOSPHATE, SKAGEX I
Each point represents an individual ship's measurement of phosphate (vertical axis) plotted against the median (horizontal axis) of all reported determinations of the same water sample. The correlation line is drawn and the equation is given together with the coefficient of determination.



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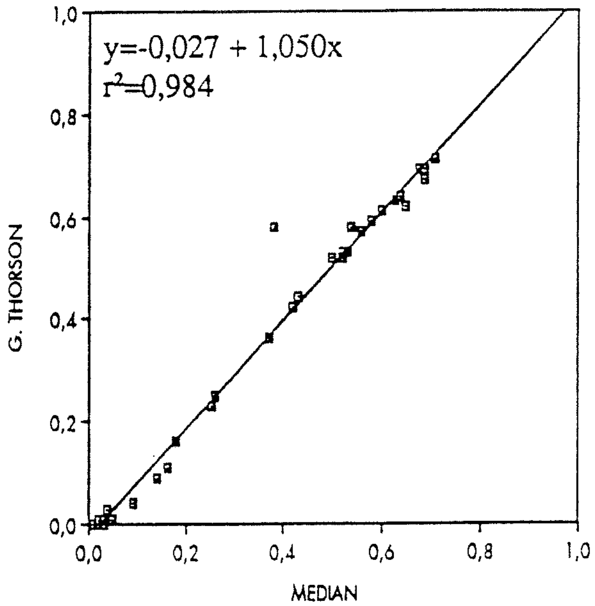

Figure 2: Cont.

Table II: PHOSPHATE, SKAGEX I. Quantities for correction of phosphate determinations. The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff.(r^2)
A. VEIMER	0.917	0.027	0.990
G. O. SARS	1.192	-0.004	0.998
HYDROMET	0.814	0.109	0.907
ARGOS	0.877	0.029	0.982
PROF. SIEDLECKI	0.990	-0.010	0.993
OCEANIA	0.953	0.000	0.991
A. V. HUMBOLT	0.999	-0.014	0.996
T. BRAARUD	1.076	0.209	0.990
SVANIC	0.864	-0.022	0.974
LEV TITOV	0.989	-0.046	0.981
G. M. DANNEVIG	1.087	-0.002	0.985
A. TISELIUS	0.881	0.101	0.904
G. THORSON	1.050	-0.027	0.984

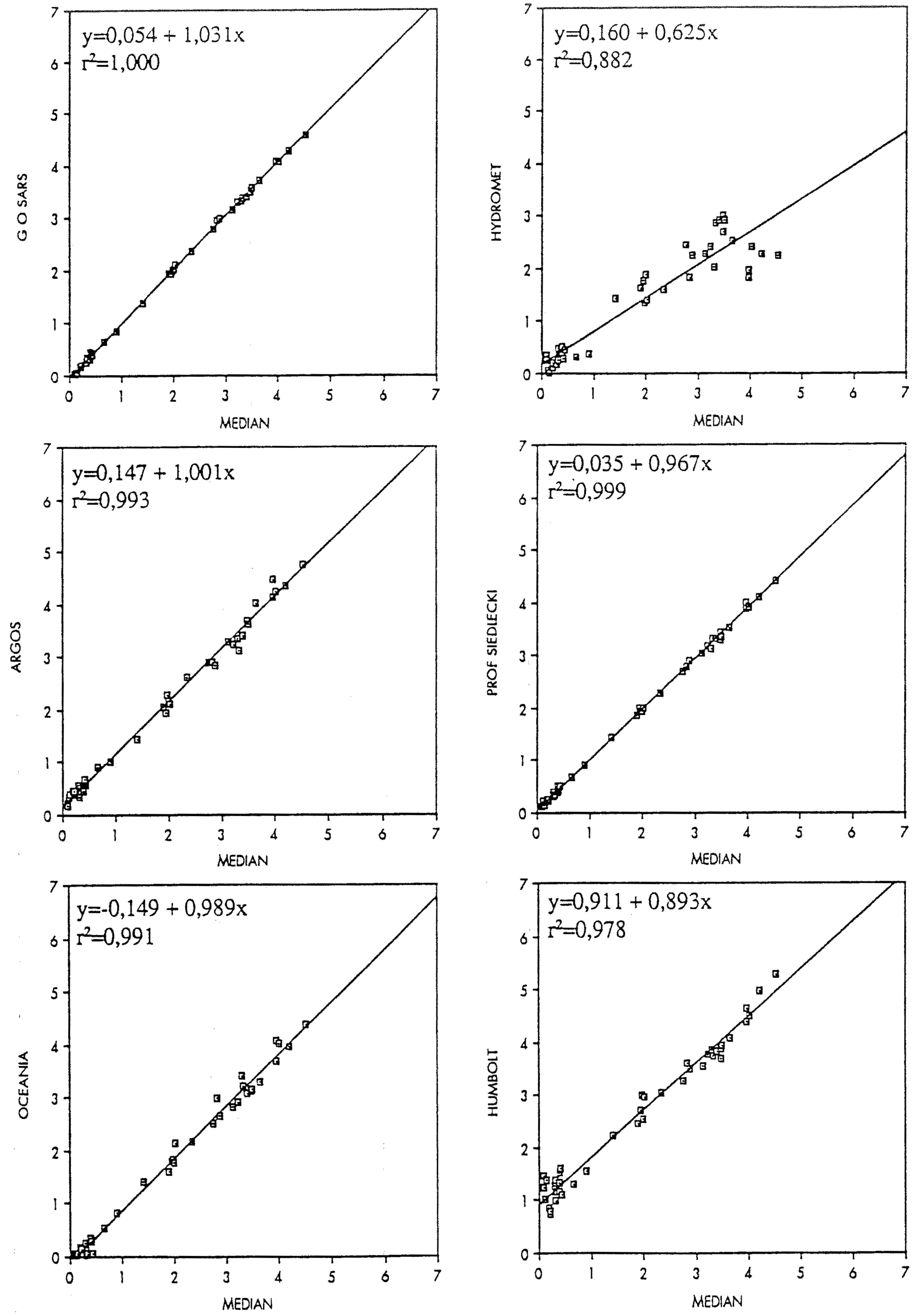

Figure 3: SILICATE, SKAGEX I
Each point represents an individual ship's measurement of silicate (vertical axis) plotted against the median (horizontal axis) of all reported determinations of the same water sample. The correlation line is drawn and the equation is given together with the coefficient of determination.

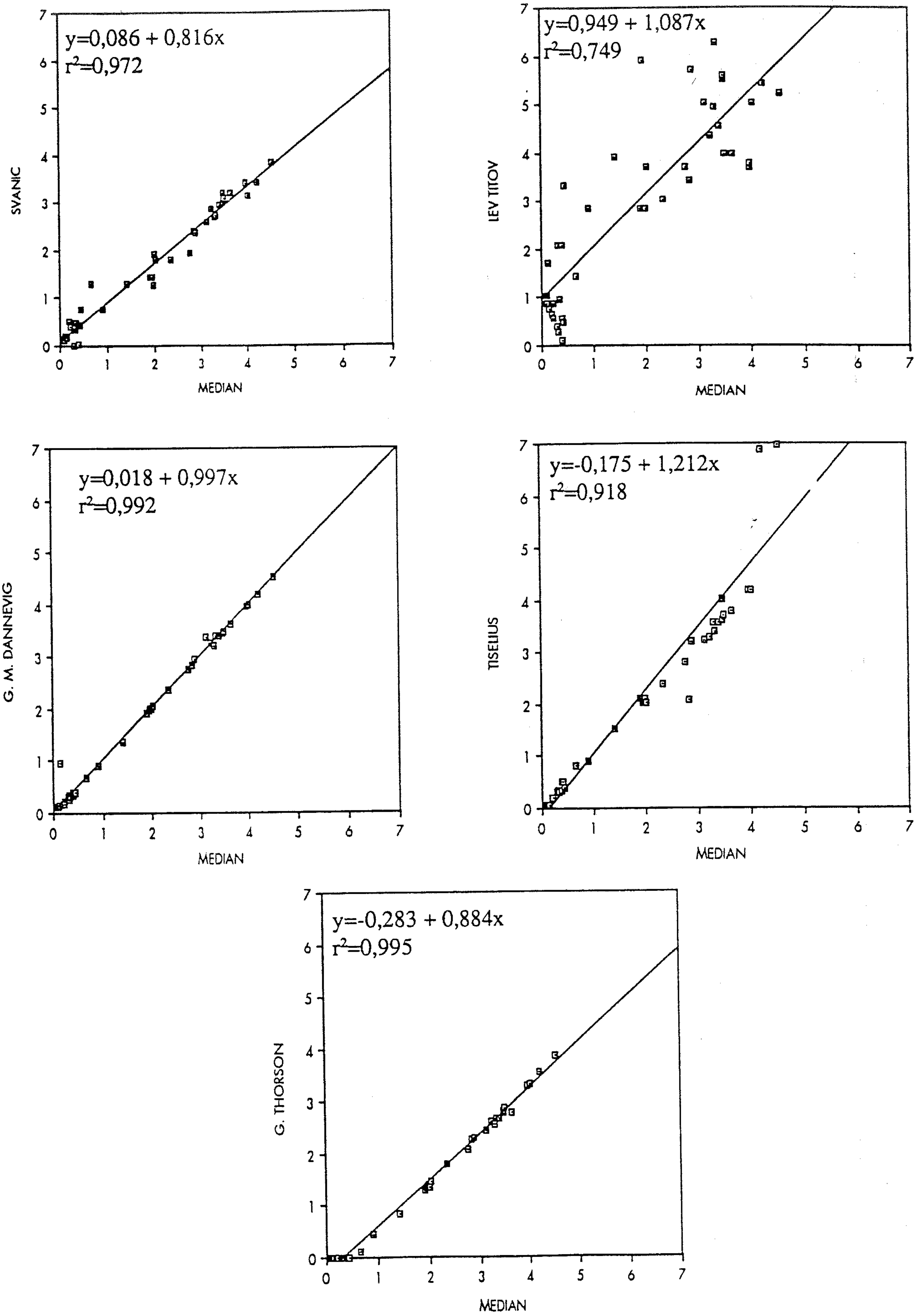

Figure 3: Cont.

Table III: SILICATE, SKAGEX I. Quantities for correction of silicate determinations. The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff.(r^2)
G. O. SARS	1.031	0.054	1.000
HYDROMET	0.625	0.160	0.882
ARGOS	1.001	0.147	0.993
PROF. SIEDLECKI	0.967	0.035	0.999
OCEANIA	0.989	-0.149	0.991
A. V. HUMBOLT	0.893	0.911	0.978
SVANIC	0.816	0.086	0.972
LEV TITOV	1.087	0.949	0.749
G. M. DANNEVIG	0.997	0.018	0.992
A. TISELIUS	1.212	-0.175	0.918
G. THORSON	0.884	-0.283	0.995

Table IV: NITRATE, comparison with *Argos*, SKAGEX IV. Quantities for normalization of nitrate determinations to an "*Argos* scale". The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff. (r^2)
G.M. DANNEVIG	1.140	0.132	0.986
J. HJORT	0.975	0.059 -	0.991
OCEANIA	0.991	-0.081	0.999
LEV TITOV	0.974	0.116	0.990

Table V: NITRITE, comparison with *Argos*, SKAGEX IV. Quantities for normalization of nitrite determinations to an "*Argos* scale". The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff. (r^2)
G.M. DANNEVIG	0.954	0.008	0.985
J. HJORT	0.796	-0.017	0.801
OCEANIA	0.994	-0.007	0.931
LEV TITOV	1.019	-0.020	0.854

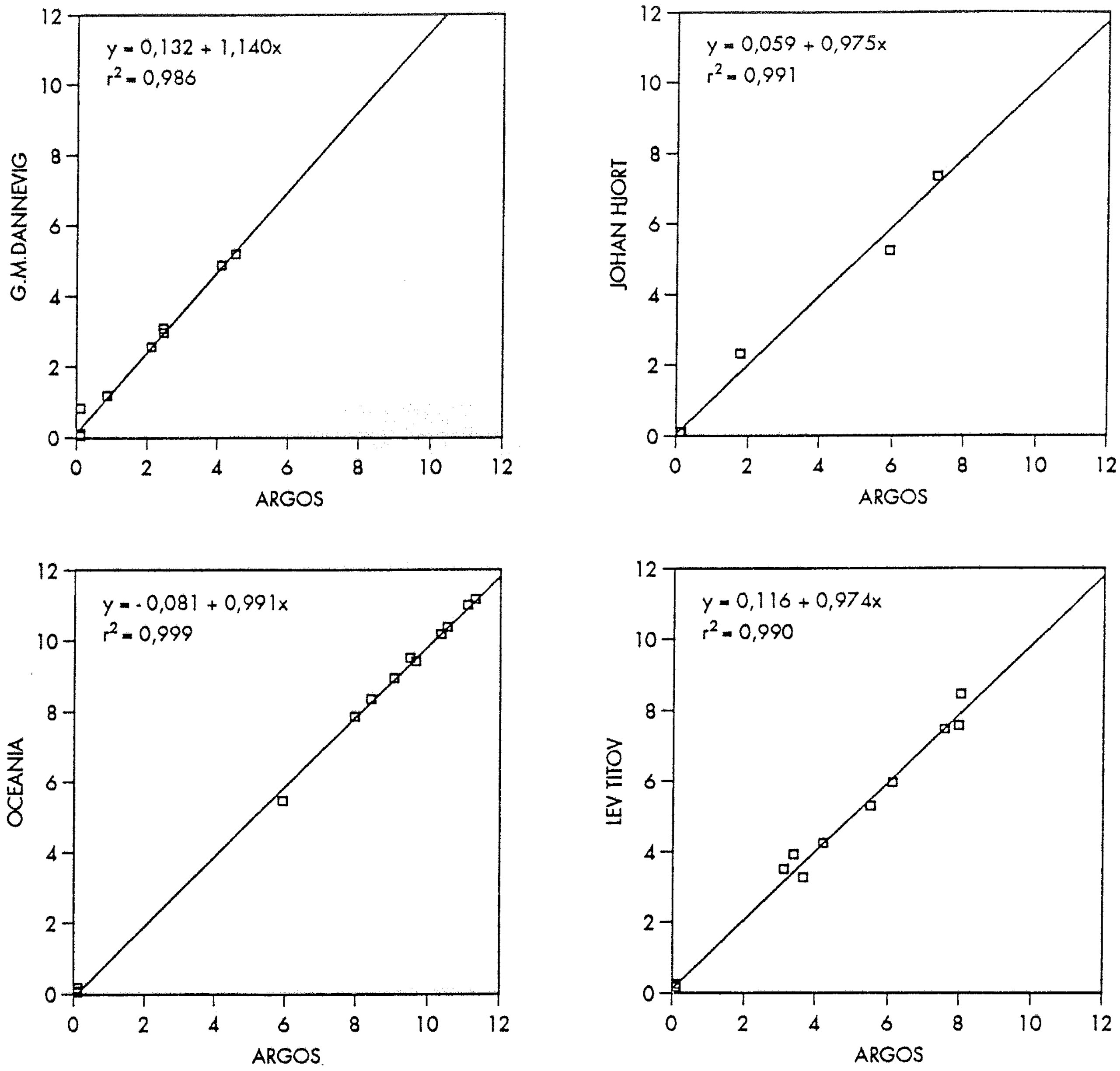

Figure 4: NITRATE, comparison with *Argos*, SKAGEX IV
Each point represents an individual ship's measurement of nitrate (vertical axis) plotted against the *Argos* measurement (horizontal axis) of the same water sample taken at the rendez-vous arranged between two. The correlation line is drawn and the equation is given together with the coefficient of determination.

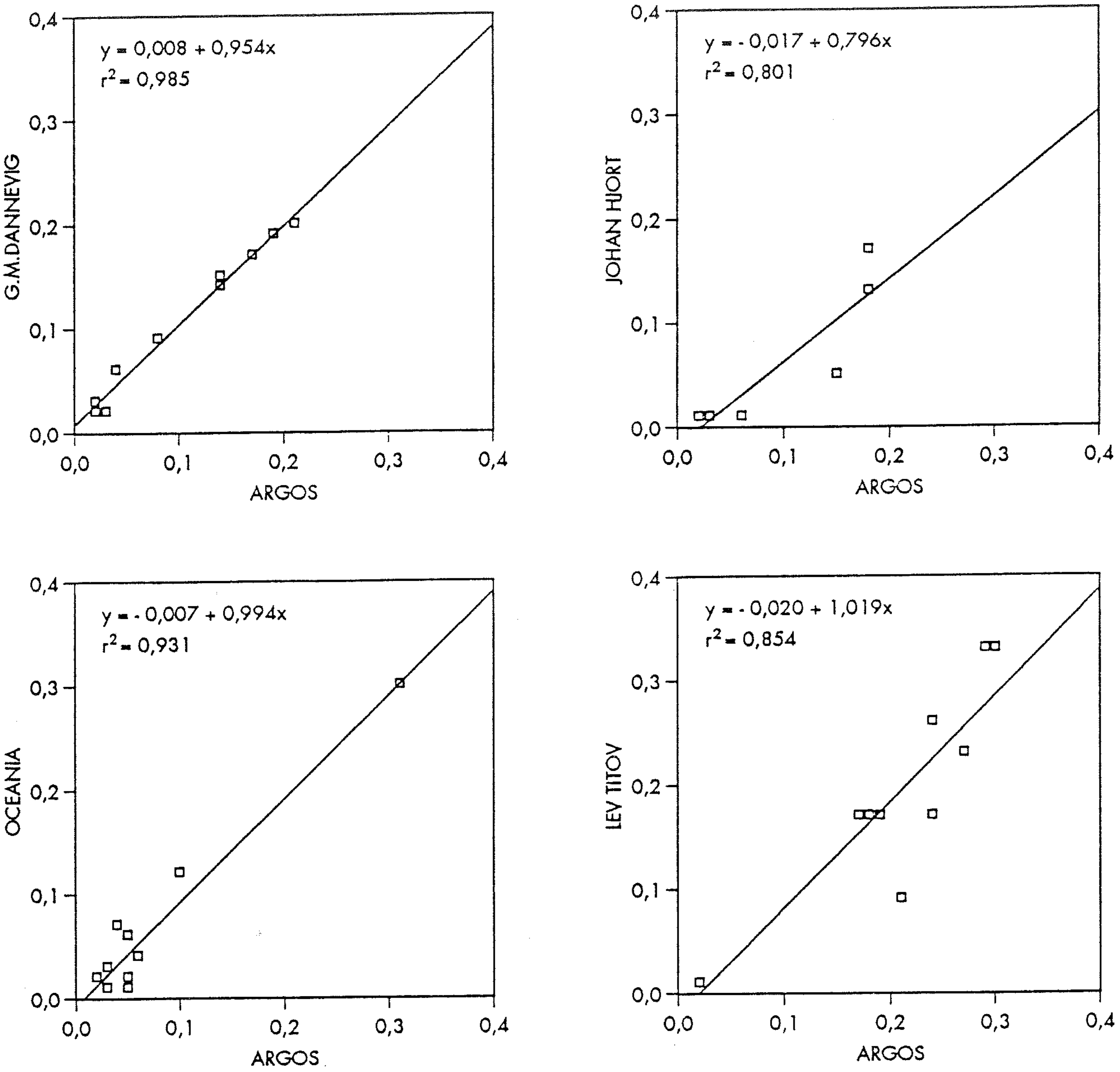

Figure 5: NITRITE, comparison with *Argos*, SKAGEX IV
Each point represents an individual ship's measurement of nitrite (vertical axis) plotted against the *Argos* measurement (horizontal axis) of the same water sample taken at the rendez-vous arranged between two. The correlation line is drawn and the equation is given together with the coefficient of determination.

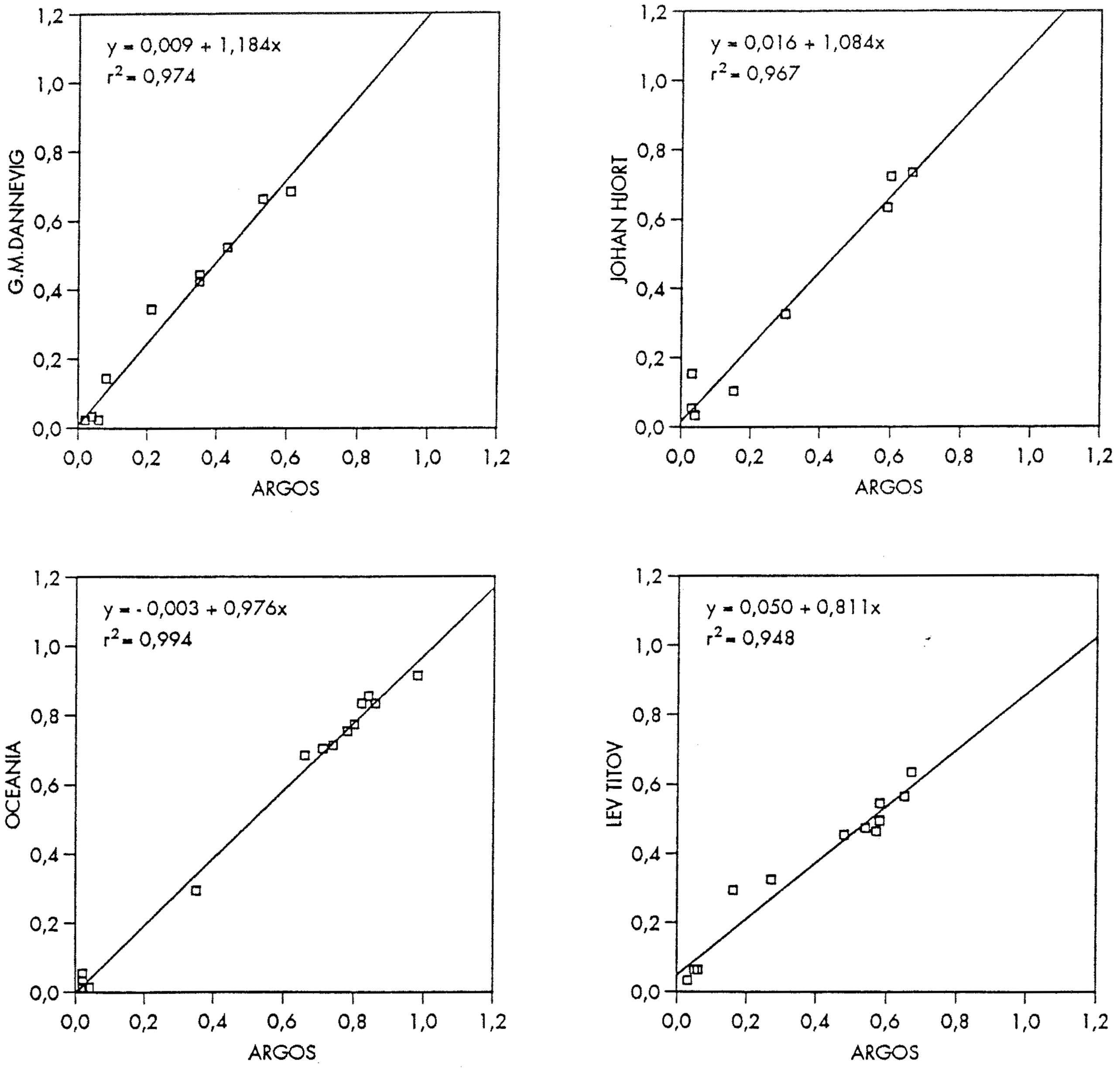

Figure 6: PHOSPHATE, comparison with *Argos*, SKAGEX IV
Each point represents an individual ship's measurement of phosphate (vertical axis) plotted against the *Argos* measurement (horizontal axis) of the same water sample taken at the rendez-vous arranged between two. The correlation line is drawn and the equation is given together with the coefficient of determination.

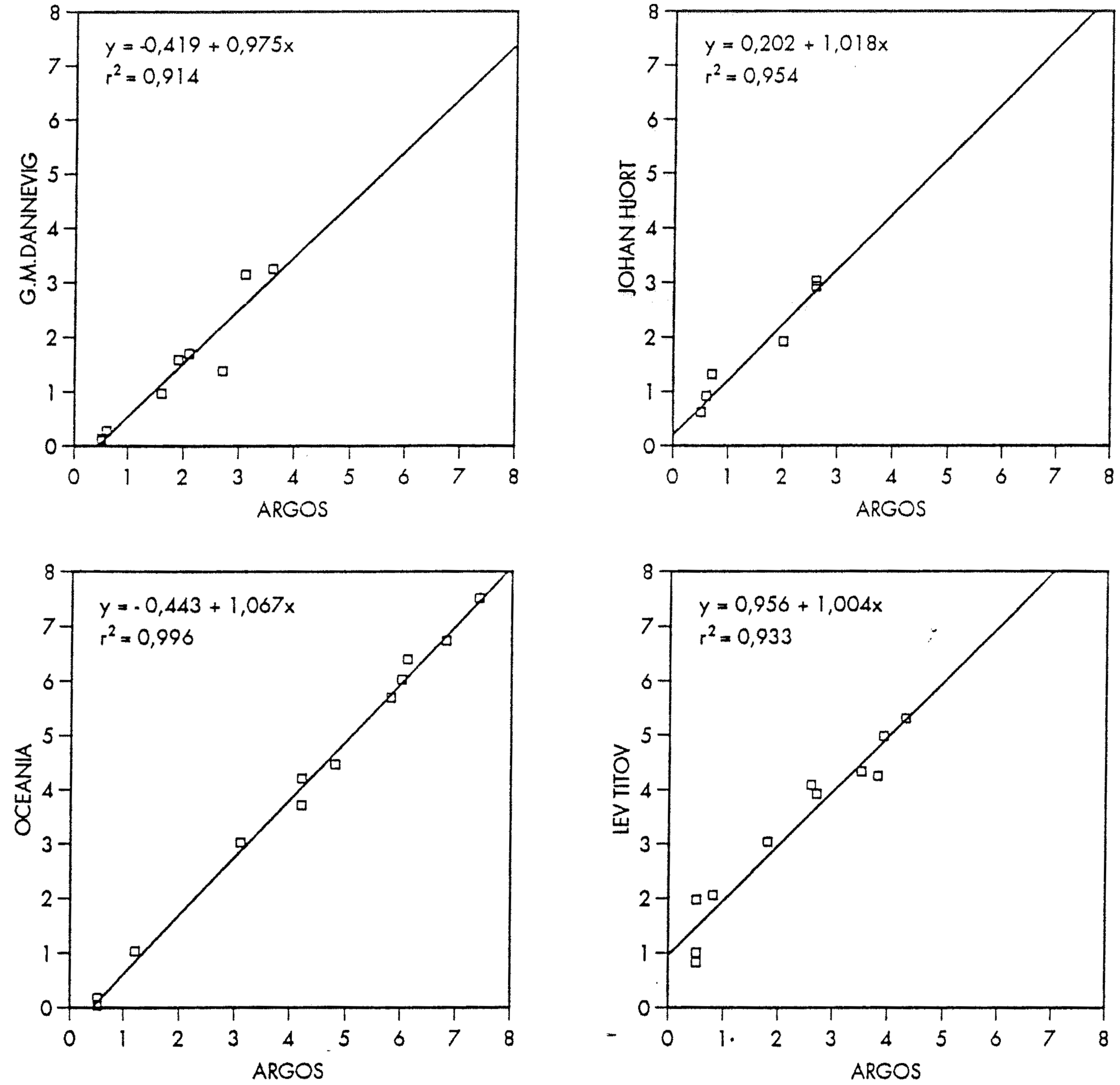

Figure 7: SILICATE, comparison with *Argos*, SKAGEX IV
Each point represents an individual ship's measurement of silicate (vertical axis) plotted against the *Argos* measurement (horizontal axis) of the same water sample taken at the rendez-vous arranged between the two. The correlation line is drawn and the equation is given together with the coefficient of determination.

Table VI: PHOSPHATE, comparison with *Argos*, SKAGEX IV. Quantities for normalization of phosphate determinations to an "*Argos* scale". The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff. (r^2)
G.M. DANNEVIG	1.184	0.009	0.974
J. HJORT	1.084	0.016	0.967
OCEANIA	0.976	-0.003	0.994
LEV TITOV	0.811	0.050	0.948

Table VII: SILICATE, comparison with *Argos*, SKAGEX IV. Quantities for normalization of silicate determinations to an "*Argos* scale". The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff. (r^2)
G.M. DANNEVIG	0.975	-0.419	0.914
J. HJORT	1.018	0.202	0.954
OCEANIA	1.067	-0.443	0.996
LEV TITOV	1.004	0.956	0.933

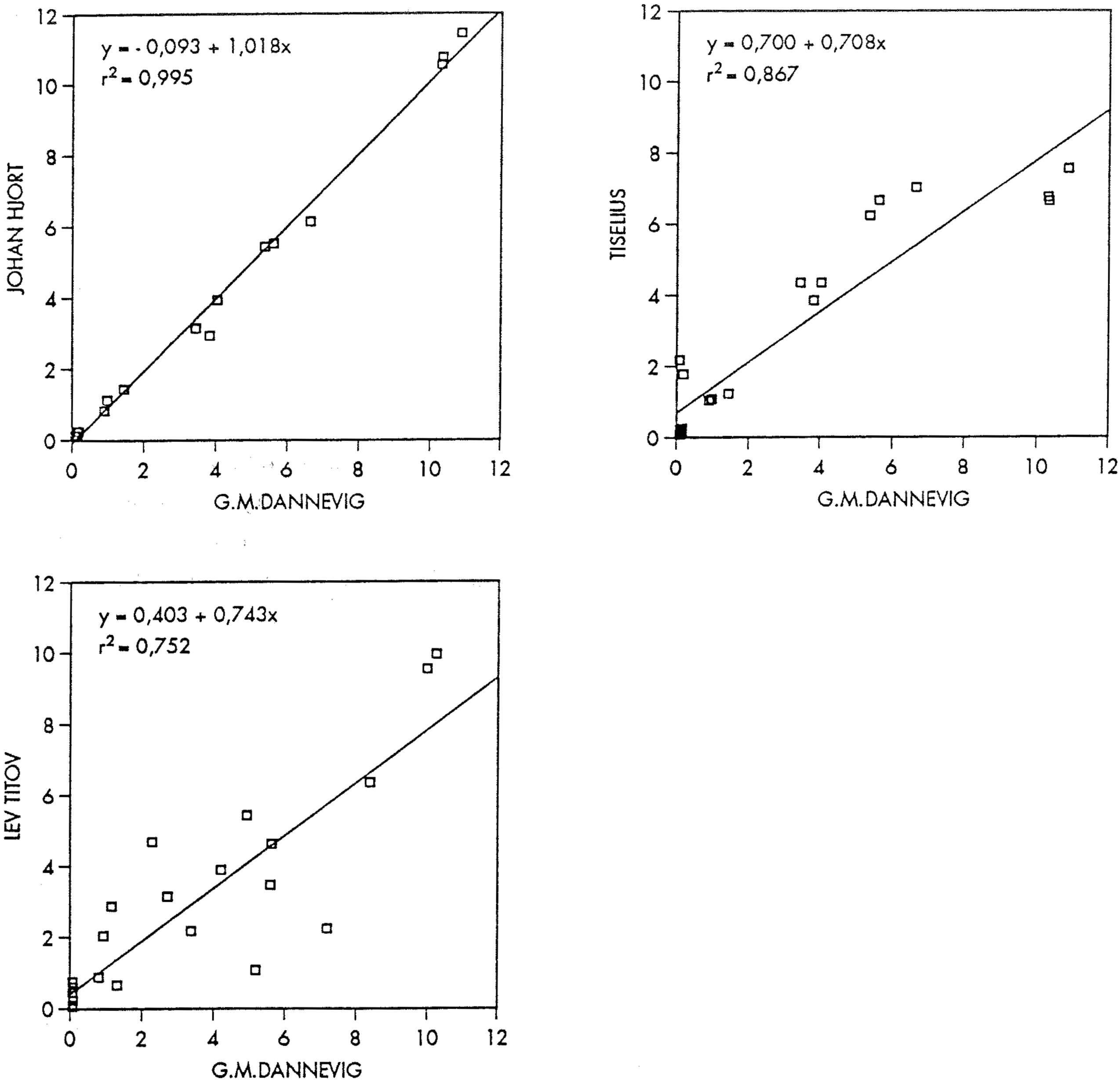

Figure 8: NITRATE, comparison between other ships than *Argos* during SKAGEX IV
Each point represents the comparison between two ships' measurements of nitrate in the same water sample taken at the rendez-vous arranged between the two. The correlation line is drawn and the equation is given together with the coefficient of determination.

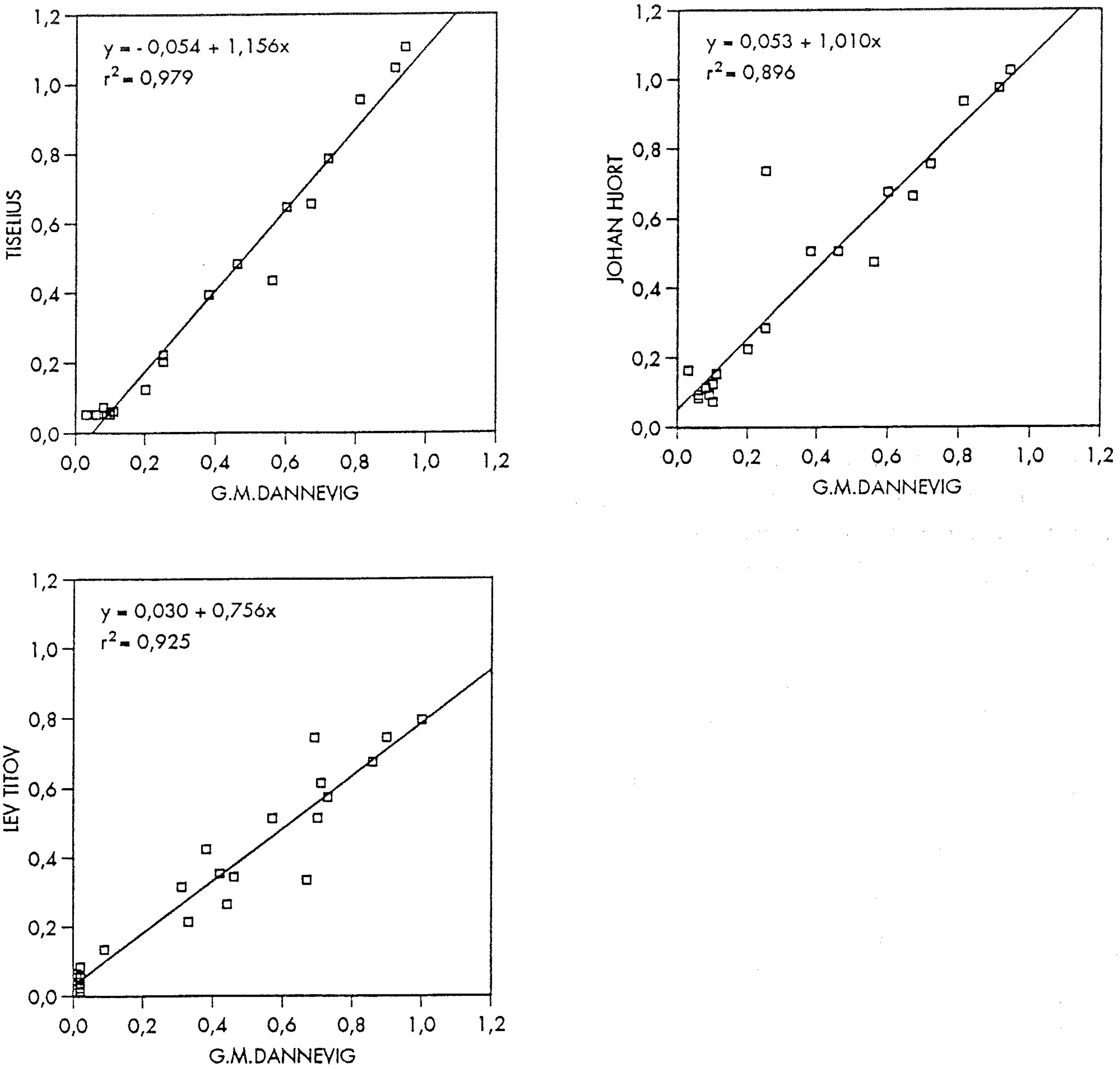

Figure 9: PHOSPHATE, comparison between other ships than *Argos* during SKAGEX IV Each point represents the comparison between two ships' measurements of phosphate in the same water sample taken at the rendez-vous arranged between the two. The correlation line is drawn and the equation is given together with the coefficient of determination.

Table VIII: NITRATE, comparison between ships others than *Argos* during SKAGEX IV. Quantities for comparison of nitrate determinations. The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff. (r^2)
J. HJORT	1.018	-0.093	0.995
LEV TITOV	0.743	0.403	0.752
A. TISELIUS	0.708	0.700	0.867

Table IX: PHOSPHATE, comparison between ships others than *Argos* during SKAGEX IV. Quantities for comparison of phosphate determinations. The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff. (r^2)
J. HJORT	1.010	0.053	0.896
LEV TITOV	0.756	0.030	0.925
A. TISELIUS	1.156	-0.054	0.979

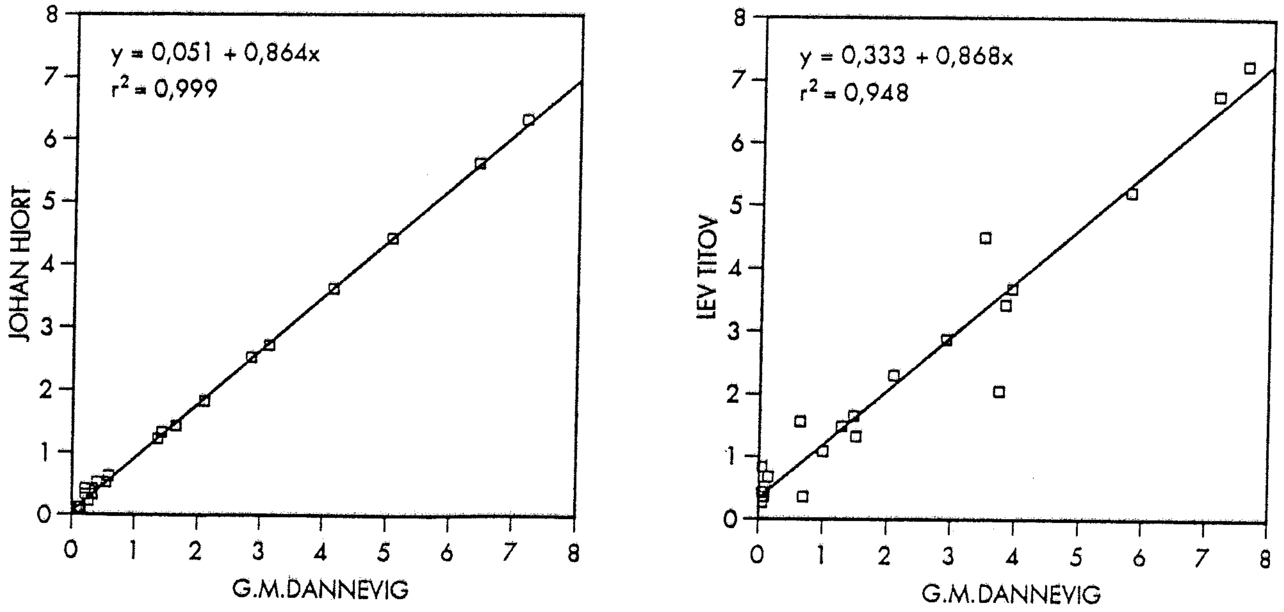

Figure 10: SILICATE, comparison between other ships than *Argos* during SKAGEX IV
Each point represents the comparison between two ships' measurements of silicate in the same water sample taken at the rendez-vous arranged between the two. The correlation line is drawn and the equation is given together with the coefficient of determination.

Table X: SILICATE, comparison between ships others than *Argos* during SKAGEX IV.
Quantities for comparison of silicate determinations. The slope (*a*), the intercept (*b*) and the coefficient of determination (r^2) for each ship (for procedures, see text).

Ship	Slope (*a*)	Intercept (*b*)	Coeff. (r^2)
J. HJORT	0.864	0.051	0.999
LEV TITOV	0.868	0.333	0.948

Presentation no 8.

Nutrient measurements by R/V "Argos" at section G during the winter expedition SKAGEX III in January 1991.

by

S. Fonselius

Nutrient measurements by R/V ARGOS at section G during the winter expedition SKAGEX III in January 1991

by

Stig Fonselius

SMHI, Oceanographic Laboratory, Box 2212, S-403 14 Göteborg,
SWEDEN

Abstract

The nutrient measurements by the R/V ARGOS during the SKAGEX III expedition in January 1991 are demonstrated with examples of the results from the 18th January at the transect G. The possible reasons for the difference between the distribution of nitrogen nutrients during summer and winter conditions are discussed.

Working area and methods

The SKAGEX program, the different water masses and the working area with the sections worked, are described in Danielssen et al. 1991. The methods used on board the ARGOS are described in Enoksson et al. 1993.

Results

The third SKAGEX expedition, SKAGEX III, was carried out in January 1991. The R/V ARGOS worked the G section three times. The nutrient conditions during the winter season differed from the summer conditions. Hardly any primary production occurred and the nutrient concentrations were comparatively high in the surface water. Figs 1 and 2 show the salinity and temperature distribution at section G January 18. An inflow from the North Sea of warmer water with high salinity is evident at stations 7 and 8. At stations 3 and 4, deep water seems to be flowing out from the Skagerrak at 100-300 m depth.

In contrast to the summer observations (SKAGEX I in May-June and SKAGEX II in September 1990, Danielssen et al. 1991) the winter situation was quite opposite. The nitrate distribution showed a minimum in the central part at station 5 below the halocline, from 100 m depth and extending down to 200 m. Closer to the bottom of the Norwegian Trench the nitrate concentration, however, was high (Fig. 3). On the other hand, the core of the inflowing water had a high nitrate concentration and this was true also for the outflowing deep water. The differences between summer and winter observations regarding nitrate were also apparent in the distributions of nitrite and ammonia. The lowest nitrite values (Fig. 4) were found in the inflowing water at stations 7-8, an increasing gradient was found towards the nitrate minimum, which coincided with the nitrite maximum, and again a minimum was found in the outflowing water at station 3. The ammonia distribution (Fig. 5) showed minimum values at stations 6 and 7 in the inflowing water and at station 3 in the outflowing water. Also ammonia had a maximum at the nitrate minimum. A comparison with the results of section F, which were carried out by the R/V DANNEVIG the same day showed that the nitrate minimum was much smaller there, indicating that it did not extend much farther in to the Skagerrak (personal discussion with D. Danielssen). The nitrate minimum at station 5 did not have any corresponding phosphate or silicate minimum. On the contrary these parameters showed somewhat elevated values at this station (Figs 6 and 7). In the bottom water of the Skagerrak the concentration of nitrate, phosphate and silicate was high and in the Jutland Coastal Water and in the Norwegian Coastal Current all nutrient showed high concentrations.

Discussion

The water with low nitrate content may have originated from the North Sea, where it was at the surface during the autumn and therefore had lost most of its nitrate. The water which flowed in to the Skagerrak in January had a high nitrate concentration and very low concentrations of nitrite and ammonia, which is normal for winter surface conditions in the North Sea (Reid et al. 1988). During the winter the North Sea water is well mixed down to the bottom (Brockmann et al. 1988).

The high concentrations of ammonia and nitrite found in the central Skagerrak deep water during SKAGEX III indicate that degradation of organic material is (or has been) taking place, but which might have been inhibited by lack of nitrifying bacteria. The potential for nitrification was measured in a large amount of water samples from the E and G transects during the SKAGEX IV expedition (Enoksson et al. 1992). The results from those measurements support the hypothesis on the inhibited nitrification in the central Skagerrak during the winter expedition. At the nitrate minimum at station 5 the phosphate and silicate showed elevated concentrations, which also supports the theory on inhibited nitrification.

References

Brockmann, U., G. Billen and W. W. C. Gieskes 1988. North Sea Nutrients an Eutrophication. Pollution of the North Sea, an Assessment. (Edit. W. Salomons, B. L. Bayne, E. K. Duursma and U. Förstner). Springer-Verlag, Berlin, Heidelberg, New York, London, Paris, Tokyo, pp 348-359.

Danielssen, D.S., L. Davidsson, L. Edler, E. Fogelqvist, S. Fonselius, L. Føyn, L. Hernroth, B. Håkansson, I. Olsson and E. Svensen 1991. SKAGEX: Some preliminary results. ICES C.M. 1991/C:2, Hydrography Comm. Ref: E.

Enoksson, V., E. Fogelqvist and S. Fonselius 1992. Nitrogen speciation and nitrification in the Skagerrak area during the SKAGEX experiment.

Reid, P. C., A. H. Taylor and J. A. Stephens 1988. The Hydrography and Hydrographic Balance of the North Sea. Pollution of the North Sea, an Assessment. (Edit. W. Salomons, B. L. Bayne, E. K. Duursma and U. Förstner). Springer-Verlag Berlin, Heidelberg, New York, London, Paris, Tokyo, pp 5-6.

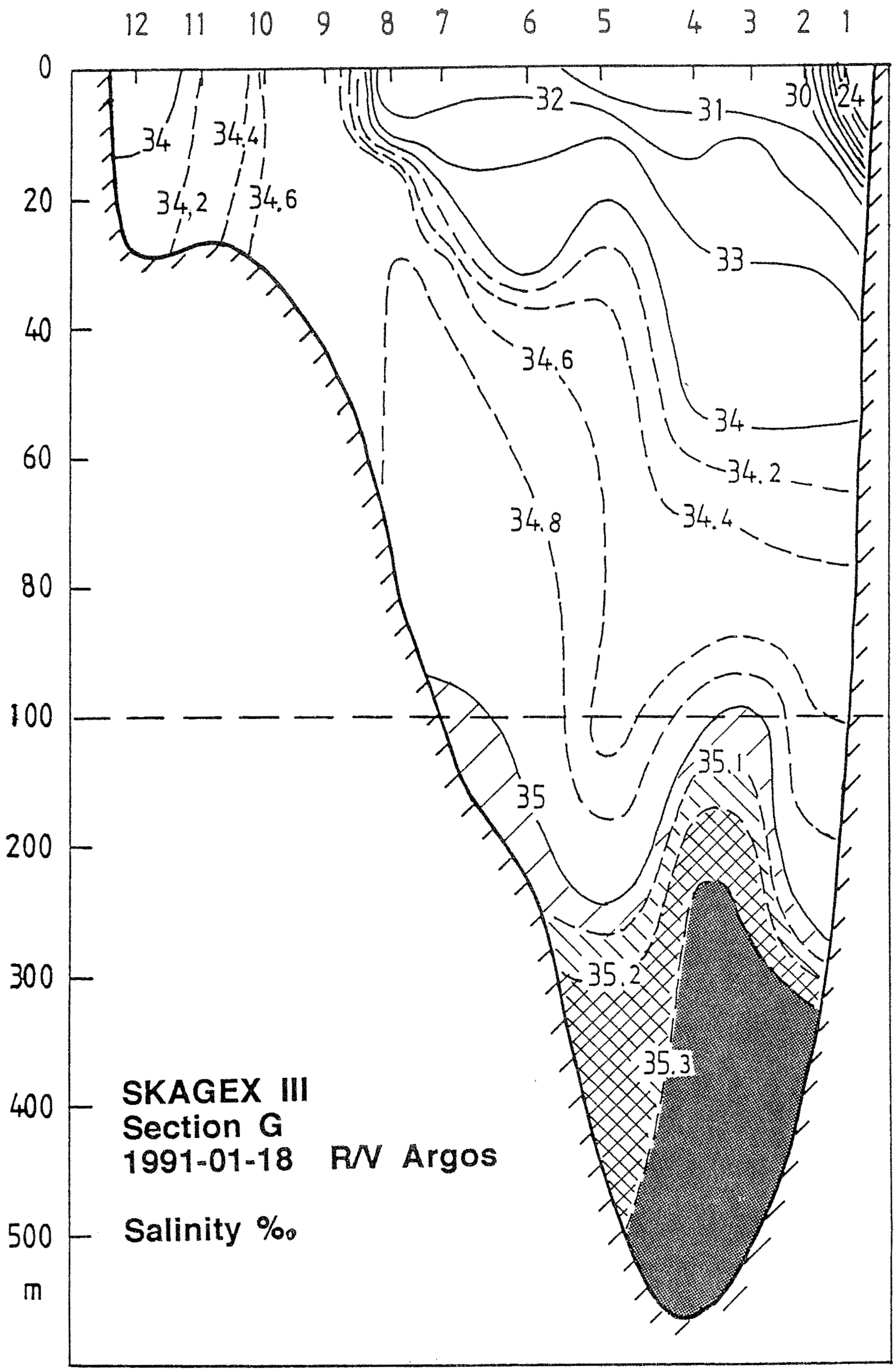

Fig. 1. Salinity in psu at section G January 18 1991. R/V ARGOS

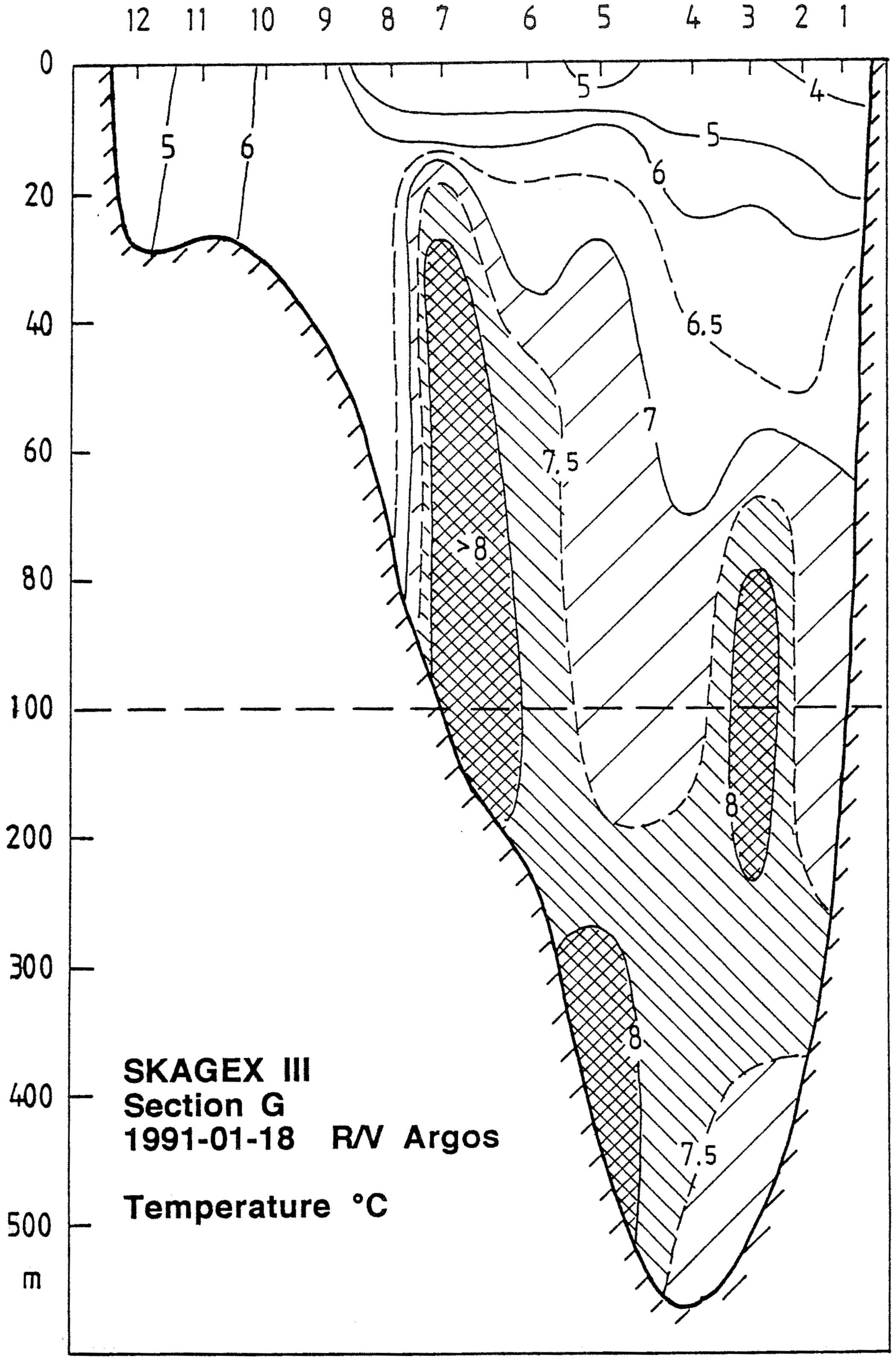

Fig. 2. Temperature in °C at section G January 18 1991. R/V ARGOS

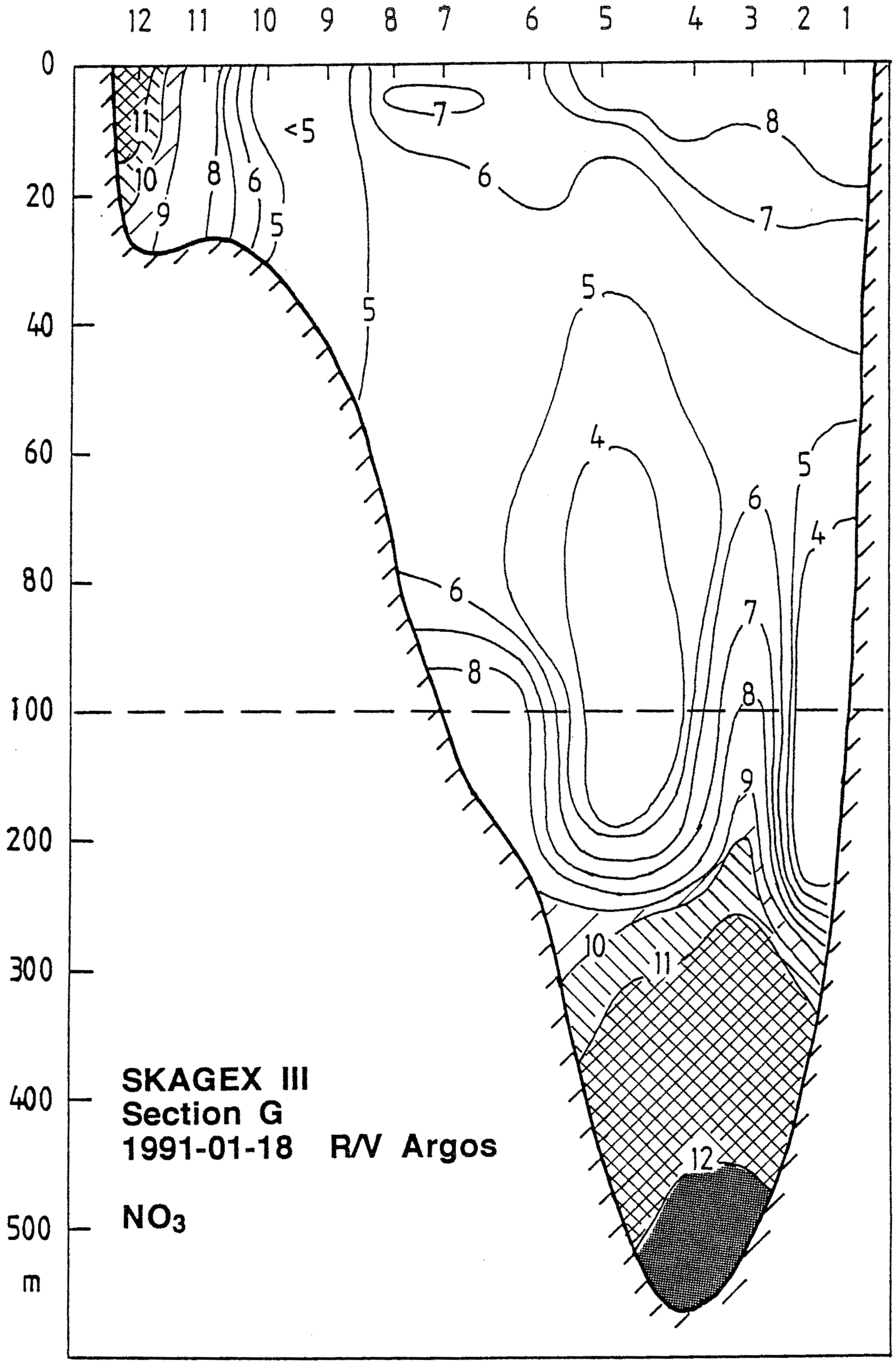

Fig. 3. Nitrate in µmol/l at section G January 18 1991. R/V ARGOS

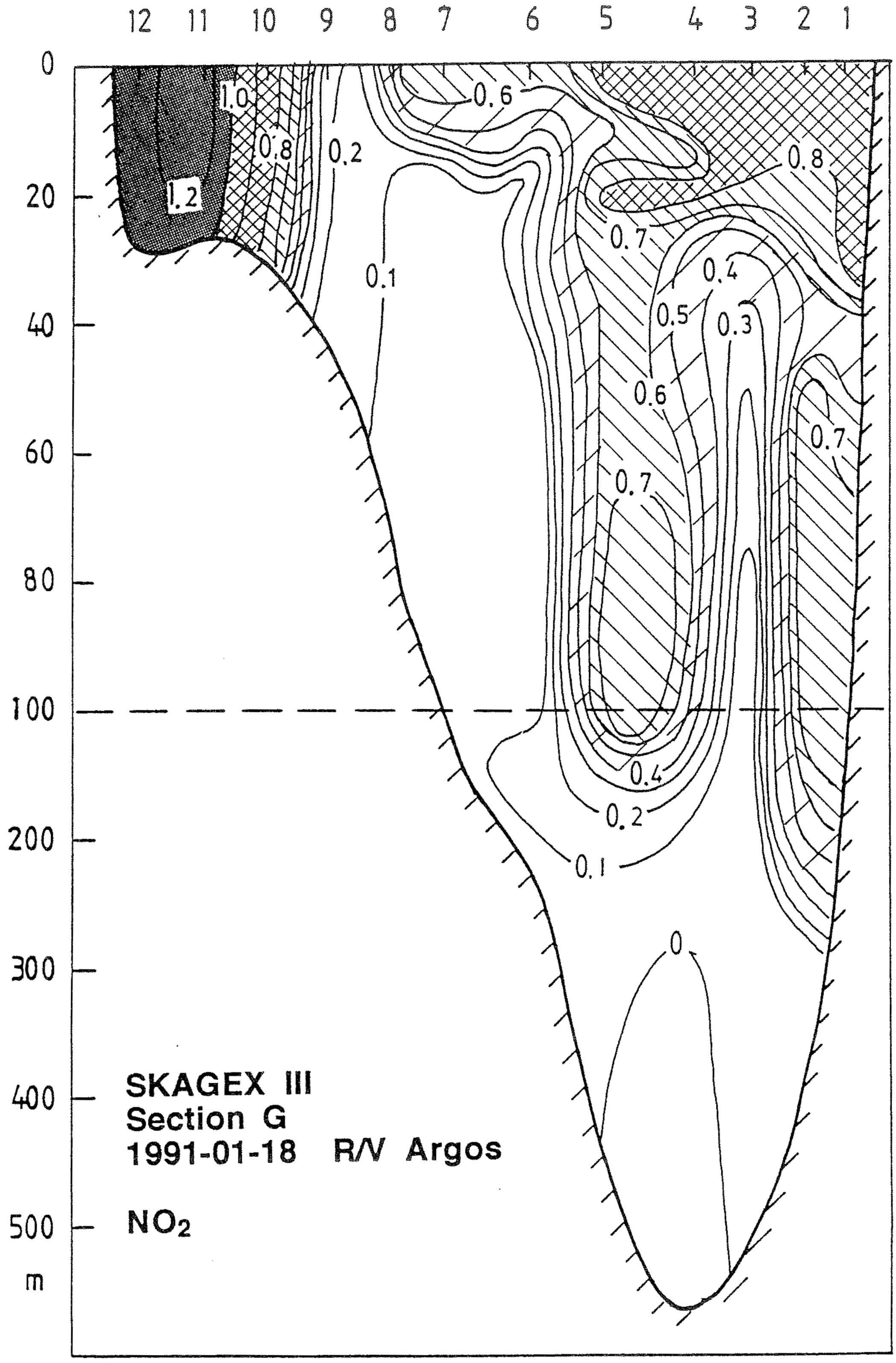

Fig. 4. Nitrite in µmol/l at section G January 18 1991. R/V ARGOS

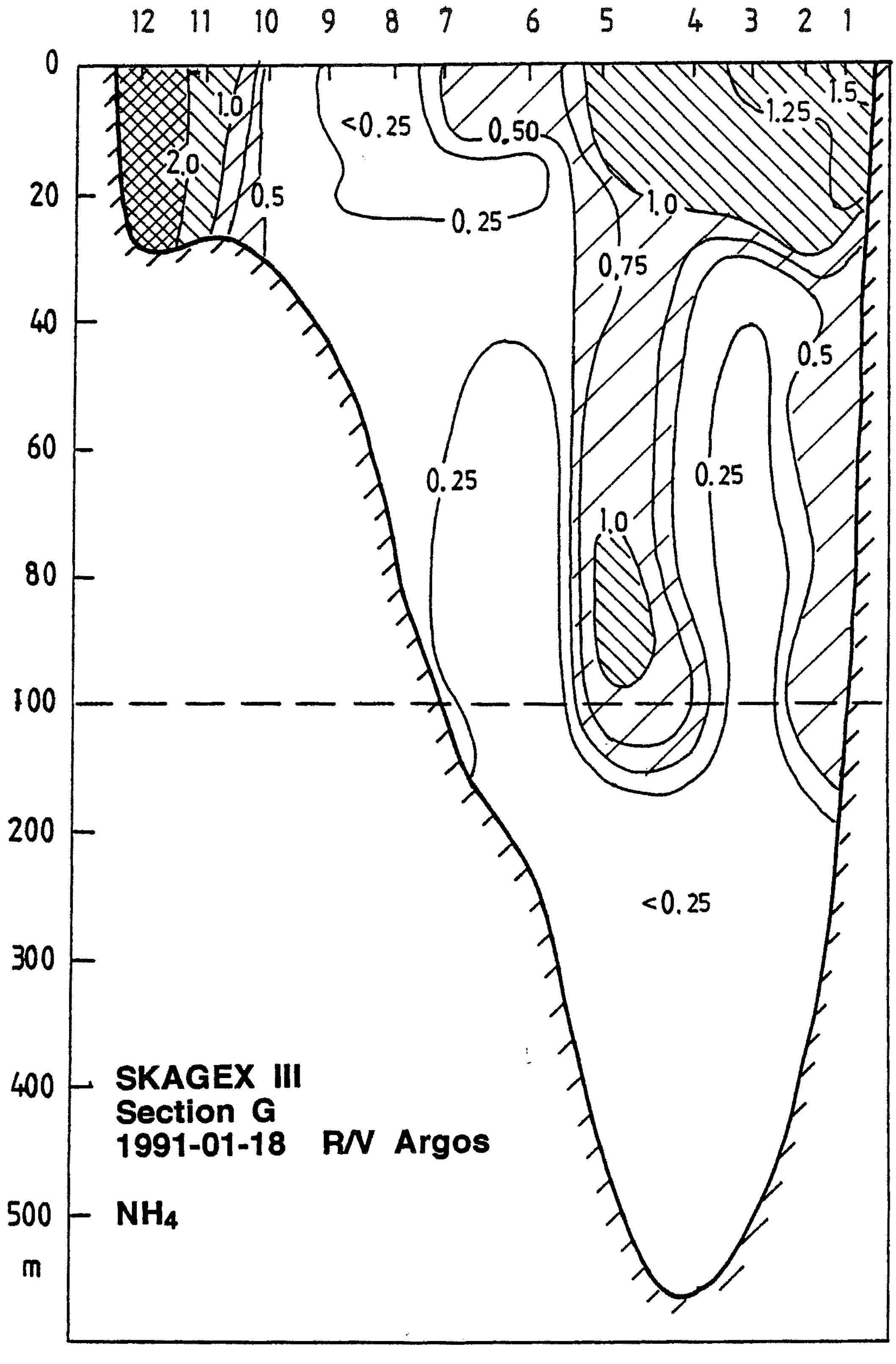

Fig. 5. Ammonia in µmol/l at section G January 18 1991. R/V ARGOS

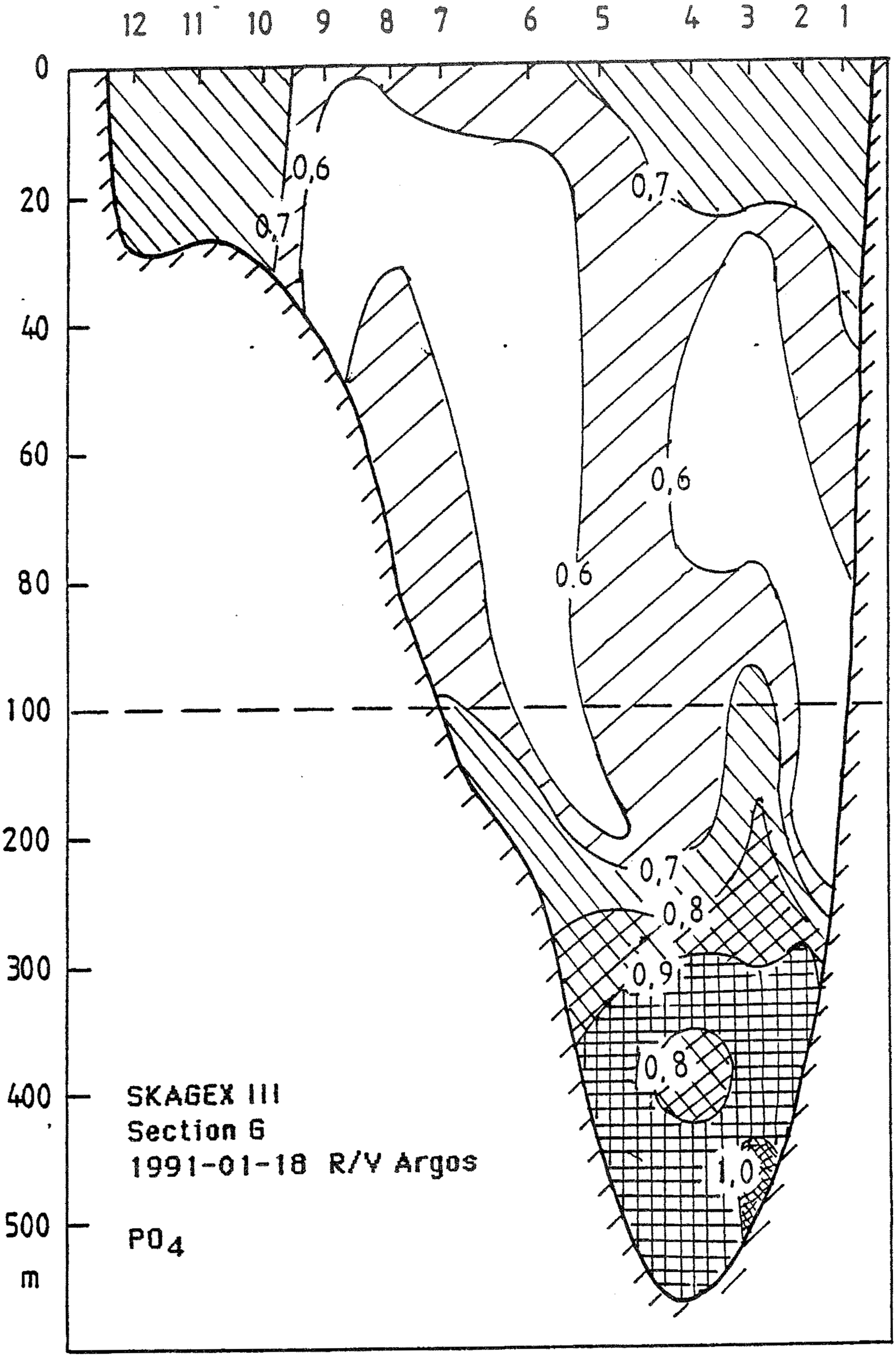

Fig. 6. Phosphate in µmol/l at section G January 18 1991. R/V ARGOS

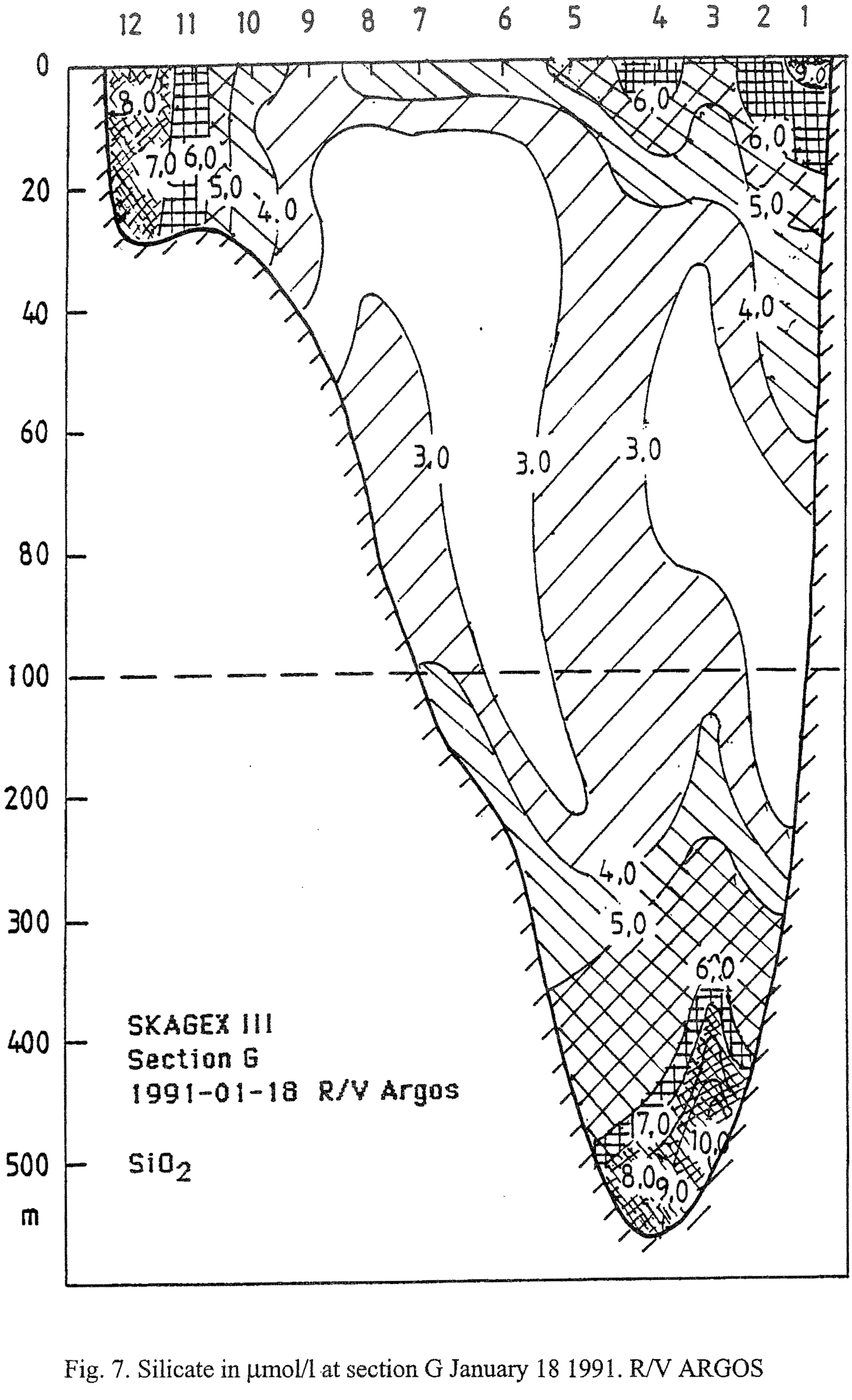

Fig. 7. Silicate in µmol/l at section G January 18 1991. R/V ARGOS

Presentation no 9.

SKAGEX 1990. Preliminary results from the nutrient intercalibration.

by

L. Føyn

ICES 1990 PAPER C.M. 1990/C:44
Ref. E
Hydrography Committee,
Ref. MEQC

SKAGEX 1990.
Preliminary results from the nutrient intercalibration.

by

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ABSTRACT

An important part of SKAGEX 1990 was the nutrient intercalibration, which was performed to simulate ordinary work at sea. 44 water samples of 0,5 liter were delivered to each of the 13 participating research vessels in Arendal harbour the morning of June 6th. The samples were sampled during the 5th of June when R/V "G. O. Sars" was working the H transect of SKAGEX. The participants should present their results before noon June 7th. From the preliminary results of the treatment of the reported data, it is demonstrated that most of the nutrient data determined during SKAGEX may be used for the purpose of SKAGEX.

INTRODUCTION

In the ICES multiship study of the Skagerrak in may - june 1990, the Skagerrak experiment - SKAGEX - (C. Res. 1989/4:1), measurements of nutrients played an important part in the synoptic survey. The Study Group on SKAGEX, (C.Res. 1989/2:28), in discussion of the nutrient measurements, expressed the need for an intercalibration between the participating ships during the field work. Although the results from the ICES nutrient intercalibration, where most of the participating laboratories had taken part, were promising, the Study Group felt that there may be clearly differences in the performance of chemical measurements during a well organized analytical scheme at a stable platform in a land-based laboratory and in a shipboard laboratory working under time pressure. The intercalibration during SKAGEX was decided to be performed as close to normal shipboard operations as possible and was taking place in the harbor of Arendal 6th - 7th of June 1990.

MATERIALS AND METHODS

The Skagerrak experiment is presented in the "Report of the Study Group on SKAGEX", C.M. 1990/C:31, and the various transects worked are presented in Fig. 1. The norwegian research vessel "G.O. Sars" covered the western part of the area and the transect H (Fig. 2) from Lindesnes on the norwegian coast to Tyborøen at the west coast of Jutland. 15 hydrographical stations were worked in the H transect, numbered from 1 to 15 starting at the norwegian coast. Stations 1, 5, 7, 8, 11 and 15 were chosen for water sampling for the intercalibrations. The stations represented the various water-masses to be found in most of the transects worked during SKAGEX. Fig. 3 and Fig. 4 presents the salinity and temperature of the transect H the day of the calibration sampling.

Water was sampled from the standard depths, 0, 5, 10, 20, 30, 50, 75, 100, 125, 150, 200 meters and 285 m as the deepest. Two 5 liter Niskin bottles were closed at each sampling depth and the water from each depth were transferred to 10 l mixing and storage polyethylene cans with taps for easy transfer to the sub-samples.

Sub-samples, 44 in all for each participating ship, were tapped into 0,5 l polyethylene bottles marked with station number and depth, and then stored under coverage on a semi-open deck space. Of the participating SKAGEX ships, 13 were equipped for on board nutrient analyses and took part in the intercalibration in Arendal.

The sampling of the water for the intercalibration was done on the last crossing, starting at midnight from Tyborøn St. H 15 the 5th of June and ending at Lindesnes, St. H 1 at 1500 hours the same day. After docking in Arendal in the morning of the 6th of June the sub-samples for the participating ships were delivered on board at each ship. CTD data from the sampled stations and forms for plotting and reporting the data were also presented to the participants at the delivery of the samples.

The participating ships were asked to report the results before noon on the 7th of June. The results were then briefly presented and discussed at the following scientific discussion of the experiences after the half-run SKAGEX.

One set of sub-samples were analyzed as part of the ordinary nutrient measurement after sampling on board "G.O. Sars" and the results are reported as G.O. Sars, a, in table 1.

RESULTS AND DISCUSSION

All the reported data are presented in table 1. The participants were asked to report their results both as vertical station plots and plotted with drawn iso-lines for the whole transect, and in tables as well. At the brief discussion in Arendal the vertical plots from the participants were copied for "overhead" projection and the plots from the various stations and parameters were presented. The similarity of the profiles was promising. Fig. 5, 6 and 7 presents the combined results from the participating ships of the values of nitrate, phosphate and silicate in water from St. H 1.

The figures 5 to 7 show that most of the participating ships are performing within reasonably good agreement. Some ships fall clearly out of the pattern and indicate analytical problems. This is most pronounced for silicate, but both for phosphate and nitrate there are also some analytical disturbances.

By looking at all the vertical profiles, the ships that do not perform according to the average pattern, can be removed before further calculations are done. This subjective method is certainly an easy way out, but in a preliminary treatment of the data it may well be justified.

Based on the remaining ships the average values are calculated. Each ship may then be plotted against the average value and the corresponding regression line calculated. This give a possibility to recalculate the various ships values according to the average values from the intercalibration. Examples of these plots are presented figs. 8, 9 and 10. For some ships the analytical performance on some of the nutrients indicate that their results on these parameters should not be used in SKAGEX.

The storage of the water for more than 24 hours without any conservation chemicals added, was considered as a possible problem. But, since the aim of the intercalibration exercise was to establish the relationship between the values from the participating ships, it was assumed that the water samples would behave more or less the same in all the bottles and therefor possible changes in the nutrient content due to biological activity could be ignored.

As mentioned above one set of samples was analyzed during the sampling on board "G.O. Sars". Figs. 11, 12 and 13 presents the two "G.O. Sars" set of nutrients values. Both for nitrate and silicate there is a good correlation between the values from the two separate set of analyses, and there are almost negligeable differences in the values from the two set of samples. "G.O. Sars",a, was analyzed as part of the routine work when working the transect and "G.O. Sars", b, as part of the intercalibration exercise.

Our analytical performance on phosphate determinations on board "G.O. Sars" the day of the sampling was unfortunately not satisfactorily as is clearly shown in fig. 12. During the intercalibration, however, our auto-analyzer seemed to have behaved well. As it is the values from the first set of samples, i.e. no storage, that are not consistent, there is reason to conclude that for the phosphate as well, there may have been only negligeable changes due to the storage.

Although there is a need for statistical work on the data from the intercalibration, the results so far strongly indicate that for the purpose of the SKAGEX most of the nutrient values determined during the synoptic surveys are comparable after adjustments according to a specific correction factor for each ship.

The SKAGEX intercalibration exercise have also demonstrated that this type of exercise should be conducted whenever more ships are working in the same area. This exercise has also clearly demonstrated the need for a common nutrient standard. Most of the discrepancy between the various ships seems to be due to slight differences in the standards that are used.

CONCLUSION

The SKAGEX intercalibration exercise;

- confirms that most of the nutrient data determined during SKAGEX can be used for the purpose of SKAGEX.
- demonstrates the need for a common nutrient standard.
- indicates a necessary caution in the use of nutrient data as absolute figures.

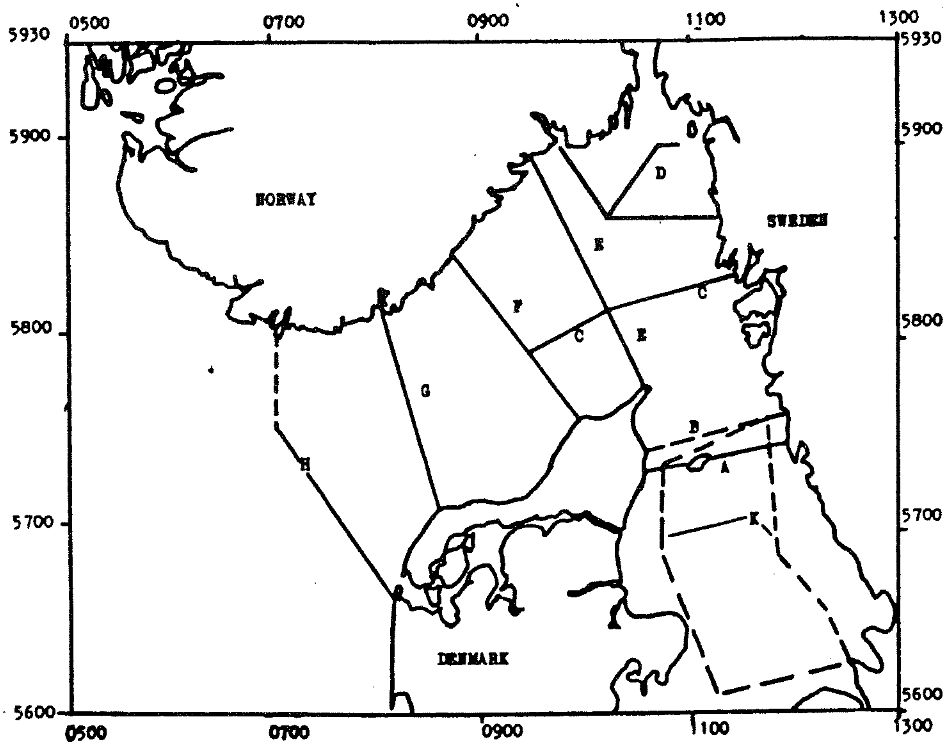


Fig. 1 Transects during SKAGEX

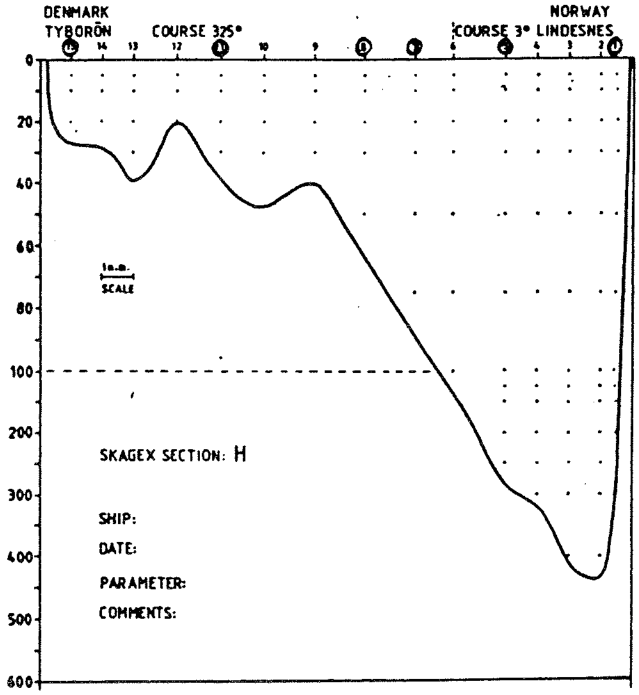


Fig. 2 The depth profile of H transect with stations and sampling depth marked. The nutrient intercalibration stations marked are St. 1, 5, 7, 8, 11 and 15.

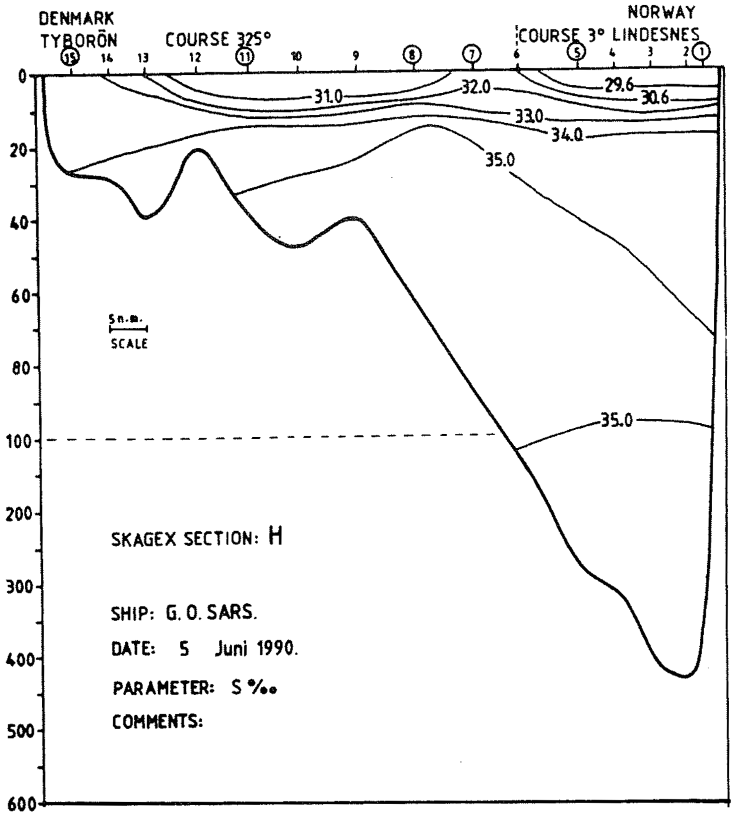


Fig. 3 The salinity distribution at H transect, June 5th 1990.

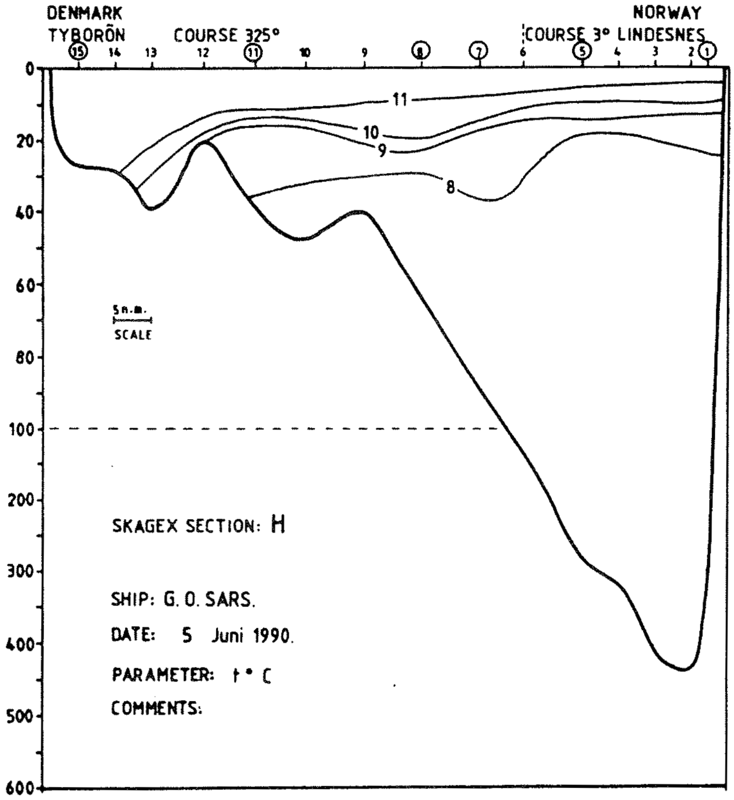


Fig. 4 The temperature distribution at H transect, June 5th 1990.

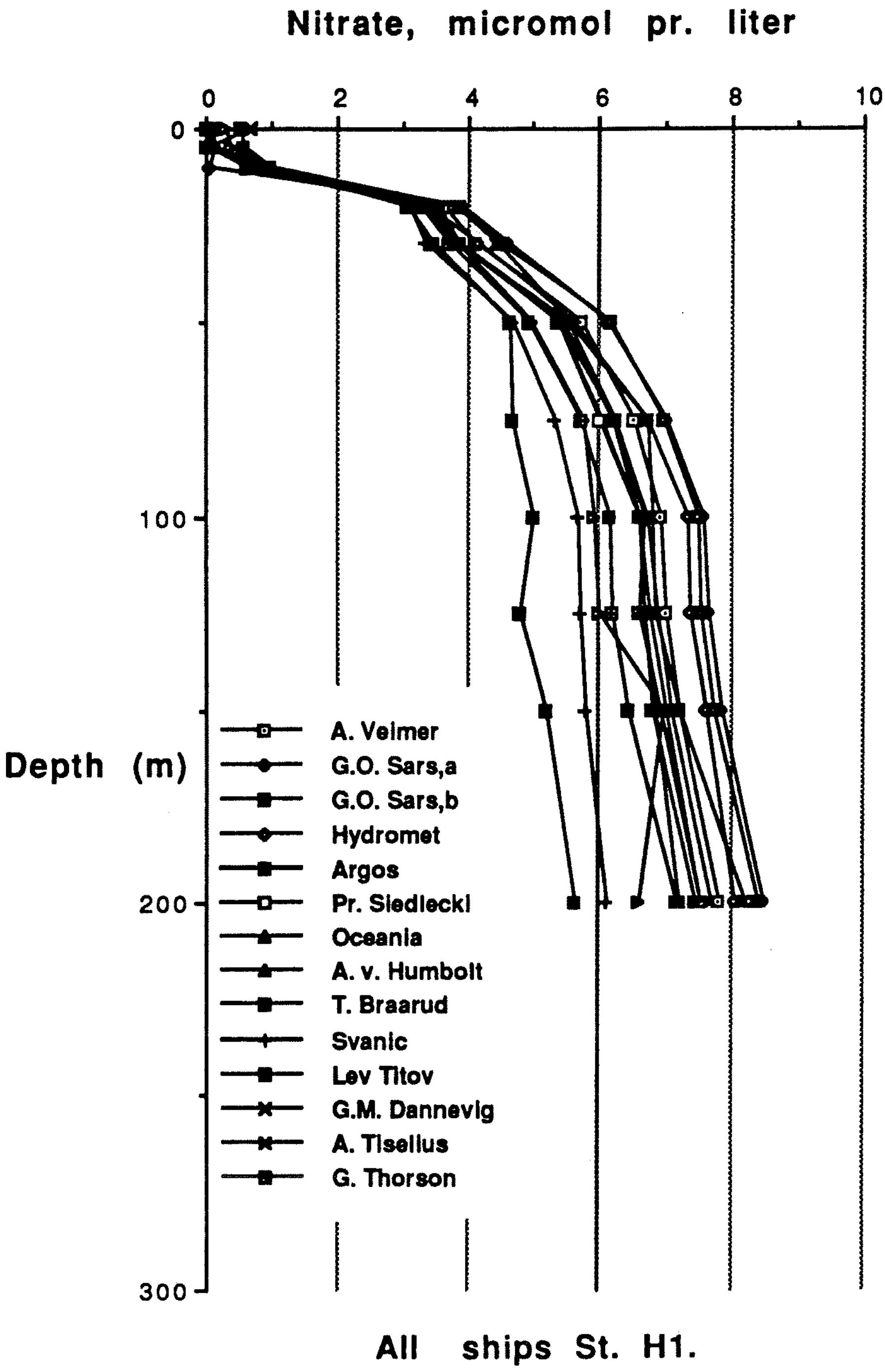


Fig. 5 The vertical profiles for nitrate (µmol NO_3 l^{-1}) values for all participating vessels of water sampled at St. H 1.

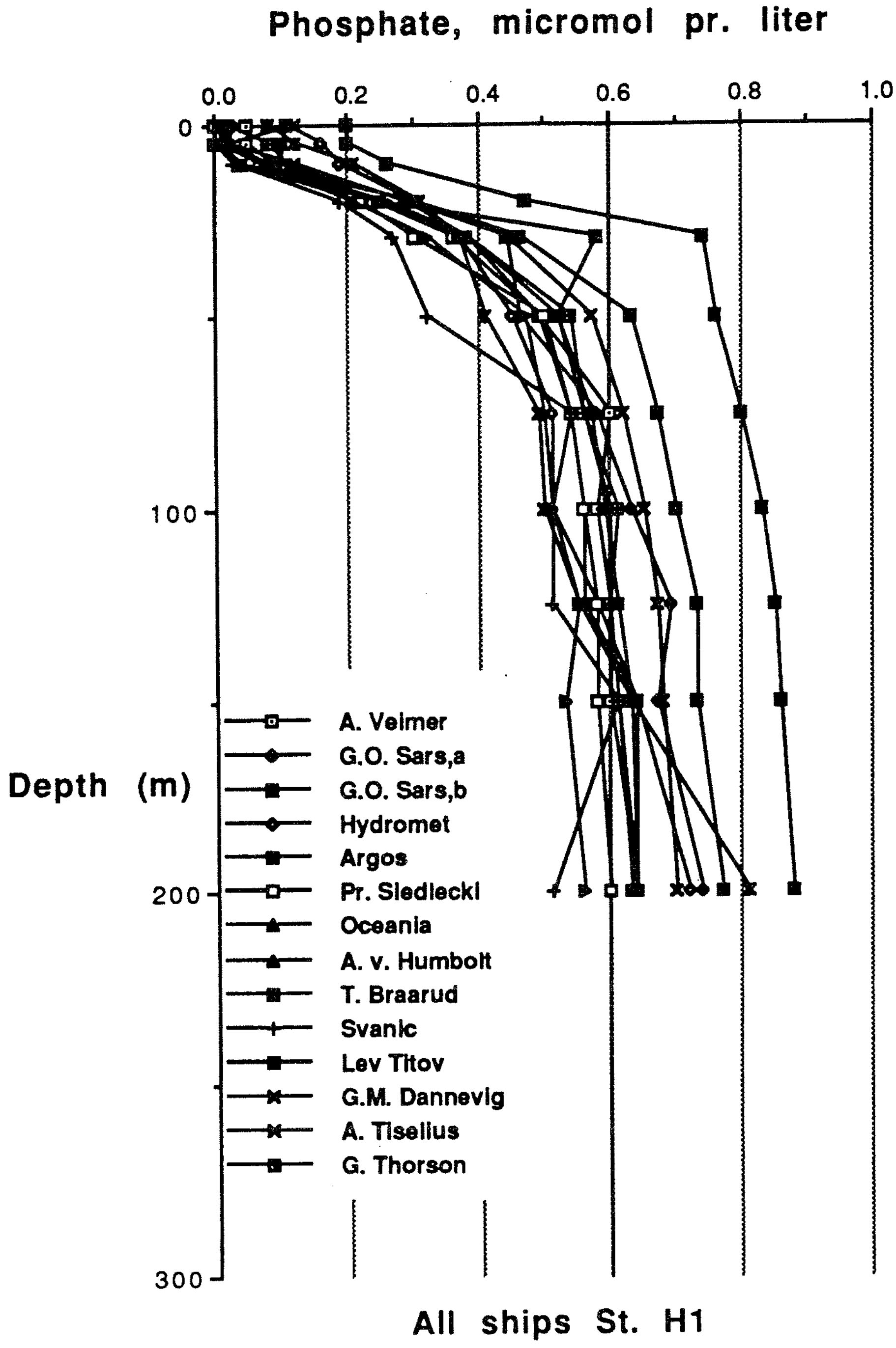


Fig. 6 The vertical profiles for phosphate (μmol PO_4 l^{-1}) values for all participating vessels of water sampled at St. H 1.

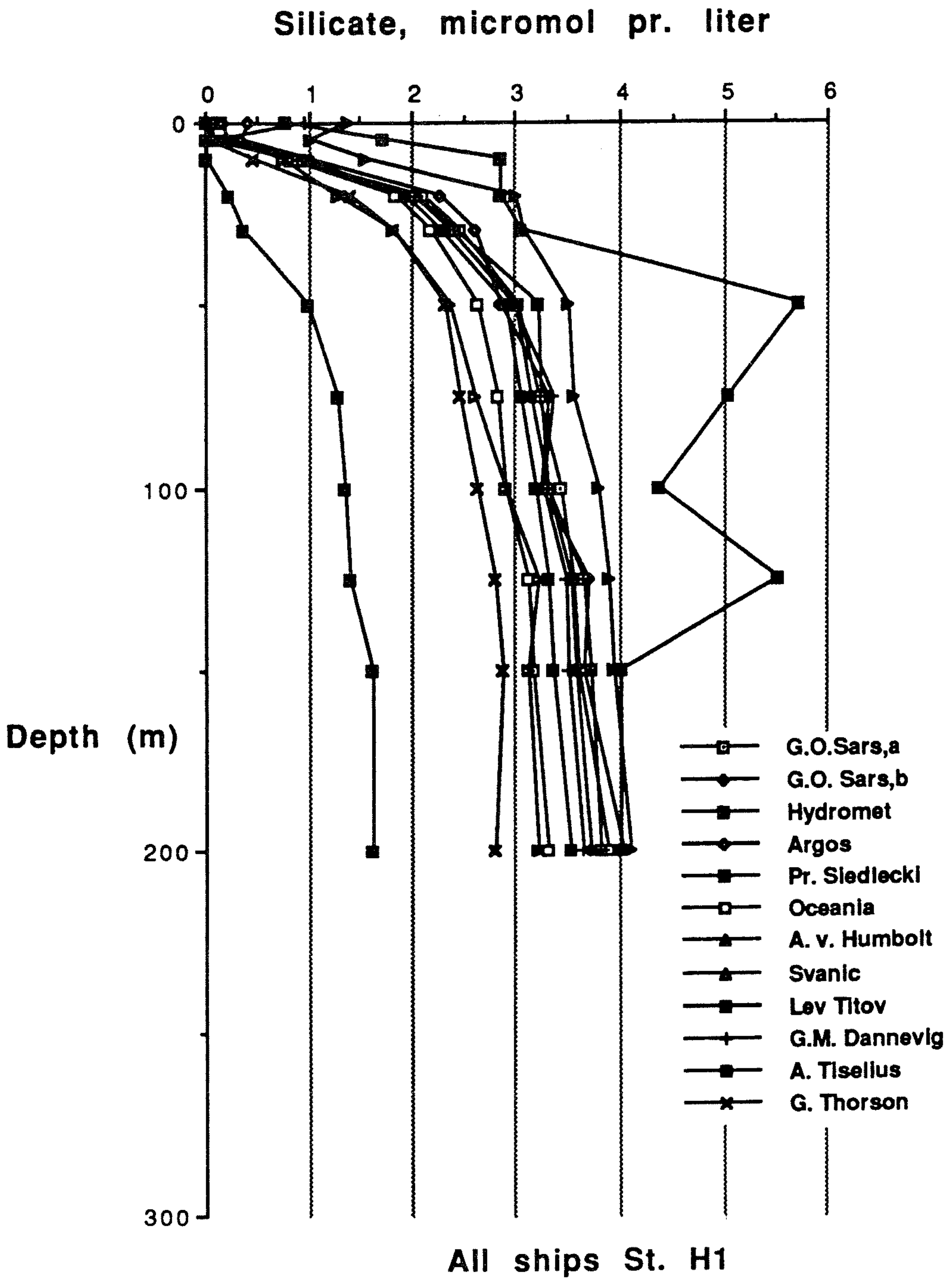
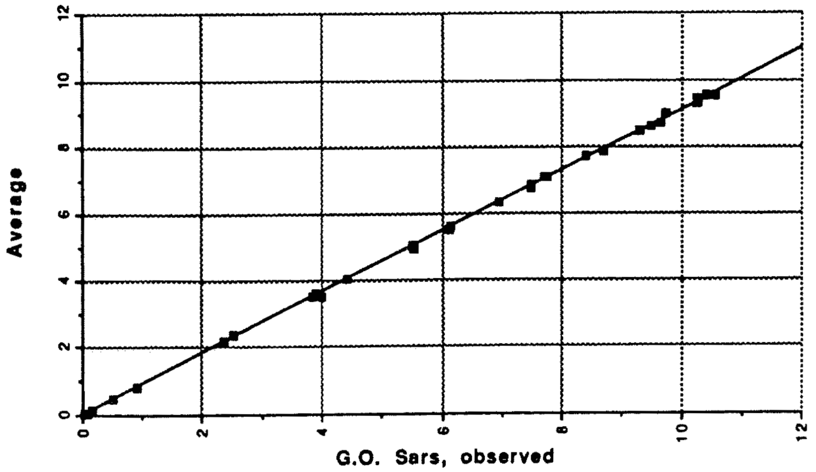


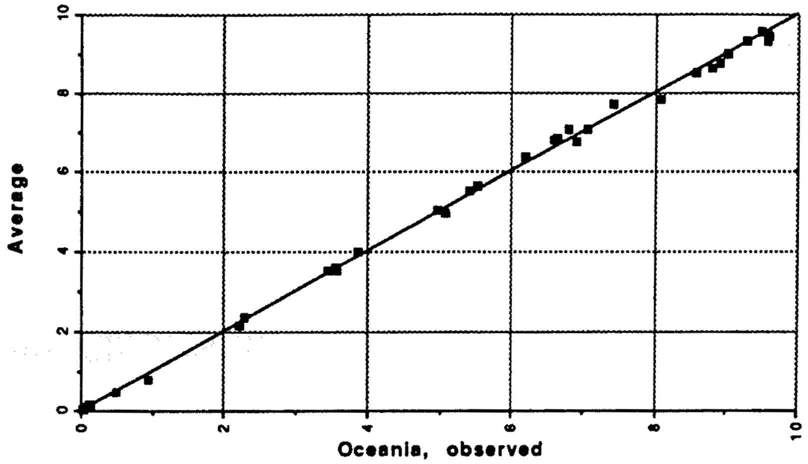
Fig. 7 The vertical profiles for silicate (µmol Si l^{-1}) values for all participating vessels of water sampled at St. H 1.

Nitrate



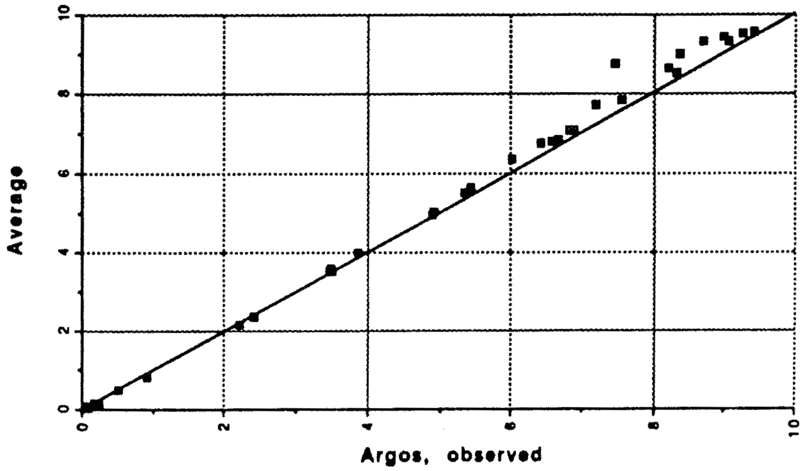
GOS, corr = - 6.5372e-3 + 0.91309 GOS, obs. R^2 = 1.000

Nitrate



Ocean. corr. = 1.3360e-2 + 0.99824 Ocean. obs. R^2 = 0.999

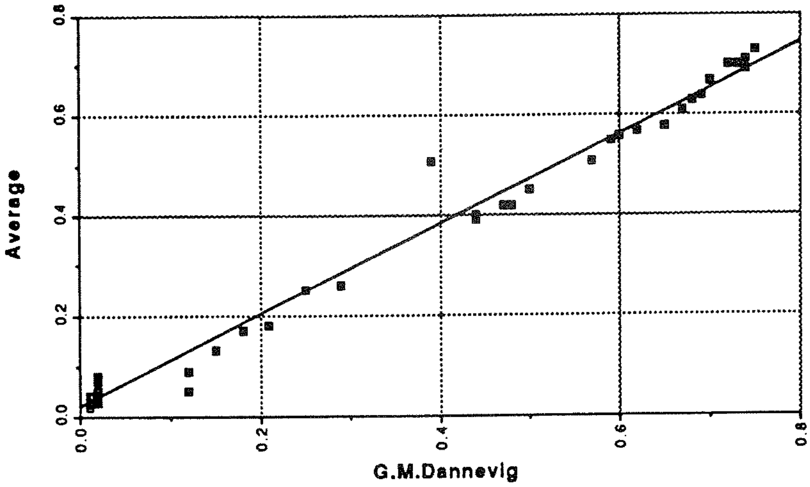
Nitrate



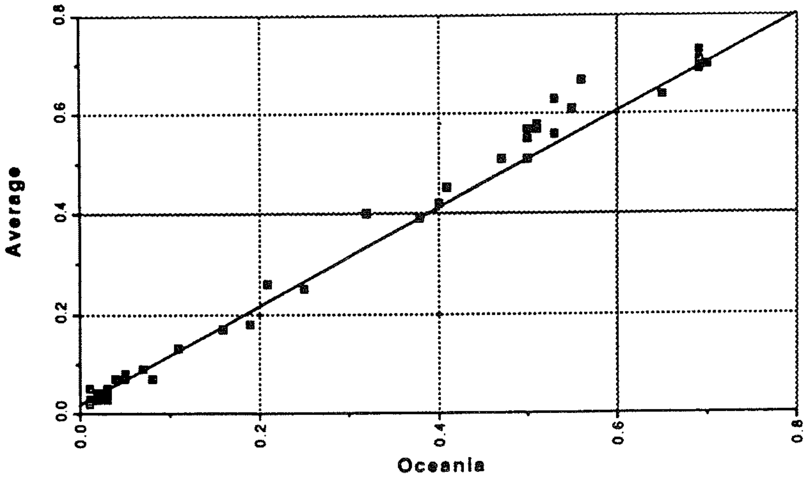
Argos, corr. = - 5.7950e-2 + 1.0537 Argos obs. R^2 = 0.998

Fig. 8 Nitrate values from some vessels plotted against the selected average value.

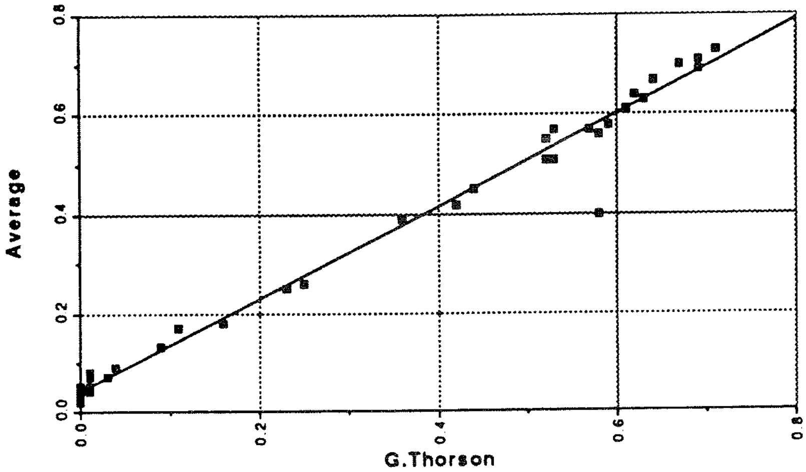
Phosphate



y = 1.9948e-2 + 0.90273x R^2 = 0.986



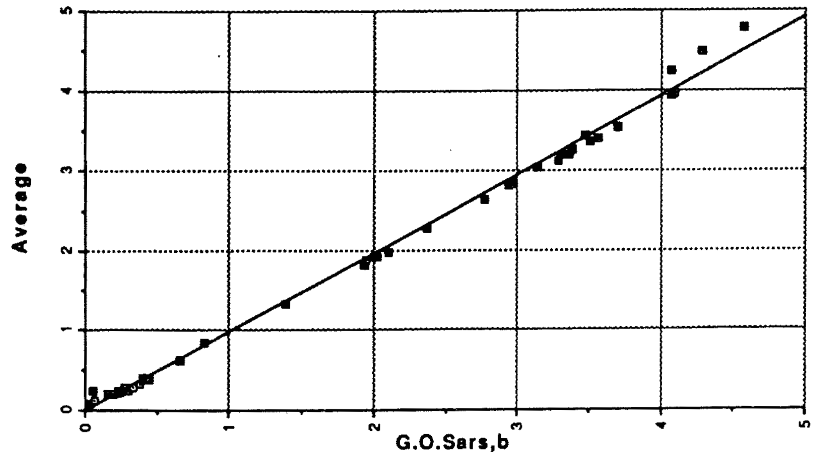
y = 1.6709e-2 + 1.0351x R^2 = 0.990



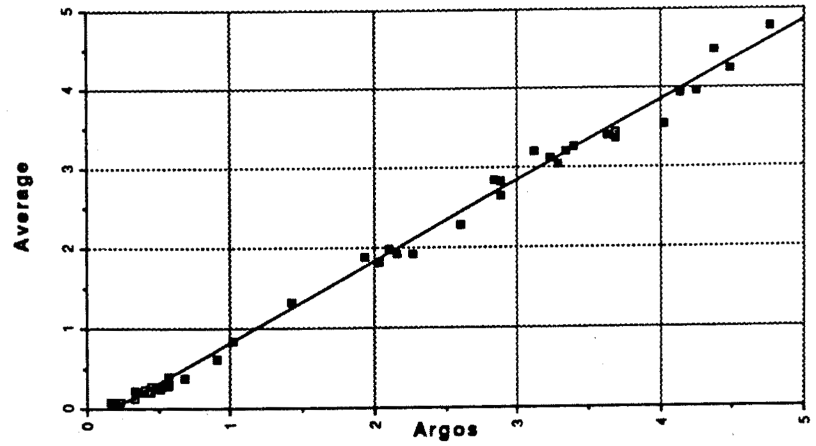
y = 3.9920e-2 + 0.93386x R^2 = 0.985

Fig. 9 Phosphate values from some vessels plotted against the selected average.

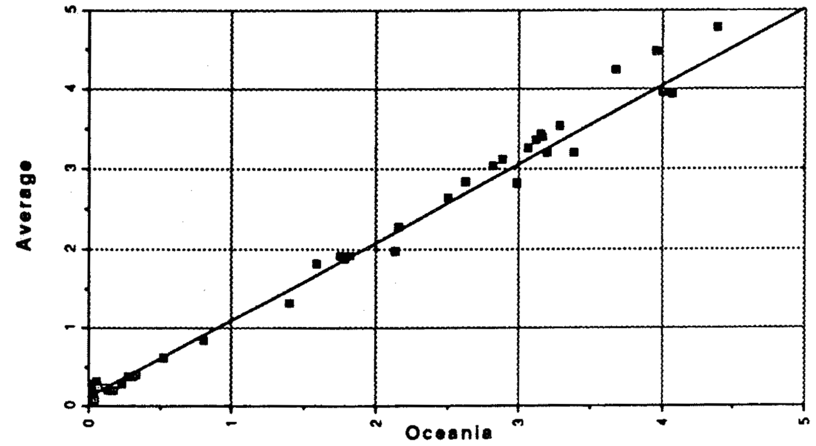
Silicate



G.O.Sars,corr. = - 1.2018e-2 + 0.98288 G.O. Sars,obs. R^2 = 0.996

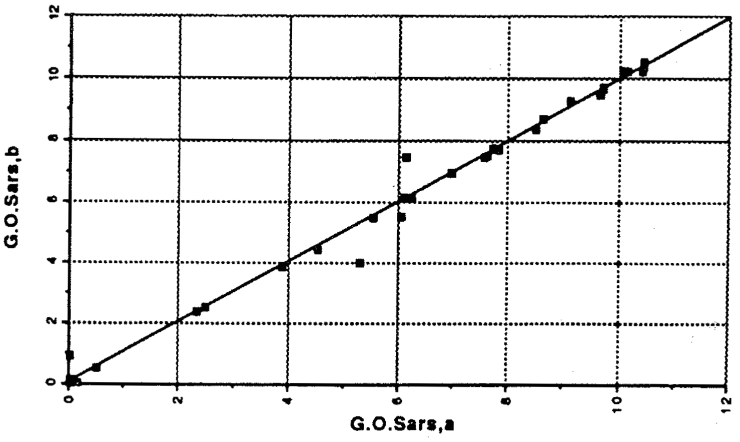


Argos,corr. = - 0.20556 + 1.0080 Argos,obs. R^2 = 0.995



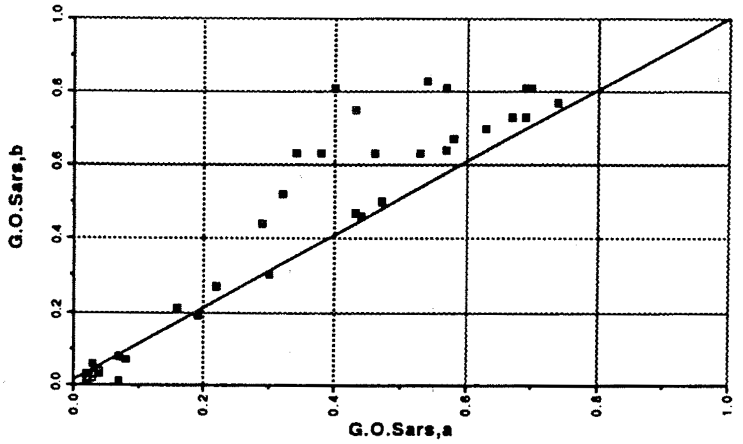
y = 0.10045 + 1.0171x R^2 = 0.990

Fig. 10 Silicate values from som vessels plotted against the selected average.



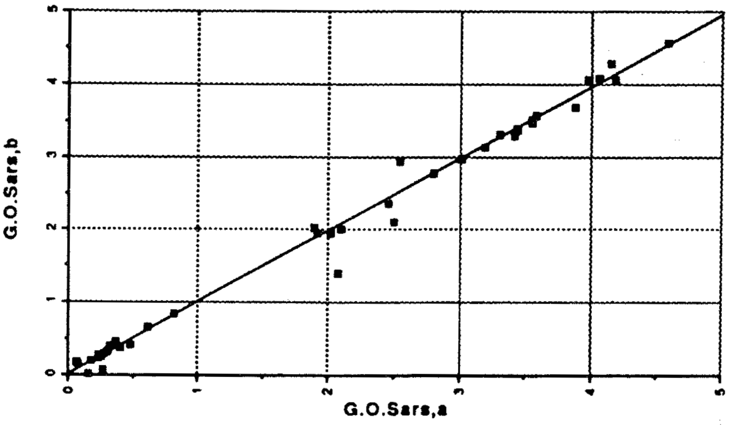
$y = 2.6664e\text{-}2 + 0.99368x \quad R^2 = 0.993$

Fig. 11 Nitrate values from R/V "G.O. Sars", **a** values determined on board during the sampling, **b** values determind during the intercalibration in Arendal.



$y = 1.2841e\text{-}2 + 1.2101x \quad R^2 = 0.910$

Fig. 12 Phosphate values from R/V "G.O. Sars", **a** values determined on board during the sampling, b values determined during the intercalibration in Arendal.



$y = -8.3054e\text{-}3 + 0.98855x \quad R^2 = 0.990$

Fig. 13 Silicate values from R/V "G.O. Sars", **a** values determined on board during the sampling, **b** values determined during the intercalibration in Arendal.

Tabel 1. All the reported values from the nutrient intercalibration.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
DEPTH	A. Veimer	G.O.Sars	Hydromet	Argos	Pr.Siedlecki	Oceania	A.v.Humbolt	T.Braarud	Svanic	Lev Titov	G.M.Dannevig	A.Tiselius	G.Thorson	Average	Standard dev.
						NITRATE									
0.00	0.10	0.07	0.03	0.08	0.00	0.04	0.28	0.53	0.04	0.08	0.67	0.09	0.02	0.16	0.21
5.00	0.10	0.06	0.02	0.06	0.00	0.02	0.37	0.57	0.03	0.07	0.05	0.07	0.01	0.11	0.17
10.00	0.80	0.90	0.87	0.92	0.70	0.94	0.95	0.96	0.96	0.61	0.73	0.98	0.62	0.84	0.13
20.00	3.60	3.85	3.38	3.52	3.36	3.44	3.30	3.05	3.09	3.27	3.25	3.82	3.28	3.40	0.24
30.00	4.10	4.44	4.15	3.87	3.82	3.87	3.81	3.45	3.35	3.68	3.80	4.40	3.77	3.89	0.32
50.00	5.70	6.13	5.58	5.35	5.34	5.42	4.94	4.62	4.65	4.91	5.33	5.50	5.50	5.31	0.43
75.00	6.50	6.96	6.71	6.02	5.98	6.20	5.76	4.67	5.30	5.69	6.24	6.70	6.23	6.07	0.62
100.00	6.90	7.48	7.31	6.58	6.57	6.59	5.91	4.96	5.68	6.13	6.69	6.78	6.66	6.48	0.67
125.00	7.00	7.50	7.33	6.66	6.73	6.65	5.97	4.78	5.70	6.18	6.85	6.84	6.58	6.52	0.72
150.00	7.20	7.71	7.58	6.82	6.98	6.80	6.95	5.20	5.78	6.42	7.06	7.20	6.90	6.82	0.69
200.00	7.80	8.40	8.03	7.20	7.49	7.42	6.60	5.63	6.12	7.14	7.69	8.20	7.53	7.33	0.80
0.00	0.10	0.07	0.08	0.10	0.00	0.12	0.37	0.44	0.13	0.07	0.05	0.10	0.00	0.13	0.13
5.00	0.10	0.06	0.14	0.06	0.00	0.14	0.75	0.40	0.09	0.16	0.05	0.10	0.00	0.16	0.20
10.00	3.40	3.99	2.21	3.46	3.26	3.58	3.27	2.58	3.29	2.82	3.56	3.60	3.28	3.25	0.47
20.00	4.90	5.53	3.95	4.90	4.77	5.07	4.61	3.71	4.42	4.44	5.10	4.40	4.87	4.67	0.49
30.00	6.80	7.49	5.24	6.41	6.61	6.92	6.39	5.11	5.94	5.94	7.20	5.80	6.87	6.36	0.72
50.00	7.90	8.70	6.15	7.56	8.06	8.08	7.18	6.11	6.72	6.80	8.22	6.20	8.09	7.37	0.89
75.00	9.30	10.25	8.03	8.70	9.65	9.57	8.94	7.30	7.61	6.94	10.02	7.68	9.58	8.74	1.11
100.00	9.20	10.24	8.35	9.00	9.61	9.59	8.42	6.97	8.01	7.38	9.64	8.90	9.32	8.82	0.95
150.00	9.00	10.24		9.05	9.56	9.29	7.86	6.66	7.40	7.83	9.30	8.86	9.35	8.70	1.04
200.00	9.40	10.54		9.26	9.56	9.58	8.12	6.53	7.48	7.79	9.23	9.01	9.68	8.85	1.13
285.00	9.40	10.40		9.42	9.75	9.48	7.71	6.71	7.55	9.15	9.38	9.09	9.65	8.97	1.07
0.00	0.10	0.07	0.11	0.07	0.00	0.10	0.28	0.35	0.17	0.17	0.06	0.10	0.00	0.12	0.10
5.00	0.10	0.05	0.08	0.05	0.00	0.02	0.20	0.35	0.12	0.17	0.05	0.10	0.00	0.10	0.10
10.00	0.10	0.04	0.04	0.05	0.00	0.03	0.17	0.35	0.18	0.25	0.05	0.10	0.00	0.10	0.11
20.00	0.10	0.16	0.23	0.19	0.14	0.11	0.30	0.35	0.26	0.33	0.17	0.25	0.03	0.20	0.10
30.00	3.40	3.90	3.18	3.50	3.54	3.55	4.21	2.69	3.30	3.39	3.69	3.82	3.41	3.51	0.37
50.00	4.90	5.49	4.47	4.93	5.00	4.96	4.31	3.67	4.34	4.77	5.06	4.86	4.92	4.74	0.45
75.00	5.50	6.15	4.67	5.43	5.44	5.52	5.33	4.03	4.79	5.08	5.69	5.62	5.59	5.30	0.54
100.00	6.90	7.76	5.81	6.88	6.86	7.07	6.37	4.95	5.95	6.27	7.16	6.80	7.18	6.61	0.73
0.00	0.10	0.06	0.12	0.10	0.00	0.11	0.25	0.44	0.09	0.16	0.05	0.10	0.00	0.12	0.12
5.00	0.10	0.07	0.11	0.08	0.00	0.04	0.24	0.44	0.08	0.25	0.05	0.08	0.00	0.12	0.12
10.00	0.10	0.06	0.09	0.08	0.00	0.02	0.20	0.44	0.06	1.60	0.05	0.06	0.00	0.21	0.43
20.00	0.10	0.16	0.12	0.24	0.12	0.14	0.37	0.44	0.15	1.26	0.05	0.20	0.02	0.26	0.32
30.00	2.20	2.37	2.08	2.21	2.20	2.22	2.34	1.94	2.04	2.67	2.10	2.12	2.01	2.19	0.19
50.00	2.30	2.52	2.28	2.41	2.42	2.29	2.46	1.98	2.14	2.64	2.35	2.36	2.19	2.33	0.17
0.00	0.10	0.08	0.02	0.08	0.00	0.08	0.23	0.49	0.15	0.07	0.05	0.08	0.01	0.11	0.13
5.00	0.10	0.07	0.01	0.06	0.00	0.02	0.19	0.49	0.16	0.16	0.05	0.08	0.00	0.11	0.13
10.00	0.10	0.07	0.01	0.09	0.00	0.05	0.22	0.49	0.09	0.66	0.05	0.08	0.00	0.15	0.20
20.00	0.40	0.51	0.23	0.52	0.48	0.49	0.56	0.44	0.46	1.74	0.49	0.40	0.35	0.54	0.37
0.00	8.60	9.48	7.93	8.22	8.84	8.79	8.66	6.54	7.65	8.81	9.08	6.86	9.28	8.36	0.90
5.00	8.60	9.65	8.31	7.48	8.70	8.90	9.07	6.69	7.95	8.65	9.39	7.90	9.40	8.51	0.84
10.00	9.20	9.72	8.61	8.37	8.70	9.01	9.08	6.84	7.61	8.70	9.41	8.14	9.47	8.68	0.80
20.00	8.40	9.28	7.49	8.32	8.59	8.57	8.61	6.44	7.04	8.73	9.29	6.89	8.77	8.19	0.92
						PHOSPHATE									
0.00	0.05	0.02	0.11	0.11	0.00	0.01	0.03	0.20	0.03	0.02	0.12	0.08	0.01	0.06	0.06
5.00	0.05	0.02	0.16	0.10	0.00	0.02	0.01	0.20	0.00	0.08	0.02	0.12	0.01	0.06	0.07
10.00	0.09	0.08	0.19	0.10	0.04	0.07	0.07	0.26	0.03	0.11	0.12	0.21	0.04	0.11	0.07
20.00	0.24	0.30	0.30	0.25	0.22	0.21	0.26	0.47	0.19	0.29	0.29	0.31	0.25	0.28	0.07
30.00	0.36	0.46	0.37	0.38	0.30	0.32	0.38	0.74	0.27	0.38	0.44	0.37	0.58	0.41	0.13
50.00	0.49	0.63	0.45	0.49	0.50	0.47	0.52	0.76	0.32	0.54	0.57	0.41	0.52	0.51	0.11
75.00	0.60	0.67	0.51	0.54	0.54	0.50	0.56	0.80	0.54	0.56	0.62	0.49	0.57	0.58	0.08
100.00	0.58	0.70	0.51	0.56	0.56	0.51	0.60	0.83	0.51	0.61	0.65	0.50	0.59	0.59	0.09
125.00	0.60	0.73	0.58	0.56	0.58	0.55	0.60	0.85	0.51	0.60	0.67	0.55	0.61	0.61	0.09
150.00	0.60	0.73	0.64	0.64	0.58	0.53	0.61	0.86	0.61	0.61	0.68	0.63	0.63	0.64	0.08
200.00	0.64	0.77	0.72	0.64	0.60	0.56	0.64	0.88	0.51	0.63	0.70	0.81	0.64	0.67	0.10
0.00	0.05	0.01	0.15	0.06	0.00	0.03	0.00	0.19	0.00	0.05	0.02	0.15	0.00	0.05	0.07
5.00	0.05	0.02	0.21	0.03	0.00	0.02	0.00	0.23	0.00	0.04	0.02	0.20	0.00	0.06	0.09
10.00	0.22	0.27	0.33	0.23	0.26	0.25	0.22	0.44	0.14	0.23	0.25	0.28	0.23	0.26	0.07
20.00	0.35	0.44	0.45	0.34	0.35	0.38	0.36	0.59	0.31	0.37	0.44	0.48	0.36	0.40	0.08
30.00	0.50	0.63	0.60	0.49	0.51	0.53	0.52	0.77	0.39	0.54	0.60	0.60	0.58	0.56	0.09
50.00	0.58	0.75	0.70	0.55	0.58	0.65	0.60	0.88	0.50	0.65	0.69	0.68	0.62	0.65	0.10
75.00	0.64	0.81	0.67	0.58	0.68	0.69	0.65	0.94	0.57	0.66	0.74	0.72	0.69	0.70	0.10
100.00	0.64	0.81	0.76	0.63	0.68	0.69	0.64	0.94	0.59	0.74	0.72	0.78	0.67	0.71	0.09
150.00	0.64	0.81		0.58	0.70	0.70	0.65	0.93	0.59	0.66	0.73	0.79	0.67	0.70	0.10
200.00	0.63	0.81		0.60	0.69	0.69	0.65	0.94	0.62	0.67	0.74	0.81	0.69	0.71	0.10
285.00	0.68	0.83		0.64	0.70	0.69	0.68	0.96		0.72	0.75	0.83	0.71	0.74	0.09

Tabel 1 continued

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
0.00	0.05	0.02	0.11	0.06	0.00	0.03	0.00	0.23	0.01	0.01	0.02	0.09	0.00	0.05	0.06
5.00	0.05	0.02	0.13	0.05	0.00	0.01	0.00	0.23	0.00	0.01	0.01	0.13	0.00	0.05	0.07
10.00	0.06	0.02	0.14	0.08	0.03	0.03	0.00	0.25	0.00	0.01	0.02	0.16	0.00	0.06	0.08
20.00	0.13	0.19	0.23	0.18	0.16	0.16	0.14	0.40	0.07	0.07	0.18	0.26	0.11	0.18	0.09
30.00	0.43	0.52	0.47	0.41	0.43	0.41	0.43	0.69	0.43	0.38	0.50	0.49	0.44	0.46	0.08
50.00	0.52	0.63	0.49	0.52	0.52	0.50	0.53	0.80	0.36	0.41	0.39	0.49	0.53	0.51	0.11
75.00	0.52	0.63	0.57	0.52	0.54	0.50	0.51	0.79	0.38	0.44	0.59	0.56	0.52	0.54	0.10
100.00	0.58	0.64	0.52	0.55	0.53	0.51	0.53	0.80	0.43	0.50	0.62	0.58	0.53	0.56	0.09
0.00	0.05	0.03	0.02	0.02	0.07	0.03	0.01	0.21	0.01	0.01	0.01	0.03	0.00	0.04	0.05
5.00	0.05	0.03	0.06	0.09	0.01	0.02	0.00	0.22	0.00	0.01	0.01	0.07	0.00	0.04	0.06
10.00	0.06	0.03	0.05	0.06	0.01	0.03	0.00	0.24	0.00	0.04	0.01	0.04	0.00	0.04	0.06
20.00	0.11	0.14	0.15	0.11	0.14	0.11	0.12	0.39	0.12	0.22	0.15	0.17	0.09	0.16	0.08
30.00	0.40	0.47	0.36	0.40	0.43	0.40	0.42	0.68	0.36	0.44	0.47	0.38	0.42	0.43	0.08
50.00	0.43	0.50	0.38	0.36	0.42	0.40	0.43	0.69	0.32	0.40	0.48	0.39	0.42	0.43	0.09
0.00	0.05	0.01	0.10	0.03	0.00	0.02	0.01	0.22	0.01	0.01	0.01	0.09	0.00	0.04	0.06
5.00	0.05	0.02	0.04	0.02	0.01	0.01	0.00	0.23	0.01	0.01	0.01	0.03	0.00	0.03	0.06
10.00	0.06	0.03	0.14	0.02	0.02	0.02	0.02	0.25	0.01	0.01	0.02	0.16	0.00	0.06	0.08
20.00	0.17	0.21	0.18	0.14	0.18	0.19	0.18	0.43	0.09	0.11	0.21	0.18	0.16	0.19	0.08
0.00	0.05	0.07	0.21	0.06	0.04	0.08	0.03	0.29	0.00	0.04	0.02	0.24	0.01	0.09	0.09
5.00	0.06	0.07	0.19	0.09	0.05	0.04	0.02	0.27	0.03	0.02	0.02	0.20	0.01	0.08	0.08
10.00	0.08	0.04	0.27	0.02	0.04	0.05	0.02	0.26	0.03	0.01	0.02	0.29	0.03	0.09	0.11
20.00	0.12	0.06	0.36	0.05	0.03	0.05	0.02	0.26	0.03	0.02	0.02	0.33	0.01	0.10	0.13
						SILICATE									
0.00		0.06	0.01	0.40	0.14	0.05	1.38		0.17	0.76	0.96	0.05	0.00	0.36	0.47
5.00		0.07	0.01	0.34	0.22	0.03	1.02		0.19	1.71	0.13	0.05	0.00	0.34	0.54
10.00		0.83	0.01	1.02	0.91	0.81	1.55		0.75	2.85	0.90	0.90	0.46	1.00	0.72
20.00		2.00	0.21	2.27	1.93	1.82	2.98		1.27	2.85	1.99	2.02	1.40	1.89	0.76
30.00		2.37	0.36	2.61	2.27	2.16	3.05		1.80	3.04	2.36	2.40	1.80	2.20	0.74
50.00		2.98	0.99	2.84	2.90	2.63	3.49		2.35	5.70	2.96	3.20	2.31	2.94	1.12
75.00		3.14	1.28	3.29	3.03	2.82	3.54		2.60	5.04	3.36	3.24	2.45	3.07	0.90
100.00		3.29	1.36	3.23	3.19	2.89	3.78		2.88	4.37	3.26	3.29	2.62	3.11	0.74
125.00		3.51	1.40	3.69	3.29	3.12	3.88		3.21	5.51	3.47	3.63	2.79	3.41	0.97
150.00		3.57	1.61	3.63	3.35	3.16	3.93		3.10	3.99	3.50	3.70	2.86	3.31	0.66
200.00		3.70	1.62	4.03	3.51	3.29	4.09		3.21	3.99	3.64	3.80	2.79	3.42	0.72
0.00		0.02	0.00	0.23	0.11	0.05	1.45		0.14	1.04	0.10	0.05	0.00	0.29	0.49
5.00		0.03	0.00	0.17	0.11	0.03	1.24		0.11	0.86	0.10	0.05	0.00	0.25	0.41
10.00		1.39	0.15	1.42	1.42	1.40	2.22		1.30	3.90	1.34	1.52	0.84	1.54	0.93
20.00		2.10	0.13	2.10	1.99	2.14	2.94		1.79	3.70	2.04	2.02	1.45	2.04	0.87
30.00		2.94	0.53	2.89	2.79	2.99	3.61		2.38	3.42	2.84	2.92	2.28	2.69	0.81
50.00		3.31	0.73	3.34	3.13	3.39	3.84		2.71	4.94	3.20	3.56	2.55	3.15	1.02
75.00		4.09	1.14	4.25	3.92	4.01	4.50		3.16	5.04	3.99	4.18	3.31	3.78	1.01
100.00		4.07	0.70	4.14	3.88	4.07	4.38		3.43	3.70	3.96	4.18	3.28	3.62	1.02
150.00		4.07		4.48	3.98	3.68	4.64		3.40	3.80	3.97	6.21	3.28	4.15	0.84
200.00		4.28		4.37	4.11	3.96	4.97		3.43	5.42	4.20	6.90	3.55	4.52	1.03
285.00		4.57		4.76	4.42	4.39	5.29		3.85	5.22	4.52	6.96	3.86	4.78	0.90
0.00		0.24	0.00	0.51	0.31	0.11	1.33		0.33	2.09	0.24	0.32	0.00	0.50	0.64
5.00		0.25	0.00	0.40	0.33	0.07	1.14		0.36	2.09	0.26	0.35	0.00	0.48	0.62
10.00		0.38	0.00	0.57	0.50	0.06	1.10		0.77	3.32	0.40	0.38	0.00	0.68	0.94
20.00		1.95	0.50	1.93	1.99	1.79	2.69		1.44	5.89	1.98	2.03	1.39	2.14	1.36
30.00		2.77	1.17	2.89	2.69	2.51	3.26		1.94	3.70	2.76	2.82	2.08	2.60	0.68
50.00		3.37	1.63	3.12	3.32	3.20	3.75		2.74	6.27	3.40	3.40	2.67	3.35	1.12
75.00		3.39	1.66	3.40	3.33	3.07	3.81		2.96	4.56	3.39	3.56	2.68	3.26	0.72
100.00		3.48	1.75	3.69	3.43	3.15	3.68		3.02	5.60	3.47	4.01	2.80	3.46	0.93
0.00		0.33	0.00	0.51	0.40	0.04	1.39		0.47	0.28	0.33	0.33	0.00	0.37	0.38
5.00		0.32	0.00	0.45	0.39	0.06	1.16		0.41	2.09	0.33	0.33	0.00	0.50	0.61
10.00		0.25	0.00	0.34	0.33	0.05	0.98		0.47	0.28	0.27	0.32	0.00	0.30	0.27
20.00		0.30	0.01	0.45	0.35	0.05	1.14		0.47	0.95	0.31	0.32	0.00	0.40	0.36
30.00		1.94	0.38	2.04	1.85	1.59	2.44		1.44	2.85	1.91	2.10	1.29	1.80	0.64
50.00		2.02	0.53	2.16	1.95	1.76	2.54		1.91	2.85	2.01	2.12	1.35	1.93	0.60
0.00		0.17	0.00	0.45	0.24	0.18	0.84		0.50	0.66	0.18	0.20	0.00	0.31	0.27
5.00		0.16	0.00	0.40	0.22	0.14	0.73		0.39	0.57	0.18	0.21	0.00	0.27	0.23
10.00		0.20	0.00	0.45	0.26	0.13	0.80		0.39	0.86	0.22	0.21	0.00	0.32	0.29
20.00		0.66	0.02	0.91	0.67	0.53	1.29		1.30	1.42	0.67	0.82	0.11	0.76	0.46
0.00		0.41	0.00	0.68	0.43	0.28	1.59		0.42	0.48	0.36	0.51	0.00	0.47	0.42
5.00		0.45	0.00	0.57	0.43	0.31	1.51		0.03	0.10	0.40	0.52	0.00	0.39	0.43
10.00		0.40	0.00	0.57	0.52	0.34	1.31		0.03	0.57	0.40	0.50	0.00	0.42	0.37
20.00		0.28	0.00	0.57	0.35	0.24	1.27		0.00	0.38	0.30	0.30	0.00	0.34	0.36

Presentation no 10.

The potential of the Jutland Coastal Current as a transporter of nutrients into the Kattegat.

by

J. P. Heilmann, D. S. Danielssen and O. Vagn Olsen

THE POTENTIAL OF THE JUTLAND COASTAL CURRENT AS A TRANSPORTER OF NUTRIENTS INTO THE KATTEGAT

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ABSTRACT

The annual distribution of and variation in nitrate concentrations during the period 1980 to 1992 along the Danish west coast and in the northern Kattegat have been examined and compared. Transport of nitrate brought about by the Jutland Coastal Current (JCC) along the Danish west coast from the eastern North Sea into the northern Kattegat seems to occur sporadically during the winter and early spring months. However, such events do not seem to occur every year. Quantification of the actual transport of nutrients into the Kattegat via the JCC is not possible until the relative transport of water by the JCC and the open North Sea into the Kattegat has been determined.

INTRODUCTION

During the last decade, considerable attention has been directed towards hypoxia/anoxia events in the bottom waters of the Kattegat. Eutrophication from anthropogenic sources (and the resulting increase in primary production and decay of organic material into the bottom layers) is believed to be the cause of the increased frequency and distribution of these events (Ærtebjerg, 1987).

The declining trend in bottom layer oxygen concentrations and the increasing trend in nutrient concentrations in the Kattegat have been described by Andersson & Rydberg (1988) and Olsen (1990). In connection with efforts to reduce nutrient input (eutrophication), a number of mass balances of nutrient inputs into the Kattegat have been constructed (i.e. Richardson and Ærtebjerg, 1991). However, there is still considerable uncertainty concerning the relative importance of the various sources.

Nitrogen loading during the last decade from adjacent rivers into the coastal waters of the southeastern North Sea has been high (Gerlach 1990). This is reflected, for example, in the increase in winter nitrate concentrations found at the Helgoland Reede (1962-1984) in the German Bight (Berg and Radach, 1985). Therefore, a good deal of interest has been focussed on the Jutland Coastal Current (JCC) as a potential source advecting nutrient rich continental coastal waters from the German Bight along the Danish west coast and into the Kattegat. The recordings of nitrate rich water volumes along the Danish coast in the Skagerrak by Danielssen and Dahl (1992) may also support this expectation. However, the JCC is not continuous but rather induced primarily by south- to westernly winds (Pedersen *et al.*, 1987, Kristensen 1991). This means that within a short period (ca. 1 month), the JCC exhibits a continous as well as an interrupted pattern. While interrupted, its western boundary often expands into the open North Sea at the bend of the Danish west coast south of Hanstholm (see Figure 1). While interrupted, the fate of such a "pool" of JCC water can become mixed up and diluted by the nutrient poorer North Sea water or, due to biological activity, the available nutrients are reduced by uptake and fixation into organic materials. However, if the duration of interruption is short, one can expect such a "pool" to continue quite unaffected into the Skagerrak and, ultimatly, reach the Kattegat. The purpose of this study was to investigate the role of the JCC in transporting nutrients from the German Bight into the Kattegat.

In order to quantitatively assess the importance of the JCC in advecting nutrients into the Kattegat, knowledge about the magnitude and origin of the water volumes entering the northern Kattegat is needed. In a study of the hydrographic conditions in the Skagerrak, Danielssen *et al.* (1991) identified six different water volumes constituting a very complicated hydrographic pattern within the Skagerrak. As yet, these hydrographic patterns are poorly understood and a satisfactory description and quantification of the water volumes in these components is still lacking. This would necessitate to operate with the simplification that two incoming water volumes are potential contributors to the renewal of the Kattegat bottom waters. These two water volumes have their origin in coastal waters along the Danish west coast and water from the North Sea.

As no quantification of the relative magnitude of these two water components is available, our approach has concentrated on an examination of the chemical characteristics of the relevant water masses. The idea was that in order to be able to follow JCC waters into the Kattegat, their chemical composition should differ significantly from the coincident incoming water mass from the North Sea. In particular, the concentration of nutrients should *exceed* those found in the incoming North Sea water if any effect of nutrient input into the Kattegat from the JCC should be identified.

Nitrogen has most often been identified as the limiting macronutrient for phytoplankton production in the Kattegat (i. e. Richardson & Ærtebjerg, 1991). The dominant inorganic form of nitrogen, and that for which sufficient data exist to enable an analysis such as the present to be carried out, is nitrate. In addition, nitrate is the dominant nutrient in the JCC.
Therefore, in an attempt to elucidate the JCC's role in transporting nitrogen into the Kattegat, this investigation has been limited to examining nitrate concentrations. The approach focusses on the annual patterns in nitrate distribution in the relevant water volumes located outside and inside the northern Kattegat.

MATERIALS AND METHODS

The annual distributions of nitrate concentrations in three regions along the Danish west coast and in one region in the northern Kattegat were examined. The available data within each region covers the entire region, thus, samplings were not restricted to a single station. In order to identify eventual similarities and differences between the adjoining regions, an interregional comparison of the selected region's annual distribution of nitrate was made.
The positions of the selected regions are shown in Figure 1 and their characteristics are as follows:

"Name" of region	Borders of regions	Characteristics: 1) Selected interval of depth (d.i.) over which mean values were generated. 2) Period covered by the data.
The German Bight	53°50'N - 55°00'N 7°50'E - 8°40'E	1) 0 - 15 m. 2) 1980 - 1991.
The coastal region off Hirtshals	57°39'N - 57°43'N 9°30'E - 10°00'E	1) 0 - 30 m. 2) 1980 - 1992.
The Norwegian Trench	57°56'N - 58°15'N 9°00'E - 9°30'E	1) 100 - 150 m. 2) 1980 - 1992.
The northern Kattegat	57°20'N - 57°40'N 10°30'E - 11°35'E	1) 25 - 50 m. 2) 1971 - 1992.

Data.

For the present investigation, we have received data from several monitoring authorities and from the data base of the International Council for the Exploration of the Sea (ICES). These data sources are listed in the following survey:

Donator of data	Covered region	Time equidistance
Biologische Anstalt Helgoland, Hamburg	German Bight (Mostly sampled at Helgoland Reede)	Few days during 1980 - 1991.
Institute of Marine Research, Bergen	The Eastern North Sea	Various
Flødevigen Marine Research Station, Arendal	The Skagerrak (The Hirtshals-Torungen transect)	About a month (except 1987)
The ICES Database	All included regions	Various

As the data material origin from several different monitoring authorities, minor uncertainties in the material as a whole will be inevitable.
The relevant water masses upon which has been focussed and followed through these regions are as follows:

a) - water of salinity <34 psu. along the Danish west coast, referred to as the JCC.

b) - North Sea (water of salinity >34 psu.).

The choice of the salinity criteria (<34 psu. regarding the JCC component and <34 psu. regarding the North Sea component) is in agreement with those used by Danielssen *et al.* (1991). Having chosen a depth interval of 100-150 meters, the North Sea component must be expected to be comprised mostly of Atlantic water.

RESULTS

The annual variations in nitrate concentrations in the coastal region off Hirtshals and in the German Bight during the period 1980-1992 are shown in Figure 2. The data material from the German Bight was mostly sampled at Helgoland Reede. Therefore, the distribution of nitrate concentrations show large fluctuations due to different positions (relative to Helgoland Reede) of the front separating coastal and offshore water masses. Although the seasonal patterns in nitrate concentrations are similar for both regions, very different patterns in the detailed distributions of nitrate concentrations in the German Bight and off Hirtshals emerge. It is important, thus, to note that not *all* peaks in nitrate concentrations in the German Bight are followed by peaks in concentrations off Hirtshals. For example, the peaks in nitrate concentrations often found in the German Bight during March are not reflected in peaks off Hirtshals.

Another apparent difference between the distributions in the nitrate concentrations is that nitrate concentrations in the German Bight have increased during the 1980s, while this increase seems not to be relected in the data material off Hirtshals. The annual variations in nitrate concentration in the coastal region off Hirtshals and in the Norwegian Trench during the period 1980-1992 are shown in Figure 3. The nitrate concentrations in the coastal water off Hirtshals show seasonal variations, which seldom significantly exceed the concentrations found in the North Sea component (i.e. The Norwegian Trench). When this occurs it is only during the months of winter and early spring in 1981, 1989, 1990 and 1992.
Figure 4 relates nitrate concentration and salinity for the coastal region off Hirtshals during the period 1980-1992. Two important observations can be made from this figure:

1) - nitrate concentration exceeding 10 µmol l^{-1} appear only during the months of winter and early spring and in relatively low salinity water <33.5 psu.
2) - water of relatively high salinity (>34.0 psu.), generally, carries nitrate concentrations below 10 µmol l^{-1} during all months.

Figure 5 shows the annual variations in nitrate concentration in the bottom waters of the northern Kattegat and in the coastal region off Hirtshals during the period 1980-1992.

For the northern Kattegat, the period from which data were available stops by the end of 1991. It is worth noting that in both water volumes, a seasonal signal can be observed. During the months of winter and early spring, the signal in peaks of nitrate concentrations off Hirtshals are followed by signals in the northern Kattegat. However, coinsidences of high nitrate concentrations (»10µmol l^{-1}) in the water volumes of both regions only occurs in 1981 and 1989. In figure 6, the variations in nitrate concentrations in the bottom water in the northern Kattegat are illustrated together with the concentrations found in the deep water of the Norwegian Trench.

During the winter and early spring in 1981, 1982, 1987 and 1989, the nitrate concentrations in the northern Kattegat exceeded the concentrations found in the Norwegian Trench. A seasonal cycle is observed in nitrate concentrations in the northern Kattegat bottom water but not in the deeper water of the Norwegian Trench. During summer months the nitrate concentrations in the northern Kattegat are always found to be below the concentrations found in the Norwegian Trench. Nitrate concentrations shown as a function of salinity (bottom water) in the northern Kattegat during the 1980s are shown in Figure 7.

Generally, nitrate concentrations above 10 µmol l^{-1} are found during the winter and early spring. These are usually related to salinities within the range of 31 to 34 psu. Figure 8 shows the annual variations in nitrate concentration in the bottom water of the northern Kattegat during the period 1972-1990. It is clear that events where the nitrate concentration exceeds 10 µmol l^{-1} occur in the last ten years of the period. These "peaks" in nitrate concentration are generally found during the winter and early spring.

DISCUSSION

Although a thorough understanding of nutrient transport into the Kattegat and the turnover in this region is still lacking, it is assumed that the recorded increase in frequency and intensity of anoxia and hypoxia in these waters during the 1980s is related to an increased eutrophication (Ærtebjerg, 1987).

Before remedial actions to reverse this eutrophication can be undertaken, it is important to identify which of the potential nutrient sources into the Kattegat have increased during the last 20-30 years. The North Sea provides the Kattegat with approximately 50 % of its annual nitrogen input (Anon., 1991a). Thus, any changes in nutrient transport via the North Sea can potentially be of great importance to the nutrient budget of the Kattegat.

However, the North Sea's input into the Kattegat via Skagerrak must, for simplicity, be considered as being composed of two components, "The North Sea" and "The Jutland Coastal Current (JCC)". A number of studies (i.e. Pedersen *et al.*, 1988 ; Jacobsen and Richardson, 1990; Kristensen, 1991; Poulsen, 1991) have demonstrated that the relative distributions of the water masses belonging to these different components are very much under the influence of the wind speed and direction. Thus, under some conditions (especially those with a prevailing south/southwest wind), the JCC can extend into the Skagerrak and its waters potentially be transported into the Kattegat. Under other wind conditions, the extension of the JCC is such that it is unlikely to affect transport of nutrients into the Kattegat. This was resently reported by Danielssen *et al.* (1997) who demonstrated that during periods of strong north westerly winds, extensions of Norwegian coastal surface water masses (salinity <30 psu.) could cross the Skagerrak and reach the Danish coast south of Hanstholm (see Figure 1). This event resulted in an interrupted pattern of the JCC and, thus, would indicate that a salinity criterium of S <34 psu. in water volumes along the Danish west coast is not allways sufficient in order to identify the present of the JCC in this region.

There is no evidence of a major change in nutrient concentrations in the open North Sea. In addition, it seems intuitively unlikely that major changes in nutrient concentrations in the North Sea would have occurred as a result of anthropogenic activities. It is, however, well known that significant increases in nutrients have occurred in European coastal waters (Gerlach, 1990). Thus, if a major increase in nitrate input via the North Sea into the Kattegat has occurred, it is reasonable to expect it to have done so through the JCC.

Unfortunately, it is not yet possible to quantify the amounts of North Sea water entering the Skagerrak/Kattegat from the two respective components (i.e. "The Jutland Coastal Current" and "The open North Sea"). Until the actual transport from these sources is known, it will not be possible to quantify the JCC's role in transporting nutrients into the Kattegat.

This study has shown that the concentrations of nitrate observed along the northern Danish coast, in waters which correspond with respect to salinity to the JCC, are considerably lower than those observed in the German Bight. This is, of course, a function of both dilution and biological activity (See Pedersen *et al.*, 1988; Jensen *et al.*, 1983; Danielssen & Dahl, 1992). The seasonal patterns in the distribution in the concentrations of nitrate found in coastal waters off the north Danish coast (Hirtshals) are similar to those observed in the German Bight (see Figure 2). This is to be expected as in such coastal waters, the nitrate concentrations vary inversely with the annual primary production cycle. Some of the high concentrations observed off Hirtshals may be explained by transport of nitrate from the German Bight along the coast. If such peaks are related, then a transport time of about 1-3 months is indicated. This is in agreement with hydrographic estimates for transport in this region (Kristensen, 1991). However, it is not possible to see all of the peaks in nitrate concentration observed in the German Bight reflected in the nitrate distributions off Hirtshals. In particular, the large peak in nitrate concentrations observed annually in the German Bight during the month of March does not seem to affect nitrate concentrations in the coastal region off Hirtshals during the following period. It is also important to note that, while there appears to be an increase in the nitrate concentration found in the German Bight during the 1980s (confirmed in Anon., 1991b) there does not, with the exception of 1989, seem to be a comparable increase off Hirtshals. High freshwater runoff from the River Elbe into the German Bight in 1987-1988 (see Gerlach, 1990) should be considered in order to explain the increase in nitrate concentrations in this region. However, such an increase cannot be identified in the data material for the region off Hirtshals. Thus, where there are similarities between the patterns of nitrate distribution in the

German Bight and the Skagerrak, it seems clear that the potential contribution of the JCC to transport of nutrients into the Kattegat cannot be evaluated only by considering the amounts of nutrients entering the German Bight.

The seasonal patterns in the distributions of nitrate concentrations in the coastal region off Hirtshals and in the bottom water of the Kattegat (Figure 5) resemble each other much more closely than those of the German Bight and off Hirtshals (Figure 2). The seasonal troughs and peaks in the nitrate concentrations argue for an immediate past history as "surface" water for the bottom in the northern Kattegat. "Surface" water in this case is used to refer to the euphotic zone, in contrast, for example, to the deeper waters of the Norwegian Trench, where nitrate concentrations remain more or less constant throughout the year at about 10 µmol l^{-1} (Figure 3). The similarity in the distributions off Hirtshals and in the bottom water of the northern Kattegat may also argue for waters entering the northern Kattegat having had an immediate past history off Hirtshals. If this is the case, the time delay in the appearence of peaks in nitrate concentration off Hirtshals and in the northern Kattegat may be explained by the duration of transport. Support for this argument can be found in Figure 4 and Figure 7 which illustrate that the high nitrate concentrations in both regions are related to salinities in the same range (31 to 34 psu.).

Assuming that the inflow from the North Sea into the Kattegat ultimately originates from either the northern North Sea or the JCC, then the JCC is only of interest as a potential carrier of excess nitrate into the Kattegat in periods in which nitrate concentrations exceed those in the northern North Sea. Figure 3 shows that the greatest concentrations of nitrate in the JCC off Hirtshals occur in the months of winter and early spring. Thus, the available data material indicates, that it is reasonable to expect the greatest potential contribution by the JCC to nutrient transport into the Kattegat to occur during winter and early spring. This is also a reasonable assumption given that biological fixation of nutrients on organic form will be at a minimum during the months of winter and early spring (i.e. the period before onset of the phytoplankton bloom).

Given the concentration of nitrate in the deeper waters of the Norwegian Trench (approx. 10 µmol l^{-1}, see Figure 3) and winter concentrations of nitrate in surface waters of the northern North Sea during Jan/Feb in the 1980s (8-10 µmol l^{-1}, Nielsen and Richardson, 1989, and Jan/Feb data taken from the ICES databank 1984-1989), we have arbitrarily chosen to regard concentrations exceeding 10 µmol l^{-1} nitrate in JCC water during the months of winter and early spring as representing periods in which the JCC can be of potential importance as an "unusual" or "excess" nitrate carrier into the Kattegat.

The data presented here (Figure 3) indicate that such winter and early spring peaks in nitrate concentration can be observed in JCC water during the 1980s (1981, 1989, 1990 and 1992). It must be noted, however, that due to the sporadic nature of these events, the sampling is difficult. Thus, peaks can have occurred which are not (or not completely) reflected in the data set. The most dramatic peak is observed in 1989. This peak can be followed into the bottom waters of the northern Kattegat. Indeed, Ærtebjerg (1990) has reported that it was possible to follow JCC water with high nitrate concentrations into the bottom water of the southern Kattegat in 1989. With respect to this event, winds during the winter and early spring 1989 were unusually dominated by south/southwesterly winds (Sehested-Hansen *et al.*, 1990) which give the JCC the greatest potential of reaching the Skagerrak/Kattegat (Poulsen, 1991).

Ærtebjerg notes (pers. comm.) that despite yearly monitoring since 1974, this 1989 event was the first unequivical indication of a major nitrate transport from the JCC into the Kattegat that has been observed. Longterm data series and covering the period from 1972-1992 for nitrate concentration in the bottom waters (Salinity >31 psu.) of the northern Kattegat (Figure 8) indicate that major nitrate transport events from the North Sea into the Kattegat may also have occured in 1981 and 1982.

In summary, the chemical data presented here suggest that the JCC has the potential to transport exceptional amounts of nitrate into the Kattegat during winter and early spring months, but that such transport only occurs sporadically. This sporadic transport into the Kattegat is most likely a function of the wind setup and need not necessarily occur in all years.

In order to quantify the effect of these exceptional JCC inflow events on the total nitrogen budget of the Kattegat and, thus, to evaluate the potential contribution of the JCC to oxygen depletion in the southern Kattegat, it will be necessary to quantify the actual water transport in these events and determine how often they occur. It is, however, already possible to determine that there is no simple cause and effect relationship between years in which a transport of nitrate from the JCC into the Kattegat can potentially be identified and the severity/extention of hypoxia/anoxia in the Kattegat.

Hypoxia/anoxia events in the southern Kattegat and Belt Seas have occurred in a number of years in which no large transport of nitrate from the JCC into the Kattegat can be traced. By contrast, in 1989, when there is good evidence of an exceptional transport event of nitrate from the JCC into the Kattegat, the intensity and extension of oxygen depletion was less than in, for example, 1986 and 1987 (Anon., 1990). However, the lesser intensive oxygen depletion in 1989 must also be seen as a result of relatively low local freshwater and nutrient input into the Kattegat from Danish and Swedish sources.

However, considerable research effort is still required to elucidate the contribution of the Jutland Coastal Current to the nutrient transport into the Kattegat and the potential role of this nutrient in the observed oxygen depletion events.

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REFERENCES

Andersson, L. & Rydberg, L. 1988. Trends in Nutrient and Oxygen Conditions Within the Kattegat: Effects of Local Nutrient Supply. Estuarine, Coastal and Shelf Science, 26: 559-579.

Anon. 1990. Iltsvind i de åbne farvande. *In* Marine områder. Fjorde, Kyster og Åbent hav. Vandmiljøplanens Overvåningsprogram 1989. Faglig rapport fra DMU, nr. 8 1990 (In Danish).

Anon. 1991a. Spørgepanelets rapport (table B4). *In* Kvælstof, Fosfor og Organisk Stof i Jord og Vandmiljøet. Rapport fra konsensuskonference 1991. Ed: Frier, J-O., & Christensen, J. R., Undervisningsministeriet Forskningsafdeling (In Danish).

Anon. 1991b. Long-term meassurements of inorganic nutrients and phytoplankton in the German Bight, North Sea. Presented by Germany at the Paris Convention for the Prevention of pollution. Sixth meetion of the working group on nutrients. Aarhus, oct/nov 1991.

Berg, J. and Radach, G. 1985. Trends in Nutrient and Phytoplankton Concentration at Helgoland Reede (German Bight) since 1962. ICES CM 1985/L:2/Sess.R.

Gerlach, S. A. 1990. *In* Nitrogen, Phosphorus, Plankton and Oxygen Deficiency in the German Bight and in Kiel Bay. Kieler Meeresforschungen 1990, Sonderheft no. 7. Institut für Meereskunde an der Universität Kiel.

Danielssen, D. S. and E. Dahl 1992. Variability of Nutrients and Chlorophyll in the Skagerrak, 1980-1990. ICES Marine Science Symposium, 195: 462-464.

Danielssen, D.S., Davidsson, L., Edler, L., Fogelqvist, E., Fonselius, S., Föyn, L., Hernroth., L. Håkansson, B., Olsson, I. and E. Svendsen 1991. SKAGEX: Some preliminary results. ICES CM 1991/C:2.

Danielssen, D.S., Edler, L., Fonselius, S., Hernroth, L., Ostrowski, M., Svendsen, E. and L. Talpsepp, 1997. Oceanographic variability in Skagerrak and Northern Kattegat, May-June, 1990. ICES Journal of Marine Science 54:

Jensen, T.G., Kullenberg, G. and O.V. Olsen 1983. The Jutland Current, carrier of North Sea signals towards the Baltic Sea. ICES CM 1983/c:5.

Jacobsen, T. & Richardson, K. 1990. JYLLANDSSTRØMMEN. En transportmekanisme fra Tyske Bugt til Kattegat?. NPo-forskning fra Miljøstyrelsen, Nr. C6 1990. Miljøministeriet, Miljøstyrelsen (In Danish).

Kristensen, K. B. 1991. The Jutland Coastal Current. Series Paper, vol 53, Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark.

Nielsen, T. & Richardson, K. 1989. Food chain structure of the North Sea plankton communities: seasonal variations of the role of the microbial loop. Marine Ecology Progress Serie, 56: 75-87.

Olsen, V. O. 1990. Trends in Oxygen and Nutrients in the Kattegat and the Sound from 1967-88. 17'th CBO Conference, Norrköping, Sweden 1990.

Pedersen, Fl. B., Richardson, K., Jacobsen, T & R. Warren. 1988. The Jutland Current: Where is it and when? Proceedings of the 16'th Conference of the Baltic Oceanographers, Kiel.

Poulsen, O. 1991. The Hydrography of Skagerrak and Kattegat, the dynamics of the Skagerrak front. Series Paper, vol 54, Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark.

Richardson, K. & Ærtebjerg, G. 1991. Effekter af kvælstof og fosfor i Kattegat og Bælthavet.*In* Kvælstof, Fosfor og Organisk Stof i Jord og Vandmiljøet. Rapport fra konsensuskonference 1991. Ed: Frier, J-O., & Christensen, J. R., Undervisningsministeiet Forskningsafdeling (In Danish).

Sehested-Hansen, I. 1990. *In* Danmarks Hydrografi 1989. Faglig rapport fra DMU, nr.11. Miljøministeriet, Danmarks Miljøundersøgelser, December 1990 (In Danish).

Ærtebjerg, G. 1987. Årsager til og effekter af eutrofiering i Kattegat og bælthavet. *In* Eutrofiering av havs- och kustområden. 22. Nordiska Symposiet om Vattenforskning, Laugarvatn 1986. Nordforsk, Miljövårdsserien, publickation 1987:1 (In Danish).

Ærtebjerg, G. 1990. Nitrat indstrømning fra Nordsøen i 1989, in Præsentationer ved det sjette danske havforskermøde. Faglig rapport fra DMU, nr. 4. Ed: Buch, E. & Sørensen, M. I. Miljøministeriet, Danmarks Miljøundersøgelser, August 1990 (In Danish).

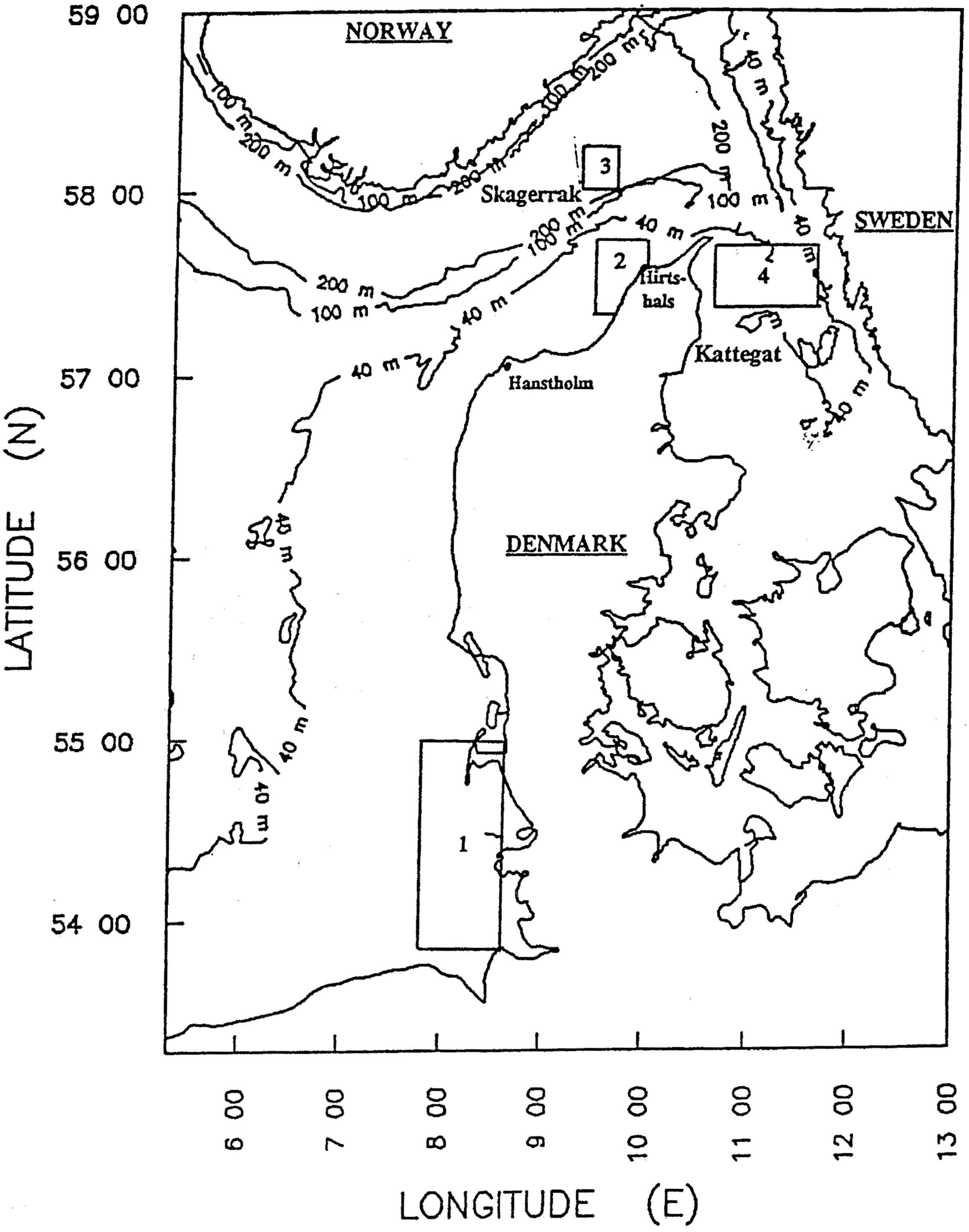

Figure 1
Map showing the selected regions. 1: German Bight, 2: The coastal region off Hirtshals, 3: The Norwegian Trench, 4: The northern Kattegat.

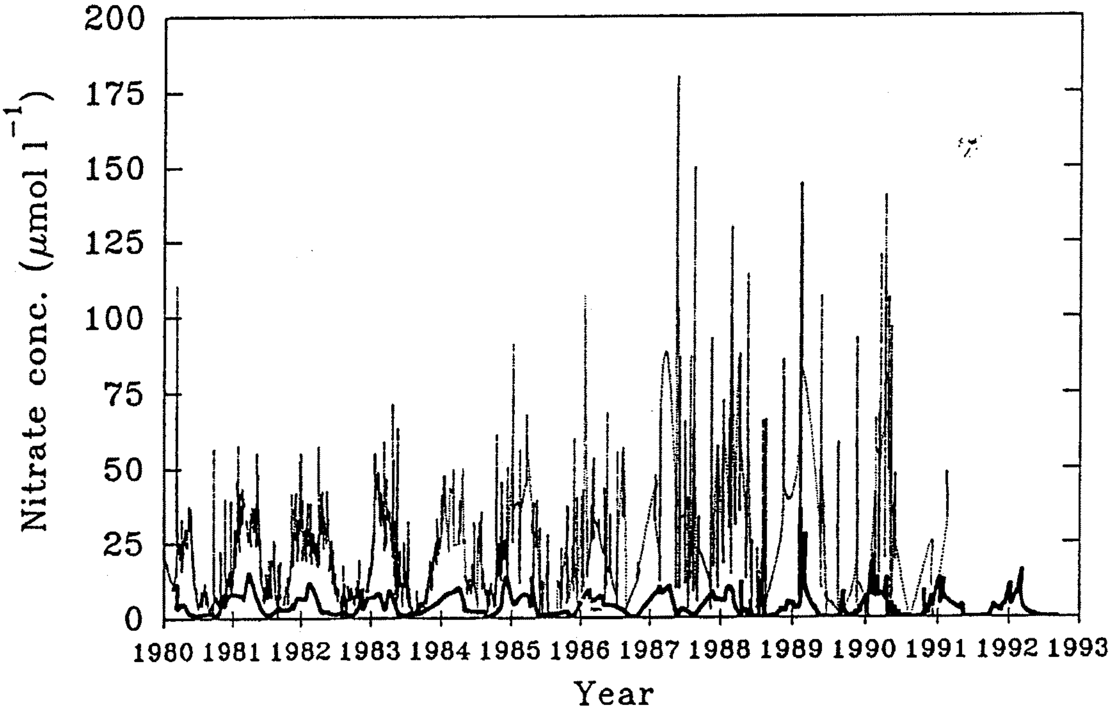

Figure 2
The solid line shows the mean nitrate concentration (μmol l^{-1}) from the coastal region off Hirtshals (d.i.: 0-30 m., salinity <34 psu.), while the dotted shows the mean concentrations in the German Bight (d.i.: 0-15 m., salinity <33 psu.) in the period 1980-1992.

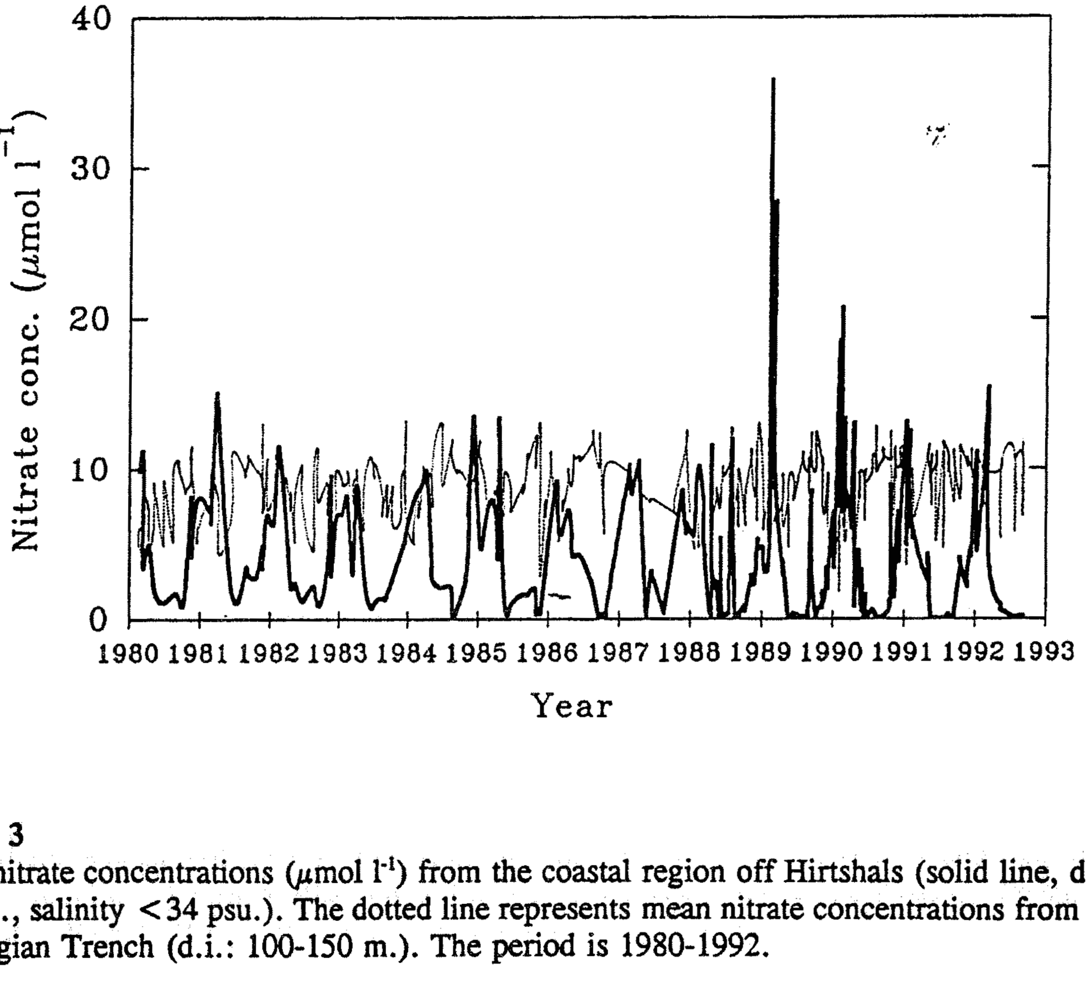

Figure 3
Mean nitrate concentrations (μmol l^{-1}) from the coastal region off Hirtshals (solid line, d.i.: 0-30 m., salinity <34 psu.). The dotted line represents mean nitrate concentrations from the Norwegian Trench (d.i.: 100-150 m.). The period is 1980-1992.

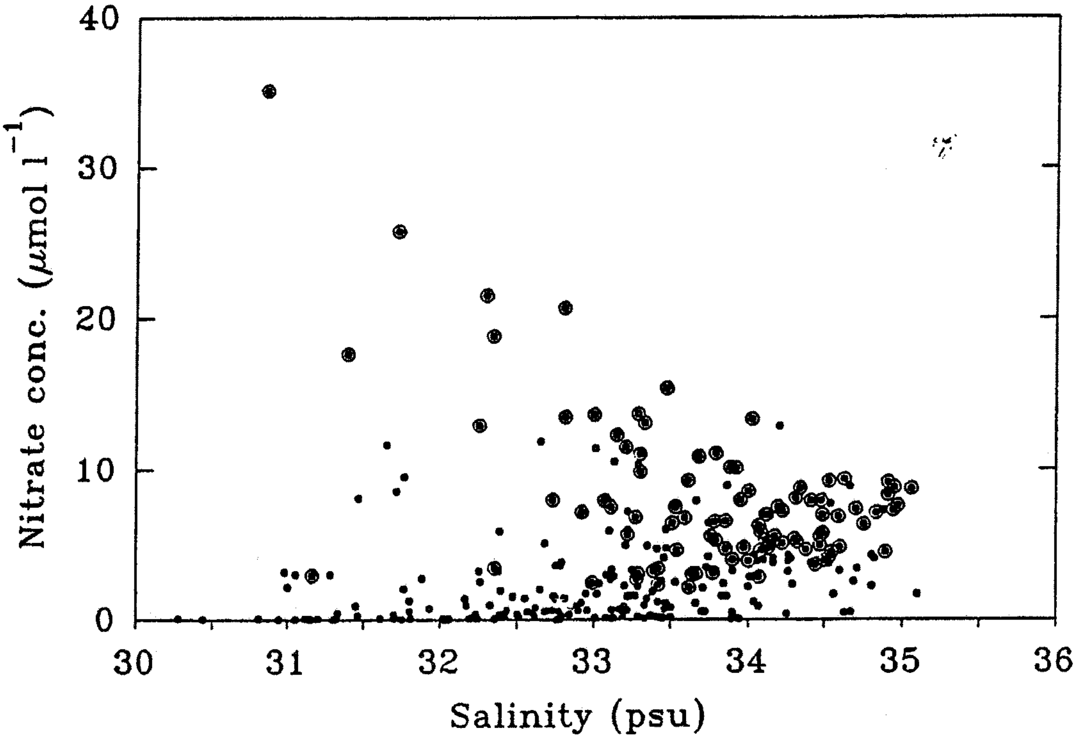

Figure 4
Nitrate concentrations (µmol l⁻¹) versus salinity (psu.) in the period 1980-1992 from the coastal region off Hirtshals, (depth >30 m.).
Hollow circels with dot represent the months: December,..,March, - while dots represent the remaining months.

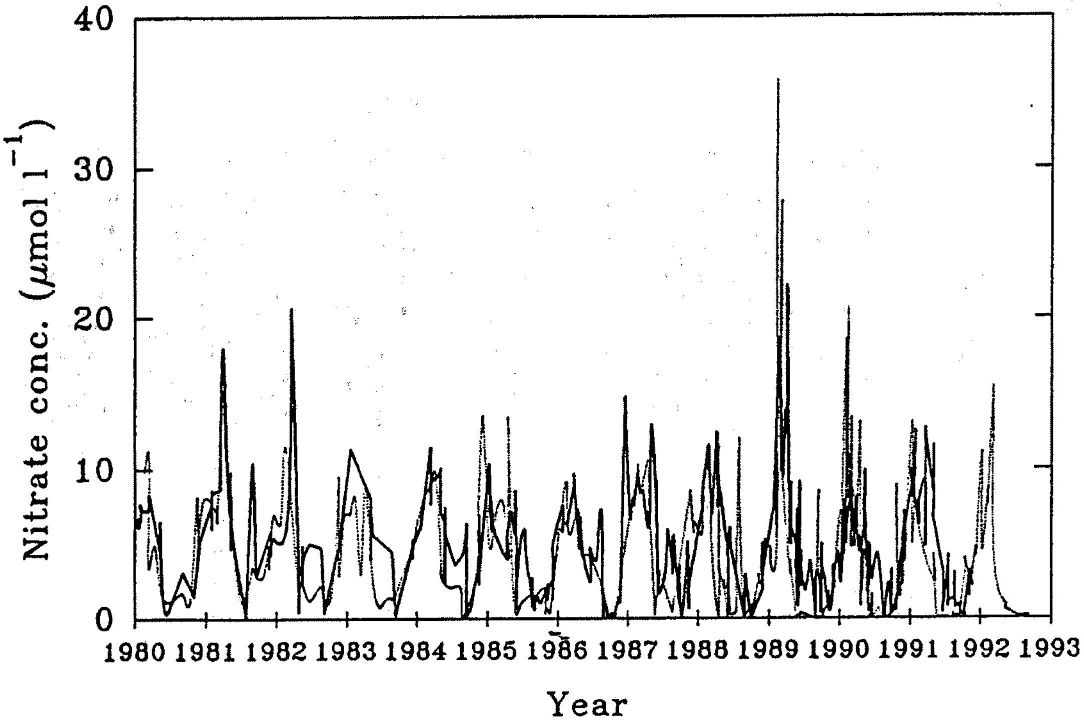

Figure 5
Mean nitrate concentrations (μmol l^{-1}) from the northern Kattegat are shown by the solid line (d.i.: 25-50 m., salinity >31 psu.), while the dotted line represents mean nitrate concentrations from the coastal region off Hirtshals (d.i.: 0-30 m., salinity <34 psu.). Period: 1980-1992.

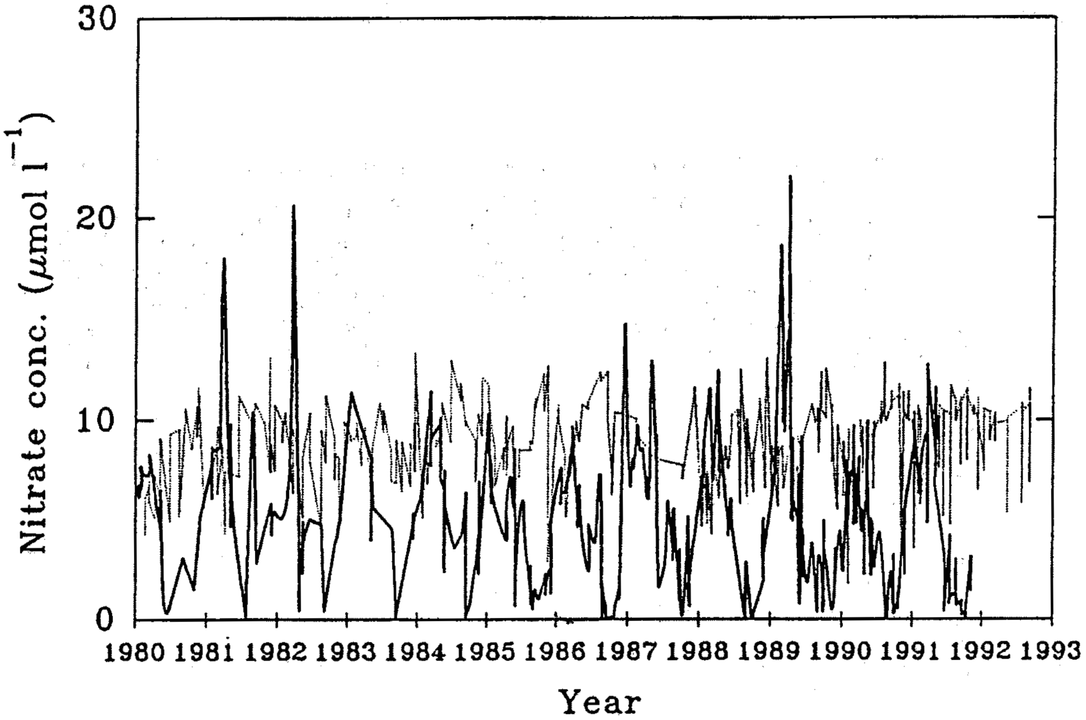

Figure 6
Mean nitrate concentrations (μmol l^{-1}) from the northern Kattegat (solid line, d.i.: 25-50 m., salinity >31 psu.). The dotted line represents mean nitrate concentrations from the Norwegian Trench (d.i.: 100-150 m.). Period: 1980-1992.

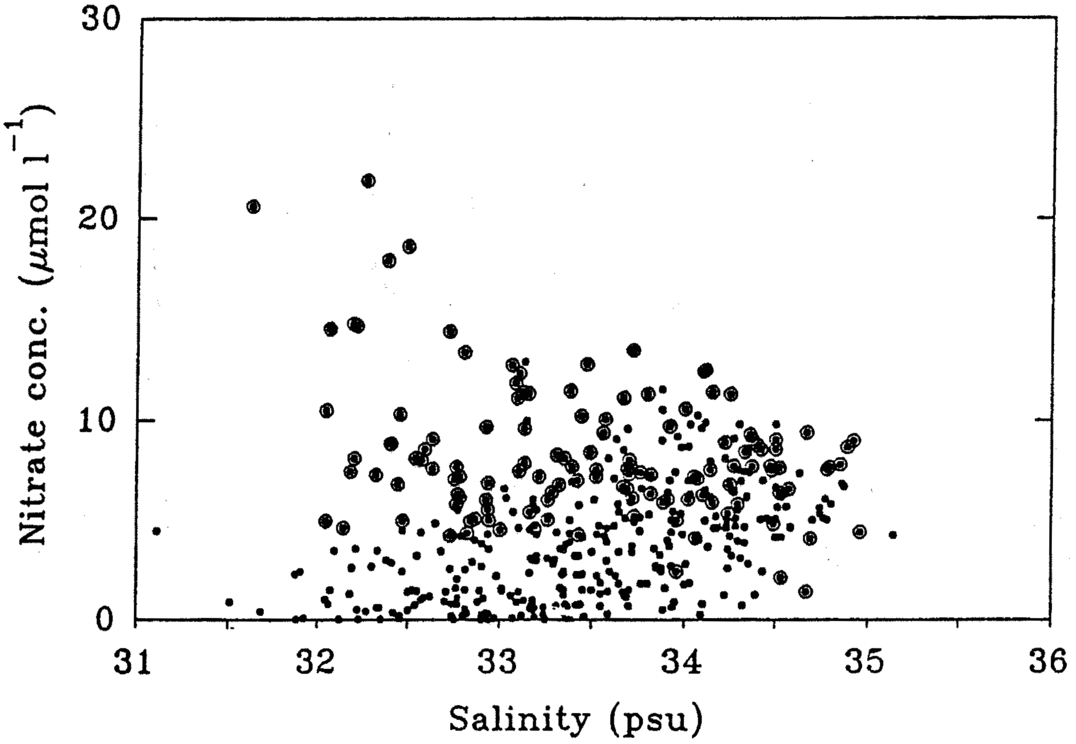

Figure 7
Nitrate concentrations (μmol l^{-1}) versus salinity (psu.) in the period 1980-1992 from the northern Kattegat, (Depth >25 m.).
Hollow circles with dot represent the months: December,..,March, - while dots represent the remaining months.

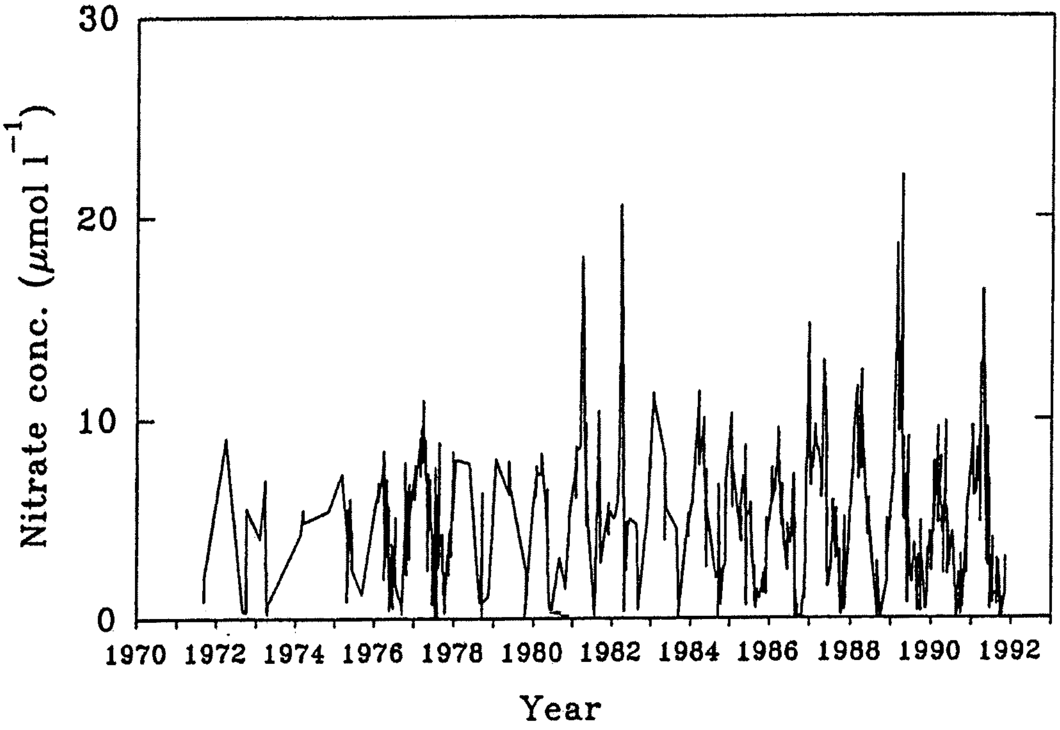

Figure 8
Mean nitrate concentrations (μmol l^{-1}) from the northern Kattegat (d.i.: 25-50 m., salinity >31 psu.) in the period 1972-1992.

Presentation no 11.

Some features of chlorophyll variability in the straits of the Skagerrak and the Kattegat.

by

G. S. Karabashev and S. A. Khanaev

SOME FEATURES OF CHLOROPHYLL VARIABILITY IN THE STRAITS OF THE SKAGERRAK AND THE KATTEGAT

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ABSTRACT

More than 250 profiles of chlorophyll fluorescence have been measured with a submersible fluorometer during SKAGEX 1, 2 and 4, in May-June 1990 and 1991 and in September 1990. In the Skagerrak, the difference between the profiles measured during several hours at stations few miles apart could be comparable with the difference of profiles measured at one and the same place in May and September. Mixing and intrutions of alien waters contributed greatly to strong variability of chlorophyll at local scales. In the Kattegat, the intersection of a temperature front with a chlorophyll front-like structure was observed in May 1990. The local accumulations of chlorophyll under the seasonal thermocline have been found in the northwestern Kattegat in May 1990 and in the northeastern Kattegat in May 1991. These phenomena indicate deep algal blooms and bias the distribution of total chlorophyll over the strait. The estimates of correlation between surface and total chlorophyll or chlorophyll at greater depth have proved that successful remote sensing of chlorophyll is possible only for the upper 5-10 m of the straits.

INTRODUCTION

The international experiment SKAGEX has been conducted in 1990-1991 intending to study synoptic variability of physical, chemical and biological processes in the straits of the Skagerrak and Kattegat. Great attention was paid to determination of chlorophyll distribution. The main results have been obtained in the series of synchronous multiship observations at sections crossing the straits. We took part in the first stages of SKAGEX on board a small ship and could not follow the same scheme of observations in the open part of the straits because of weather dependence of our carrier. Therefore we collected data on events and phenomena that did not demand regular measurements at predefined places and time. The aim of the present work is to add some information on chlorophyll variability in the Skagerrak and the Kattegat which may be absent in the main data set collected during SKAGEX field activities.

INSTRUMENTATION AND DATA PROCESSING

The measurements have been carried out with the submersible multichannel fluorometer MZF (Karabashev and Khanaev, 1988). It measures separately in one and the same time the fluorescence of chlorophyll, fluorescence of dissolved organic matter (DOM), light scattering at fixed angle (turbidity), water temperature and hydrostatic pressure (depth of submersion). These quantities were logged 8 times per second by an on board computer. The profiles were averaged over 0.5 m thick layers. The intensities of fluorescence and scattering values were expressed in arbitrary units of linear scale, temperature and depth in °C and meters.

The reproducibility error, E, for the fluorometer measurements was estimated *in situ* as the lower limit of data scattering about the average value when repeated observations were made in steady homogeneous water layers of the straits. Temperature errors were $E_T = \pm 0.03°C$. The errors of fluorescence measurements were 4-6%.

The instrument was deployed at stations down to 250 m of depth during SKAGEX 1 and 2 (May-June and September of 1990, research ship "Shelf") and to 60 m in SKAGEX 4 (May of 1991, research vessel "Lev Titov"). The stations position are shown in Fig. 1. The water sampling for chlorophyll was counted in SKAGEX 4 just after deployment of fluorometer. The chlorophyll determinations have allowed to calculate the regression of chlorophyll on fluorescence and hence to convert the profiles of chlorophyll fluorescence to profiles of concentrations of chlorophyll. Applying the regression to data from SKAGEX 1 and 2 the possible error of chlorophyll determination with MZF fluorometer during SKAGEX exercises has been estimated. This error made up 0.4 mg m^{-3}.

RESULTS

Fig. 2 and 3 show seasonal variability of chlorophyll in the central and northern Skagerrak. The chlorophyll maxima scattered between 8-10 and 35-40 m depths both in May-June and in September. The shape of profiles drastically changed during survey even at neighbour stations (E3 - E4 in May, E7 - E8 in September). The seasonal mutations of the shape differed across the Skagerrak. For example, the spring and autumn profiles at station E1 were difficult to distinguish but they had nothing in common at st. E4. The profiles of complex shape were measured at several stations (E6 in May, E5 in September). The chlorophyll concentration was higher in September than in May below 50 m depth at half of the stations at section E.

The mezoscale variability of the shape of the chlorophyll profiles in the area of the Jutland Current has been studied on 2nd of June, 1990 in the vicinity of st. E10 and E11. Thirteen stations have been occupied during several hours. They were located 2-3 km apart along a line connecting these stations (the 1st section) and

along another line parallel to the coast and coming through st. E11 (the 2nd section). The vertical gradient profiles of temperature have been computed and compared with corresponding profiles of chlorophyll.
There was no significant variability of the shape of the profiles at the 2nd section. The profiles of chlorophyll and temperature changed concertedly at the 1st section (Fig. 4). The maximum of chlorophyll has disappeared at distance less than 2 km from st. E10 revealing variability comparable to that of profiles at neighbour stations at section E (Fig. 2 and 4). The temperature gradient profiles looked like mirror image of the chlorophyll profile except that the maxima of chlorophyll were several meters deeper than maxima of temperature gradient. This difference was common in open Skagerrak at Section D, E, F and is inherent to areas of the ocean with shallow thermocline.

Three surveys at sections L, B, A, S in the Kattegat have been carried out in late May, early and mid June of 1990. They have shown the magnitude of chlorophyll variability and degree of stability of its vertical distribution over a 3 week period in the strait (Fig. 5-8). Almost all chlorophyll profiles had maxima at depths from 8-10 to 20-25 m. There were near bottom maxima in some cases and profiles of complex shape were observed at western stations for section L and B. The variability of profile shape diminished southward for each survey. The profiles from the 1st survey were distinguished by greater amplitude and lesser thickness of their maxima.

The same materials were used to map the horizontal distributions of chlorophyll and temperature at different depths in Kattegat. Kriging interpolation has been used. The maps were plotted for horizontal cross section of the strait in depth range from 3 to 35 m with vertical step of 2-3 m. The maps presented in Fig. 9-11 account for the distributions in the upper mixed layer (depth 5 m), at the depth of the thermocline (15 m) and below (25 m).

The temperature front oriented meridionally existed to the East of the island of Leseø during the 1st survey at all depths (Fig. 9-11). The front separated colder waters in the southeast of Kattegat from the warmer waters in the northern Kattegat. At 5 m depth moderate amount of chlorophyll was almost evenly distributed increasing 1.5 fold beyond the front. A patch of colder water appeared at 15 m just north of the same island. Strong maximum of chlorophyll was attached to the patch (Fig. 10). The stripe of high chlorophyll concentration had stretched from the maximum to the southeast crossing the temperature front at an angle of 50-70°. The chlorophyll concentration decreased across the stripe making it look like a "chlorophyll" front.

The patch of cold water north of the island became greater and high chlorophyll concentration was localized around it at 25 m depth (Fig. 11). The content of chlorophyll was moderate and rather constant in the rest of the Kattegat at depth of 25 m. So the fronts crossed in a layer not more than 10-15 m thick.

The 2nd survey was conducted after the surface water was warmed up several degrees. The pattern of the horizontal distribution of the temperature had changed at 5 m, but remained the same at 25m. There was nothing remarkable in chlorophyll distribution at 5 m depth in the 2nd survey. Two moderate maxima of chlorophyll not related to the extreme of temperature were observed at depth of 15 m. The horizontal variability of chlorophyll at 25 m was poor and revealed no connection with the temperature variability in the 2nd survey or that of chlorophyll in the first one.

The isotherms shaped as a "tongue" protruding southward may be seen at all depths in Fig. 9-11 for the 3d survey. The waters inside a "tongue" were colder than surroundings waters of Kattegat at 5 m and warmer at 15 and 25 m. The chlorophyll distribution at 5 m was flat having nothing in common with the temperature distribution. The minimum of chlorophyll, shaped like the temperature "tongue", was attached to the latter at 15 m. The weak minimum and weak maximum of chlorophyll coincided with western and eastern borders of the temperature "tongue" at 25 m depth correspondingly. The temperature front separating colder waters near the Swedish coast in the southeast was present at 25 m during the entire SKAGEX I period. The position of the front varied from survey to survey but it did not effect on chlorophyll distribution at 25 m depth.

The studies of the frontal zone initiated by Dr. Dybern were undertaken in May of 1991 on board R/V "Lev Titov". It was expected that the studies would allow to disclose characteristics of the boundary separating Baltic water from the waters of the straits. The area between sections C and B was chosen and 34 stations at 7 sections were occupied during 2 days. These stations are marked with letters L, M, N in Fig. 1. The concentration of chlorophyll in the frontal zone (FZ) was mapped at different depths from 4 to 36 m for the 2 m vertical step of mapping. The total chlorophyll in the layer from 4 to 80 m has been computed for each station and the map of its distribution has been plotted in the same way as concentration at fixed depths. The total chlorophyll is a measure of its content under 1 square meter ofthe sea surface. The bottom countour was mapped, as well, using depth of bottom at stations L, M, N.

Some results from FZ are presented in Fig. 12. There were no reproducible signature of an expected frontal boundary in all the maps of chlorophyll distribution. The total chlorophyll varied from 70 to 90 mg m^{-2} without a clearly defined extreme in the north of FZ. A maximum exceeding 150 mg m^{-2} was found in the west of the central and southern parts of the FZ. The values less than 50 mg m^{-2} have been found in the south east. The largest chlorophyll concentrations at 5 m depth gravitated to the northeast. The chlorophyll increased eastward in the central and southern parts of FZ. The strong maximum above underwater valley in the south of FZ distinguished chlorophyll distribution at 20 m.

The distributions of chlorophyll at sections limiting the frontal zone from west and east are given in Fig. 13. The eastern section above the continental slope reveals a single maximum at depth of the thermocline. Similar maximum is found in the western section. These maxima are common. But the western section demonstrates extraordinary accumulation of chlorophyll occupying a layer from 25-30 m down to the bottom and extending 20-30 km southward from the centre. The layer of low chlorophyll at 20-25 m provides evidence that the deep accumulation of chlorophyll has no direct connections to chlorophyll in the upper maximum. Obviously it was the deep chlorophyll and not the chlorophyll in the upper maximum that determined the specific distribution of total chlorophyll in FZ. Seasonal and synoptic changes of total chlorophyll at section C are compared in Fig. 14. Both were not as strong offshore (st. C7-C9) as in the coastal area of Skagerrak (C2-C4). The difference between consequent measurements were greater in May 1991 than in September 1990. Synoptic variations of total chlorophyll turned out to be comparable to that of the seasonal.

Collected data were used to estimate covariability of surface chlorophyll with chlorophyll in deeper layers and with the total chlorophyll in layers from 3 to 40, 3 to 60 and 3 to 80 m of depths. The data sets were formed according to different criteria (near shore - off shore, the Skagerrak only, the Kattegat only, spring, autumn etc.). The amount of data pairs in a set was sufficient to secure 95% significance level if the absolute values of the correlation coefficient T>=0.7. It was found that correlation under study was poor in most cases and depended on criteria of data selection. The lack of connection between surface chlorophyll and the total chlorophyll or with the deep chlorophyll may be noticed in the distribution presented above in many figures.

DISCUSSION

Striking diversity of the shape of chlorophyll profiles across the Skagerrak at section E (Fig. 2) provided evidence that local processes played a more important role in shaping the vertical distributions of chlorophyll than seasonal changes in the environment or the phytoplankton community at the moment of observations. The smallest difference between spring and autumn profiles occurred at st. E1 and E2 in the Norwegian Coastal Current. These profiles had smoothed maxima. Probably it was due to intensive water mixing in the current of which the velocity field remained about the same in May and September. It may be assumed that strong vertical mixing at the offshore boundary of the Jutland Current had caused radical variations of chlorophyll and temperature profiles south of station E10 (Fig. 4). There are no strong permanent current and vertical mixing in the active layer of the open Skagerrak and upwelling of water ("doming") is here major dynamic factor of phytoplankton abundance and composition (Richardson, 1989; Fonselius, 1990). The spring profile of chlorophyll at st. E4 (Fig. 2) may be considered as an ultimate manifestation of the effect of "doming" on the vertical distribution of phytoplankton in the Skagerrak. It was established that the transition from intensive mixing in near shore waters to intensive "doming" in the central Skagerrak is accompanied by a change from large to small size phytoplankton (Richardson, 1989). Taking into account this phenomenon and difference of shape of the profiles of chlorophyll by mixing without "doming" (st. E1) and by "doming" without mixing (st. E4) one may assume that profiles of complex shape correspond to an intermediate situation when phytoplankton of different size accumulates at different depths at one and the same location regardless of season.

The existence of subsurface maxima of chlorophyll inthe Kattegat was reported earlier and agrees with data of other SKAGEX participants (Danielssen et al., 1991). The southward decrease in variability of the shape of chlorophyll profiles in the Kattegat illustrated in Fig. 5-8 is obviously due to increasing homogeneity of hydrophysical conditions south of the transitional area between the Skagerrak and the Kattegat. Higher variability of the shape at sections L and B may be better understood taking into account horizontal distributions of chlorophyll in Fig. 9-11 together with the profiles in Fig. 5-8.

The distributions from the first survey exhibit strong maximum of chlorophyll concentration centring at st. B5 and occupying the whole water column below thermocline from 20-25 m to the bottom (profiles B4-B6 in Fig. 6 and left map in Fig 11). At the same time there is an usual maximum in the thermocline which spreads over a greater area (upper maximum at st. B5 in Fig. 6 and left map in Fig. 10). Just this maximum formed a front-like structure in the chlorophyll distribution. The maxima were separated from each other at some stations with low chlorophyll layer. This hints ona possible difference of phytoplankton composition in and below the thermocline. It was established (Danielssen et al., 1991) that in May-June 1990 the upper peaks at stations B were dominated by diatoms and the lower ones by dinoflagellates. Attachment of deep chlorophyll maximum to a patch of colder water (Fig. 11, left) allows to suppose that there was local increase of nutrients which favoured development of dinoflagellates below the thermocline in the end of May. Warmer water has been found at the same location during next survey when horizontal distributions of chlorophyll in the thermocline and deeper were almost flat (Fig. 10 and 11, centre). It supports our supposition that deep water phytoplankton bloom in the northwestern Kattegat was caused by patchiness of environmental parameters.

There is a similarity between the vertical distributions of chlorophyll in the vicinity of the cold water patch at st. B4-B6 during first survey in May 1990 and the chlorophyll profiles above the western slope of the underwater valley in FZ in May 1991. Their common feature werea strong peak in the thermocline, low chlorophyll at 20-25 m depth and high evenly distributed chlorophyll at greater depths. These features were expressed more clearly in FZ (Fig. 13, west). According to chemical determinations during the SKAGEX 4 mission on board "Lev Titov", the nitrate concentrations was high exactly at the location and depths were the deep chlorophyll was observed. The findings of our SKAGEX missions show that blooms of phytoplankton occur sometimes in the Kattegat below the thermocline. Supposedly, the local increase of nutrient content in the water triggers the blooms which contribute greatly to estimates of total chlorophyll.

The shape of a "tongue" in the temperature field (Fig. 9-11, right) indicate instrusion of alien waters into the Kattegat before the beginning of the last survey. The "tongue" tempts into conclusion that the branch of the Jutland Current intruded the Kattegat, the more so that deep penetration of this current in the strait is mentioned in recent reviews (Fonselius, 1990). However, the authors of the thorough analysis of water masses inthe SKAGEX area (Danilssen et. al., 1991) avoid thethe notion of Jutland current at all and infer that from June 3 to the beginning of third survey the flow along western coast of Denmark brought Southern North Sea Water (SNSW) into the Skagerrak. If so the "tongue" would be a mixture of SNSW and Surface Water (SW) from Skagerrak. The SNSW is several degrees colder than SW but both waters are nutrient poor. It explains low chlorophyll content of intruding waters relative to intruded waters of the Kattegat and moderate temperature of water inside the "tongue". The fluorescence of DOM inside the "tongue" was as low as in distant parts of the open Skagerrak pointing out significant contribution of SNWS to intruding mixture of waters.

Observation in May 1991 have given another example of influence of a current on synoptic chlorophyll variability. The phenomenon of "boiling water" is a reliable sea surface signature of a boundary between strong countercurrents (Fedorov and Ginsburg, 1992). This phenomenon has been noticed by an officer of the watch when "Lev Titov" sailed from stations C4 to C5 on 17th of May 1991. The distributions of water temperature and fluorescence of DOM measured together with chlorophyll at section C show that water properties have changed in opposite directions on both sides of the supposed boundary since 13 of May 1991. It explains the difference of variations of total chlorophyll along the section C on 13th and on 17th of May presented in Fig. 14.

CONCLUSIONS

The results ofthe observations presented in this study confirm and clarify the connections between the variability of chlorophyll and water movements in the straits of the Skagerrak and the Kattegat. The results provide evidence that watermovements contribute to chlorophyll variability both at coarse and local scales in the straits, at least as much as sunlight, nutrients or other variable factors controlling development of phytoplankton. Therefor it is necessary to support chlorophyll measurements with the adequate observations of the water velocity field, otherwise this connections will remain difficult to quantify.

The results return us to the well known problem of inadequacy of observations at stations in a rapidly changing marine environment. At the same time they warn that remote sensing of chlorophyll in the straits cannot solve the problem because

1) only the surface layer a few meters thick can be remotely sensed;

2) there is no reproducible covariability of the surface and the deep chlorophyll;

3) deep chlorophyll contributes greatly to the total chlorophyll.

The only solution seems to be the routine employment of a submersible instrumentation enabling continuous underway measurements of chlorophyll and sea water properties with space resolution of 10^1 m and the depth resolution of 1 m.

ACKNOWLEDGMENTS

The fruitful interaction with the international team of SKAGEX participants is gratefully acknowledged. We are also indebted to SKAGEX leader Dr. B. I. Dybern for his inspiring interest and support to this study. The study would not have been possible without the friendly assistance of masters and crewmen of the Russian research ship "Shelf" and research vessel "Lev Titov" from Lithuania.

REFERENCES

Danielssen, D.S., Davidsson, L. Edler., E. Fogelquist, S. Fonselius, L. Føyn, L. Hernroth, B. Hakansson, I. Olsson and E. Svendsen. 1991. SKAGEX: some preliminary results. ICES C.M. 1991/C:2 Ref: E, 14 p.

Fedorov, K.N., and A.I. Ginsburg. 1992. *The Near-Surface Layer of the Ocean.* VSP Utrecht The Netherlands 259 p.

Fonselius, S. 1990. Skagerrak - the gateway to the North Sea. SMHI Oceanography, Nr. 38, 29 p.

Karabashev, G.S and S.A. Kanaev. 1988. submersible multichannel fluorometer for marine studies. Zhurnal Prikladnoy Spektroskopii, 49 : 515-518 (In Russian).

Richardson, K. 1989. Phytoplankton distribution and activity in the Skagerrak: a review. ICES C.M. 1989/L : 243, Sess. Q, 15 p.

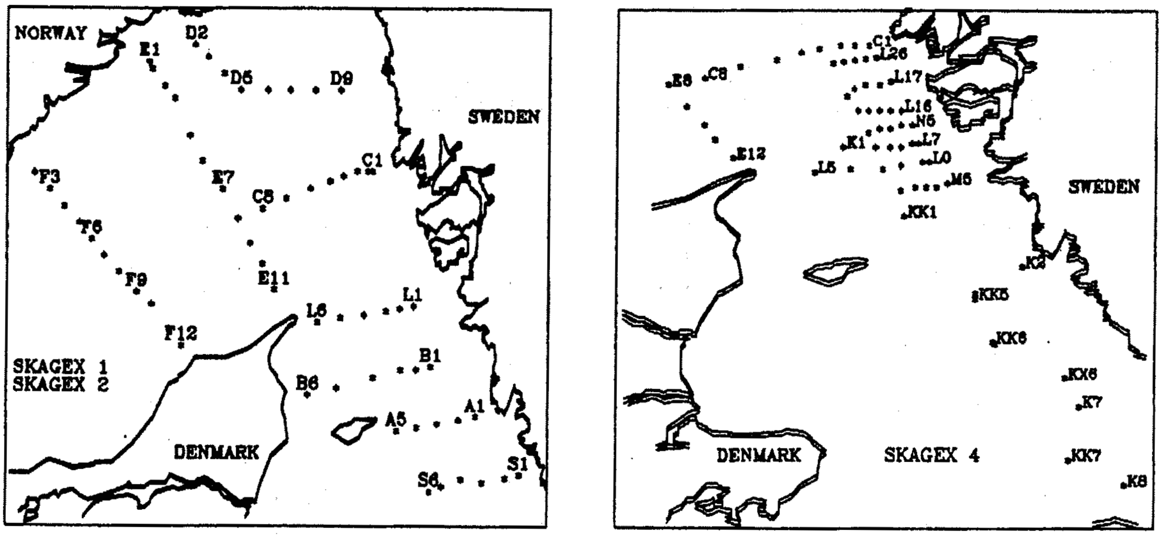

Fig. 1. The positions of the stations occupied by fluorometer MZF in the straits of the Skagerrak and the Kattegat during SKAGEX 1, 2 and 4.

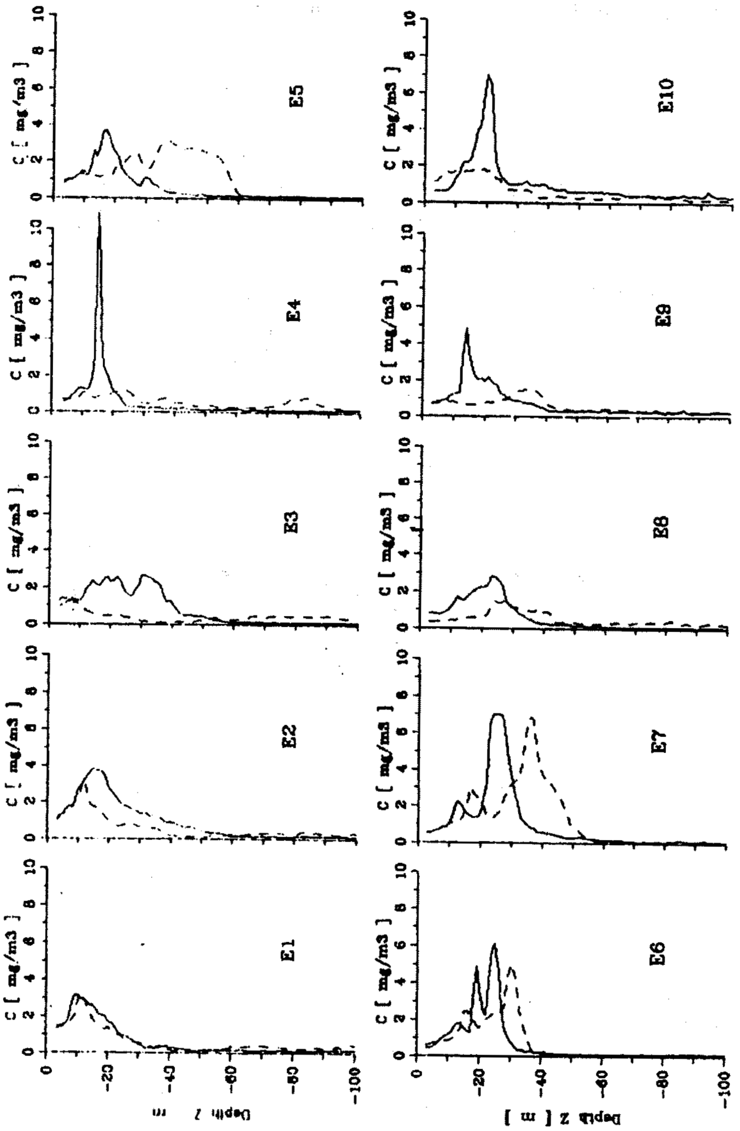

Fig. 2. The vertical distributions of chlorophyll concentration, C, at stations of sections E in Skagerrak measured on 90.05.31 (solid) and 90.09.07 (dashed).

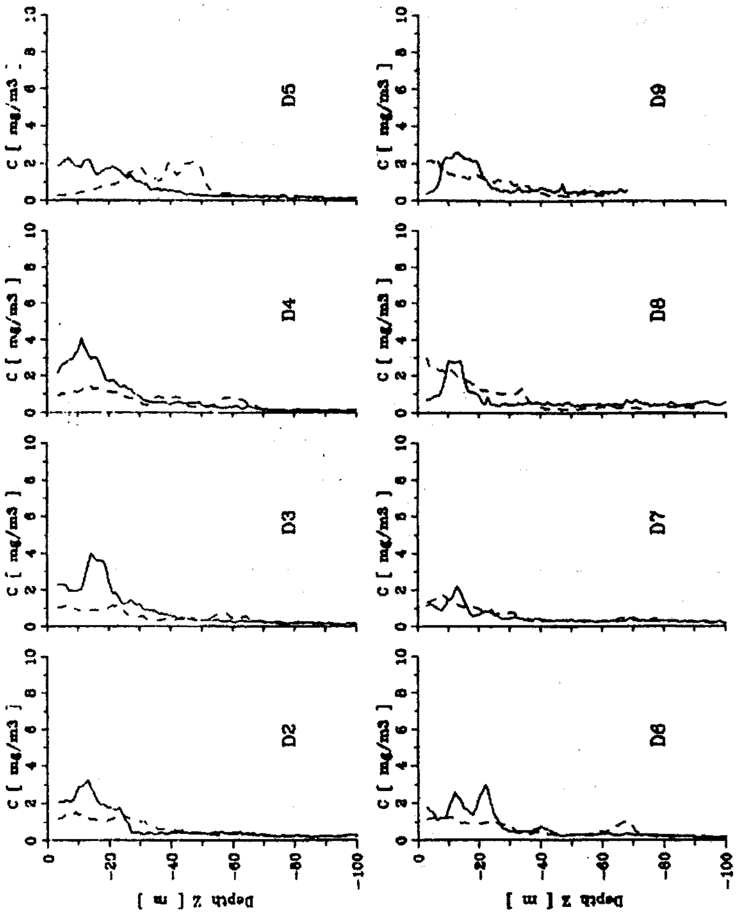

Fig. 3. The vertical distributions of chlorophyll concentration, C, at stations of sections D in Skagerrak measured on 90.06.01 (solid) and 90.09.08 (dashed).

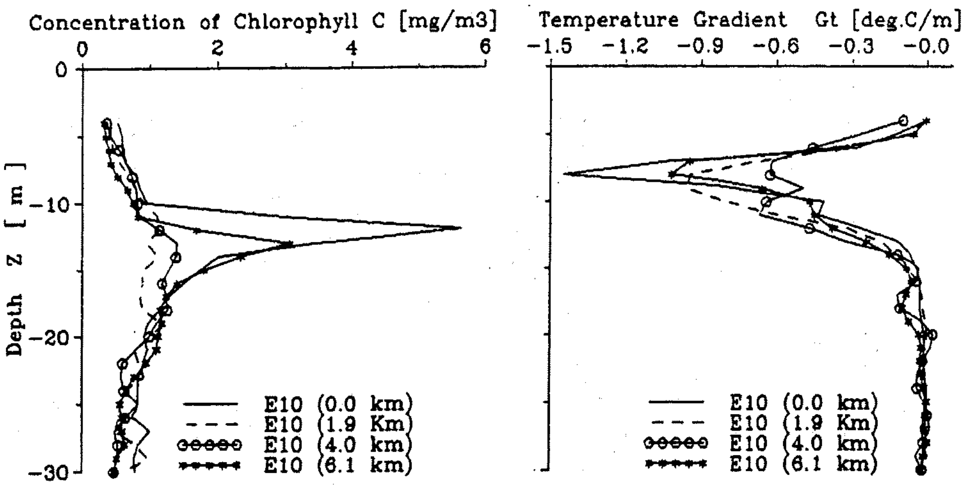

Fig. 4. The profiles of chlorophyll concentration, C, and vertical temperature gradient, Gt, measured on 90.06.02 at the track between stations E10 and E11 (in brackets - distance from st. E10.

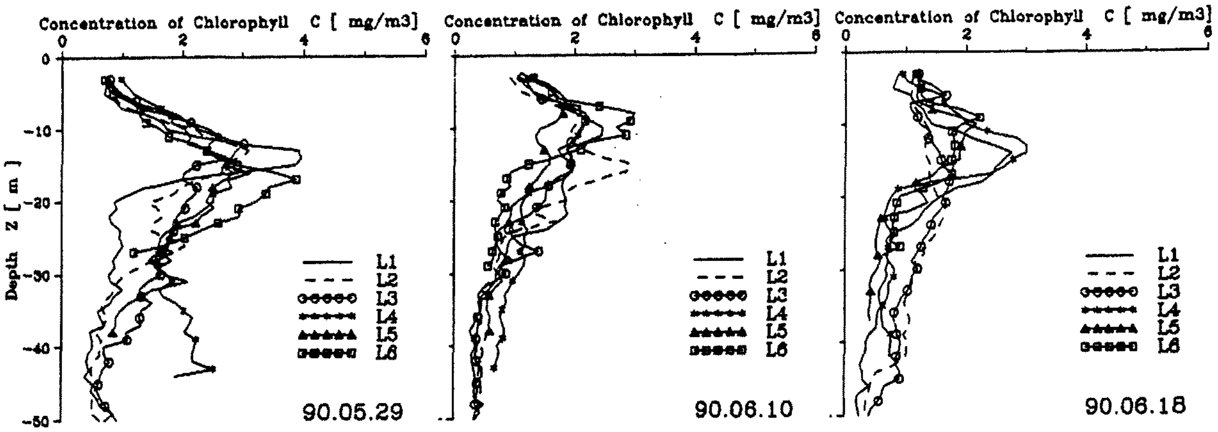

Fig. 5. The profiles of the chlorophyll concentration, C, measured at section L on 90.05.27, 90.06.10 and 90.06.18.

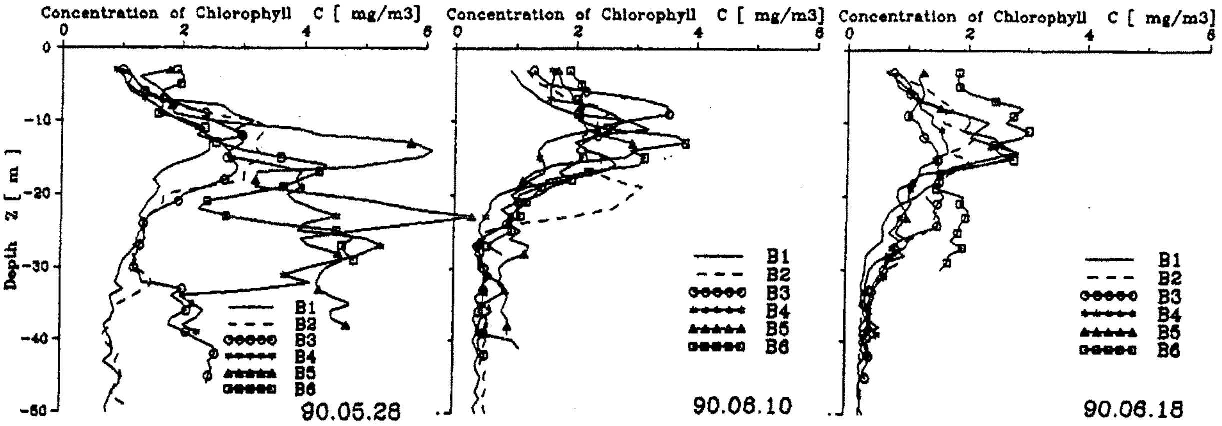

Fig. 6. The profiles of the chlorophyll concentration, C, measured at section B on 90.05.28, 90.06.10 and 90.06.18.

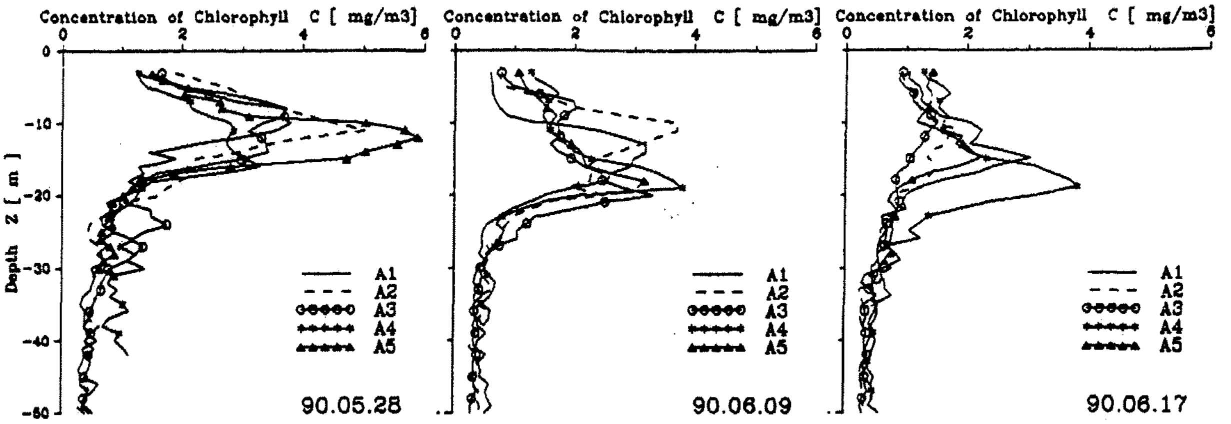

Fig. 7. The profiles of the chlorophyll concentration, C, measured at section A on 90.05.28, 90.06.09 and 90.06.17.

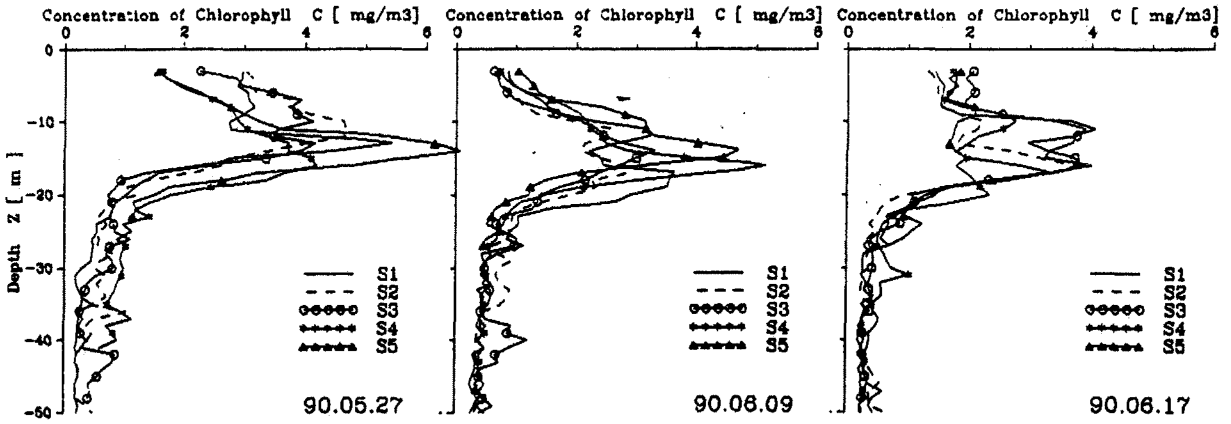

Fig. 8. The profiles of the chlorophyll concentration, C, measured at section S on 90.05.27, 90.06.09 and 90.06.17.

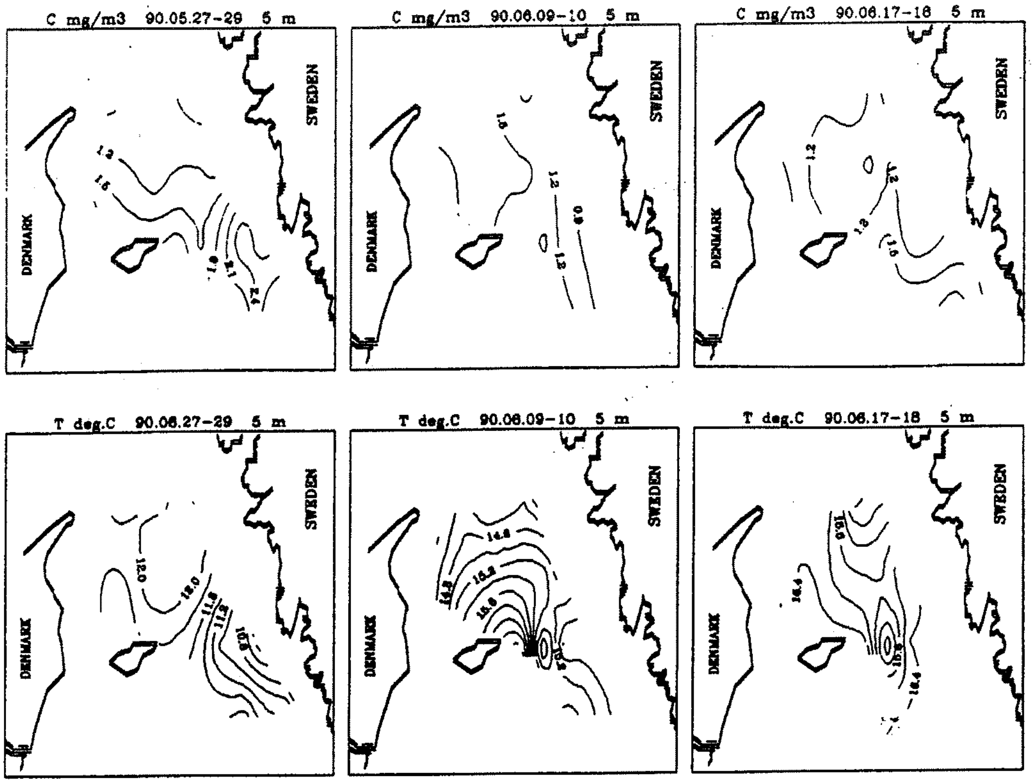

Fig. 9. The distributions of the chlorophyll concentration, C, and water temperature, T, at depth of 5 m according to data from three surveys in the Kattegat.

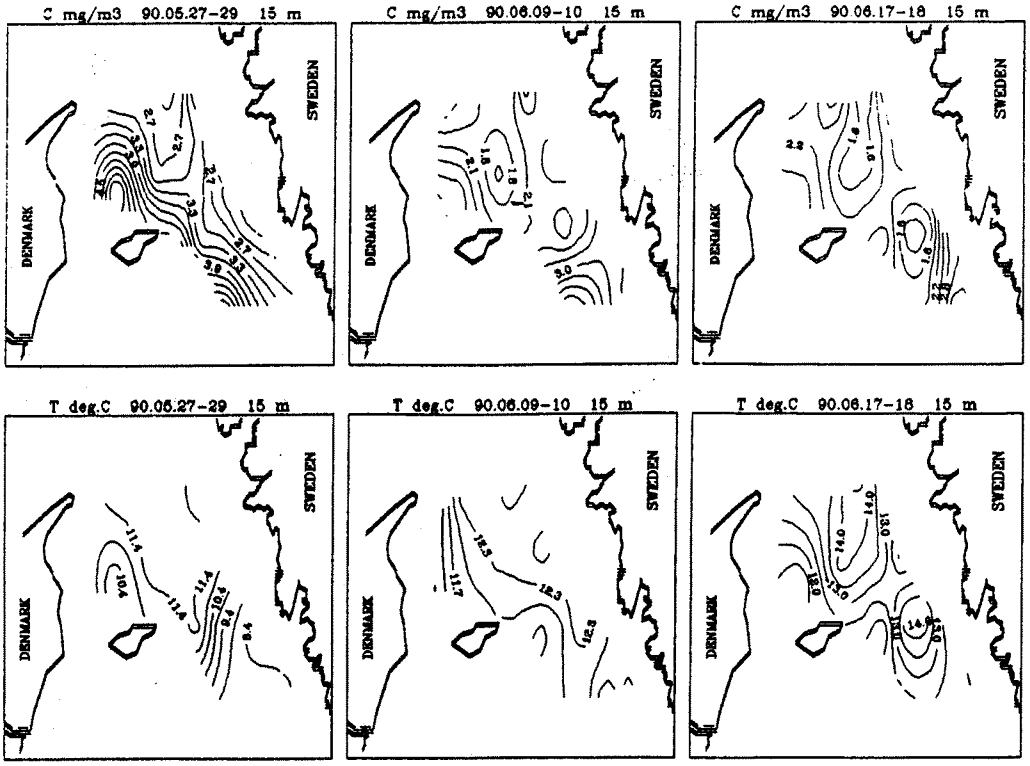

Fig. 10. The distributions of the chlorophyll concentration, C, and water temperature, T, at depth of 15 m according to data from three surveys in the Kattegat.

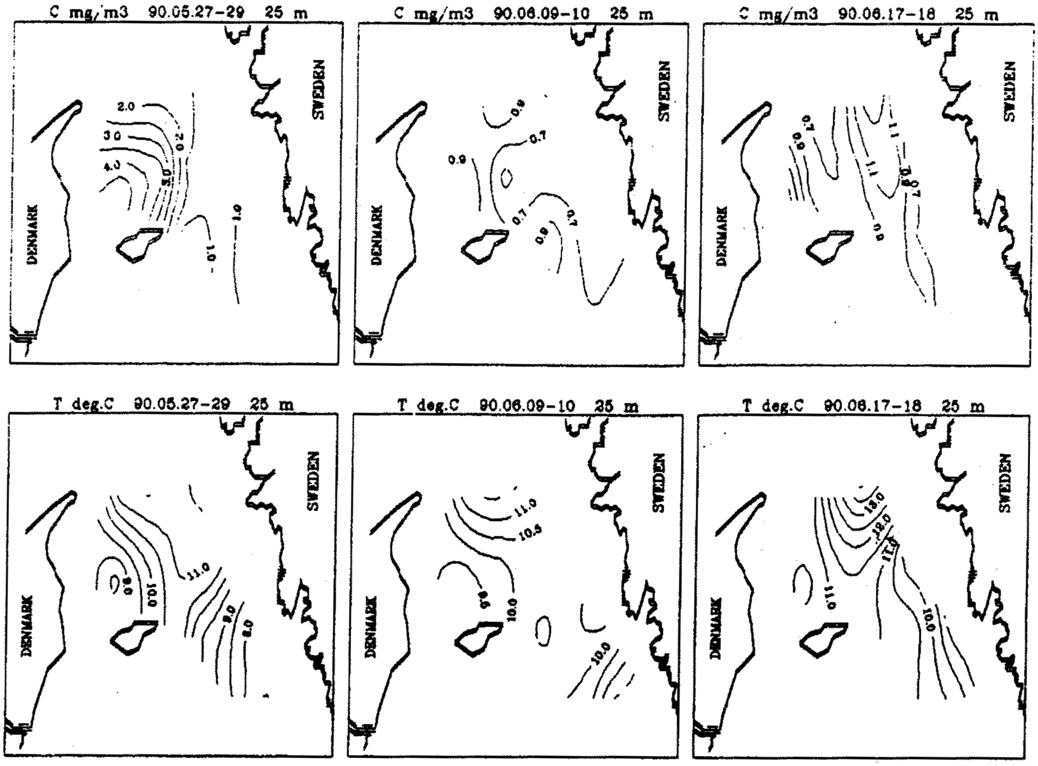

Fig. 11. The distributions of the chlorophyll concentration, C, and water temperature, T, at depth of 25 m according to data from three surveys in the Kattegat.

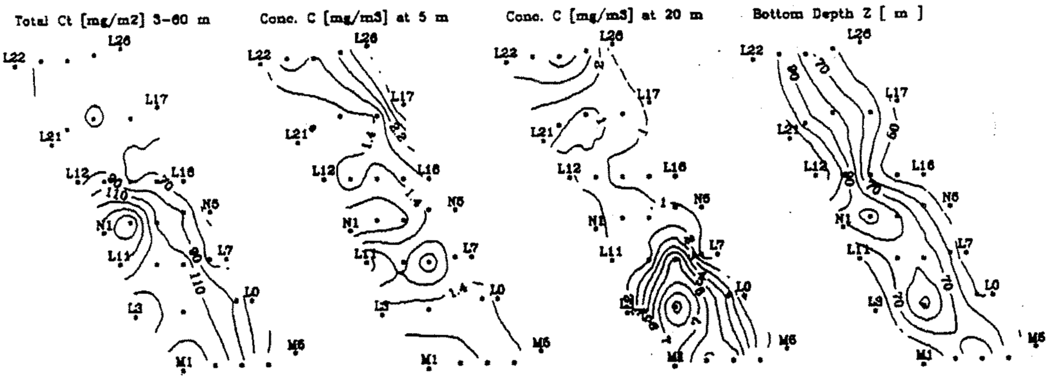

Fig. 12. The distribution of the total chlorophyll, Ct, the chlorophyll concentration, C, and the depth of bottom, Z, in frontal zone according to measurements at stations L, M, N in SKAGEX 4.

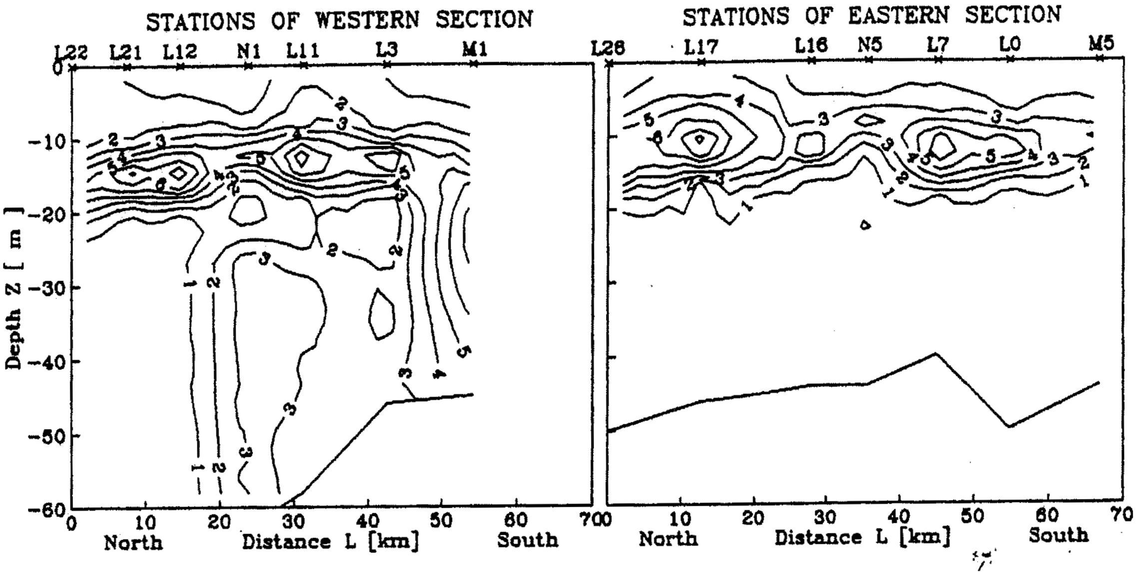

Fig. 13 The distributions of chlorophyll concentration, C mg m-3 at the western and eastern limits of frontal zone. Broken line shows bottom contour.

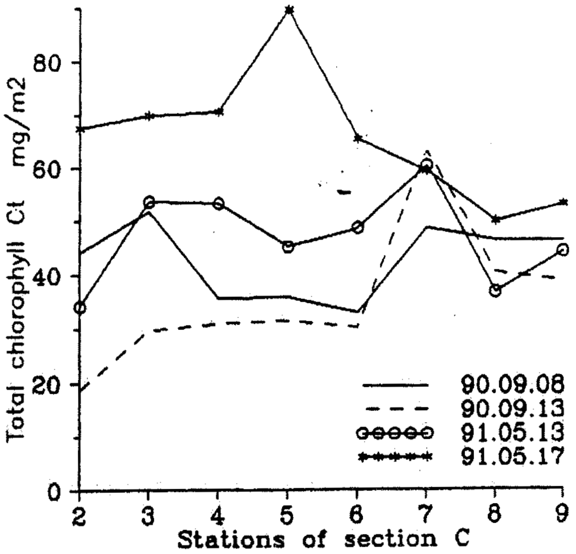

Fig. 14. The variability of total chlorophyll, Ct, along the section C on different dates. Ct was computed for depth range of 4-60 m.

Presentation no 12.

The unusual and unexpected variability of optical properties of water in the Skagerrak and the Kattegat.

by

G. S. Karabashev

THE UNUSUAL AND UNEXPECTED VARIABILITY OF OPTICAL PROPERTIES OF WATER IN THE SKAGERRAK AND THE KATTEGAT

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The general features of the variability of optical properties of sea water are known (Jerlov, 1976). But the amount of optical observations at sea is small and the diversity of factors effecting on optical properties of sea water is large. This raises hopes that the employment of a new technique even in a well studied area can help to discover an unknown phenomenon. This have been shown during three cycles of SKAGEX field activities in 1990-1991 when a multichannel submersible fluorometer (Karabashev, Khanaev, 1988) and a shipborne spectral transparency meter (Karabashev et al., 1987) have been used to collect data aboard the RV «Shelf» and «Lev Titov» in the Skagerrak and the Kattegat. The materials and methods of data collecting are described elsewhere in this volume. These data provided evidence that in some cases the fluorescence, turbidity or light attenuation in sea water behaved unusually. These cases are discussed in the present paper.

1. The spectra of the light attenuation coefficient.

A light beam is attenuated in sea water because of scattering by suspended particles and absorption by colored substances. the scattering-absorption relation varies in wide limits depending on water origin nevertheless attenuation spectrum of any water has the only minimum in the visible. On the red side of the minimum the attenuation rapidly increases with wave length of light due to absorption by «pure water» (Jerlov, 1976). on the opposite side the attenuation increases with decreasing wave length. The rate of increase is high when dissolved organic matter (DOM, or «Yellow substance» is abundant in sea water. Accumulation of particles (turbid water) yields «flat» spectra of light attenuation. As a rule the wave length dependence of light attenuation in sea water is structureless over the range from 300 to 450 nm (Jerlov, 1976).

This rule was broken by the attenuation spectra measures on four water samples collected in the Skagerrak at 10 m depth at southern sections A and S (see Karabashev et.al., this volume) during SKAGEX II in September 1990 (Fig.1). The maxima at 315-335 nm distinguished these spectra. We have not detected similar structures for water samples to the north of the sections A and S at depths from 0 to 250 m and at these sections but deeper than 10 m. Attenuation measurements in SKAGEX IV in May 1991 have not indicated the maxima in water samples from the Kattegat but the maxima have been detected in surface waters of the Baltic sea west of Bornholm.

The same type of maxima have been measured earlier in filtered water samples from surface microlayer of the Atlantic ocean at low and moderate latitudes (Karabashev, Kuleshov, 1990). There is no mechanism of light scattering which results in attenuation maxima over the UV spectral range. We admit that some dissolved organic substance of natural origin causes the UV attenuation maxima in sea water. Connection of the maxima with the surface waters indicates that this substance may be «Younger» than the «Yellow substance» causing background attenuation of UV light in the water. The location of waters exhibiting UV maxima in the Kattegat hints on their Baltic origin. If so these maxima can be used to label baltic waters penetration the kattegat.

2. Chlorophyll-turbidity relationship.

The phytoplankton is a main source of light scattering particles in waters of the open ocean. If the depth of the seasonal pycnocline is less than 50-70 m the phytoplankton accumulates nearly at this depth and suspended particles from dead phytoplankton sink slowly because of density stratification of water column. In average the particles remain at the same depth as living phytoplankton. This results in similarity of the chlorophyll fluorescence and turbidity vertical profiles except that turbidity maximum is not as strong relative to its background as maximum of chlorophyll fluorescence (Karabashev, 1987).

A different pattern has been observed at central stations for sections E and F during SKAGEX I (Fig. 2 and 3). Here moderate turbidity values were measured much deeper than corresponding values of chlorophyll fluorescence. The isoline of 75 arbitrary units clearly indicates a dive of moderate values for turbidity in Fig. 2 and 3. It is easy to see that chlorophyll accumulated below the thermocline in the middle of the Skagerrak and hence the source of light scattering particles was located in a layer where density of water did not change with depth. The particles were free to sink in this layer. The thermocline was deeper on both sides of the sections («doming» effect) and no anomalies in chlorophyll-turbidity relation occured here. Obviously location of a chlorophyll maximum is determined mainly by light energy and nutrients limiting phytoplankton growth. The first of the factors is independent from density or temperature of water. This provides relative stability of the depth of a chlorophyll maximum in spite of changing depth of a pycnocline due to «doming» specific to the Skagerrak. The similarity of turbidity distributions at sections E and F makes probable that a «ribbon» of more turbid water existed in the Skagerrak during SKAGEX I. The «ribbon» stretched along the axis of the strait being 50-60 m thick and several kilometers wide. If turbidity «ribbon» occures in the Skagerrak as regularly as «doming» one can assume that modern sediments along the axis of the

Skagerrak differ from sediments on both sides of the latter because transformation of particles in sea water depends on their sinking rate.

3. Chlorophyll maxima in aphotic layer.

Recently chlorophyll maxima associated with viable phytoplankton have been discovered in the aphotic layer of the Baltic sea (Karabashev, Khanaev, 1991). The maxima of this kind in the straits have not been reported before. During SKAGEX I we have observed maximum of chlorophyll fluorescence at station D3 at a depth of 200 m. It was several times brighter than the background fluorescence below or above this depth. The examples of similar maxima have been obtained in SKAGEX II at stations E1-4 (Fig.4). A fine structure was abundant in near shore profiles during the first series of observations but it disappeared afterwards. A coarse structure of the maxima had common features at neighbour stations or at one and the same station in both series of measurements. These features indicate that the shape of aphotic maxima of chlorophyll fluorescence depended on water movements. At present it is difficult to explain the origin of the maxima and their role in biological productivity of the Skagerrak.

4. Accumulation of chlorophyll below thermocline in the Kattegat.

The chlorophyll profiles of a particular shape have been measured at several locations in the Kattegat during SKAGEX I and IV. The profiles have maxima in the thermocline as usual but below it chlorophyll fluorescence increased again from background level to the values comparable with that of thermocline maximum. These values remained almost constant until sea bottom. The profiles of the kind have been discovered at western stations for section B during SKAGEX I and in the east of northern Kattegat during SKAGEX IV (Fig.5).

Accumulation of chlorophyll between thermocline and the bottom is a local phenomenon indicating a possibility of deep water algal blooms in the Kattegat. In SKAGEX IV the bloom was associated with local maximum of nitrates. The minimum of chlorophyll at depth of 20-25 m provides evidence that there is no connection between such a bloom and chlorophyll in the upper maximum. The latter covers a deep water bloom that leads to underestimation of total chlorophyll by remote sensing or by insufficient water sampling. The accumulation of phytoplankton under the thermocline have also been observed by other participants of SKAGEX I at the western stations of section B (Danielssen et al., 1991).

The results presented in the study are preliminary. It is necessary to quantify the effects and phenomena on the basis of further investigation.

References

Danielssen D.S., L. Davidsson, L. Edler, E. Fogelquist, S. Fonselius, L. Føyn, L. Hernroth, B. Hakansson, I. Olsson and E. Svendsen. 1991. SKAGEX: some preliminary results. ICES, C.M. 1991/C:2, Hydrography Comm., Ref: E, 14p.

Jerlov N.G. 1976. Marine Optics, Elsevier, Amsterdam, 230p.

Karabashev G.S. 1987. Fluorescence in the ocean. Gidrometeoizdat, Leningrad, 200p, (in Russian).

Karabashev G.S., A.F. Kuleshov, A.A. Timoshevski, J.F. Khabeta. 1987. Shipborn spectral transmissiometer with data acquisition system. Okeanologia, 27, 1028-1034 (in Russian).

Karabashev G.S., S.A. Khanaev. 1988. Submersible multichannel fluorometer for marine studies. Zhurnal Prikladnoy Spektroskopii, 49, 515-518 (in Russian).

Karabshev G.S., A.F. Kuleshov. 1990. Spectral dependence for the light attenuation coefficient in waters of a surface microlayer of the ocean. Doklady Akademii Nauk SSSR, 310, 1228-1230 (in Russian).

Karabashev G.S., S.A. Khanaev. 1991. The maxima of fluorescence of chlorophyll in the aphotic layer of the Baltic Sea. Okeanologia, 31, 430-433 (in Russian).

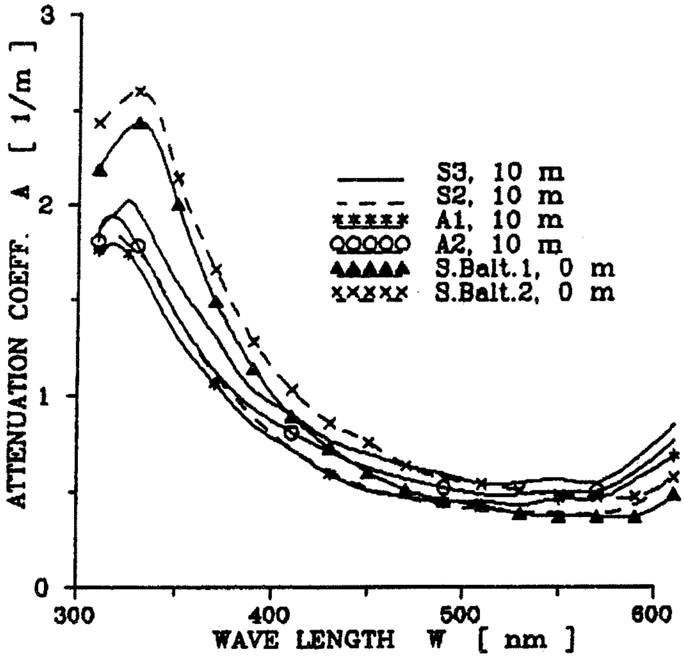

Fig. 1. The spectra of light attenuation coefficient A for water samples collected at stations of sections A and S in the Kattegat (September 1990) and in the south-western Baltic sea (May 1991).

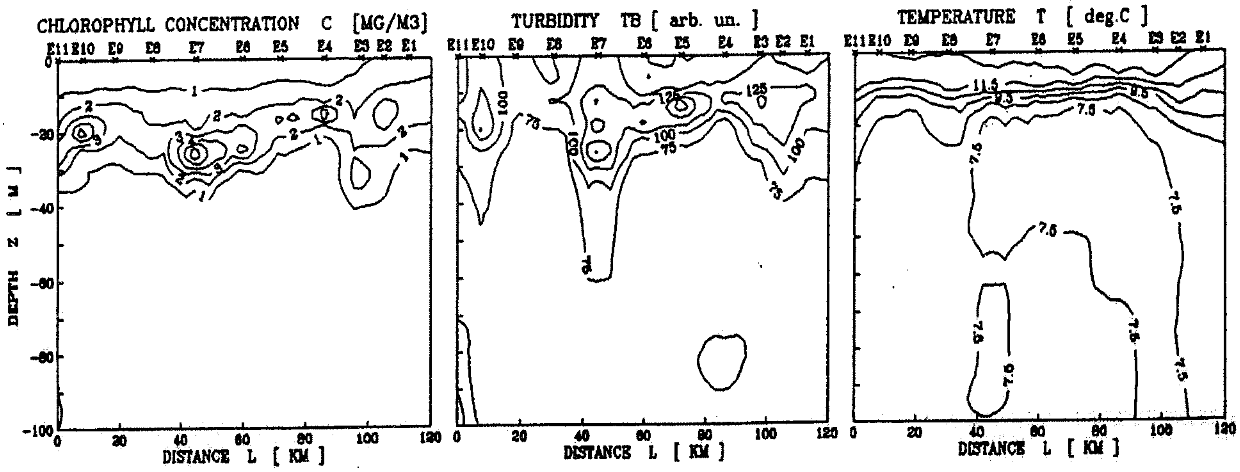

Fig. 2. The distributions of Chlorophyll Concentration, Turbidity and Temperature of sea water for transect E in the Skagerrak observed during SKAGEX 1.

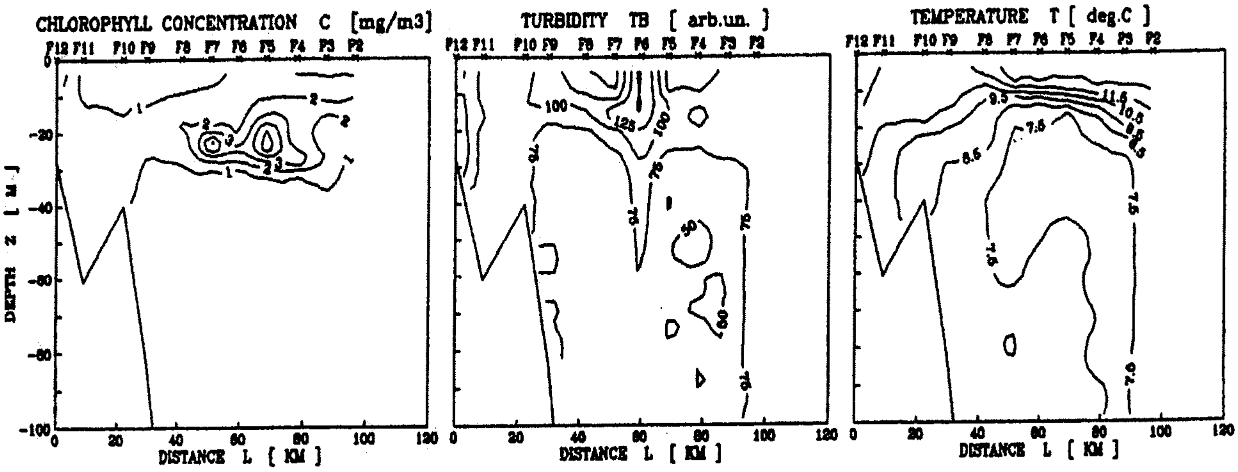

Fig. 3. The distributions of Chlorophyll Concentration, Turbidity and Temperature of sea water for transect F in the Skagerrak observed during SKAGEX 1.

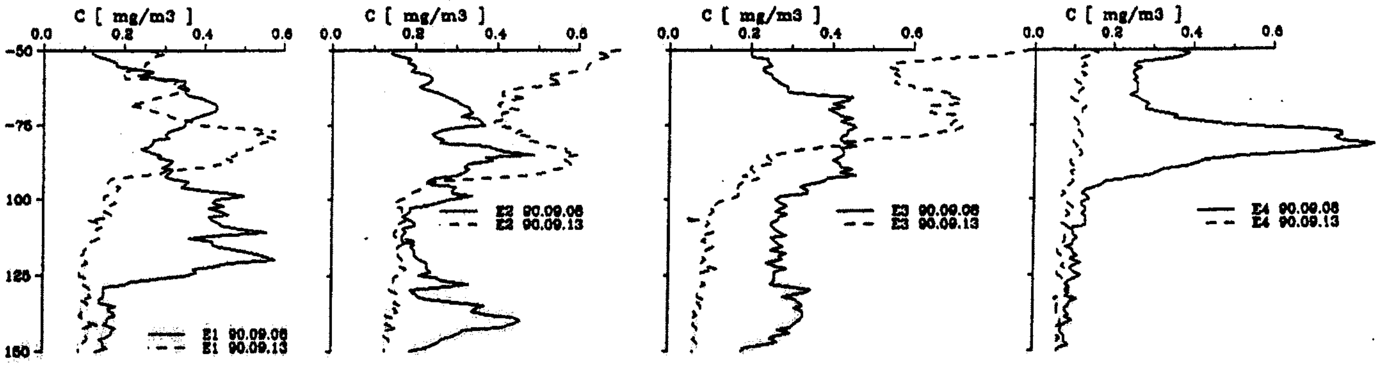

Fig. 4. The profiles of chlorophyll concentration C at northern stations of transect E in the Skagerrak in September 1990.

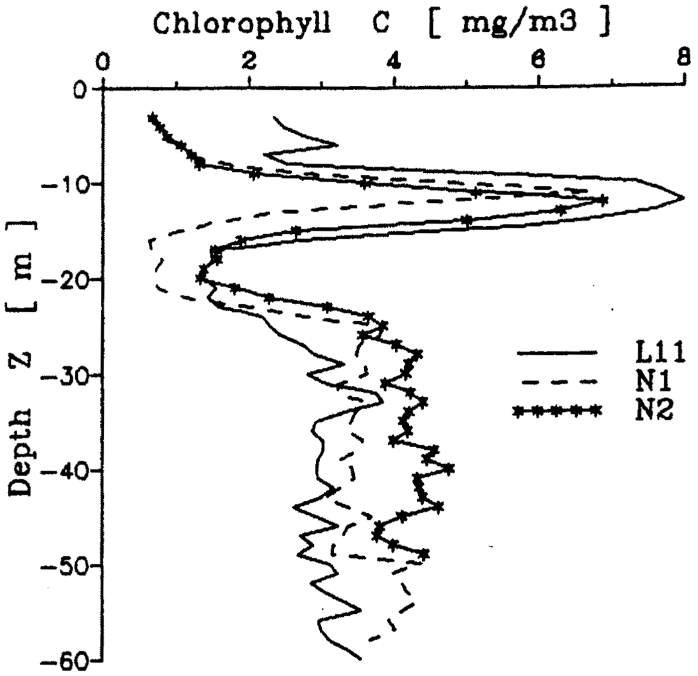

Fig. 5. The profiles of chlorophyll concentration C at stations L11, N1 and N2 measured in May 1991.

Presentation no 13.

Zooplankton near the drifting buoy in Skagerrak in June 1990.

by

A. Korshenko and E. Yastrebov

ZOOPLANKTON NEAR THE DRIFTING BUOY IN SKAGERRAK IN JUNE 1990

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ABSTRACT

Zooplankton temporal variations in 0-10, 10-20 and 20-50 m layers were studied near the drifting buoy placed in the eastern part of Central Skagerrak from 10 to 18 June 1990. The buoy had a sail about 1 meter depth and served as a marker for the upper water layer movement. First week the buoy slowly moved in a low salinity lens towards the cape Skagen and then was caught by the Jutland current and drifted with very high speed to the north parallel to the Swedish coast. In general zooplankton had a similar specific and age stages composition during the experiment. The dominant forms were calanoids, mainly Pseudocalanus, Paracalanus and Calanus. In terms of biomass, calanoids Chaetognatha, gelatinous Appendicularia, and Cnidaria dominated inthe zooplankton. In the lens zooplankton was highly vertically stratified. Many forms and age stages strongly decreased in abundance below the pynocline near the 10 m depth and below 20 m depth. Temporal variations in abundance depended mainly on internal waves at the pycnocline. Changes in zooplankton between the lens of low salinity water and the Jutland current were relatively small end clearly expressed inthe surface layer. The dominant copepods slightly increased in their abundance with exception of nauplii and first copepodites which numerically drastically decreased. It was suggested, that intensive spawning of Pseudocalanus and Calanus in/below low salinity water took place in the Central Skagerrak. The similarity in zooplankton structure over the eastern Skagerrak during our experiment seemed to be a result of mobility of surface water, intensive mixture processes and low Baltic sea influence. Organisms transport with the parcels of low salinity water from central part of Skagerrak across the frontal zone to the Jutland current and then to the coastal area, seem to be a usual process.

INTRODUCTION

The first part of the large international multi-ship experiment in the Skagerrak area SKAGEX-I was carried out in the period of May-June 1990. The great number of data through the synoptic observations was collected (Danielssen et al., 1992). The aims were to identify the different water masses and their origin, interrelations and variations over time as well as chemical and biological processes dependent on water circulation, in particular harmful algal blooms. Zooplankton studies were made at some obligatory transects during the experiment by many ships and as a voluntary parameter in the central part of Skagerrak in June 10-18 aboard the RV "Lev Titov". The aim of the voluntary investigation was to estimate the temporal variations of mesozooplankton community in upper water layers and its relation with the horizontal and vertical hydrological structure.

MATERIAL AND METHODS

During the SKAGEX-I hydrological, hydrochemical and zooplankton studies were carried out aboard the RV "Lev Titov" from 10th to 18th of June 1990 near the drifting buoy placed in the eastern part of Central Skagerrak (Fig. 1). The buoy had a sail at about 1 meter depth and served as marker of the upper water movement. Standard parameters (salinity, temperature, oxygen, pH, NO_2, NO_3, PO_4, Si) were measured four times a day at 5 and 11 a.m. and 5 and11 p.m. of local time at the depth 0, 5, 10, 20, 30 and 50 m (Mamaev et al., 1993).

The mesozooplankton was sampled two times a day at 11 a.m. and 11 p.m. of local time. A Juday net with mesh size of 180 µm was used for vertical hauls of the water layers 0-8 (10) m, 8(10)-20 and 20-50 m. At the depth 8-10 m was a maximum of salinity gradient at the beginning of the experiment. Samples were preserved in 4% buffered formalin.

For assessment of the abundance of different zooplankton not less than 100 specimens from the few most abundant groups and not less than 500-600 specimens per sample totally were counted in Bogorov´s chamber under binocular microscope. This method provided near 20% of estimated errors for the main groups (Kozova, Melnik, 1978). The number of some highly aggregated samples forms like Oithona spp. and larvae Ophiuroidea were estimated very approximately. Adult Calanus finmarchicus and C. Helgolandicus as well as copepodite stages of Acartia species and Centropages hamatus & typicus were not separated.

A significant part of small zooplankton was lost, because near 50% of calanoids with length less 0.8 mm can pass through the sieve with mesh size of 180 µm (Timonin, 1983). So the abundance of all smallest forms represented in Table 1 was estimated very approximately. But we took the abundance and length of all forms for biomass determination which were performed by the counting method using relationship between body length and wet weight (Recommendations, 1985, Svetlichny, 1983). Individual body length and wet weight of organisms from our samples is presented in Table 2. After Baltic Marine Biologists (Recommendations, 1985) we suggested 1 mm^3 of body volume equal to 1 mg wet weight. Counting mesozooplankton biomass should be less than original due to the lack of smallest forms and was significantly less than sexton volume, because the great number of phytoplankton (Coscinodiscus), mucus and organic particles were in the water during our investigation. Using counting method we estimated mesozooplankton biomass for one of our stations S-9 (three layers) and upper layer of St.C-3. For the latter specific determination and counting were made by the Polish Sorting Centre (Table 5).

RESULTS

Hydrography

The first six days of the experiment the drifter slowly moved to the south towards Skagen cape with the complicated curve track sometimes with small loops [Fig. 1 and (Mamaew et al., 1993)]. The surface salinity was less than 24-25‰. At that period big pulsations of salinity were at 10 m depth. At the surface and 5 m depth salinity was quite stable.

In daytime of June 16 the buoy changed the swimming direction towards the Swedish coast and a day later to the north. The drifting speed was very high. At 10 m depth level salinity stabilized near 32‰ but at the surface and 5 m depth a significant increase up to 28-32‰ occured. The drastic changes up to 4‰, during 6 hours was recorded at the 5 m depth. The deep water had a salinity more than 34‰ from the 20 m depth.

Zooplankton community composition

Near 70 different taxonomic groups and age stages were found in the mesozooplankton community. The dominant forms were adult and copepodite stages of 16 species of calanoid copepods (Table 3), Cyclopoida (Oithona spp.), Appendicularia and larvae of bottom invertebrates Ophiuroidea, Bivalvia and Gastropoda (Table 1). In several samples the sufficient part of total number and especially of total biomass of zooplankton were formed by gelatinous forms, mainly Hydromedusae and Scyphomedusae.

Regarding the calanoids the most abundant species were from genera Pseudocalanus, Paracalanus and Calanus. Subdominant forms were Acartia clausi and two species of Centropages. Species like Scolecithricella minor, Candacia cf.armata, Metridia lucens or Euchaeta sp. occurred in samples very seldom.

Vertical distribution

The specific composition of zooplankton community was nearly the same at the surface and down to 50 m depth. The vertical distribution of zooplankton showed a sharp decrease in abundance of organisms with the depth especially below 20 m (Fig. 2). Especially big fall of abundance up to 8-31 times was in Pseudocalanus population. In many cases (e.g. stages of the genera Pseudocalanus, Paracalanus and Acartia) the differences between medium and deep layers had a statistical significance on a 95% confidence level (Table 1). For few groups (Hydrozoa, Scyphozoa and Paracalanus) a most significant decreasing of abundance with depth occurred between upper and medium layers. The smallest changes with depth were found in Calanus populations and for adults of Centropages typicus as well as Chaetognatha.

Temporal variations

The structure of mesozooplankton community near the drifting buoy during 8 days of experiment was relatively stable. We did not find changes in the specific composition of zooplankton but only in abundance of some dominant forms and age stages.

In the upper layer 0-10 m above the halocline the numerous copepodites and adults of Pseudocalanusan had no significant trends (Fig. 3a, b). Only in the last two days after a big salinity change in the upper layer, an obvious decreasing of the youngest copepodites and nauplii Pseudocalanus was recorded. We tested the significance of differences in plankton numbers before and after a salinity front which was passed bythe buoy in the morning 16 June simultaneously with a sharp change of swimming direction (Table 4). After the front the reduction of Pseudocalanus nauplii abundance was significant in all layers as well as a number of Calanus eggs in contrast to the oldest copepodites of these species (Fig. 3c). A significant change was also recorded for several other group including Chaetognatha, Pondon sp., Scyphomedusae (Fig. 3c). In the medium layer below the halocline (10-20 m) the number of oldest stages of Pseudocalanus slightly increased after passing the salinity front with the great decrease of nauplii and COP I at the same time. A moderate increase in abundance was recorded also in Acartia and Calanus populations except Calanus eggs. Statistically supported changes were in number of Chaetognatha and Hydromedusae.

In the deep water down to 50 m Pseudocalanus groups were more abundant after June 16, as well as Chaetognatha, Abundance of Calanus stages was quite stable. The copepods´ nauplii and eggs strongly decreased similar to upper layers.

Biomass determination

It seems very important to compare the abundance and biomass determination at the obligatory station and that according to our voluntary programme. On the station S-9 in layer 0-10 m the main part of total biomass of zooplankton was formed by copepods Calanus and Pseudocalanus, and gelatinous forms of Appendicularia and Cnidaria (Table 5). In the medium layer 11-20 m the calanoids biomass decreased up to 4 times, while that of other forms was similar to the upper layer. At the station C-3 (0-20 m) situated near shore calanus abundance and biomass were practically the same as that of medium level at the st. S-9 (11-20 m). For other forms the sharp differences up to 4 times were recorded in comparison with upper layer and more than 3 times with medium layer.

In the deep water the calanoids Calanus and Pseudocalanus were dominant in terms of biomass. The organisms from genera Acartia, Paracalanus and Centropages were very seldom and had no importance. Regarding other zooplankton Chaetognatha had a big part of the total biomass. These organisms were less abundant than in upper layers but significantly larger in size. Other subsurface dominant like medusae or Appendicularia practically disappeared from zooplankton community.

DISCUSSION

During our drifting experiment the buoy had the track as expected from the features of the main currents and surface water masses (Fonselius, 1989, Danielssen et al., 1992). With parcel of water belonging to a surface lens of low salinity masses the buoy had a slow and meandering movement to south. The lens occupied the eastern part above the "dome" ["ridge" in (Danielssen et al., 1992)] area of Central Skagerrak and had the borders formed by main currents. The thickness of the lens was up to 10 m in the centre and slowly decreased towards the ends. It seems that internal waves were common in the pycnocline in the down side of the lens. The waves brought the big changes in salinity near buoy in a short time (Fig. 1).

At June 16 the water parcel together with the buoy was caught by the Jutland Current. After that the buoy made a typical way as two others from the RV "Argos" at the same period in June 10-18 1990. After the frontal zone between the low salinity lens and the Jutland Current the internal waves together with the pycnocline lifted to 5 m depth and caused a big salinity jump. It was supposed that low salinity parcels from Central Skagerrak mixed and disappeared in the Jutland water with more or less visible decrease of surface salinity.

Mesozooplankton community in the whole investigated area had a similar taxonomic composition. The obvious vertical and horizontal variabilities in abundance of dominant forms seems to reflect the spatial hydrological structure. Very abundant plankton near surface drastically decreased below pycnocline approximately at 10 m depth in the lens area. Although the borders between the medium and deep layers were not distinct, the great decrease of organisms with depth was obvious. Only few groups were more or less independent from depth, mainly typical sea forms Calanus and Chaetognatha. New forms or species did not appeared in deep water except Microcalanus pusillus.

The largest station to station variations in plankters abundance were in surface 0-10 m and medium 10-20 m layers. This seems to be the combined result of internal waves in the pycnocline and sampling technique. In time when pycnocline was lifted due to internal waves close to surface, the plankton net caught some part of below pycnocline community. After a short time the pycnocline depth increased and net brought plankton only from the upper layer. Taking into account the sharp differences between the layers in plankton abundance, one can suggest that alternations in "pure" and "mixed" samples caused the sufficient changes in organisms abundance. Significantly higher variability of abundance in two upper layers influenced the width of confidence intervals (Fig. 2).

A transition from the lens area to Jutland Current water is generally insignificantly reflected in zooplankton structure on the contrary to the nutrients in deep water which significantly decreased after frontal zone (Mamaev et al., 1993). The dominant copepods Calanus and Pseudocalanus increased a little in Jutland waters in all three layers. The opposite situation was with Pseudocalanus nauplii, copepodites 1 stage and Calanus eggs. The decrease was very large and statistically significant. It is possible to suggest, that intensive spawning of Pseudocalanus and Calanus in or under the low salinity waters in Central Skagerrak took place. In the Baltic Sea the spring spawning of deep-water Pseudocalanus in the subsurface layer and near the low-salinity lenses in estuarine frontal zone in the coastal area were recorded (Sidrevics, 1984, Korshenko, Gupalo, 1988, 1991).

The origin of the Calanus populations near the Swedish coast was not clear and the long-distant transport from the North Sea to the Swedish coast was suggested (Lindhal, Henroth, 1988). But in some cases Calanus females with eggs and nauplii in the Kattegat and north of Denmark in early spring occurred (Eriksson, 1973, cit. Lindahl, Hernroth, 1988). The latter did not controvert the possibility of relatively active Calanus spawning in the Central Skagerrak according to our data.

Except the copepods age stages, the substantial increase in abundance of Chaetognatha in the Jutland Current was the only important mark of differences between two water masses (Table 4). All other forms showed a relatively slight preference to the Central or Jutland waters. The high level of similarity in zooplankton community at the investigated area seemed to be the result of constant mixture processes in upper layer of Skagerrak due to surface water mobility from wind directions and speed (Fonselius, 1989).

It is important to note nearly the complete lack in our samples of typical Baltic species which could be used as indicator of the Baltic Sea influence. Even at the station S-9 situated close to the Swedish coast we did not find Baltic species. At the same time at the nearest st. C-3 few specimens of Acartia longiremis and Temora longicornis were recorded. We can suggest that if the low salinity waters in Central Skagerrak originated from the Baltic Sea, they lived in Kattegat long time before and that period of time is sufficient for the extinction of typical Baltic species. If the brackish waters were the result of Scandinavian rivers discharge, they only pick up a plankton inhabitants from surroundings. In both cases it does not controvert the hydrological results of SKAGEX-I and previous investigations (Fonselius, 1989). The small influence of Baltic waters on salinity and nutrients was also shown during our investigation and it was suggested that relatively fresh Norwegian Coastal water covered the big part of Skagerrak (Danielssen et al., 1992).

On the basis of our data the temporal changes in zooplankton community near the drifting buoy generally was according to the following scheme:

1. Highly vertically stratified and stable community was drifting in a low salinity lens in the Central Skagerrak; the high level of plankton variability in samples from upper two layers mainly was due to the mixing of surface and subsurface waters as a result of internal waves at the pycnocline;

2. Slight changes in community occurred mainly in the surface layer after the frontal zone when parcels of surface low salinity waters passed across the border of the Jutland Current, mixed with surrounding water and disappeared;

3. The relatively stable community occurred in the Jutland water with more soft vertical differences and without visible influence of the Baltic Sea zooplankton despite the position close to the Swedish coast.

Until further data on involving the parcels of low salinity water fromthe Central Skagerrak to the Jutland Current, we can only speculate that this mechanism should be the usual type of water transport with particles and organisms from the ridge area above the pycnocline to the coastal part. This was suggested for some toxic algae blooms situations (Richardson, 1989). It seems that the bloom started at the pycnocline, offshore in the Central Skagerrak and later spread to the coast. Our results of complex experiment near the drifting buoy showed the possibility of such kind of particles transport. More detailed dynamical investigations on the border between dome area/Jutland Current and Jutland/Baltic current is needed for a further research of a plankton development in Skagerrak.

REFERENCES

Danielssen, D.S., Edler, L., Fonselius, S., Hernroth, L., Ostrowski, M., Svendsen, E. and Talpsepp, L. 1992. Oceanographic variability in Skagerrak/Northern Kattegat, May-June, 1990 - 1992, 47 pp (in press).

Fonselius, S. 1989. Hydrographic variabilities in the Skagerrak surface water. ICES CM/C:35, 19 pp.

Korshenko, A.N. and Gupalo, E.Y. 1988. Coastal fronts and spring reproduction of calanoids in the Baltic Sea. 16 conference of the Baltic Oceanographers, Kiel, 5-9 September 1988. Kiel: CBO, 49 pp

Korshenko, A.N. and Gupalo, E.Y. 1991. Plankton population in the frontal zone near the mouth of Kurshy Bay, Baltic Sea. In: Phytoplankton studies in the monitoring of the seas, with reference to the Baltic Sea. Moscow Hydrometeoizdat, p. 295-305. (Russ./res.Engl.).

Kozova, O.M. and Melnik, N.G. 1978. The Instruction for the plankton samples treatment by counting method. Irkutsk, 52 pp. (Russ.).

Lindahl, O. and Hernroth, L. 1988. Large-scale and long-term variations in the zooplankton community of the Gullmar fjord, Sweden, in relation to advective processes. Mar. Ecol. Progress Ser., 43 : 161-171.

Mamaev, A., Kirjanov, S. and Ivanov, D. Characteristics of the surface water in the Eastern Skagerrak in June 1990 (in press).

Anon. 1985. Recommendations on methods for marine biological assessment.

The Baltic Marine Biologist. Publ. No. 10, Ed. by L. Hernroth. 32 pp.

Richardson, K. 1989. Phytoplankton distribution and activity in the Skagerrak: a review. ICES CM/L:24, 15 pp.

Sidrevics, L.L. 1984. The main regularities of zooplankton distribution in open areas SE, E and NE Baltic. In: Biological productivity of Baltic Sea. Moscow 2 : 187-204. (Russ.).

Timonin, A. G. 1983. The closing nets for vertical hauls. In: Modern methods for the quantitative assessment of distribution of marine mesozooplankton. Moscow Science, p. 158-173. (Russ.).

Table 1. Means and 95% confidence intervals of abundans (ind. per m^3) of main zooplankton groups in the three upper layers near the drifting buoy in the Central Skagerrak, 10 - 18. 06. 1990.

	Group	0 - 10 m		10 - 20 m		20 - 50 m
	Pseudocalanus minutus					
1.	Female	1017.4±365.3		1047.5±952.3		124.8±76.1
2.	Male	782.2±311.8		414.1±390.2		38.8±76.1
3.	COP 4-5 female	803.2±221.7		667.7±615.0		34.7±33.4
4.	COP 4-5 male	755.0±261.6		677.9±562.3	S	36.8±30.5
5.	COP 3	788.6±273.2		724.5±812.2		43.3±44.8
6.	COP 2	987.8±320.3		506.0±688.2		16.2±17.4
7.	COP 1	544.2±227.6	S	193.1±233.9		16.2±17.4
8.	Nauplii	650.3±304.3		388.7±148.6	S	73.9±35.4
	Paracalanus parvus					
9.	Female	641.6±140.6	S	153.8±110.4	S	15.1±9.9
10.	Male	379.5±109.2	S	75.8±52.5	S	9.7±8.3
11.	COP 4-5	870.0±209.5	S	140.6±104.2	S	21.7±15.0
12.	COP 3	643.9±201.8	S	64.8±27.8	S	17.2±10.3
	Acartia clausi					
13.	Female	165.3±54.8		143.1±54.8	S	56.0±48.1
14.	Male	296.0±185.0	S	97.3±72.9	S	11.7±14.6
15.	COP 4-5	382.2±105.0		388.0±384.4		28.1±26.6
16.	COP 3	136.8±77.0		76.9±54.2	S	8.4±9.9
17.	COP 2	91.7±42.6	S	32.5±32.6		4.2±4.9
18.	COP 1	19.8±18.2	S	1.3±2.9		1.3±2.1
	Calanus finmarchicus & Calanus helgolandicus					
19.	Female	9.7±14.5		14.1±17.4		16.7±9.8
20.	Male	9.3±18.4		1.2±2.6		2.3±5.0
21.	COP 4-5	256.1±84.2		293.3±247.5		66.8±25.4
22.	COP 3	232.3±72.8		173.0±110.6	S	16.8±11.3
23.	COP 2	124.3±44.7		78.3±37.5	S	14.1±14.6
24.	COP 1	54.1±35.2		22.7±16.4	S	6.7±10.2
25.	Nauplii	5.5±6.9		2.2±3.2		3.4±4.4
26.	Ova	271.3±304.1		331.9±156.2	S	102.2±57.7
	Centropages hamatus					
27.	Female	16.4±14.5		51.8±36.8	S	5.7±5.8
28.	Male	61.0±24.8		51.4±31.3	S	9.4±10.2
	Centropages typicus					
29.	Female	24.1±19.4		23.2±33.9		2.9±4.2
30.	Male	4.2±5.1		9.6±17.9		0.2±0.4
	Centropages spp.					
31.	COP 4-5	111.5±49.0		78.7±96.4		10.9±12.7
32.	COP 3	131.5±49.7		115.1±174.5		15.0±21.7
33.	COP 2	122.9±61.7	S	44.2±48.5	S	4.7±5.6
34.	**Oithona spp.*	1782.6±591.3	S	3369.1±983.7	S	714.4±261.3
35.	*Evadne nordmanni*	562.6±280.0		965.4±583.2	S	215.1±128.3
36.	*Podon spp.*	69.0±43.9		48.4±44.0		4.6±3.9
37.	**Appendicularia*	964.9±266.4	S	173.5±113.1	S	26.5±21.0
38.	*Scyphozoa*	290.9±74.5	S	29.0±35.9		9.6±9.4
39.	*Hydrozoa*	267.7±88.1	S	25.2±19.9	S	4.1±2.5
40.	*Cirripedia* larvae	65.5±30.8		64.4±53.1	S	11.4±12.4
41.	*Bivalvia* larvae	1965.1±469.7		1342.2±989.6	S	105.8±103.5
42.	*Gastropoda* larvae	750.4±173.8	S	286.3±183.9	S	40.8±44.5
43.	*Plychaeta* larvae	95.9±43.8		147.4±49.5	S	31.4±10.4
44.	**Ophiuroidea* larvae	879.4±583.1		317.8±192.4	S	46.0±34.1
45.	*Chaetognatha*	28.3±21.6		31.3±37.5		8.8±9.7
46.	*Ostracoda*	43.4±47.9		17.6±21.5		2.0±2.2

* - abundance of these forms assessed very approximatelly because of high level of clumping in aggregates.

S - letter S indicates a statistically significant difference between means of two neighboring layers on a 0.05 Sign. level.

Table 2. Average length and wet weight of main zooplankton groups.

Group	Number of specimens	Length mm	Kl/Formula*	Weight mg	BMB** mg
Pseudocalanus minutus					
Female	74	1.26	2.90	0.058	0.060
Male	22	1.01	3.51	0.036	0.050
COP 4-5 female	70	0.92		0.023	0.035
COP 4-5 male	67	0.93		0.024	0.035
COP 3	46	0.71		0.021	0.012
COP 2	35	0.58		0.017	0.012
COP 1	13	0.50		0.015	0.012
Nauplii	28	0.39		0.019	
Paracalanus parvus					
Female	43	0.84	3.91	0.022	
Male	31	0.89	3.43	0.025	
COP 4-5	54	0.66		0.011	
COP 3	12	0.55		0.011	
Acartia clausi					
Female	31	1.13	2.86	0.042	
Male	12	1.06	2.74	0.040	
COP 4-5	27	0.86		0.017	
COP 3	7	0.63		0.012	
COP 2	5	0.56		0.007	
Calanus spp.					
Female	5	2.98	2.51	0.846	
Male	1	2.88	2.74	0.745	
COP 4-5	49	2.08		0.283	
COP 3	48	1.49		0.103	
COP 2	26	1.12		0.046	
COP 1	8	0.93		0.015	
Nauplii	6	0.49		0.024	
Ova	62	0.66	2/3 Π R3	0.071	
Centropages hamatus					
Female	14	1.38	3.49	0.094	0.070
Male	18	1.22	3.05	0.053	0.040
Centropages typicus					
Female	10	1.68	3.26	0.155	
Male	8	1.61	3.12	0.135	
Centropages spp . COP 4-5	21	0.97		0.025	0.015
Oithona spp.	105	0.78	1.91	0.009	
Evadne nordmanni	44	0.69	1/3LHh	0.052	0.030
Podon sp.	6	0.59	1/3LHh	0.045	0.025
Appendicularia	41	1.91	2/3LHh	0.067	
Scyphozoa	14	0.82	2/3LHh	0.223	
Hydrozoa	22	0.90	1/3LHh	0.103	
Cirripedia larvae	12	0.41	1/3LHh	0.015	
Bivalvia larvae	48	0.33	1/3LHh	0.010	
Gastropoda larvae	14	0.29	2/3LHh	0.014	
Polychaeta larvae	47	0.92	LHh	0.042	
Ophiuroidea larvae	85	0.19	1/3LHh	0.003	
Chaetogonatha	23	5.59	2/3LHh	0.752	0.250
Ostracoda	17	0.56	1/3LHh	0.012	

* for Copepoda coefficient K of equation W = Kl x 10 -2 x L3 was taken from L. S. Svetlichny (1983), for all other groups we used equation W = KLHh, where L = total length, Hh = width in both dorso-ventral and lateral directions, K= approximate coefficient.

** from Anon (1985)

Table 3. Calanoida species from Central Eastern Skagerrak on 10 - 18 June 1990.

1. *Centropages hamatus* Lilljeborg
2. *Centropages typicus* Kroyer
3. *Temora longicornis* Muller
4. *Metrida lucens* Boeck
5. *Candacia cf. armata* (Boeck)
6. *Acartia clusi* Giesbrecht
7. *Acartia bifilosa* Giesbrecht
8. *Acartia longiremis* (Lilljeborg)
9. *Acartia sp.*
10. *Scolecithricella minor* (Brady)
11. *Calanus finmarchicus* (Gunner)
12. *Calanus helgolandicus* (Claus)
13. *Paracalanus parvus* (Claus)
14. *Psedocalanus minutus* (Kroyer)
15. *Microcalanus pusillus* (G. O. Sars)
16. *Eiuchaeta sp.*

Table 4. Mean abundance ind. per m^3 of zooplankton in three layers before (B) and after (A) a salinity frontal zone in the upper layere was passed by the buoy in the morning of June 16. 1990.

Group/Layer	0 - 10 m			10 - 20 m			20 - 50 m		
	B		A	B		A	B		A
Psedocalanus minutus									
Female	1035		982	723		1939	72		153
Male	815		716	385		493	12		38
COP 4-5 female	803		804	610		824	12	S	81
COP 4-5 male	726		814	538		1061	9	S	66
COP 3	793		780	581		1117	13	S	47
COP 2	1118		728	567		339	9		19
COP 1	776	S	81	244		54	9		7
Nauplii	929	S	93	462	S	103	83	S	23
Paracalanus parvus									
Female	703		517	177		90	20		5
Male	398		342	86		48	11		6
COP 4-5	914		781	163		78	26		13
Acartia clausi									
Female	120	S	256	127		188	33		71
Male	334		221	79		147	7		4
COP 4-5	412		322	248		772	22		34
Calanus spp.									
Female	0		29	19		2	19		17
Male	0		28	0		4,5	0		7,6
COP 4-5	180	S	408	198		555	67		67
COP 3	203		290	143		254	10		22
COP 2	118		136	66		112	8		10
COP 1	66		31	24		19	1,7		2,7
Nauplii	0		17	0		8,3	0,8		3,3
Ova	388		39	428	S	66	152	S	14
Centropages hamatus									
Female	15		19	45		72	2,2		7,7
Male	60		62	42		77	4,7		8,9
Centropages typicus									
Female	25		23	24		22	1,6		0
Male	2,9		6,8	13		0	0		0,6
Centropages spp.									
COP 4-5	72	S	190	30		213	8		14
COP 3	118		158	41		318	11		23
COP 2	131		107	30		85	4,5		5,3
Oithona spp.	1918		1510	3690		2486	683		821
Evadne nordmanni	615		456	802		1416	163		300
Podon sp.	39	S	128	30		99	3,6		6,5
Appendicularia	1128		637	145		252	17		19
Scyphozoa	343	S	186	30		25	7,5		2,2
Hydrozoa	227		348	13	S	58	2,3		6,6
Cirripedia larvae	74		49	76		32	6		6,2
Bivalvia larvae	2057		1781	1526		837	66		43
Gastropoda larvae	769		713	307		230	21		19
Polychaeta larvae	107		73	132		190	31		29
Ophiuroidae larvae	306		84	28		38	13		16
Chaetognatha	4,9	S	75	3	S	109	0,8	S	22
Ostracoda	10	S	110	14		27	2,6		1,2

S - letter S indicates a statistically significant difference between means on a 0,05 Sign.level.

Table 5. Abundance (C) ind. per m^3 and biomass (B) mg per m^3 of mesozooplankton on stations S-9* and C-3** in the Eastern Skagerrak 17 - 18. 06. 1990.

Group/Station			S-9				C-3	
Layer	0 - 10 m		11 - 20 m		23 -48 m		0 - 20 m	
	C	B	C	B	C	B	C	B
Pseudocalanus minutus								
Female	360	19.59	156	9.50	130	7.56	266	15.43
Male	160	5.48	22	0.80	11	0.44	112	4.02
COP 4-5 female	940	22.40	89	2.11	81	1.75	106	2.44
COP 4-5 male	800	17.92	148	4.00	70	1.62	102	2.46
COP 3	940	19.55	30	0.73	30	0.61	118	2.74
COP 2	600	10.44	52	0.94	26	0.43	67	1.61
COP 1	100	1.36	22	0.28	19	0.32	96	2.02
Nauplii	80	1.12	119	1.95	26	0.77	6.4	0.11
Ova	80	0.56	44	0.79	3.7	0.01		
Paracalanus parvus								
Female	700	14.78	37	1.09	0	0	122	2.71
Male	320	8.10	7.4	0.13	0	0	6.4	0.16
COP 4-5	960	11.52	81	0.73	3.7	0.05	112	1.28
COP 3	200	2.62	0	0	7.4	0.04		
Acartia clausi								
Female	240	9.51	126	5.53	3.7	0.16	42	1.76
Male	140	6.15	37	1.30	3.7	0.15	58	2.30
COP 4-5	180	2.74	89	1.85	3.7	0.08	26	0.44
COP 3	80	1.19	22	0.15	0	0		
COP 2	20	0.26	30	0.17	0	0		
Acartia longremis								
Female	0	0	0	0	0	0	6.4	0.13
Male	0	0	0	0	0	0	3.2	0.04
Calanus spp.								
Female	20	14.91	0	0	1.9	1.60	3.2	2.71
Male	0	0	0	0	0.4	0.28	3.2	2.02
COP 4-5	500	144.18	44	13.33	48	12.66	106	29.84
COP 3	320	34.56	178	17.47	11	1.29	77	7.93
COP 2	100	4.65	74	3.31	7.4	0.35	29	1.32
COP 1	0	0	22	0.34	3.7	0.05	16	0.24
Nauplii	20	0.69	15	0.06	11	0.38		
Ova	40	9.00	156	8.11	170	12.88	19	1.36
Centropages hamatus								
Female	0	0	67	6.18	0.7	0.07	9.6	0.90
Male	60	4.08	37	2.48	0	0	29	1.52
Centropages typicus								
Female	20	2.87	0	0	0	0	0	0
Male	0	0	0	0	0	0	3.2	0.08
Centropages spp.								
COP 4-5	160	4.45	52	1.17	0	0	32	0.80
COP 3	120	0.99	0	0	0	0	3.2	0.02
COP 2	160	0.24	0	0	0	0	0	0
Temora longicornis								
Female	0	0	0	0	0	0	3.2	0.16
Male	0	0	0	0	0	0	12.8	0.38
COP 4-5	0	0	0	0	0	0	16.0	0.24
Total CALANOIDA	8420	375.91	1756	84.45	673	43.55	1612	89.17
Oithona spp.	660	5.01	1156	8.78	735	7.69	365	3.32
Evadne nordmanni	80	3.34	756	39.31	22	0.80	269	13.84
Podon sp.	20	0.09	37	1.67	0	0	13	0.58
Appendicularia	420	44.02	281	10.39	15	0.82	67	4.50
Scyphozoa	220	38.66	22	8.69	0	0	32	7.13
Hydrozoa	280	29.20	37	35.76	3.7	6.76		
Cirripedia larvae	20	0.90	74	0.85	3.7	0.09	22	0.34

table 5 continued

Bivalvia larvae	620	6.94	452	5.06	67	0.49		
Gastropoda larvae	380	5.93	148	2.31	7.4	0.02	74	1.02
Polychaeta larvae	20	0.69	295	12.44	33	1.30	13	0.53
Ophiuroidea larvae	1780	5.12	422	1.56	30	0.43		
Chaetognatha	60	1.24	52	16.17	33	44.67	9.6	7.22
Ostracoda	100	0.50	89	0.94	0	0		
Euphausiidae	20	0.48	0	0	4.5	1.19	9.6	0.77
Noctiluca	80	7.10	281	8.00	74	3.64		
Varia	720	43.71	178	6.98	30	0.83	221	6.30
Coscinodiscus sp.	0	0	133	1.25	204	4.48		
Total	13900	568.84	6169	244.62	1935	116.76	2707	134.72

* - St. S-9 in the drifting experiment of R/V "Lev Titov", 18.06.1990, 0600 - 1000 UTC.
58° 27,0´ N 10° 54,4´ E. Depth = 72 m

** - St. C-3 on SKAGEX section C, R/V "Alexander von Humbolt", 17.06.1990.
58° 19,0´ N 10° 56,5´ E. Depth = 80 m

Presentation no 14.

Subsurface phytoplankton populations east of Skagen in may 1991: A study of structure and productivity in relation to physical factors.

by

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SUBSURFACE PHYTOPLANKTON POPULATIONS EAST OF SKAGEN IN MAY 1991: A STUDY OF STRUCTURE AND PRODUCTIVITY IN RELATION TO PHYSICAL FACTORS.

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ABSTRACT

High *in situ* primary productivity in a subsurface chlorophyll maximum, moving from 15 to 18 m depth during three days, was found in May 1991 at a station east of Skagen i northern Kattegat. The downward movement was connected to sinking pycno- and nutriclines. Parallel measurements in an incubator of the potential productivity and the comparison of *in situ* and incubator assimilation numbers suggested that the light conditions not was the limiting factor on this occasion.

Keywords: primary production, subsurface chlorophyll maxima, nutricline.

INTRODUCTION

A feature that has attracted considerable attention in recent years, is the presence of subsurface phytoplankton concentrations in the Kattegat-Skagerrak region. The Skagerrak Experiment (SKAGEX), carried out during four different occasions in 1990-1991, showed for the first time the vast extent of this phenomenon, particularly obvious in the "ridge"-area in central Skagerrak (Danielssen et al. 1991, 1992). Previous studies, e.g. by Lindahl (1983), have pointed out that the initiation of blooms of dinoflagellate species may occur in off-shore, subsurface populations.

Although these subsurface concentrations of phytoplankton have been observed and described by several authors, very little is known about the mechanisms that form them and this is also true for the physical, chemical and biological processes within these communities.

The subsurface phytoplankton populations are often easy to detect in the vertical profiles of fluorescence, where it appears as sharp, narrow peaks. It is not unusual to find more than one peak and they may be separated by only one metre or even less. The depth at which these peaks appear varies. It can be shallower than 10 metres, but also as deep as 40 to 50 metres (Danielssen et al. 1991). They are mostly found just above or within a nutri- or pycnocline (Richardson and Christoffersen, 1990).

When chlorophyll analyses is made on water samples from these peaks, corresponding peaks are generally found although the chlorophyll profile, by no means always is proportional to the fluorescence profile (Lindahl et al., unpubl.data).

However, the question to what extent the subsurface chlorophyll peaks represent photosynthetically active phytoplankton populations needs much additional attention.

It is obvious that sinking populations from a previous bloom, in poor physiological state, will be registered in the fluorescence and chlorophyll profiles as will chloroplasts incorporated into mixotrophic or heterotrophic organisms.

Microscope analysis of samples from these peaks do however in most cases show an abundance of cells in good physiological condition, indicating photosynthetic activity. The problem is, that the depths at which these peaks are found, are generally close to, or below the level which is generally considered the photic zone in these waters.

In this paper we report on a study that addressed questions connected to vertical distribution of subsurface chlorophyll peaks. Such questions were:

-To what extent are the populations photosynthetically active?
-At which depths are they active and what is the light regime at those depths?
-What can be the cause behind the sharp vertical zonation?
-Is there also a species zonation?

The study was carried out as a special task during three days of SKAGEX IV (14-16 May, 1991). It was a joint effort between the Kristineberg Marine Biological Station in Sweden and the Institute of Marine Research in Flödevigen, Norway. Two research vessels were engaged, R/V "Arne Tiselius" from Kristineberg and R/V "G.M. Dannevig" from Flödevigen.

Although the study was carried out in a limited area in northeastern Kattegat, it has been possible to compare our results with those from a much larger geographical area. During the same week, other SKAGEX research vessels were operating along transects in both Skagerrak and Kattegat (Fig. 1) and their data were kindly made available to us.

MATERIAL AND METHODS

Study area

A general feature of the Kattegat hydrography is the presence of a low salinity surface layer and a high salinity deep layer. Low salinity water leaves the Baltic through the Belts and the Öresund. It is generally transported northwards as boyant coastal currents along the Danish and the Swedish coasts. As these currents enter Skagerrak, they unite into a counter-clockwise circulation following the Swedish westcoast and the Norwegian southcoast towards the North Sea. The salinity increases from about 14 PSU in the south to about 25 PSU in the north due to mixing (entrainment) with the deep layer of higher salinity (32-34 PSU), originating from the Skagerrak/North Sea (Svansson, 1975). Changes in wind stress and barometric pressure distributions are important factors responsible for the dynamic of the coastal current. The halocline is generally found at about 15 metres depth, but the depth as well as the currents may vary considerably due to the fluctuating flows from the Baltic and Skagerrak (Svansson, 1975; Rydberg, 1977, Rydberg et al. 1990; Shaffer & Djurfeldt, 1983).

This study was carried out in northwestern Kattegat, in a limited area approximately 7 nautical miles southeast of Skagen (Fig.1). The centre was an anchor station (Y 1, N 57°37', E 10°46') which was surrounded by a grid of 7 stations, one nautical mile apart. The depths varied between 17 and 26 metres.

At the Anchor station the sampling programme included the following parameters; salinity, temperature, light, Secchi-depth, phosphate, nitrate, nitrite, silicate, fluorescence, chlorophyll *a*, potential primary production, *in situ* primary production and phytoplankton (qualitatively and quantitatively).

At the Grid stations, the programme included; temperature, salinity, dissolved oxygen, phosphate, nitrate, nitrite, silicate and chlorophyll *a*.

During each of the three days, sampling was carried out during 11.^{00} and 17.^{30} hours, local time.

Hydrographic variables.

Temperature and salinity were measured by a CTD-sond and water-bottles were used for the collection of the water-samples. In addition to the hydrographic standard-depths, samples were also taken in fluorescence peaks and in the subsurface chlorophyll layer. The under-water light energy was measured by a submersible quanta-meter and the Secchi-depth with a 20 cm Secchi-disc.

Phosphate, nitrate + nitrite (below called only nitrate) and silicate were measured directly after sampling in an autoanalyser according to the New Baltic Manual (1972). Speed and direction of wind and surface current were only estimated.

Biological variables.

The vertical distribution of the phytoplankton community was studied by *in situ* fluorescence. The chlorophyll *a* concentration was measured *in-vitro* by a fluorometer after 24 h extraction of GF/F filters (100 ml sample) in 90% acetone. The latter fluorometer was calibrated against a chlorophyll *a* extract. The primary productivity was measured by the ^{14}C-technique both *in situ* at 8 depths in the surface layer and at 6 to 8 depths in the subsurface chlorophyll layer down to 20 metres depth. Three hours incubation time was used *in situ* starting soon after noon. The potential productivity of different mixed samples and of fluorescence and chlorophyll peaks was studied by use of an incubator. The incubator measurements were carried out for two hours at 300 $\mu E \cdot m^{-2} \cdot s^{-1}$ and at a temperature 1 to 2 °C higher than the surface water temperature. Parallel *in situ* and incubator experiments were carried out on water from the same water-bottles (Table 1). The treatment of all samples followed the recommendations of Baltic Marine Biologists (1976). The radioactivity was measured by the liquid scintillation counting technique without any filtration of the sample water (Schindler et al., 1972).

Phytoplankton samples were collected in such a way that it covered the layer of maximum fluorescence. During the first day of the study, this layer was between 11 and 14 metres and thus 11, 12, 13 and 14 metres were sampled. Although the layer descended during the two following days, we continued to monitor these depths (including all parameters) for comparative reasons.

Phytoplankton samples from the subsurface chlorophyll layer and fluorescence peaks were preserved with Lugol's solution and a rough cell count were carried out onboard by use of an inverted microscope after sedimenting 10 ml of sample. Due to an unfortunate mistake too little Lugol's was added for a longer storage. This has made the later and more precise analysis of these samples next to impossible and especially the diatoms could not be counted in all samples. This concerns the samples from 16 May and those from the peak of fluorescence 15 May.

RESULTS

Grid stations.

The daily measurements of temperature, salinity, nutrients and chlorophyll *a* at the Grid stations showed that the stratification and concentrations in general were the same at the Grid stations as at the Anchor station. The movements of the pycno- and nutriclines at the main station (see below) could also be observed at the grid stations, however, occasionally with some vertical displacement compared to the Anchor station.

Anchor station.

14 May

The 14th of May was a sunny day with a westerly wind of about 15 $m \cdot s^{-1}$. Surface current was moderate (about 1 knot) heading north. Secchi-depth and underwater light was not possible to measure due to the heaving of the sea. The surface water was homogeneous down to 9 metres depth with a salinity of 23 PSU and a temperature of 9.2 °C (Figs. 2a and b). A mixture of surface and deep water was present from 9 to 16 metres depth with a sharp pycnocline at 10 metres. Below 16 metres deep water of 34 PSU and 5.5 °C temperature was found.

The surface water was depleted of nitrate (<0.4 $\mu mol \cdot l^{-1}$) while phosphate was measured in concentrations between 0.10 and 0.15 $\mu mol \cdot l^{-1}$ (Figs. 2c and d). Below 10 metres depth the concentration of nitrate increased from about 8 $\mu mol \cdot l^{-1}$ at 13 metres depth to 10 $\mu mol \cdot l^{-1}$ at 20 metres. Phosphate increased linearly from 10 metres depth down to 20 metres, where 0.6 $\mu mol \cdot l^{-1}$ was measured. Silicate was not measured.

The primary productivity *in situ* was about 5 $\mu gC \cdot l^{-1} \cdot h^{-1}$ from surface down to 10 metres depth (Fig. 2e). A peak of 25 $\mu gC \cdot l^{-1} \cdot h^{-1}$ was found at 13 metres and still at 15 metres a productivity of 8 $\mu gC \cdot l^{-1} \cdot h^{-1}$ was found.

Chlorophyll *a* had a similar vertical distribution with low concentrations in the surface water (1.5 $\mu g \cdot l^{-1}$), a peak of slightly more than 10 $\mu g \cdot l^{-1}$ at 12 - 13 metres (Fig 2f) and a very low concentration in the deep water.

The potential productivity of the mixed surface water sample was 3.1 $\mu gC \cdot l^{-1} \cdot h^{-1}$, while the mixed sample from 11, 12, 13 and 14 metres was 16.8 $\mu gC \cdot l^{-1} \cdot h^{-1}$. The primary productivity/chlorophyll quotients of these samples were 1.0 and 2.1 respectively, indicating that the potential production was twice as high in the subsurface layer when compared with the mixed surface layer. The primary productivity/chlorophyll quotients of the corresponding *in situ* samples were also calculated to 1.0 (mixed surface water) and 2.1 (subsurface layer), indicating that the *in situ* growth in the subsurface layer was twice as high per unit chlorophyll when compared with the surface layer.

The plankton flora in the subsurface chlorophyll layer was a mixture of species. The diatoms *Leptocylindrus danicus* (up to $1.4 \cdot 10^6$ cells$\cdot l^{-1}$), *Chaetoceros* spp (up to 600 000 cells$\cdot l^{-1}$) and flagellates <10µ (up to $5.6 \cdot 10^6$ cells$\cdot l^{-1}$) were most numerous.

15 May

The 15th of May was cloudy with a NW wind of 7 m$\cdot s^{-1}$. The surface current was strong (estimated to 2 knots) running northwards. The light at the surface was 120 µE$\cdot m^{-2} \cdot s^{-1}$ and the 1% light level was at 21.5 metres depth. The Secchi-depth was 8.5 metres. The salinity and temperature of the surface water were still 23 PSU and 9.2 °C respectively (Figs. 2a and b). A small halocline (3 PSU) was present between 7 and 12 metres depth, but the main pycnocline was between 12 and 16 metres. The deep water was still present from 16 metres and downwards.

The nitrogen concentration was low (0.15 µm$\cdot l \cdot l^{-1}$) down to 13 metres depth except at 11 metres where 0.8 µmol$\cdot l^{-1}$ was measured. No phosphate (detection limit = 0.05 µmol$\cdot l^{-1}$) was detected from the surface down to the same depth (Figs. 2c and d). The nitrate concentration increased to 5 µmol$\cdot l^{-1}$ at 15 metres depth and further to 9 µmol$\cdot l^{-1}$ at 20 metres. The phosphate concentration increased almost linearly from almost 0 at 14 m to 0.9

$\mu mol \cdot l^{-1}$ in the deep water at 20 m depth. Silicate concentrations were about 0.1 $\mu mol \cdot l^{-1}$ in the surface water, between 0.05 and 0.1 $\mu mol \cdot l^{-1}$ in the 11 to 15 metres depth layer and 2.1 $\mu mol \cdot l^{-1}$ at 20 metres.

A second set of chemical and chlorophyll data was taken during the afternoon, three hours after the first set. From these data it was obvious that the nutricline and the chlorophyll peak had sunk about 2 metres in three hours.

The *in situ* primary productivity was low at the surface and increased slowly with depth so that 7 $\mu gC \cdot l^{-1} \cdot h^{-1}$ was measured at 12 metres depth (Fig 2e). At 13 and 14 metres the productivity increased more rapidly and a conspicuous peak of 52 $\mu gC \cdot l^{-1} \cdot h^{-1}$ was found at 15 metres. At 20 metres the productivity was almost zero.

The chlorophyll distribution over depth had a pattern similar to that of the productivity with concentrations less than 1 $\mu g \cdot l^{-1}$ in the surface water, between 1.7 and 4.1 $\mu g \cdot l^{-1}$ in the depth interval 10 to 13 metres, a peak of 17.8 $\mu g \cdot l^{-1}$ at 15 metres and 1 $\mu g \cdot l^{-1}$ at 20 metres (Fig 2f). When normalized to the chlorophyll concentration, the *in situ* productivity/chlorophyll quotients were 3.8, 2.3 and 2.9 for the samples mixed surface water (1 - 10 metres), mixed subsurface layer (11 - 14 metres) and at the depth of maximal productivity (15 metres) respectively. The corresponding quotients found in the incubator were 4.5, 2.2 and 2.9 respectively. The *in situ* and incubator quotients thus indicate that the phytoplankton population in the surface water was growing about twice as much compared with the algae in the mixed subsurface layer (6% light level) and about 40% faster as in the fluorescence/chlorophyll maximum at 15 - 16 metres depth at the 3% light level

According to the onboard analysis of the plankton flora of the subsurface chlorophyll layer, *L. danicus* (up to 1.1 10^6 cells·l^{-1}) and flagellates less than 10μ (up to 1.6 10^6 cells·l^{-1}) were the most abundant. The vertical distribution of the dinoflagellate *Dinophysis norvegica* this day was particularly interesting: at 11 to 13 metres depth 1 100 to 4 700 cells·l^{-1} were found, at 14 metres 14 300 cells·l^{-1} and in the fluorescence peak at 16 metres 24 400 cells·l^{-1}. During the other sampling days the maximum abundance of this species was 7 200 cells·l^{-1} (16 May, at 18 metres depth).

16 May

The 16th of May was sunny with a northerly wind of 12 m·s^{-1}. The surface current was still running towards the north and so strong (~2.5 knots) that our ship (25 metres long), when anchored, turned the stern more or less against the wind and remained in that position during the day.

The light at the surface was 530 μE·m^{-2}·s^{-1} and the 1% light level was found at 20 metres depth. Secchi-depth could not be measured due to the strong current. In the surface water the salinity had increased from 22.7 to 24.3 PSU and the surface water body had continued to expand deeper. The pycnocline was in the depth interval 15 to 20 metres but not as sharp as during the previous days (Figs. 2a and b).

The concentration of the nitrogen compounds was 0.08 μmol·l^{-1} or lower down to 15 metres depth (Fig. 2c). At 20 metres depth, 1.9 μmol·l^{-1} was measured. Thus, almost no nitracline was detected. The concentration of phosphate was below detection limit (0.05 µmol·l^{-1}) down to 15 metres, almost 0.1 at 18 - 19 metres and 0.21 at 20 metres depth (Fig. 2d). The top of the nutricline had thus sunk from 11 metres on the 14th, via 14 metres on the 15th, to 18 metres on the 16th (Figs. 2c and d). The silicate concentration was around 0.1 µmol·l^{-1} down to 12 metres depth, varied between 0.2 and 0.9 µmol·l^{-1} in 13 to 19 metres depth interval and 2.9 µmol·l^{-1} at 20 metres.

The primary productivity between the surface and 15 metres depth was in the range 1 to 6 µgC·l^{-1}·h^{-1}. The bulk of the productivity followed the downward movement of the pycno- and nutricline so that maximum production (23 µgC·l^{-1}·h^{-1}) during this day was found at 18 metres (Fig. 2e). At 19 and 20 metres depth a productivity of about 15 µgC·l^{-1}·h^{-1} was found. The chlorophyll concentration showed a distribution over depth similar to the productivity (Fig 2f). The concentration was about 2 µg·l^{-1} down to 15 metres depth, increased to 10 µg·l^{-1} at 18 metres and was around 7 µg·l^{-1} at 19 - 20 metres.

The *in situ* primary productivity/chlorophyll quotients were 1.7, 2.6 and 2.3 for the mixed surface water, the mixed subsurface layer (11 - 14 metres) and the fluorescence peak (19 metres) respectively (Table 1). The corresponding potential productivity was 3.1, 2.9 and 2.4 respectively, measured at a light level of 66% of that at surface this sunny day. The quotients indicate that the algae were light limited in the *in situ* mixed surface sample compared to the growth in the incubator. In the samples of the mixed layer and the fluorescence peak on the other hand, the growth per unit chlorophyll was almost the same *in situ* and in the incubator although the *in situ* light levels were 6% and 1% of surface light or about 14% and 6% of the light in the incubator respectively.

In the subsurface layer flagellates of 3 - 6 µm (up to 10^6 cells$\cdot$l^{-1}) and *D. norvegica* dominated. However, the remains of the diatoms that was found indicate that they probably dominated the plankton flora.

DISCUSSION

Subsurface phytoplankton populations in the Skagerrak - Kattegat area have been described by several authors e.g. Dahl & Danielssen (1981), Pingree et al. (1982), Lindahl (1986) and Dahl et al. (1987). The Skagerrak Experiment in 1990 and 1991 confirmed these earlier findings and it could be shown that they were common and often covering large areas in both Skagerrak and Kattegat. Throughout SKAGEX I (24 May -20 June, 1990), large subsurface chlorophyll concentrations were found in central Skagerrak in association with the "ridge" (Danielssen et al. 1991, 1992). During SKAGEX IV in May, 1991, the same phenomenon was widespread along the "ridge" and over northern Kattegat and eastern Skagerrak (unpublished data collected by the vessels "Argos", "G.M. Dannevig", "Johan Hjort", "Arne Tiselius" and "Lev Titov".

Preliminary analysis of the data from SKAGEX IV collected by the above mentioned ships, indicate that the hydrography found at our anchor-station Y 1, was representative for a situation that prevailed all over northern Kattegat. The many fluorescence profiles that were taken by these ships during the week of SKAGEX IV, showed the same sharp peaks at depths between 10 and 20 metres, in water of similar salinity and nutrient content.

In Danielssen et al. (1991), a nitrate-salinity diagram is used to identify the different water-masses in Skagerrak and Kattegat. If this is applied to identify the origin of the water below the nutricline in this investigation, it would indicate that it was Jutland Coastal Water. According to Ærtebjerg (pers. comm.), such water entered northern Kattegat in March-April, 1991, and formed an intermediate layer with a salinity of 32-34 PSU and characteristic nitrate and phosphate levels. However, whether or not this water has remained in northern Kattegat until the middle of May, must still remain speculations.

The present results indicate that the primary production in subsurface phytoplankton communities can be considerable, even when the algae are present at 14 to 20 m depth. This observation was in accordance with studies on subsurface production in southern Kattegat in 1988 (Richardson & Chrisstoffersen, 1990) and in 1990 (Bjornsen & Nielsen, 1991). In the present investigation the main part of the primary production was made up in the subsurface chlorophyll layer and the addition from the surface water was of less importance.

It must also be stressed that the peak and the bulk in productivity followed the downward movement of the subsurface chlorophyll layer, which in turn followed the downward movement of the pycno- and nutriclines. The downward movement of the phytoplankton community occurred although the incident light energy changed considerably during the three days (14 and 16 May were sunny while 15:th was cloudy). The peak in chlorophyll was found in water of 32 PSU, or more. It was surprising that the highest productivity was found on the cloudy day. Further, when this peak value was transformed to an assimilation number (primary production/chlorophyll) it was found to be the highest value of all from the subsurface chlorophyll layer during the three days. This peak was dominated by 24 400 cells$\cdot l^{-1}$ of *D. norvegica*, which was the maximum abundance of this specie and in a class for itself.

The calculated assimilation numbers (productivity/ chlorophyll) demonstrate that the growth *in situ* was more efficient in the subsurface chlorophyll layer at 11 to 19 m than in the surface water by a factor of up to 2, except for the 15 May. The larger assimilation number of the surface water on the cloudy 15 May depended on a lowered chlorophyll concentration while the productivity was unchanged. The phosphate concentration of the surface water was at the same time under the detection limit (<0.05 $\mu mol\cdot l^{-1}$), which indicates that phosphate probably not was the limiting nutrient, neither on this day nor on the other days. A two-fold increase in the assimilation number in a population of *G. aureolum* at 14.2 m depth was found by Bjornsen and Nielsen (1991) in southern Kattegat, and they concluded that the phytoplankton growth was enhanced in the pycnocline.

The large difference in the assimilation numbers of the mixed surface sample between the three days of both the *in situ* and the incubator measurements can not be directly explained with the available data. However, it is possible that changes in the composition of the phytoplankton community, due to the advection of new water masses to the area, have occurred. This may find support in the strong surface current during the period, the observed changes in the phosphate concentration on the 15:th and the salinity on the 16:th of the surface water.

The assimilation numbers calculated from the productivity and chlorophyll measurements of the subsurface chlorophyll layer were more constant during the three days when compared to those of the surface water. There was also a closer relation between corresponding assimilation numbers of the *in situ* and the incubator measurements than in the surface layer. Further, the comparison between the *in situ* and the incubator results suggests that the light conditions at the depths of the subsurface chlorophyll layer was not limiting the *in situ* growth of the phytoplankton. Although this seems somewhat unlikely it is not impossible. Richardson and Kullenberg (1984) have shown that low light adapted cells of cultured *Gyrodinium aureolum* are better equipped to utilize low light than high light adapted and, at the same time, as well able to utilize high light as their high light adapted counterparts. However, no *G. aureolum* cells was observed during the present study.

The peak in primary productivity all three days was found in the mixed layer of surface and deep water. This corresponded to the 5 to 1% light level, e.g. the lower end of the photic zone. The shape of the haloclines suggests that the mixing of deep and surface water increased during the three days of investigation, since the gradient of the salinity became less sharp. The increased surface current and the increased surface salinity on 16 May should have increased the efficiency of the mixing process. Thus, the supply of nutrients to the mixed layer of surface and deep water should theoretically has increased at the same time as the layer was displaced downwards. In fact, the assimilation numbers increased from 2.1 to 2.9 in the mixed sample 11 - 14 m measured in the incubator and from 2.1 to 2.6 *in situ*. It can thus be concluded that the mixing of surface and deep water most likely was an important process for the high subsurface productivity measured *in situ*.

It has been suggested that entrainment process is essential for the development of subsurface chlorophyll maxima in the Skagerrak coastal areas (Lindahl, 1993). However, without having measured the currents, the mixing or if the production was new or regenerated, it is not possible to exactly answer which factor(s) was the most important for the development of the shape of the productivity curves over depth. In the present data it can be seen that the peaks in productivity always were where the nitrogen/phosphate ratio was 10 or more, which indicate that nitrogen may have been limiting. Nitrogen as the limiting factor also explains the common downward movements of both the nutriclines and the productivity peaks. Similar results were found in the northwestern Mediterranean where there was a significant positive correlation between the depths of deep chlorophyll maxima and of the nitraclines (Estrada et al., 1993).

In conclusion, the present results points out that high productivity of the subsurface chlorophyll layer may occur in border area between Kattegat and Skagerrak and that the light conditions at 15 to 18 m depth not was the limiting factor on the present occasion. It is also obvious that the hydrodynamic processes plays a great roll in the development and dynamics of the layers.

REFERENCES

Baltic Marine Biologists. 1976. Recommendations on methods for marine biological studies in the Baltic Sea. BMB Publ. no 1, 98 pp.

Bjornsen, P.K. and Nielsen, T.G. 1991. Decimeter scale heterogeneity in the plankton during a pycnocline bloom of *Gyrodinium aureolum*. Marine Ecology Progress Series, 73: 263-267.

Dahl, E. and Danielsen, D.S. 1981. Hydrography, nutrients and phytoplankton in the Skagerrak along the section Torungen - Hirtshals, January - June 1980. *In* The Norwegian Coastal Current, pp 294-310. Ed. by R. Sætre and M. Mork. University of Bergen, Norway.

Dahl, E., Danielssen, D.S., Semb, A. and Tangen, K. 1987. Precipitation and run-off as a fertilizer to a *Gyrodinium aureolum* Hulburt bloom. Rapports et Procès-Verbaux des Réunions du Conseil International pour l'Exploration de la Mer, 187: 66-73.

Danielssen, D.S., Davidsson, L., Edler, L., Fogelqvist, E., Fonselius, S., Föyen, L., Hernroth, L., Håkansson, B., Olsson, I. and Svendsen, E. Skagex: some preliminary results. ICES CM 1991/C:2, 35 pp.

Danielssen, D.S., Edler, L., Fonselius, S., Hernroth, L., Ostrowski, M., Svendsen, E. and Talsepp, L. 1992. Oceanographic variability in Skagerrak/Northern Kattegat, May - June 1990. Accepted for publication in ICES Journal of Marine Science.

Estrada, M., Marrasé, C., Latasa, M., Berdalet, E., Delgrado, M. and Riera, T. 1993. Variability of deep chlorophyll maximum characteristics in the Northwestern

Mediterranean. Marine Ecology Progress Series, 92: 289-300.

ICES Cooperative Research Report. 1972. New Baltic Manual. Ser. A. no. 29, 145 pp.

Lindahl, O. 1983. On the development of a Gyrodinium aureolum occurrence on the Swedish west coast in 1982. Marine Biology 77, 143-150.

Lindahl, O. 1986. Offshore growth of *Gyrodinium aureolum* (Dinophyceae) - The cause of coastal blooms in the Skagerrak area? Sarsia, 71: 27-33.

Lindahl, O. 1993. Hydrodynamical processes: A trigger and source for flagellate blooms along the Skagerrak coasts? *In* Toxic Phytoplankton Blooms in the Sea, pp. 775-782. Ed. by T. Smayda and Y. Shimizu. Elsevier, Amsterdam, 952 pp.

Pingree, R., Holligan, P., Mardell, G. and Harris, R. 1982. Vertical distribution of plankton in the Skagerrak in relation to doming of the seasonal thermocline. Continental Shelf Research, 1: 209-219.

Richardson, K. and Kullenberg, G. 1984. Physical and biological interactions leading to plankton blooms: A reveiw of *Gyrodinium aureolum* blooms in Scandinavian waters. ICES Special Meeting on the causes, dynamics and effects of exceptional marine blooms and related events, A2, 13 pp.

Richardson, K. and Christoffersen, A. 1990. Seasonal distribution and production of phytoplankton an the southern Kattegat. ICES CM 1990/L:13, 31 pp.

Rydberg, L. 1977. Circulation in the Gullmaren - a sill fjord with externally maintanied stratification. Institution of Oceanography, University of Gothenburg, Sweden, Report no. 23, 19 pp.

Rydberg, L., Edler, L., Floderus, S. and Granéli, W. 1990. Interaction between supply of nutrients, primary production, sedimentation and oxygen consumption in SE Kattegat. Ambio, 19: 134-141.

Schindler, D.W., Schmidt, R.V. and Reid, R.A. 1972. Acidification and bubbling as an alternative to filtration in determining phytoplankton production by the C method. Journal Fisheries Research Board of Canada, 29: 1627-1731.

Shaffer, G. and Djurfeldt, L. 1983. On the low-frequency fluctuations in the eastern Skagerrak and in the Gullmaren. Journal of Physical Oceanography, 13: 1321-1340.

Svansson, A. 1975. Physical and chemical oceanography of the Skagerrak and the Kattegat. Fishery Board of Sweden, Institution of Marine Research, Report no. 1, 88 pp.

TABLE 1: Chlorophyll a concentration, productivity and assimilation numbers (productivity /chlorophyll) of *in situ* and incubator measurements during 14 - 16 May at station Y1.

DAY AND SAMPLE	SAMPLING TIME p.m.	CHLORO-PHYLL $\mu g \cdot l^{-1}$	PRODUC-TIVITY $\mu gC \cdot l^{-1} \cdot h^{-1}$	ASSIMILA-TION NUMBER
14 May				
In situ				
Means 1, 5, 10 m	1.00	3.1	3.1	1.0
Means 11, 12 ,13, 14 m	1.00	8.2	17.1	2.1
Inkubator				
Mix 1, 5, 10 m,	1.00	3.1	3.1	1.0
Mix 11, 12 ,13, 14 m	4.50	8.2	16.8	2.1
15 May				
In situ				
Means 1, 5, 10 m	1.15	1.1	4.2	3.8
Means 11, 12, 13, 14 m	1.15	4.0	9.3	2.3
Productivity-max. 15 m	1.15	17.8	52.4	2.9
Inkubator				
Mix 1, 5, 10 m	1.15	1.1	4.9	4.5
Mix 11, 12, 13, 14 m	1.15	4.0	8.9	2.2
Mix 11, 12, 13, 14 m	5.20	4.5	10.4	2.3
Fluorescence-max. 16 m	5.45	9.4	27.0	2.9

16 May

In situ

Means 1, 5, 10 m	0.05	1.8	3.1	1.7
Means 11, 12, 13, 14 m	0.05	2.0	5.1	2.6
Fluorescence-max. 19 m	0.05	7.6	17.1	2.3

Inkubator

Mix 11, 12, 13, 14 m	0.05	2.0	5.7	2.9
Fluorescence-max. 19 m	0.05	7.6	18.3	2.4
Mix 1, 5, 10 m	0.05	1.8	5.6	3.1
Fluorescence-max. 19 m	3.10	8.2	22.1	2.7

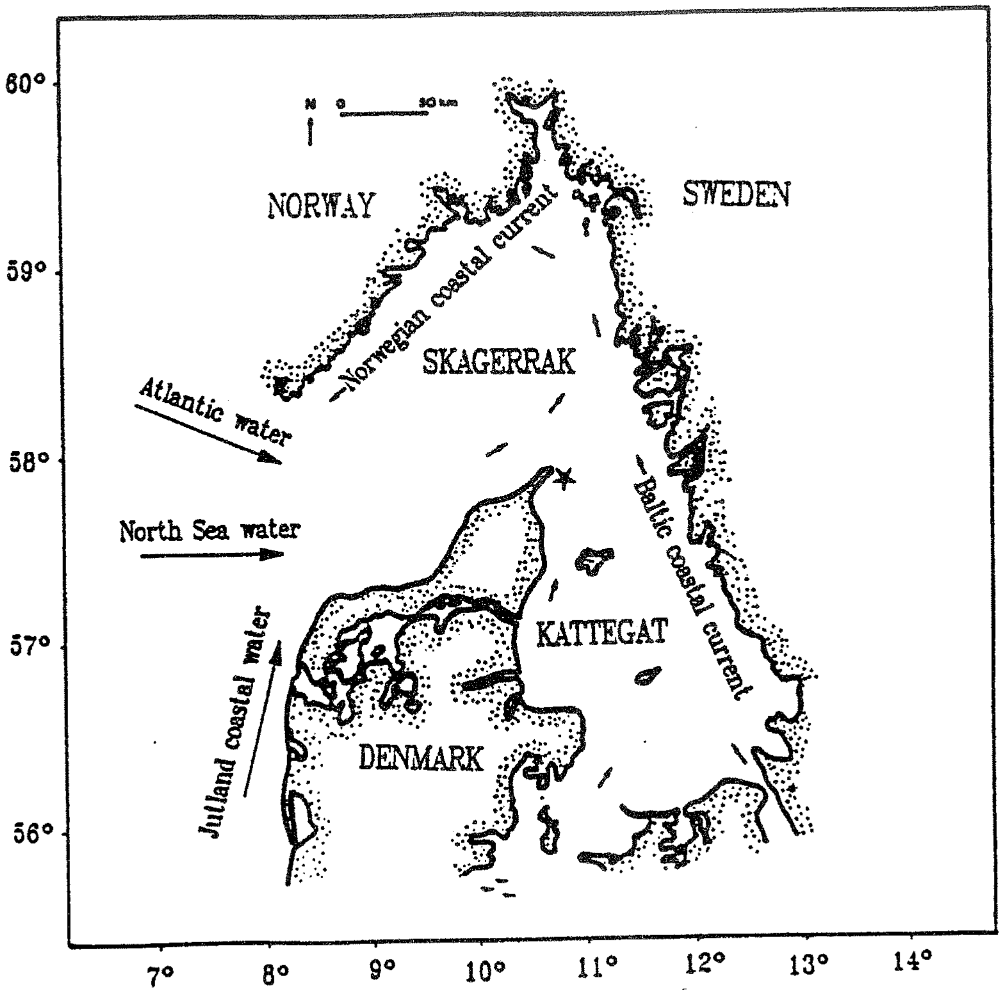

Fig. 1. Map of Northern Kattegat and Skagerrak with the investigated station (*).

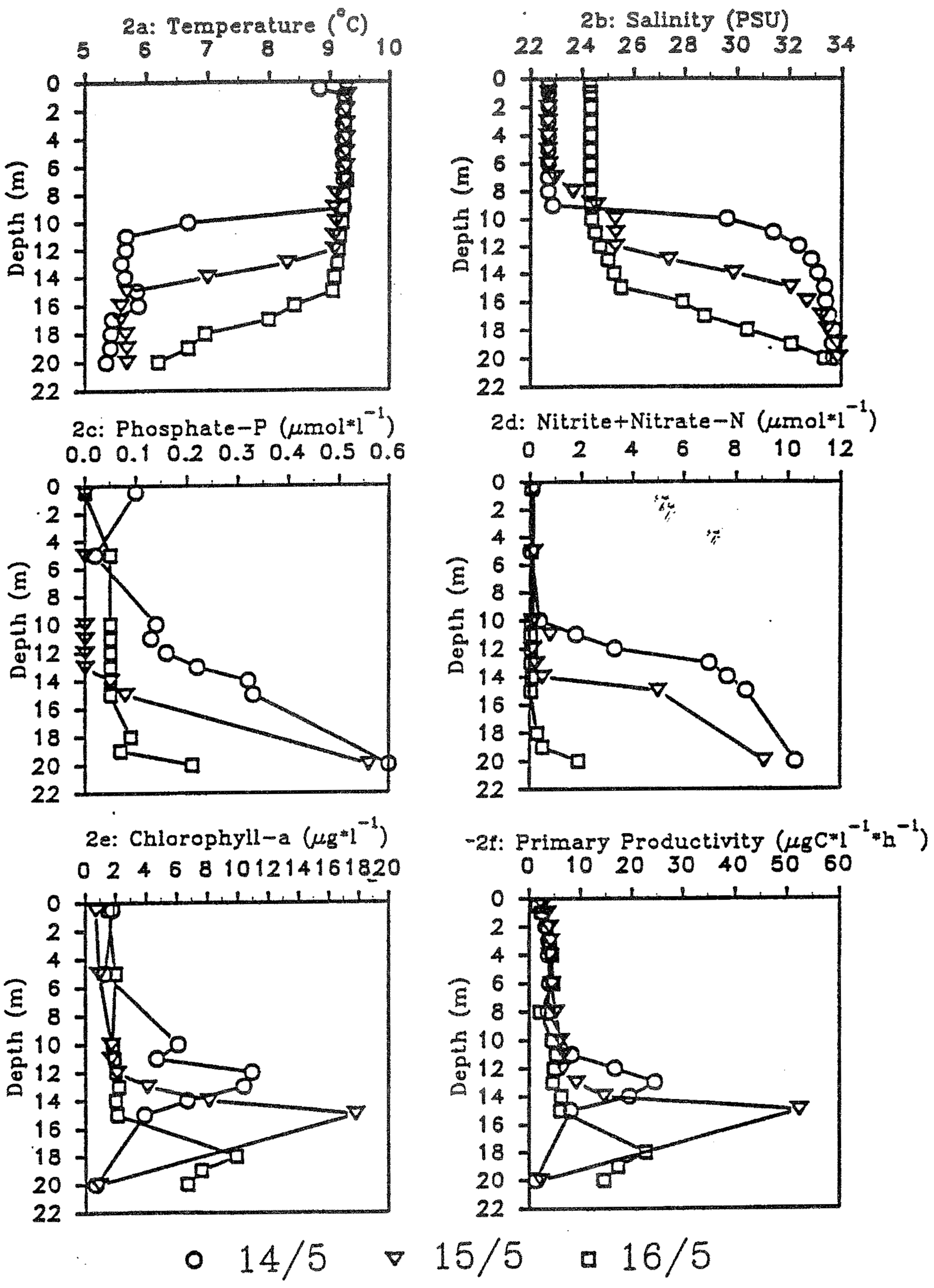

Fig. 2. a. Temperature, b. Salinity, c. Phospahte - P, d. Nitrite + Nitrate - N, f. Primary productivity during 14 - 16 May 1991 east of Skagen.

Presentation no 15.

Elements of mesoscale circulation in the Western Skagerrak. SKAGEX I, 1990.

by

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ELEMENTS OF MESOSCALE CIRCULATION IN THE WESTERN SKAGERRAK - SKAGEX I - 1990

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ABSTRACT

The investigation carried out at section H in the western Skagerrak in the second part of SKAGEX I-90, June 8 - 20, allowed to state that the northern extent of the Jutland Current, was greatly affected by various coinciding factors such as: an extensive spreading of low saline surface waters towards the Danish coast, prevailing northwesterly winds forcing inflows of Central/Southern North Sea waters into the Skagerrak.

The entire Skagerrak region was characterized by great, spatial and temporal variability in all measured parameters and this variability was often found to be much higher than the sampling intervals (75 hours). However, the supplementary measurements allowed to observe some short-term phenomena and these are described in details. Sudden changes in velocity and direction of water advection together with convection process in the surface layer led to formation of «quasi-intrusive» structures but no «salt-fingers» type of structures was observed below the base of pycnocline. These quasi-intrusions are not only an important element in energy transfer in water column, from the mixed layer to below the base of pycnocline, but also play an important element in energy transfer in water column from the mixed layer to below the base of pycnocline, but, also play an important role in transformation of water masses.

The entire surface layer down to 30 m of the western Skagerrak underwent a convective mixing and Ekman transport. Below the well pronounced pycnocline the circulation had mostly a geostrophic character. Thus the calculated geostrophic currents are discussed in the context of presence of quasi-intrusive structures, in the middle and northern part of section H.

INTRODUCTION

Skagerrak is a peripheral part of the North Sea but, on the other hand, it is a hydrological transitional zone where an exchange of oceanic waters with the Baltic waters takes place, (Stigebrandt, 1983). Taking into account the bathometry of Skagerrak the eastern extension of the Norwegian Trench resembling, by its shape a big fjord, is a most important element of that region, (Fonselius, 1990). An axis of this suboceanic fjord lies along the Norwegian coast, Fig. 1, therefore all the hydrographic profiles crossing the strait are clearly unsymmetric. The great depths of the fjord favour spreading of dense oceanic bottom waters, Ljøen, 1981 a.

The very recent SKAGEX data allowed Danielssen et al., 1991 to distinguish six water masses being of importance in the Skagerrak and differing in salinity, temperature and nutrients content.

Almost all the published salinity profiles made in that region are similar to vertical salinity distributions recorded in the estuaries of big rivers i.e. are of so called «estuarine type», (Rodhe, 1987). As a consequence of the above fact there is lack of symmetry in distribution of measured parameters; besides, low saline waters, spreading on the surface as a thin layer, easily undergo influence of atmospheric parameters. Therefore a number of scientists see interdependence between the barometric pressure (winds) and the surface circulation, (Aure and Sætre, 1981; Sætre et al., 1988; Bo Pedersen et al., 1989).

A cyclonic circulation i usually observed in the entire Skagerrak and it causes, in its centre, an upward movement of waters from the deeper part of the Norwegian Trench, (Rodhe, 1987; Fonselius, 1989). This circulation is most often aided from the south by the stream of well mixed Jutland Current waters having salinity 32 - 34 PSU and high content of nitrates. The Jutland Current flows to the Skagerrak from the German Bight and it may even reach Kattegat during its maximal extension, (Jensen et al., 1983 a; Richardson et al., 1987). The investigation, Jensen et al., (1983 a) b; Bo Pedersen et al., (1989), Danielssen et al., (1991), indicated however that there is a possibility of blocking of these waters near the western coast of Jutland Peninsula. Finding of the direct causes as well as solving of this problems require further specialistic studies, in particular with respect to hydrochemistry and hydrobiology. In the eastern and northern surface waters of the Skagerrak there develops flow of low saline waters called the Baltic Current in vicinity of the Swedish coast which continues as the Norwegian Current along the Norwegian coast. Both currents delimit the cyclonic circulation, with respect to the Norwegian Coastal Current, may undergo disturbances leading even to occurrence of upwelling, Sætre et al., 1988; Danielssen et al., 1991. Though the phenomena such as circulation from east and north. The classical model of circulation its definition, location, time of occurrence and also the disturbing mechanisms affecting the Jutland and Norwegian currents were given a priority in oceanographic studies not much attention was given so far to short-term changes of hydrological phenomena having a mesoscale character as well as to interrelation between advection and convection in the surface layer. A separate problem is a question whether below the base of pycnocline, an averaged circulation of waters can have a baroclinic character.

METHODS

The presented material was collected onboard R/V "Professor Siedlecki", (Sea Fisheries Institute in Gdynia), in the second half of SKAGEX I-90 expedition, 8 - 20 June 1990. According to the approved method the sampling was done on 15 oceanographic stations located on the most westerly profile, marked with letter «H», Fig. 1. Almost all the measurements were repeated at the stations five times, (on average at 75-hour-intervals). Apart from the obligatory and nonobligatory oceanographic measurements, (during 13 days), there were made, in synoptic hours, the meteorological observations.

The vertical profiles of temperature and salinity were obtained with the Neil Brown Mark III CTD System. The samplings of water for the following parameters; oxygen, phosphate, nitrate, nitrite, silicate were made with General Oceanics Rosette Sampler combined with the Neil Brown CTD Measuring System. The chemical analyses were manually conducted directly after collection of samples and unified methods for determination were used, (Calberg 1992; Grashoff 1976, Grashoff et al., (eds) 1983). The spectrophotometric measurements were made with a Beckman instrument (model 25). The oxygen content was determined with the Winkler method.

The average vertical profiles of temperature and salinity calculated on a basis of all the measurements conducted in days 8 -20 June 1990 were used for calculations of geostrophic currents. The relative velocities of geostrophic currents between the stations were calculated according to method by Zubov and Mamaev, (1956). The geostrophic currents velocities were calculated for particular pairs of stations and the dynamic hights were used in that process. The dynamic hights were used in that process. The dynamic hights were calculated for each station and the depth levelling correcting factors were taken into account in these calculations.

The obtained hydrochemical results are presented in figures which have an uneven depth scale and that follows the SKAGEX recommendations concerning elaboration of data. Some of the physical parameters, namely salinity, T-S, density, were also drawn in uneven intervals what may wrongly suggest a presence of vertical gradients.

VARIABILITY OF HYDROLOGICAL PARAMETERS IN THE WESTERN SKAGERRAK

The recent investigations have shown a close dependence between the velocity and direction of wind and the spreading of surface waters in the Skagerrak. This dependence can be observed both in the region being under influence of Jutland Current and the zone being under effect of the Norwegian Coastal Current, (Bo Pedersen et al., 1989; Rodhe 1987; Sætre et al., 1988).

As it arises from the data presented by numerous authors, (Jensen et al., 1983 a, b; Brockman et al., 1985; Føyn, 1986, 1987; Richardson et al., 1987 a, b; Danielssen et al., 1991), the nutrients data may serve as an additional source of information on water masses and their dynamics in the Skagerrak and adjacent regions. Based on the historical as well as on the SKAGEX data it can be said that waters of Jutland Current are characterized by elevated nitrates values the latter being strongly affected by both - mixing with the North Sea waters while proceeding towards the north/north east and by the biological uptake in the period of biological activity.

During the oceanographic studies carried out at section H (8 -20 June 1990) there decidedly prevailed light and moderate winds from NW, 36 % for all observations, and W sector, 28% of observations, Fig. 2. Such a direction of wind was, on occasions, a limiting factor in the northern extent of Jutland Current. As it is reported by Danielssen et al., 1991, based on moored current meters records the ADCP (Acoustic Doppler Current Meter) and the drifting buoys the Jutland Current pulsated into Skagerrak on May 23 to 25, June 4 to 6, 11 and 20, what was found by shore authors to be correlated, to some extent, with winds varying from S to W. However it should be pointed out here that the waters of this current were present at stations H-13 to H15 during the entire period of «Prof. Siedlecki»s studies and on some occasions on the neighbouring profile «G». The fluctuating character of nitrates concentrations at the above stations resulted therefore from two facts - firstly from not a continuous supply of nutrients due to fluctuating character of the Jutland Current. Figs. (5, 10), and secondly from the biological uptake, (Fig. 6), However these coinciding facts did not result in a total depletion of nutrients in the most southern part of the profile H.

An analysis of figures representing horizontal distributions of temperature, salinity, nitrates at selected level of 10 m in the entire Skagerrak in days 8 - 20 June 1990, (Figs. 3, 4, 5), allows to observe a close correlation between the decreasing tendency in nitrates concentrations observed in days 11 - 17 June 1990 in vicinity of northwestern part of Jutland Peninsula - and the increasing area covered with waters having salinity > 34 PSU. That resulted from the inflow of waters from the North Sea in that period. The maximum area of highest salinities and lowest temperature was observed on 17 June 1990 and that coincided with the lowest values of nitrates content in the above mentioned region. That hydrological situation is a reflection of blocking phenomenon of Jutland Current reported by Danielssen et al., (1991), in days 9 - 10 and 12 - 19 June 1990. It is worth pointing at this moment that this coincided with the fact that in days 16 and 17 June there were recorded NNW winds of strength 8 - 15 m/sec. These strong winds, persisting for nearly 48 hours, additionally increased the process of convective mixing. The measurements performed three days later i.e. on 20 June showed that situation was reversed which means the area of highest salinities drastically diminished and high concentrations of nitrates again appea(red what remained in agreement with change of wind direction and strength, SW; 3m/sec.), and in agreement with reported Jutland Current activation, (Danielssen et al., 1991).

The northern part of section H was increasingly under influence of relatively warmer and low saline surface waters of the Norwegian Current. The salinity in the current´s main stream reached its minimum on 19 June and that was equal 24.88 PSU, (Figs. 4, 8).

A main feature in distribution of temperature and salinity during five sampling days was steady development of mixed layer and increasing vertical gradients in near-surface layer, Figs. 7, 8. The time changes, in the central part of profile H are best illustrated by isopleths of temperature and salinity, Fig. 11. The sharp bends of isolines can be observed there and, the thermohaline changes in the entire analyzed layer took place in no longer time than some hours. It was characteristic that below thermo- and halocline the amplitudes were very low Table I.

Table I. The extreme values of T, S σ_t at selected depths at station H6, calculated from 8 measurements, 8 - 20 June 1990.

Depth /m/	T/°C/			S /PSU/			σ_t		
	T_{max}	T_{min}	ΔT	S_{max}	S_{min}	ΔS	σ_{tmax}	σ_{tmin}	Δo
10	14.28	8.87	5.37	33.50	29.15	4.35	26.051	21.622	4.429
60	8.11	7.38	0.73	35.29	35.14	0.15	27.508	27.439	0.069
120	7.92	7.38	0.54	35.37	35.26	0.11	27.576	27.530	0.046

The vertical distribution of salinity showed a steady tendency of increase in values towards the bottom, while the thermal structure was more complicated; local minima and maxima were alternating resulting in occurrence of closed isopleths, Fig. 11. A further analysis of temperature changes in time allows to detect slow warming up. Station H6 can be an example to prove it; the temperature in the layer between 45 and 85 m increased of over 0.7°C during 13 days of investigations. It can be concluded from the above that in the Skagerrak the salinity rather than the temperature is a factor which stabilizes the density. Warming up of surface waters is, in this time of the year, Figs. 3, 7, related, to some degree, to occurrence of bigger amounts of low saline waters of Baltic origin in the northern part of profile H in the second half of June 1992, Figs. 4, 8.

An intensified outflow along the southern Norwegian coast immediately initiates a compensating recirculation and this arises from a rule «current - counter current». According to so-called estuarine model of water masses exchange in two-layer-reservoir that counter-current should appear to the left from the stream of surface current and should encompass first of all the deeper layers, (Rodhe 1987).

CHARACTERISTIC FEATURES OF MESOSCALE CIRCULATION

A slow movement of more saline waters carried to the Skagerrak from the central/southern North Sea, mainly in bottom and subsurface layer, caused that isolines representing density above 27.20 were in a characteristic way bending along the southern slope of the Norwegian Trench, Fig. 9. This density distribution results from the Coriolis force which deflects all the movements in the northern hemisphere to the right. The above mechanism, forcing waters to the Skagerrak, was reinforcing the process of upward movement of deepest waters in the central part of the cyclonic gyre. That phenomenon finds its reflection in Fig. 12 representing isopleths of density at selected levels, 40 and 60 m. At both levels between stations H1 and H4 the horizontal gradients of density increased, at 40 m depth two times and at 60 m only one time - close to the end of investigations, what in consequence had to cause an increase in geostrophic flows across the northern part of analyzed profile. At the same time there were observed bigger disturbances in the shape of thermo- and halocline base, Fig. 7 and 8. The above described features allow to state that in the Skagerrak, in particular in the second half of June 1990, in the outflowing waters there appeared a strong baroclinic circulation, (Danielssen et al., 1992), together with elements characteristic for the mesoscale frontal zones e.g. intrusions.

So called instrusive lateral mixing of two water masses most often takes place along the same density planes, therefore that phenomenon can be easily analyzed on a basis of T-S diagrams,(Stern 1967). At station H6, located in the central part of the profile, a disturbance having character of instrusion of warmer and more saline waters was observed at the base (26.00) and below (26.50) pycnocline in days 16-19 June 1990, Fig. 13. This quasi- instrusive layer was characterized by a low thickness, about 15 m, and approximately of 75-hour-duration. An appearance of this layer was, most probably, partly connected with development of the surface mixed layer and presence of local thermal inversions, Fig. 11, what destabilised the vertical distribution of density. Occurrence of this phenomenon should also be related to southward spreading of surface waters flowing in the Norwegian Current in the second half of June, Figs. 4, 7, 8, 9.

During that time scatter of all points representing the station H6 on T-S envelope was within a field delimited by curves representing the neighbouring stations H5 and H7. So, the highly saline waters from the central Skagerrak, flowing in the subsurface layer, constituted a quasi-instrusive layer; the halocline was slightly rising up towards the surface while the surrounding sea surface was under influence of less saline waters of the Norwegian Current, Fig. 8, 11. Formation and development of such phenomena allow to presume that intensification of water advection in Norwegian Current, caused a local increase in convective mixing not only in the mixed layer but also at the base of pycnocline or even below. That was supported by distribution of Väisälä-Brunt frequency calculated at each investigated station and simply means that the energy transfer from the mixing layer can reach deeper layers of the ocean.

The temperature and salinity variability in time and space brought about a thought of analyzing the average hydrological situation observed during the study. In order to achieve this the average temperature, salinity and density values were calculated on discrete levels, every 10 m, fig. 14. Even a brief analysis of this figure and Table I allows to state that only a thin surface layer was characterized by differentiated temperature and salinity. Below 30 - 40 m the thermo-haline variability at all stations was very low. So, summing up, it can be said that during 13 days of research work the following consistent hydrological elements in the western Skagerrak were observed: 1) markedly developing thermo- and halocline, therefore a pycnocline, 2) bending up of all the isolines in the central part of the profile, 3) unsymmetric distribution of those isolines, so called "estuarine type".

Among the analyzed elements the temperature showed the greatest variability and that was observed not only in the mixed layer and the thermocline but also in the entire water column. Undoubtedly is arises from the fact that the vertical thermal structure was less stable in short time intervals than the salinity structure and oscillated, on particular depth levels, around the average value; on isopleths these are numerous local maxima and minima, Fig. 11. As the variability of physical features below the base of pycnocline, in particular salinity, which is a decisive factor with respect to density, was low, therefore it can be assumed that the water circulation there, had mostly a geostrophic character. Most certainly in such a sense the authors of papers cited in the introduction interpret the general circulation in Skagerrak as a cyclonic one, (Rodhe 1987; Fonselius 1989, Svanson 1989). The only problem which the above authors faced was proper positioning of reference level, zero level, of the geostrophic flow. Keeping this in mind the authors of the presented paper decided that the determination of circulation would be based on calculations for the pairs of stations. The geostrophic flow was always extrapolated to the level of deeper station what allowed obtaining the mean circulation values on the profile "H", Fig. 15.

The above figure shows a classical model of cyclonic circulation in days 8 - 20 June 1990 with the zero velocity zone being situated in vicinity of station H6 and H7. This general distribution of current as well as their very much differing velocities are very similar to those obtained by Danielssen et al., 1991, the latter being based on current meters data. The waters were outflowing from the Skagerrak in the deepest part of the profile and the average velocity was of 10 cms^{-1}. There could be distinguished two streams which were separated by a doming of lines of equal velocity near the station H4. The main stream was positioned along the Norwegian coast and the velocity in this stream was a few times higher than further offshore. The maximum of flow velocity, above 30 cms^{-1}, Fig. 15, was coinciding with the area of the lowest salinity values, below 29.00 PSU; Fig. 14. So, it can be reckoned that strongly stratified waters outflowing from the Skagerrak have typical baroclinic structure and they extend to the deeper layers than only the surface one with the lowest salinity. Rodhe, (1987), states even furthermore and says that the velocity of the near coast stream overlaps the velocity of general cyclonic circulation and the Ekman transport.

The water circulation near the Danish coast looked entirely different as the average flow velocities were much lower, (~ 2 cms^{-1}) and the isolines of equal velocity were often horizontal. Between the station H10 and H11 there was observed a local counter-current. Such phenomenon in a shallow part of the Skagerrak was already mentioned by Rodhe, (1987). An analysis of average geostrophic flows and of the other hydrological factors, Figs. 14, 15, shows that the southern Skagerrak, which is under pulsating influence of Jutland Current, is rather characterised by a barotrophic circulation. Therefore the mean flow velocities were much lower there and the direction of circulation can be subjected to frequent changes e.g. influence of winds. Taking into account entirely different character of circulation in the southern and northern part of profile H and unsymmetric bottom topography, the values of geostrophic flow velocity, Fig. 15, should be understood as approximate ones. In particular the flow velocities between station H7 and H15 are much lower than one would expect and it results from the fact that the southern part of the profile is characterized by a clearly barotropic flow.

It is worth pointing that the quasi-instrusion described in the previous paragraph (Fig. 13) was positioned in the area of the greatest horizontal flow gradient i.e. at station H6 where the change of flow direction from outflowing to inflowing was observed. As the horizontal movement of water masses is connected with upward or downward movement of water - there are, in Fig. 15, additionally marked arrows indicating the zones of most intensive vertical movement. A distinct upward movement of water masses towards the surface was clearly observed in the central part in investigated section. Similar upward movement was also observed in the northern part of the section, thus suggesting the upwelling in the uppper layer.

CONCLUSIONS

1. The pulsating character of Jutland Current governed by significant and variable inflows of North Sea surface water masses had its reflection in horizontal distribution of temperature, salinity and nitrates in the surface layer in region off the northwestern Jutland peninsula. The biggest area characterized by high, >34 PSU, salinities, low temperature and low nitrates, Figs. 3, 4, 5, was observed on 17 June - thus the impact of North Sea water on the extension of Jutland Current seems to be the most visible then. That blocking corresponded well with direction, NNW, and strength, 8-15 m/sec., of wind which persisted for nearly 48 hours in days 16 - 17 June 1990.

2. The entire surface layer, down to 30 m, of the western Skagerrak undergoes a convective mixing and Ekman transport. Below the well pronounced pycnocline the circulations has most often a geostrophic character. Resulting from non-symmetric character of bathometry the inflowing and outflowing water masses differ very much. The Jutland Current occupying more shallow part of Skagerrak undergoes, most of all, the steady wind-stress, the bottom friction and the tidal mixing effect. It results in the barotrophic circulation there.

The outflowing waters occupying the northern part of section «H» are much lighter, therefore together with the deeper water masses create a distinct baroclinic structure extending to deepest layers with high density. This is the main reason for which the geostrophic current at section H should be treated as a general view, helping to understand the hydrological situation correlated with the presence of intrusive structures.

3. Sudden changes in velocity and direction of water advection in the surface layer most probably connected with development of surface mixed layer and presence of local thermal inversions, may lead to emerging of instrusive structures. However, in the investigated case the intrusions, in their classical understanding, were not observed as there was not observed a clear salinity decrease with the depth, in 7.5 - 9.4 °C temperature range. Therefore the authors used the term «quasi-intrusive» structure. An example of classical T-S envelope, drawn on the background of equal density lines, is shown in Fig. 13 b. Only in

case when branch B of the T-S line is a mirror reflection of branch A may the lateral mixing take place along the equal density planes. Therefore it cannot be expected that microstructure of «salt fingers» type occurred along the type of branch B observed in our investigation. These features are very important element in energy transfer from the mixed layer down to below the base of pycnocline and also play an important role in transformation of water masses.

4. Frequency, e.g. oscillating character of temperature variation below the thermocline, of variability of mesoscale circulation in Skagerrak was found too high to be in agreement with the assumed, in SKAGEX 1990, measurements intervals, on average 75 h on every station. Only thanks to supplementary measurements at selected station of profile H, Fig. 1, was it possible to record some characteristic elements of mesoscale circulation. The analysis of satellite images indicated considerable changes of thermal situation on the sea surface within 24 h.

REFERENCES

Aure, J. and Sætre, R. 1981. Wind effects on the Skagerrak outflow. In: Sætre., Mork. M. (eds). The Norwegian Coastal Current. Pp 263-293.

Bo Pedersen, F., Richardson, K. and Jacobsen, T.S. 1989. The Jutland Current: where is it and when? CBO Proceedings, Kiel.

Brockmann, U.H. and Katter, G. 1985. Distribution of nutrients in the North Sea during February, May and July 1984. ICES, C: 46. H.C.

Calberg, S.R. 1972. New Baltic Manual with methods for sampling of physical, chemical and biological parameters. ICES Cooper. Rep. Ser. A, pp. 26-89.

Danielssen, D.S., Davidsson, L., Edler, L., Fogelquist, E., Fonselius, S., Føyn, L., Hernroth, L., Hakansson, B., Olsson, e. and Svendsen, E. 1991. SKAGEX; Some Preliminary Results. ICES, C : 2. H.C.

Danielssen, D.S., Edler, L., Fonselius, S., Hernroth, L., Ostrowski, M., Svendsen, E. and Talpsepp, L. 1992. Oceanographic cariability in Skagerrak/Northern Kattegat, May - June 1990. Paper prepared for and presented at Skagex Workshop in Lysekil in Nov. 1992.

Fonselius, S.H. 1989. Hydrographic variabilities in the Skagerrak surface water. ICES, C: 35, Sess. Q.

Fonselius, .H. 1990. Skagerrak - the gateway to the North Sea. SMIH Oceanography. No. 38.

Føyn, L. 1986. The use of nutrient distribution in the North Sea in explaining the dynamics of the different water masses. ICES. C:25. H.C.

Føyn, L. 1987. Winter, late autumn distribution of nutrients in the North Sea. ICES. C: 24. H.C.

Grashoff, K. 1976. Methods for seawater analysis. Verl. Chemie-Weinheim, New York.

Grashoff, K., Ehrhardt, E. and Kremlings. K. (eds). 1983. Method of seawater analysis.

Jensen, T.G., Kullenberg, G. and Vagn Olsen, O. 1983 a. The Jutland Current, carrier of the North Sea signals towards the Baltic Sea. ICES, C:5. H.C.

Jensen, T.G., Kullenberg, G. and Vagn Olsen, O. 1983 b. The Jutland Current. ICES, C: 6. H.C.

Ljøen, R. 1981a. On the exchange of Deep Waters in the Skagerrak Basin. In: Sætre, R., Mork, M. (eds.). The Jutland Current. ICES, C: 5, H.C.

Ochocki, S., Renk, H., Nakonieczny, J. and Lorentz, Z. Potential primary production and chlorophyll in the Skagerrak - June 1990. (In preparation).

Richardson, K., Jacobsen, T. and Vagn Olsen, O. 1987a. The Jutland Current: A mechanism for transporting nutrients to the Kattegat? CBO Proceedings, Copenhagen, Vol. II.

Richardson, K. and Vagn Olsen, O. 1987b. Winter nutrient concentrations and primary production in the eastern North Sea. ICES, C: 23. H.C.

Rodhe, J. 1987. The Large-scale Circulation in the Skagerrak; interpretation of some observation. Tellus, Vol. 39 A.

Sætre, R., Aure, J. and Ljøen, R. 1988. Wind Effects on the lateral Extension of the Norwegian Coastal Water. Continental Shelf Research, Vol. 8, No. 3.

Stern, M.E. 1967. lateral mixing of water masses. Deep Sea Research Vol. 14.

Stigebrandt, A. 1983. Model for Exchange of Water and Salt Between the Baltic and the Skagerrak. Journal of Physical Oceanography, Vol. 13, March.

Zubov, N.N. and Mamaev, O.J. 1956. Dinamicheskij metod vychislenija elementov morskih techenii. Leningrad, pp. 3-75.

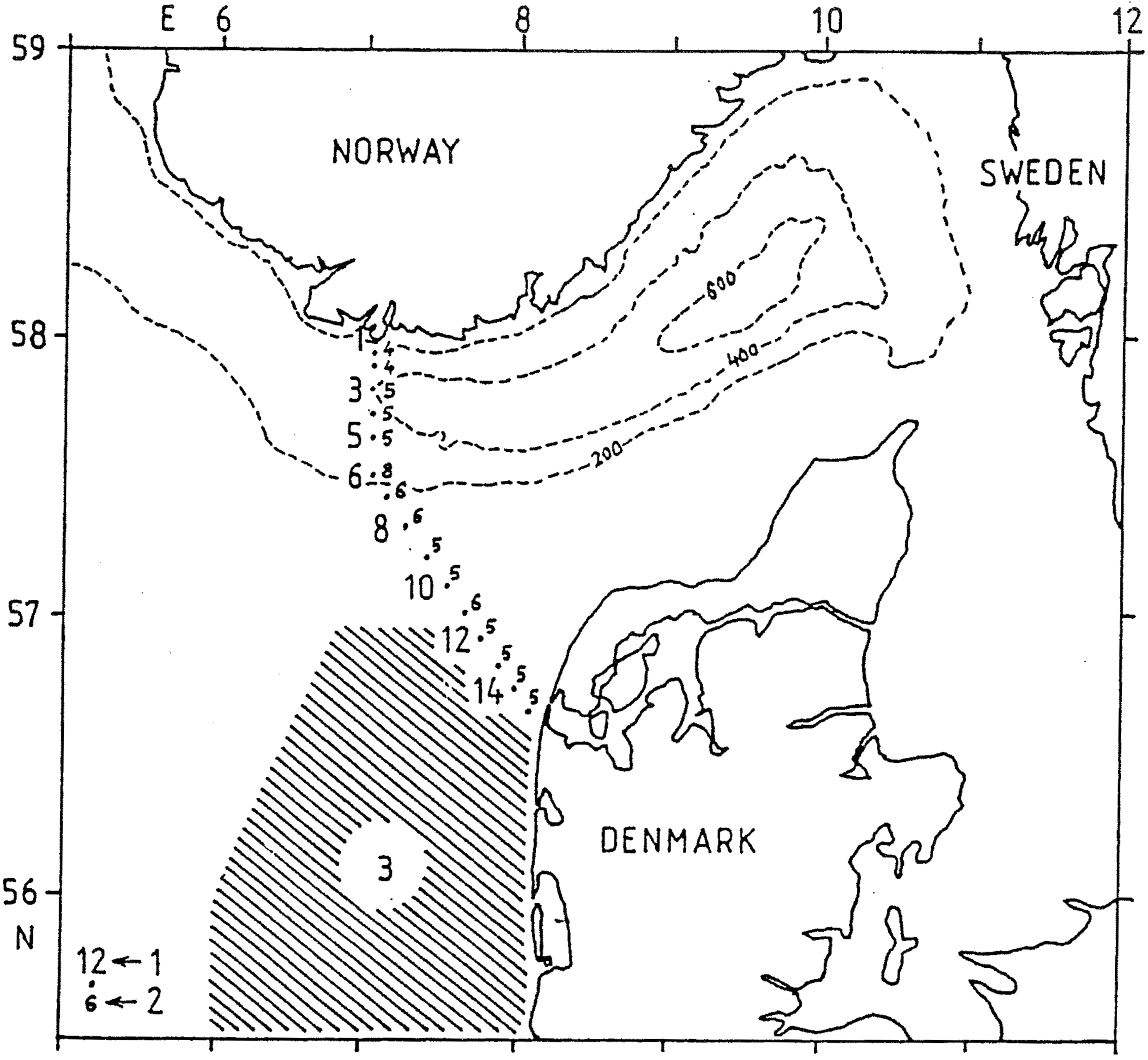


Fig.1. Distribution of oceanographic stations during SKAGEX expedition. R/v Profesor Siedlecki 8 - 20 June 1990.

1 - stations numbers on the section H,
2 - number of measurements done at particular stations,
3 - shaded - region of additional stations

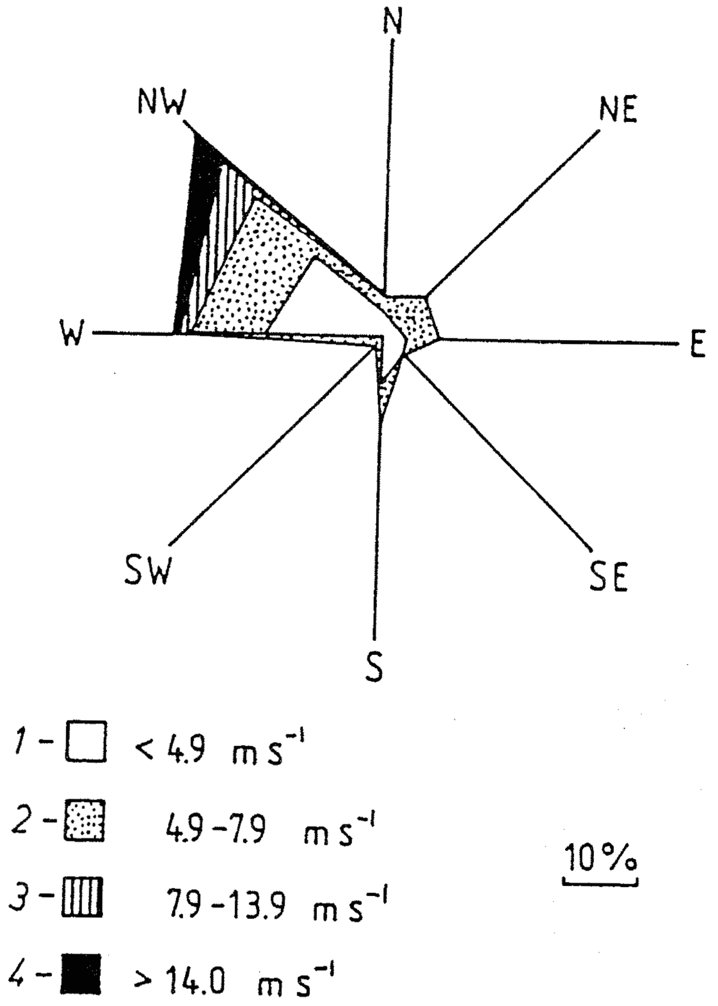


Fig.2. Share of wind velocity and direction / in % / in the western Skagerrak in days 8 - 20 June 1990

1. weak winds and gentle breeze,
2. moderate winds,
3. relatively strong and strong breeze,
4. very strong breeze.

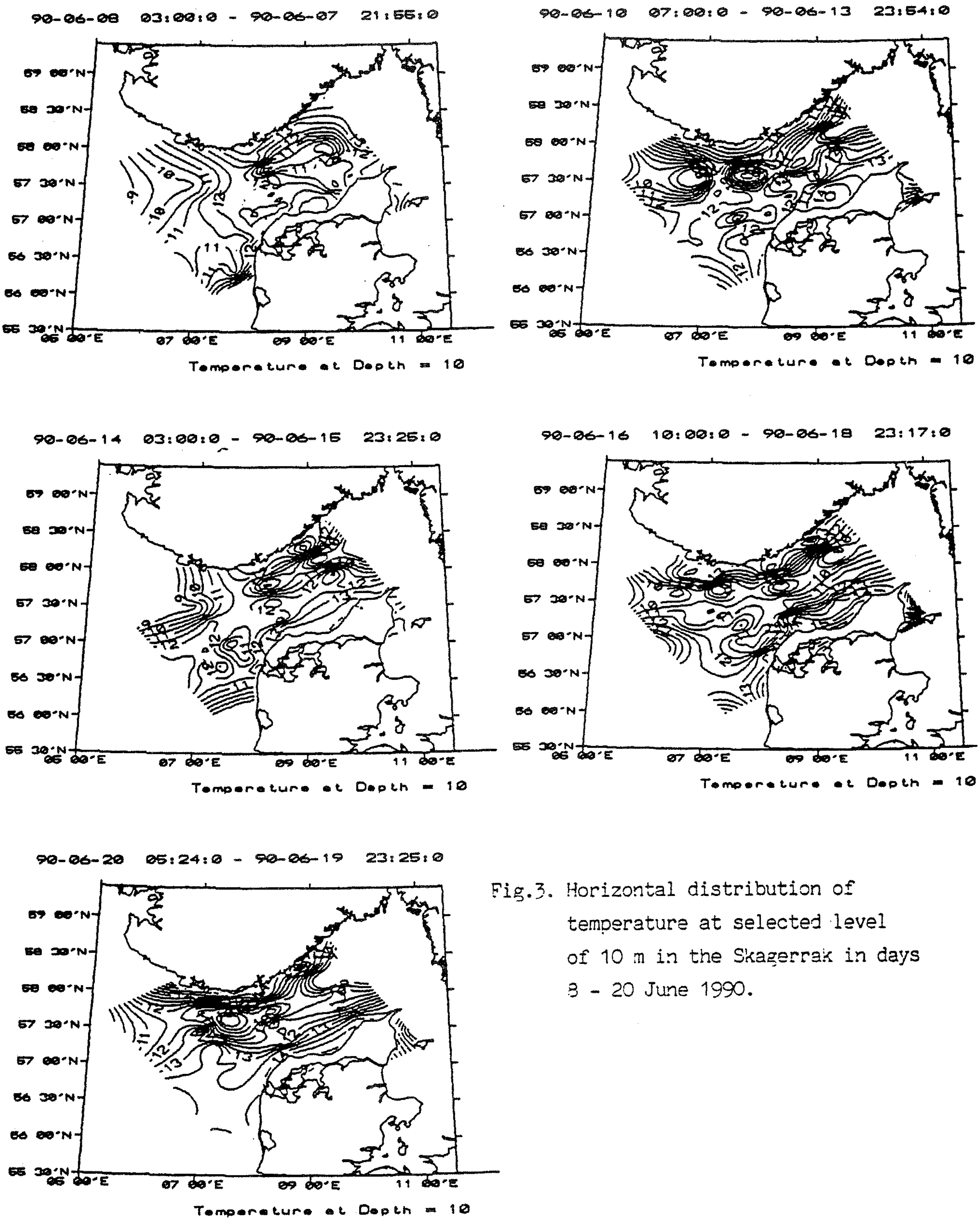
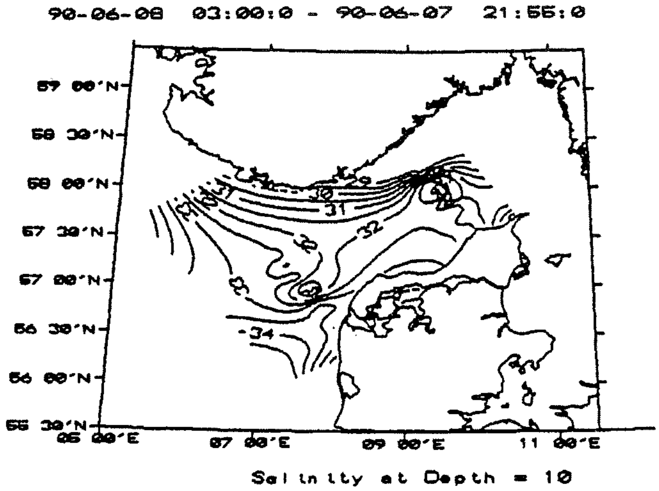
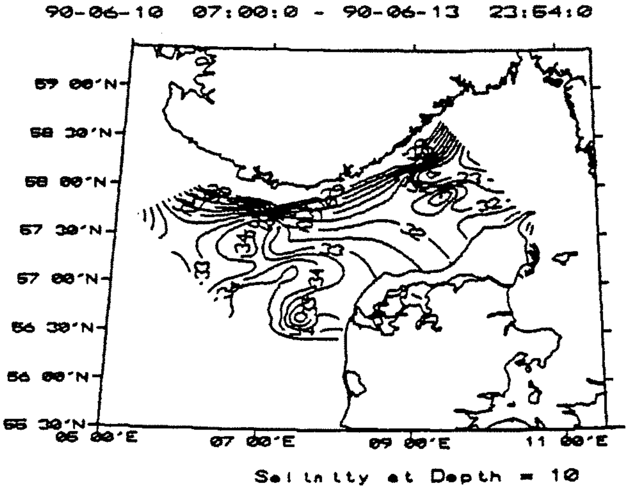
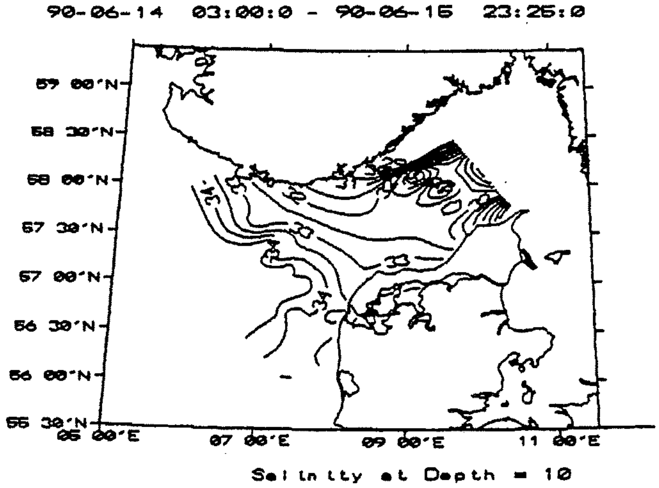
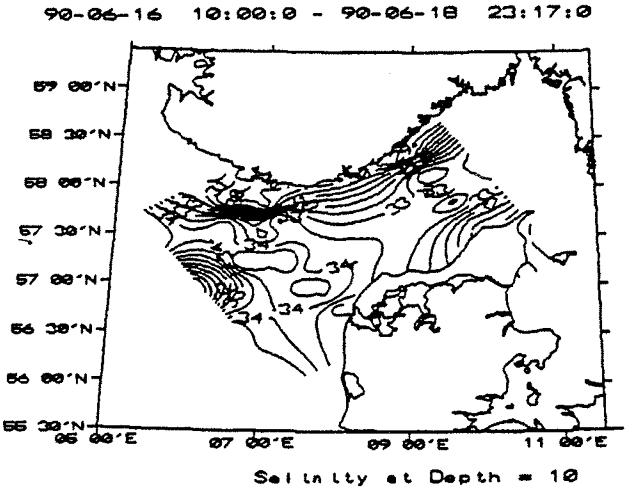


Fig.3. Horizontal distribution of temperature at selected level of 10 m in the Skagerrak in days 8 - 20 June 1990.









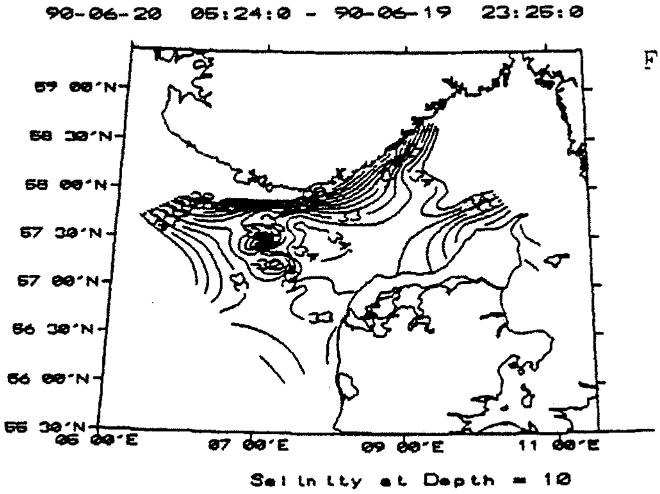
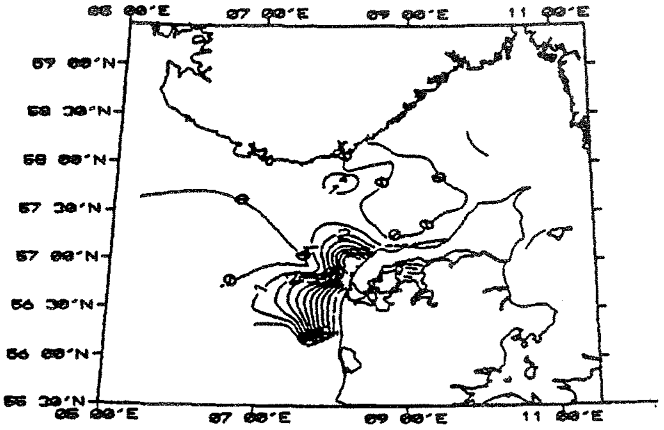


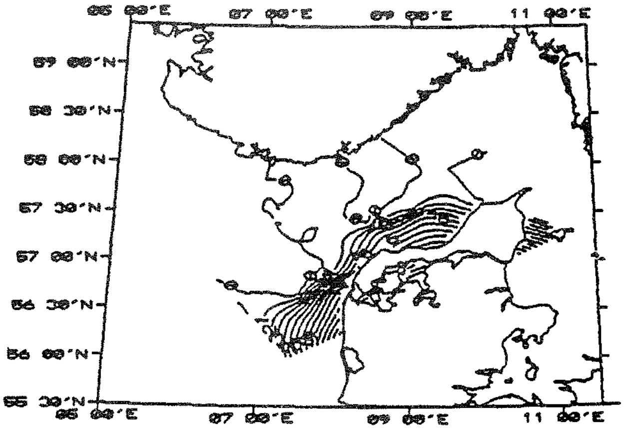
Fig.4. Horizontal distribution of salinity at selected level of 10 m in the Skagerrak in days 8 - 20 June 1990.

90-06-07 15:27:0 - 90-06-09 15:00:0



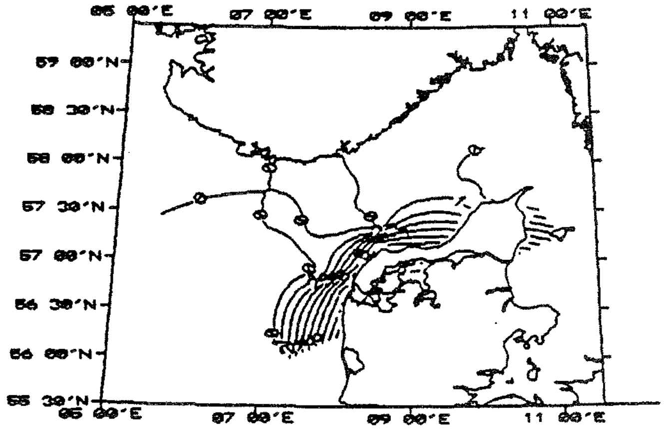
Nitrate at Depth = 10

90-06-10 00:04:0 - 90-06-13 14:00:0



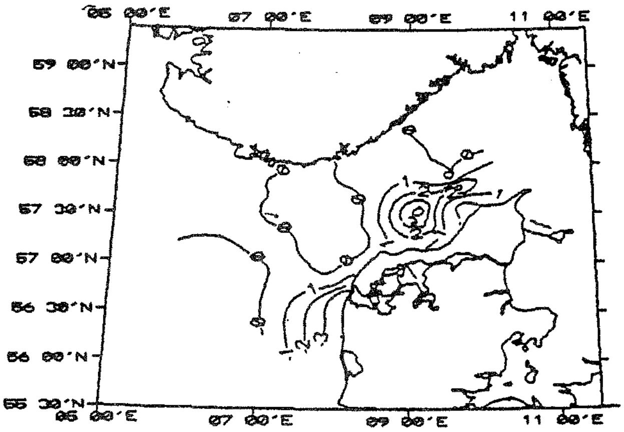
Nitrate at Depth = 10

90-06-14 00:41:0 - 90-06-14 17:18:0



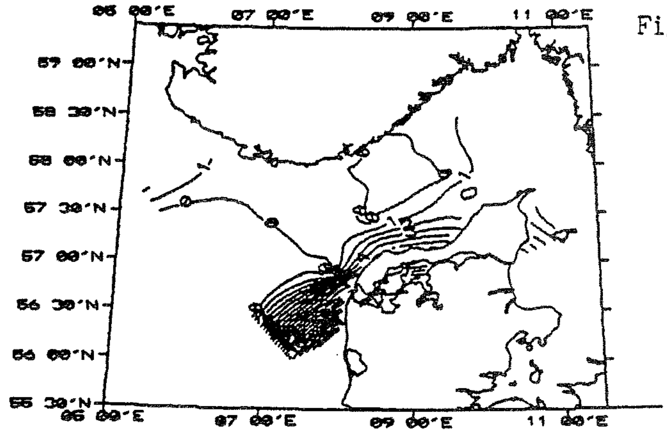
Nitrate at Depth = 10

90-06-16 03:30:0 - 90-06-18 07:02:0



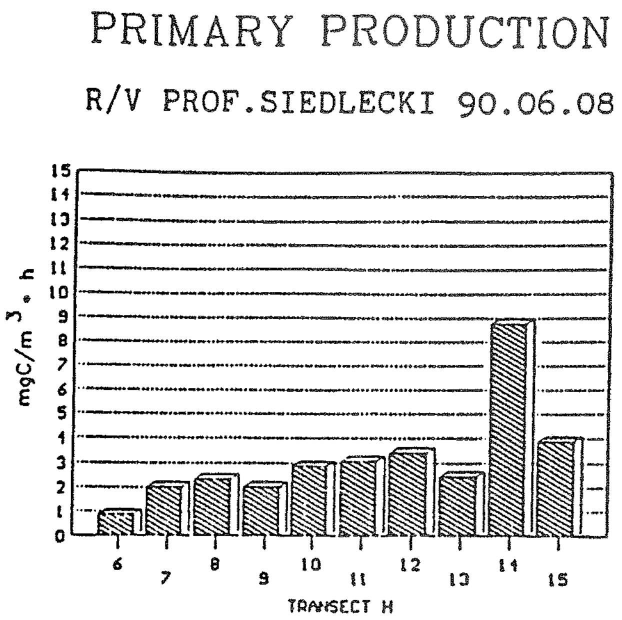
Nitrate at Depth = 10

90-06-19 19:16:0 - 90-06-20 17:38:0

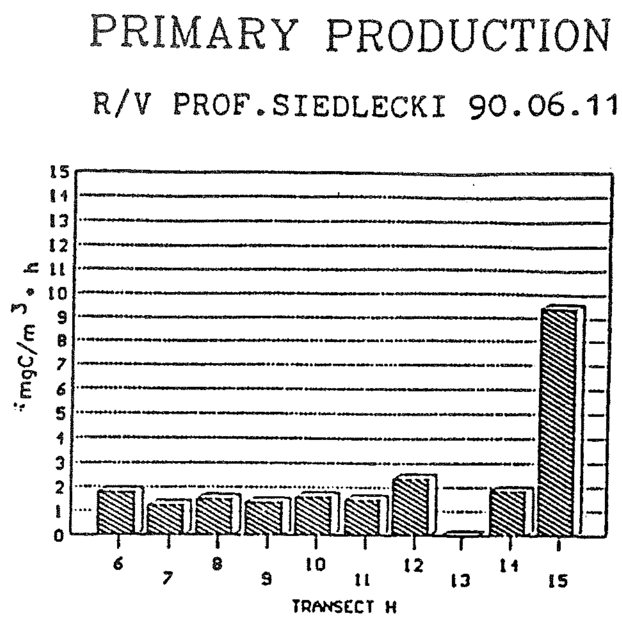


Nitrate at Depth = 10

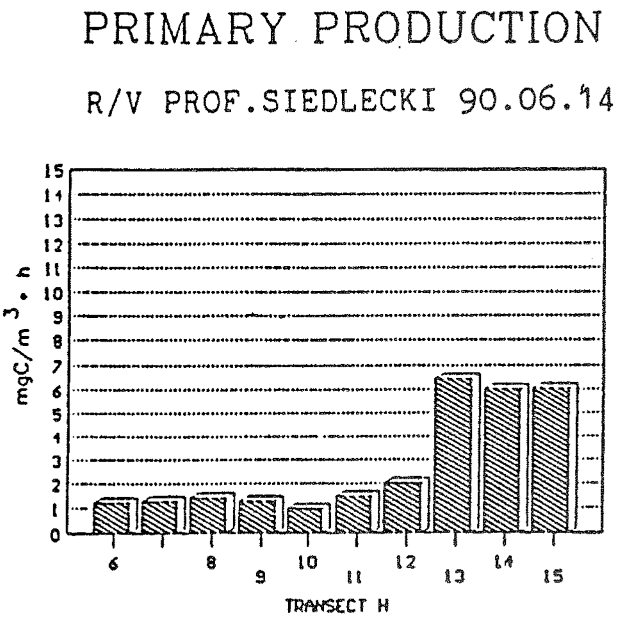
Fig.5. Horizontal distribution of nitrates at selected level of 10 m in the Skagerrak in days 8 - 20 June 1990.


PRIMARY PRODUCTION

R/V PROF.SIEDLECKI 90.06.08


PRIMARY PRODUCTION

R/V PROF.SIEDLECKI 90.06.11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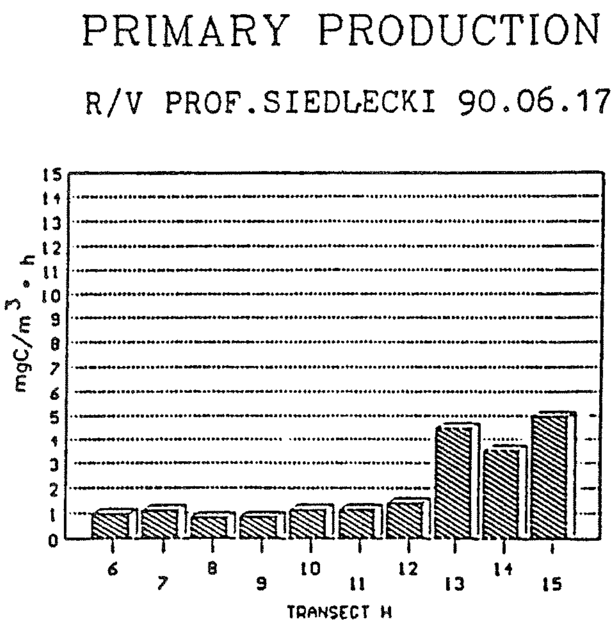
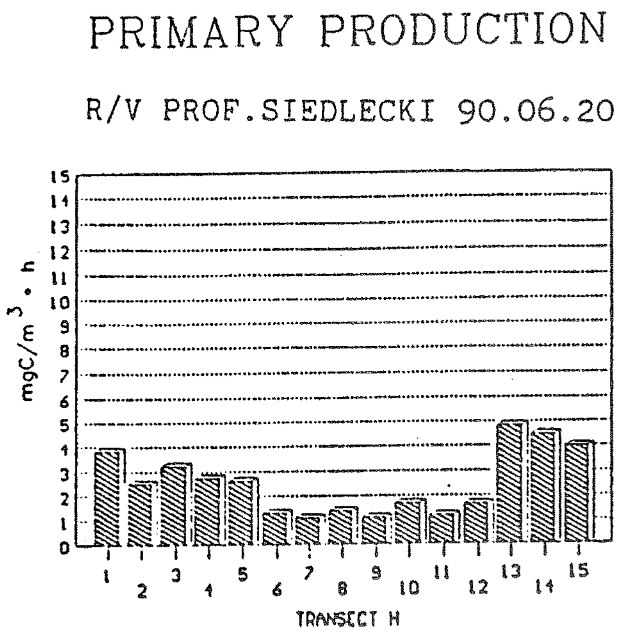
R/V PROF.SIEDLECKI 90.06.14


PRIMARY PRODUCTION

R/V PROF.SIEDLECKI 90.06.17


PRIMARY PRODUCTION

R/V PROF.SIEDLECKI 90.06.20

Fig.6. Potential primary production /mgC/M^{3}h/. SKAGEX 8-20 June 1990 /after Ochocki et al./.

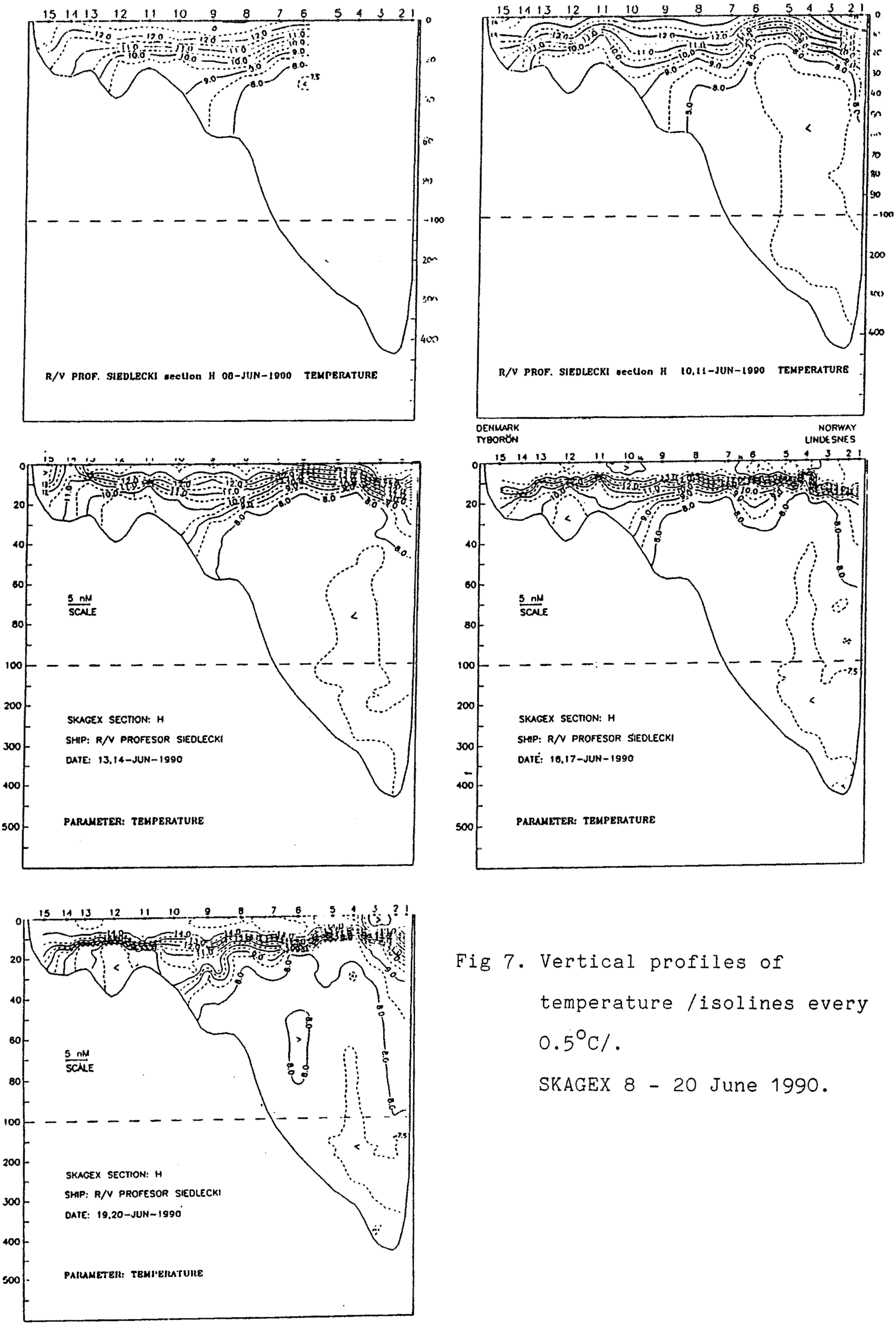
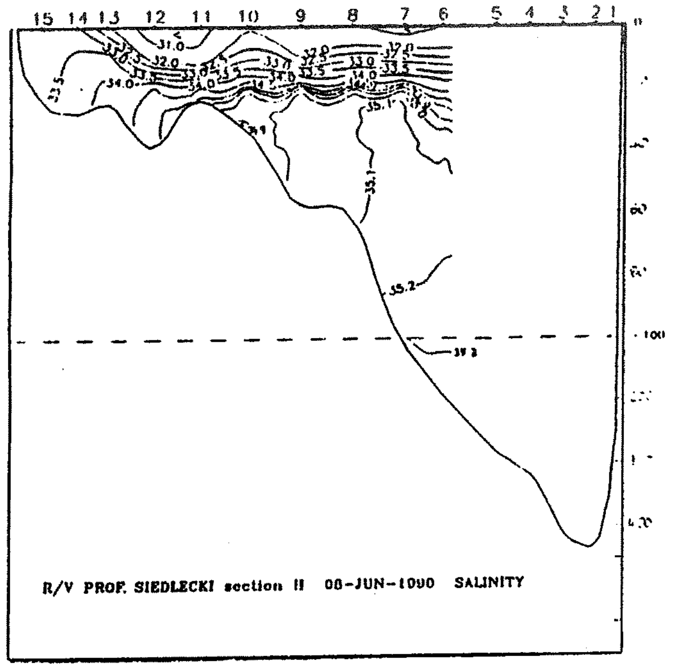
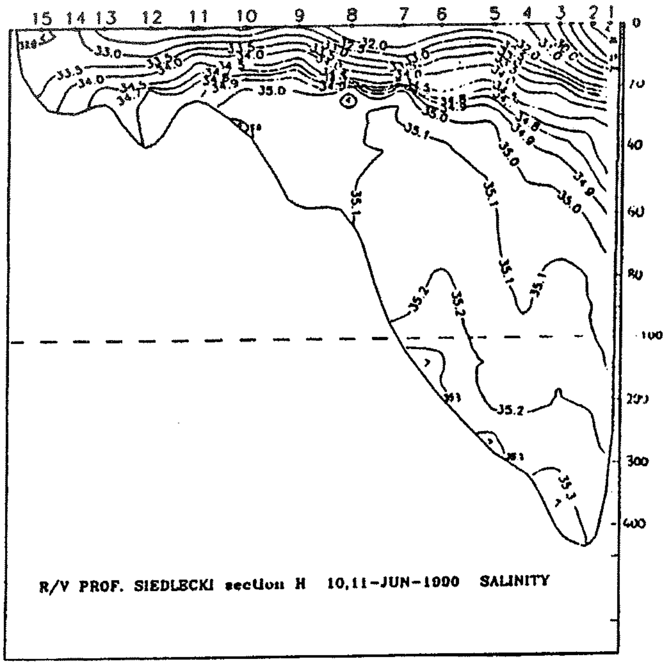
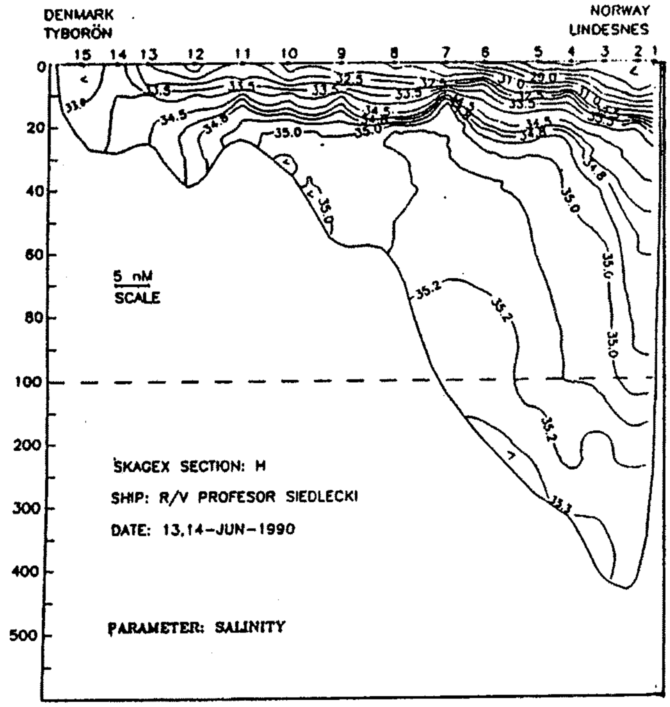
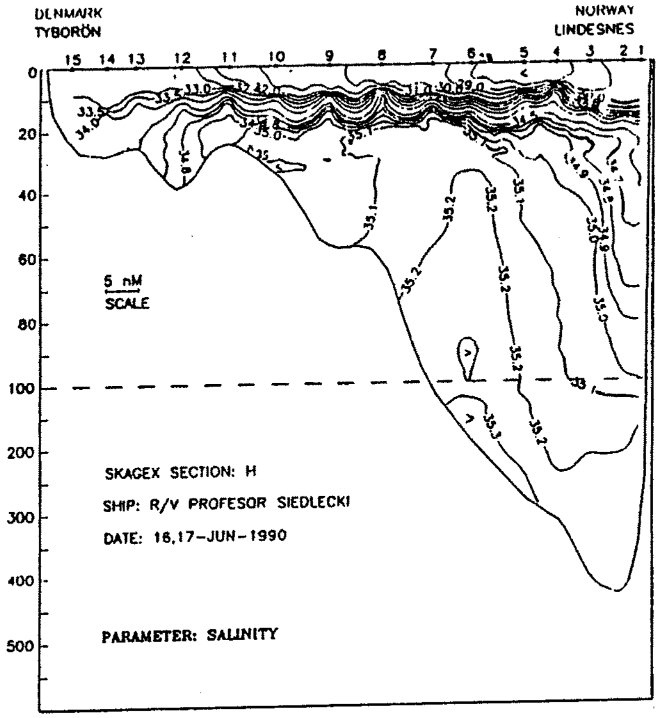


Fig 7. Vertical profiles of temperature /isolines every 0.5°C/.
SKAGEX 8 - 20 June 1990.









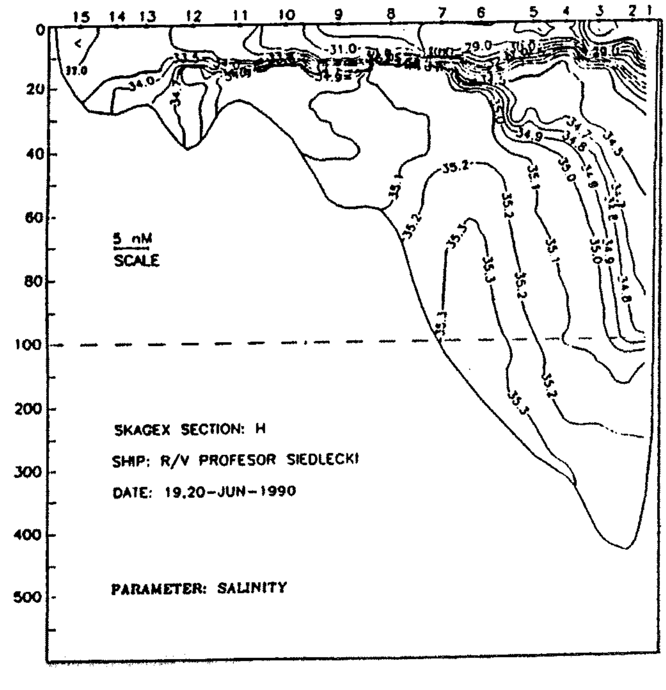


Fig. 8. Vertical profiles of salinity /PSU/. SKAGEX 8 - 20 June 1990.

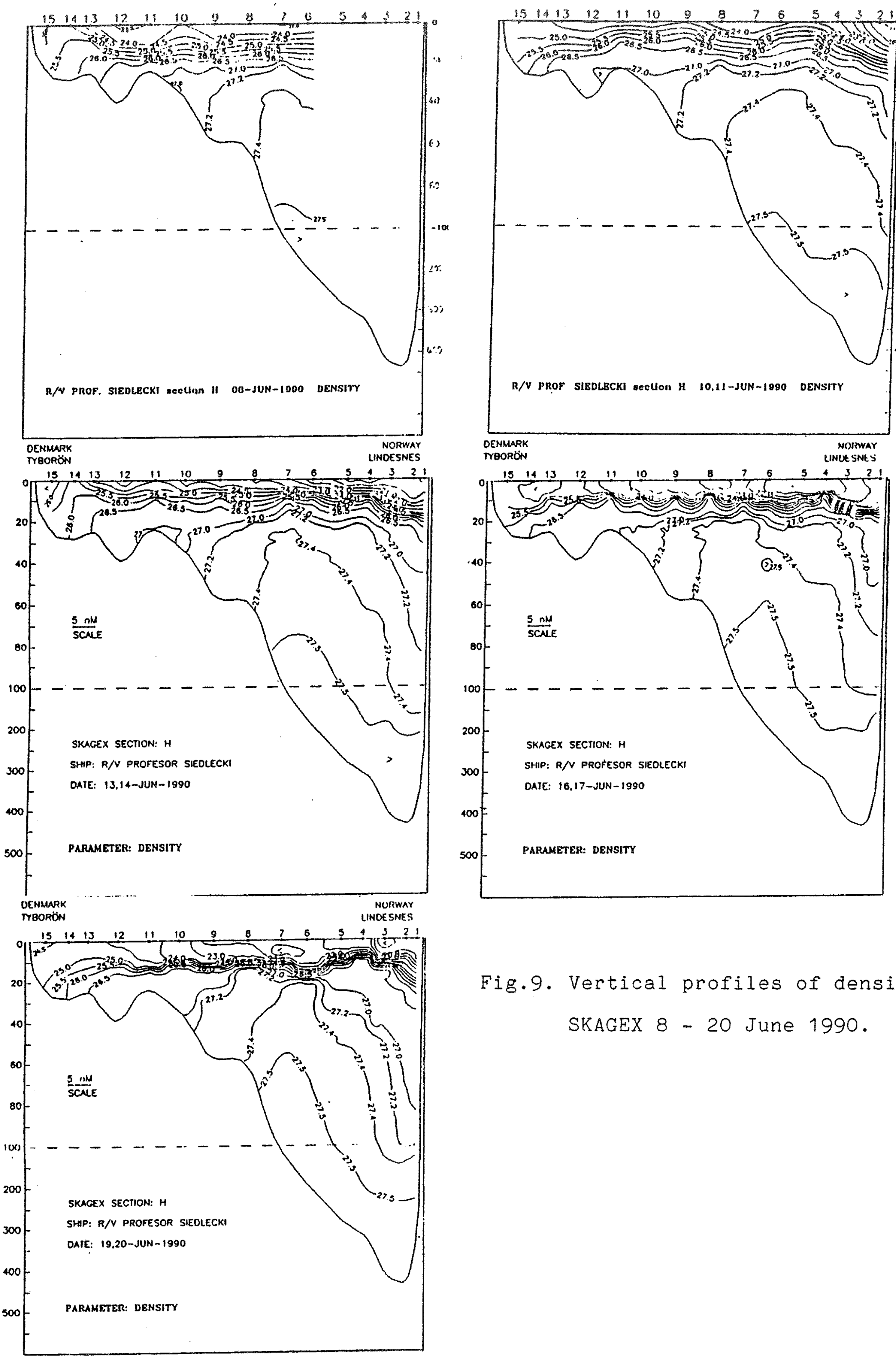
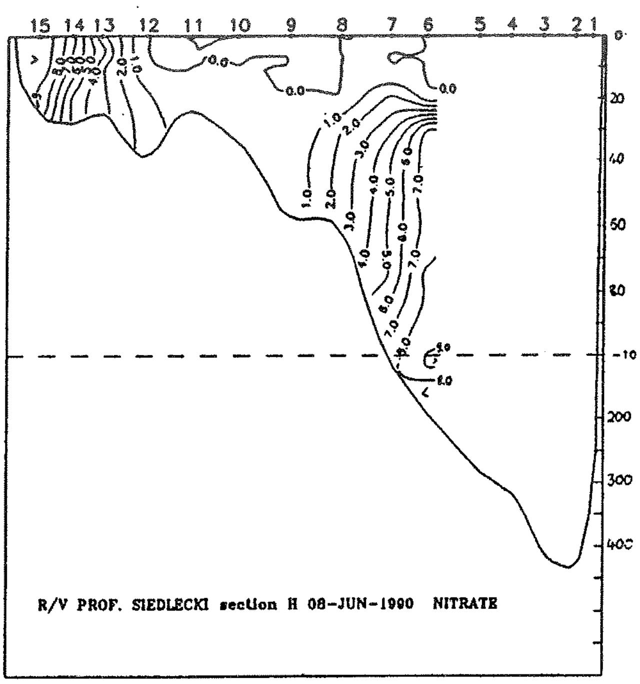
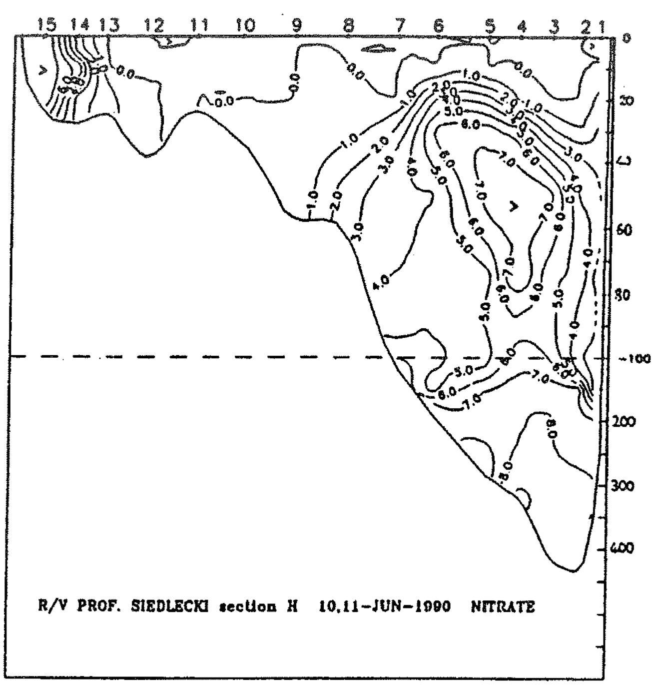
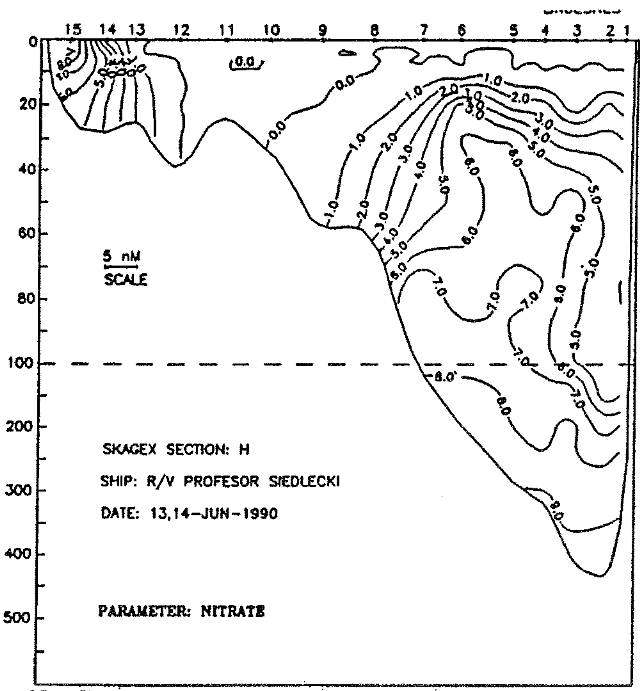
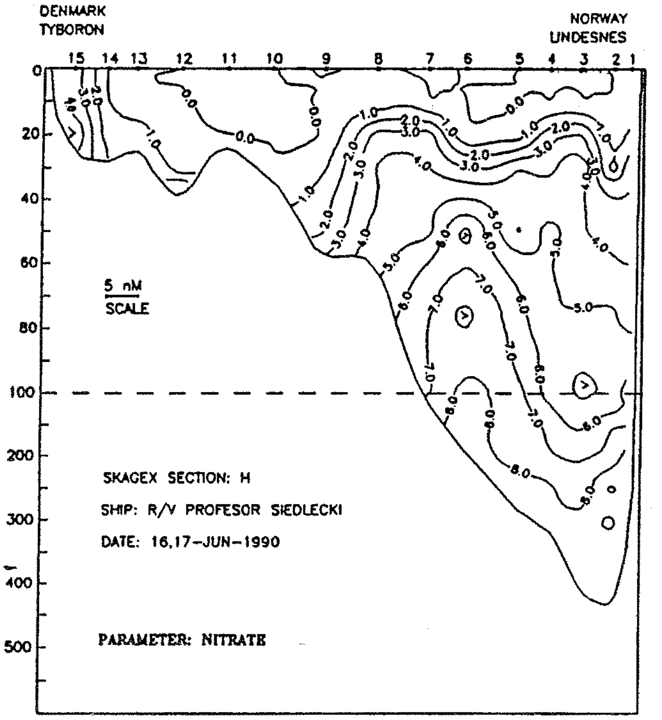


Fig.9. Vertical profiles of density.
SKAGEX 8 - 20 June 1990.









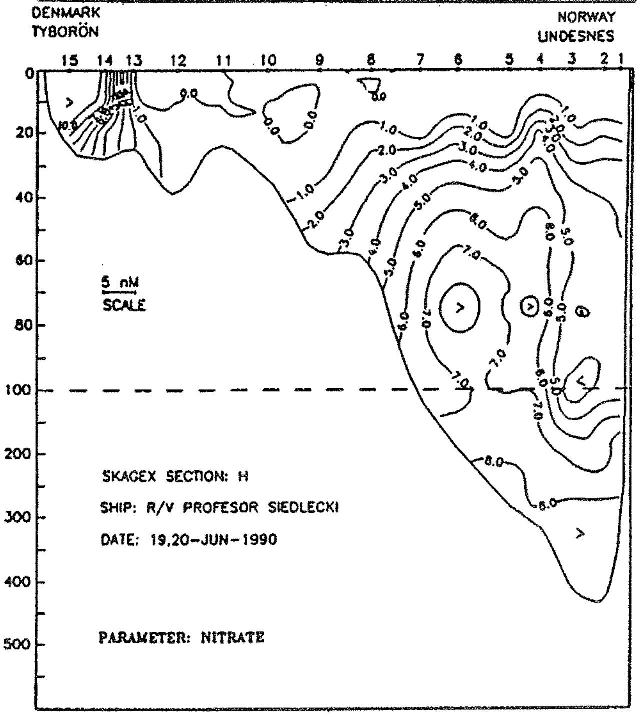


Fig.10. Vertical profiles of nitrates /umol/l/. SKAGEX 8 - 20 June 1990.

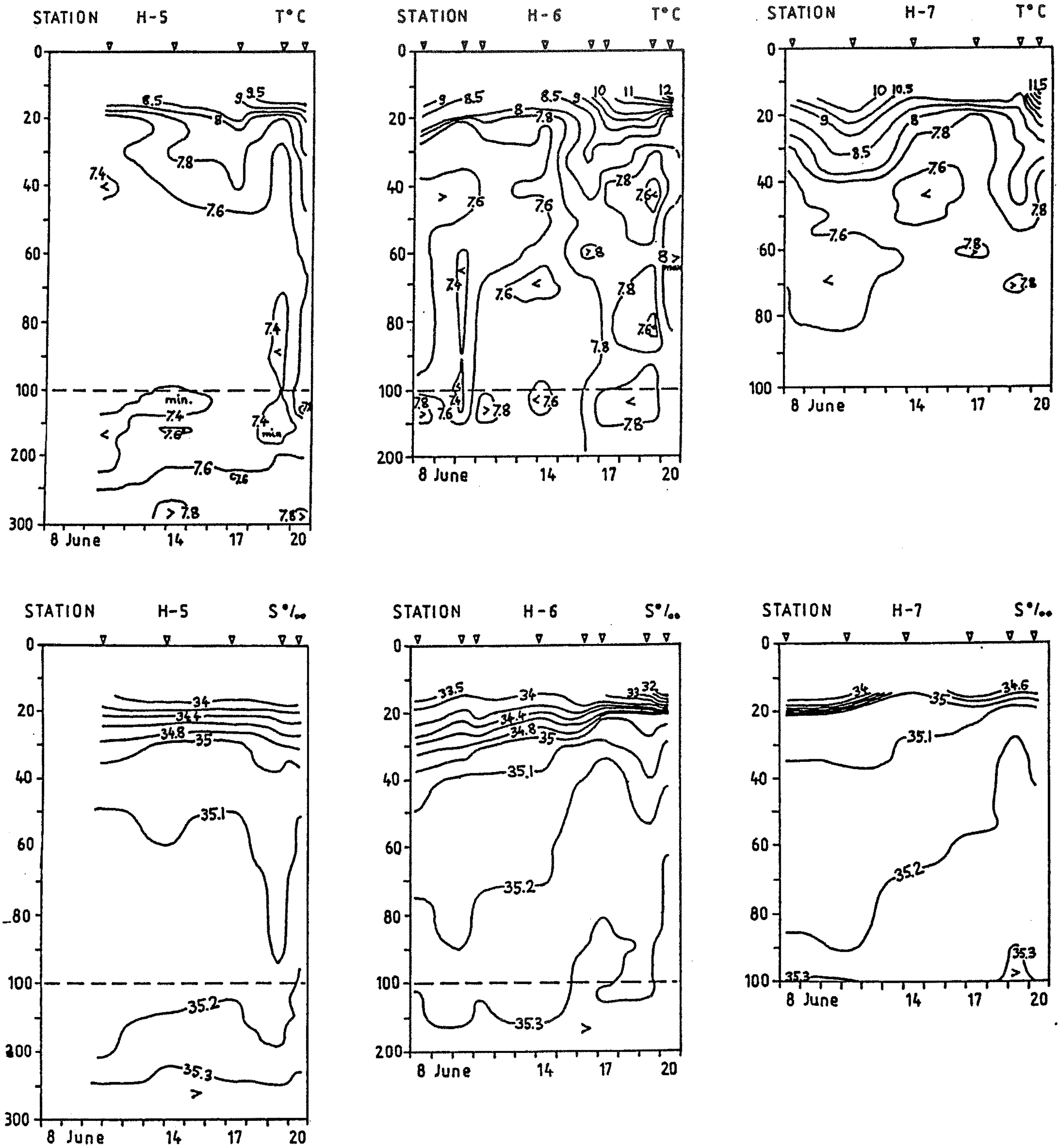


Fig.11. Isopleths of temparature and salinity at three stations in the middle of profile H. SKAGEX 8 - 20 June 1990.

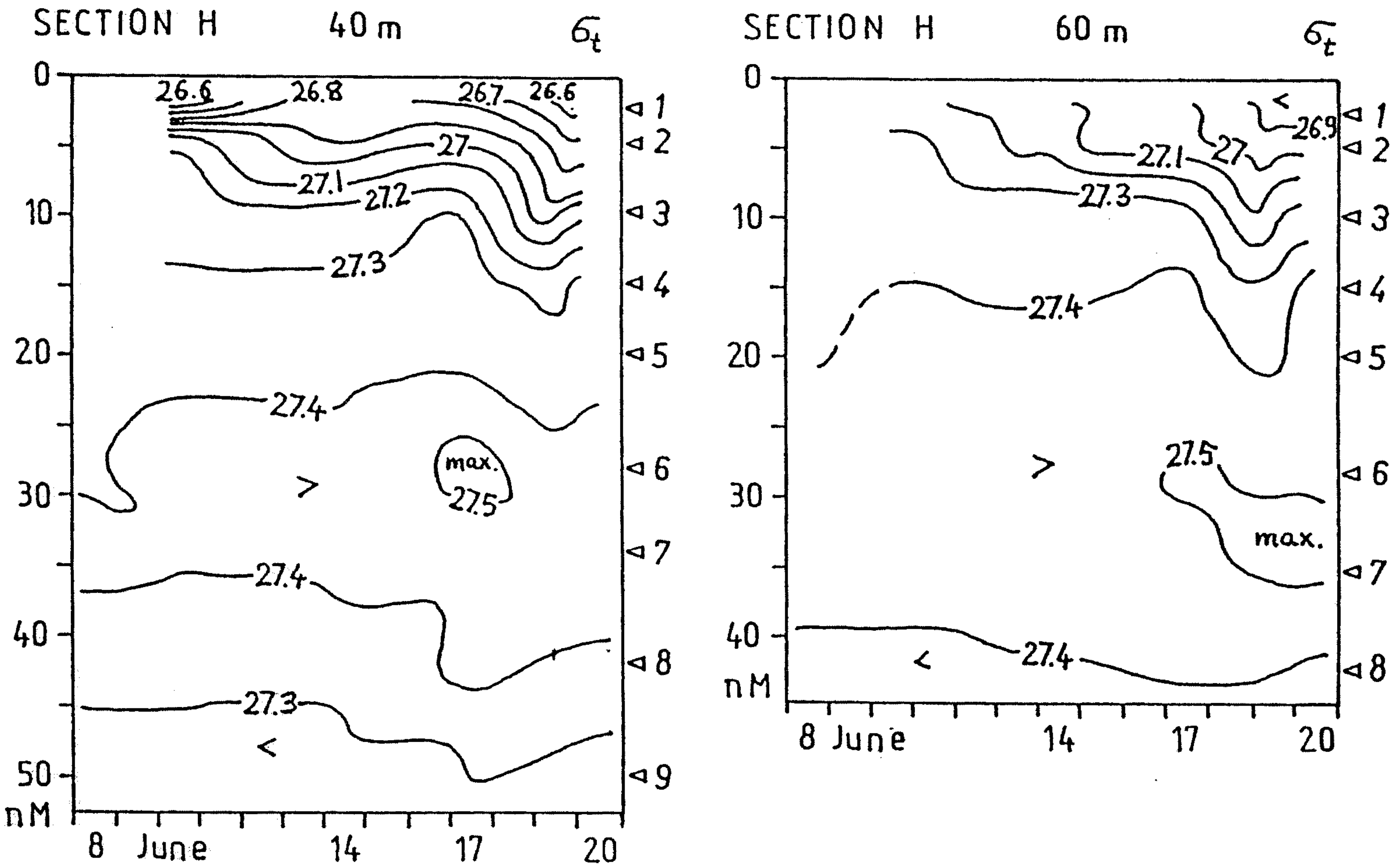


Fig.12 Isopleths of density at 40 and 60 m in the middle and northern part of profile H in days 8 - 20 June 1990.

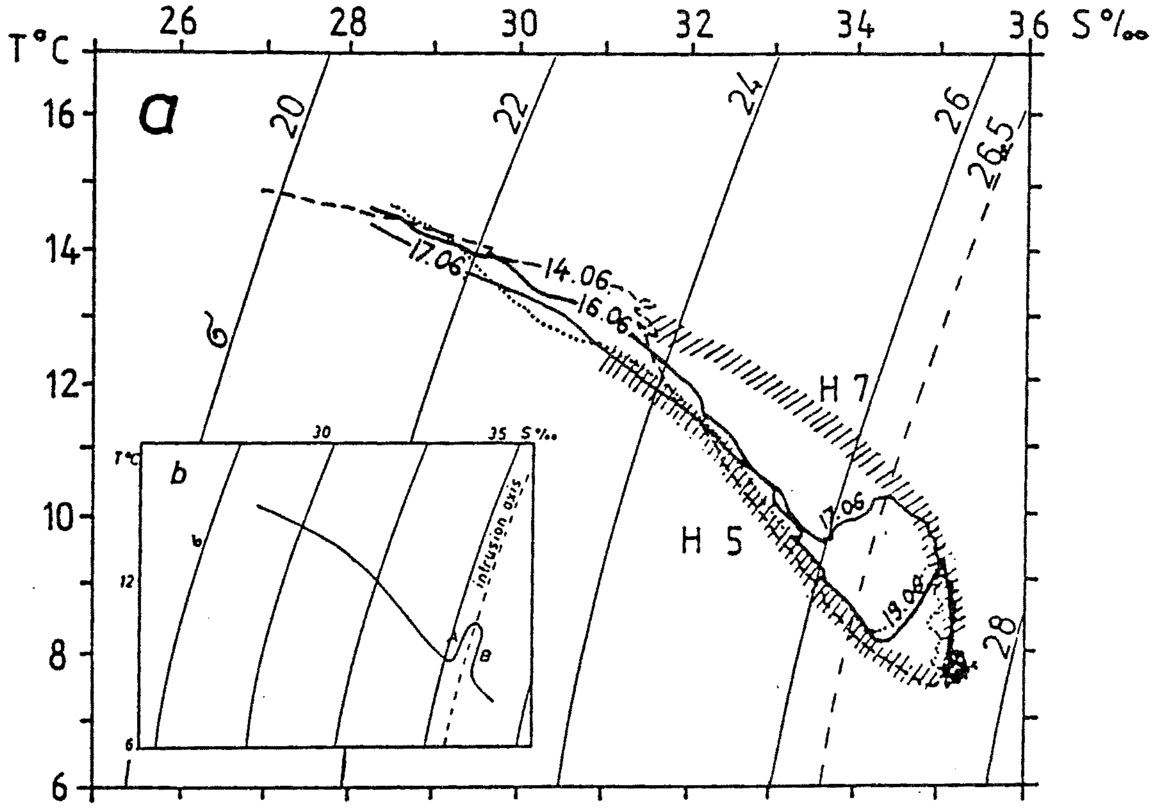


Fig 13. (a) T-S envelopes for stations H 6 and two neighboring stations /H 5 and H 7/, (b) a schematic diagram of T-S envelope favouring the lateral mixing. SKAGEX 14-19 June 1990.

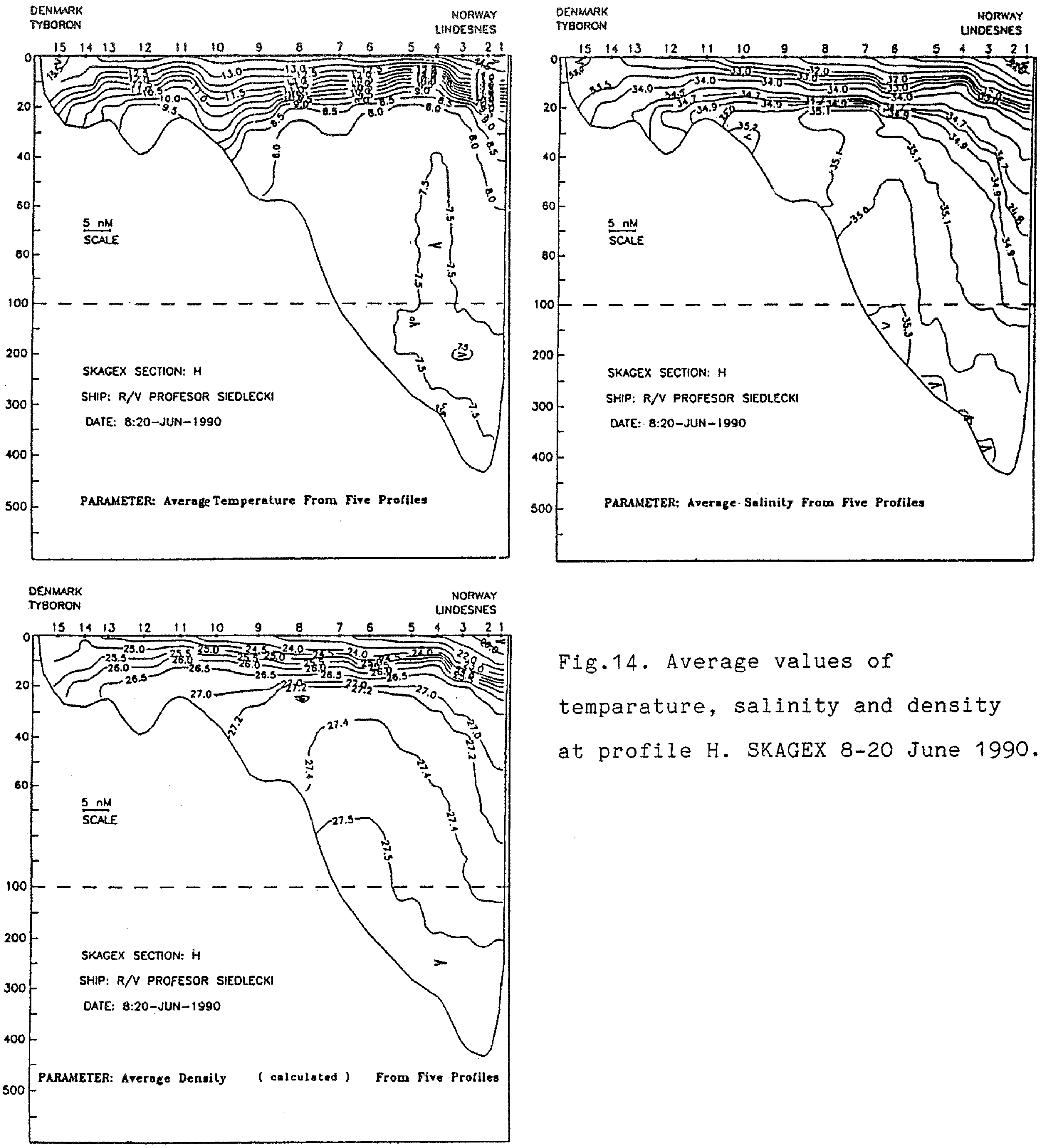


Fig.14. Average values of temparature, salinity and density at profile H. SKAGEX 8-20 June 1990.

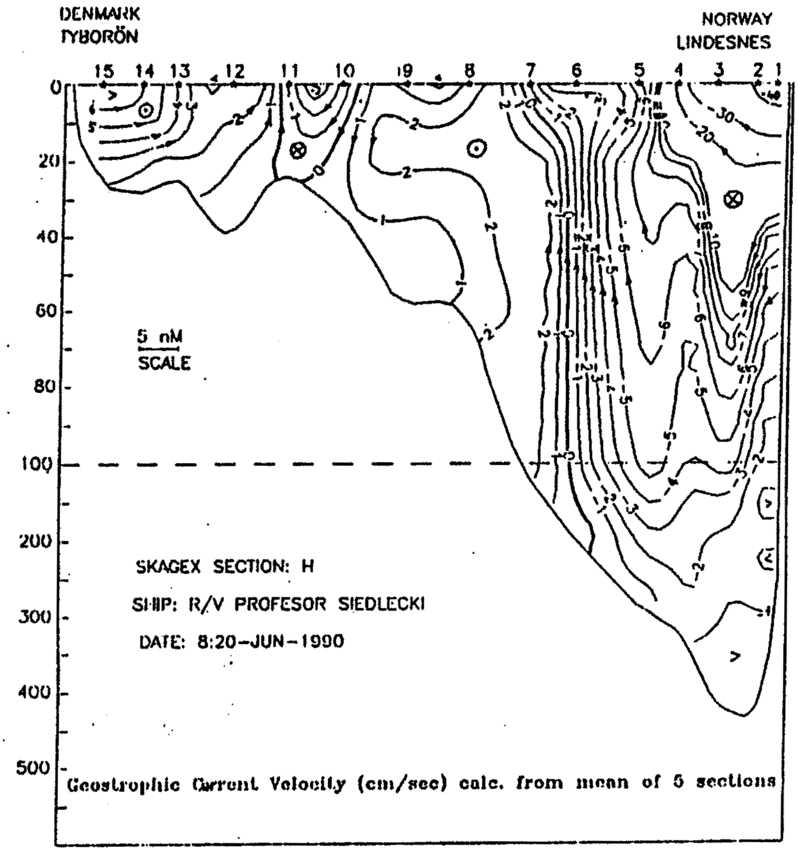


Fig.15. Mean values of geostrophic flow at profile H. SKAGEX 8 - 20 June 1990.

Presentation no 16.

Characteristics of the surface water in the eastern Skagerrak in June 1990.

by

A. Mamaev, S. Kirianov, D. Ivanov

CHARACTERISTICS OF THE SURFACE WATER IN THE EASTERN SKAGERRAK IN JUNE 1990

Alexander Mamaev, Sergey Kirianov, Dmitry Ivanov
State Oceanographic Institute,
Moscow

During the second stage of SKAGEX I R/V «Lev Titov» worked in the Eastern part of Skagerrak with its voluntary programme. The main purpose of the investigations was to obtain data on time and spatial variability of the chemical and biological fields in the surface waters above the «dome» area.

Data, obtained during the first stage of SKAGEX I, pointed to the existence of the comparatively warm and low saline water above the "dome" area. Some observations (Richardson, 1989) showed that strong shallow pycnocline might be one of the main reasons for algal blooms in the Central Skagerrak. In our opinion hydrological conditions in May - June 1990 under the warm and low saline surface water were favourable for the bloom. It was therefore interesting to look at the changes in hydrological and hydrochemical characteristics of this water mass. To confirm the existence of this water mass, in the beginning of the second stage of SKAGEX I R/V «Lev Titov» made transect T1 - T10 (Fig. 1). According to the Fig. 2a and b, the place for the beginning of the experiment was chosen in the point T3 with temperature of surface water 14,71°C and salinity 23,83‰.

To mark this watermass we deployed a surface drifter in point T3. The drifter was equipped with underwater sail and radar reflector. To obtain data on the spatial variability of parameters on a scale much less than the average distance between SKAGEX stations, measurements were undertaken in coordinates connected with the drifter at polygon «SPIDER» (Fig. 3) with 6 n.m. in diameter. Time variability was investigated by means of taking water samples in the vicinity of the drifter in 6 hours intervals during an 8 days period. CTD measurements were made to the depth of 50 m, water samples were taken from 0, 10 and 20 m. The following characteristics were measured: water temperature, salinity, pH, nitrite, nitrate, phosphate and silicate. Samples of phyto- and zooplankton determinations were also taken.

The Polygon of the oceanographic coordinates «SPIDER» included 37 stations, located at 6 transects. The distances between the stations at each transect was 1 n.m. Position of each station was determined from the vessel with the help of radar in polar coordinates, using the angle and the distance from the drifter, that served as a centre of the polygon.

It was noted that there had been evident patchiness of nutrients against the background of comparatively smooth fields of temperature and salinity (Fig. 4a, b, c, d). At polygon «SPIDER» their values differed by a factor of 10 or even more. Patches were from 1 to 3 n.m. in diameter but, as a whole, concentrations of nutrients in this waters were rather low.

Time variability of nutrients during the 8 days was even less than spatia variability at «SPIDER» polygon. Time variability of temperature (Fig. 5a) showe that in the first part of the drift the temperature had the tendency to becom higher and in the second part - to become lower. Maximums and minimum were due to the daily changes.

The plot of salinity (Fig. 5b) points to the two zones - with values of about 24% and 27‰. There was a zone between them where salinity changed very fast. As i was established from the trajectory coordinates, it happened just after the drifte had passed the eddy zone during the 14 and 15 of June. Based on these data it ma be suggested that this was the zone of the front between surface low saline wate of the central Skagerrak and the waters of the Jutland current.

The drift of our buoy was in the beginning rather slow, with velocities about 10- 20 cm/s and with several circkles. Then more than a day the drifter was in th region with intensive eddy activity (Fig. 6). Coefficient of horizontal turbulen diffusion estimated with the help of the second drifter by Richardson method wa here in the order of 10^6 cm/s. After the frontal zone velocities were about 20 - 3 sm/s, drifter turned to the Northeast. In the last period of the observations th drifter moved along the shore to the North-North-West with velocities up to 5 cm/s. On the Fig. 1 the trajectory of Argos buoy is also presented.

Fig. 7 shows nitrite and nitrate concentrations at transect T11-T17, made acros the eddy zone on June 14. In the centre of the transect there is some loca upwelling zone, or maybe some residual traces of this upwelling zone, or mayb some residual traces of this upwelling, because they appear mostly in nutrient and less in temperature and salinity.

Transect T18-T27 made through the drifting area just after taking the drifter o board the ship, showed that, in general, the structure of the investigated wate mass had not changed (Fig. 8 a, b, c, d). On the salinity plot it may be recognized a zone of low saline surface water, the frontal zone. The zone of the Jutlan current, strong shallow pycnocline and the upper part of the «dome». Under th pycnocline there is a little maximum of nutrients.

The position of the investigated water mass of lower salinity and highe temperature during the second stage of SKAGEX was obtained also from th pictures of satellite surface temperature and from the profiles of the standar Skagex transects.

It may be supposed that the formation of this surface water mass of low salinity i the Central and Eastern parts of the Skagerrak is one of the main reasones fo algal blooms. Formation of this water mass lead to very high vertical stability o the waters at the pycnocline. If this situation coincides in Spring with othe necessary conditions (water temperature, nutrients sufficiency, etc.) algal bloo may happen. In our opinion it should be payed more attention to the dynamics o the upper layers of Eastern Skagerrak in order to understand the formation o favourable conditions for algal blooms.

LITERATURE

Richardson, K. 1989. Phytoplankton distribution and activity in the Skagerrak: a review. ICES C.M. 1989/L:24, Sess.Q.

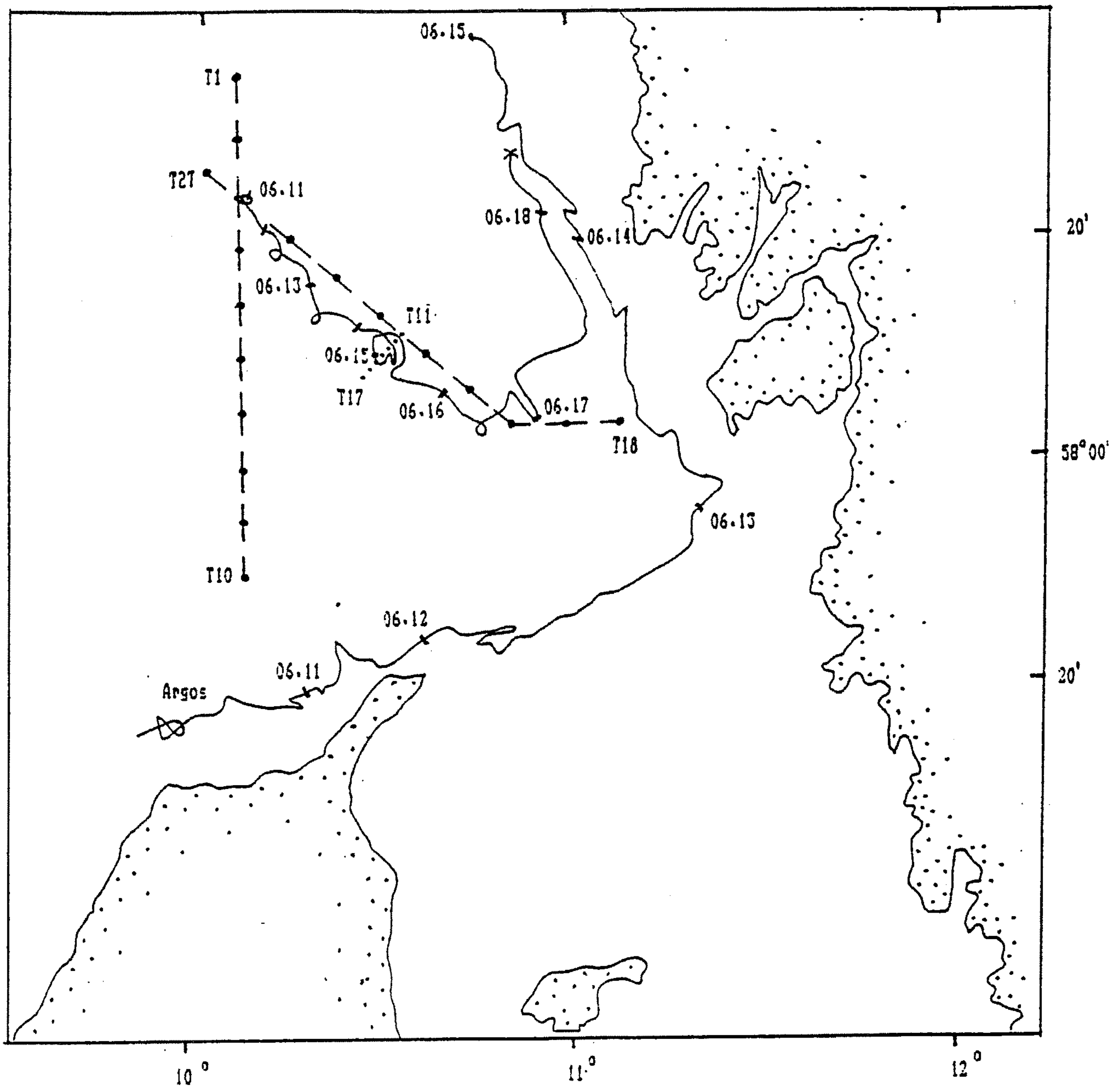


Fig. 1. Position of transects made by R/V Lev Titov during 09.06.90 - 18.06.90 and drifters trajectories.

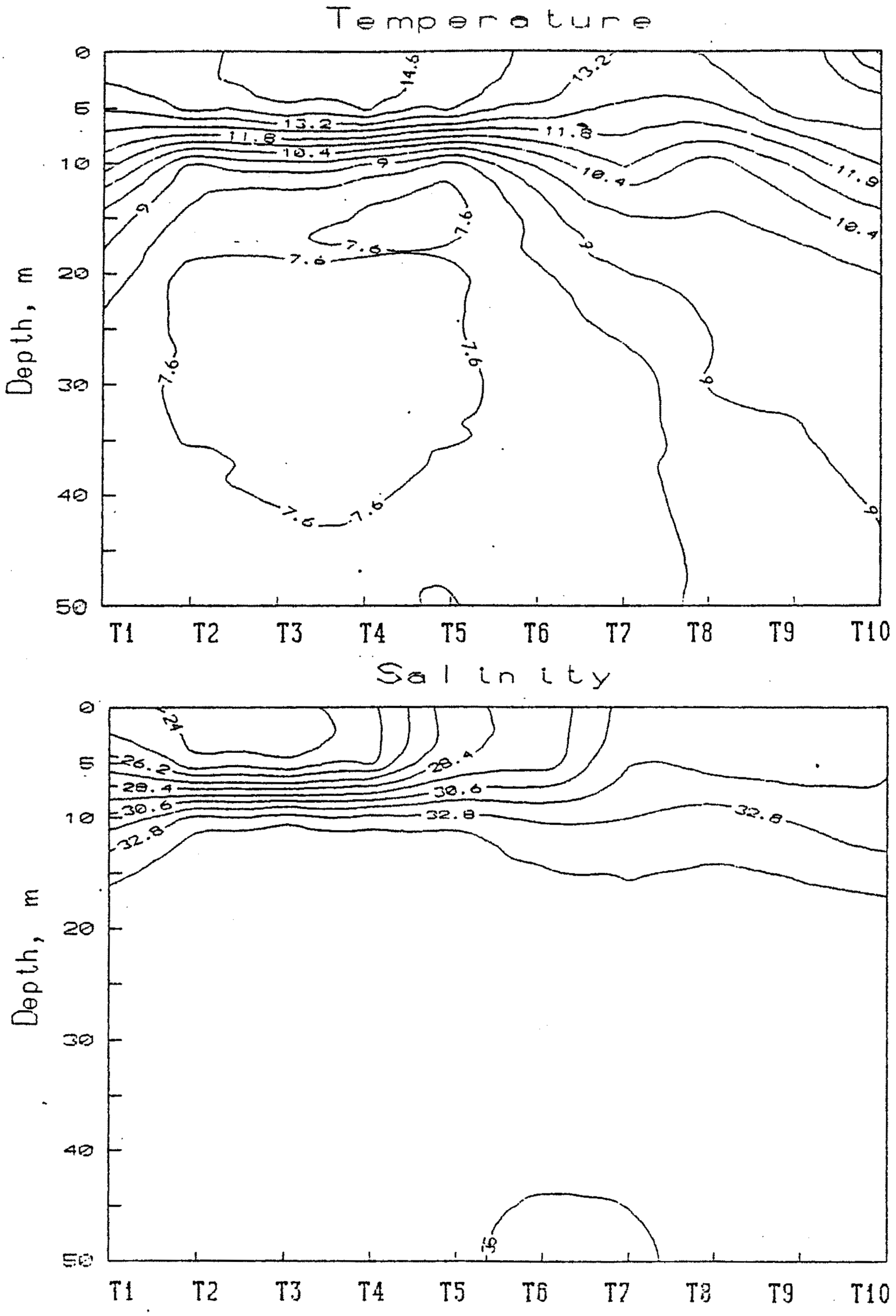


Fig. 2 a and b. Temperature and salinity distribution at section T1-T10, 09.06.90.

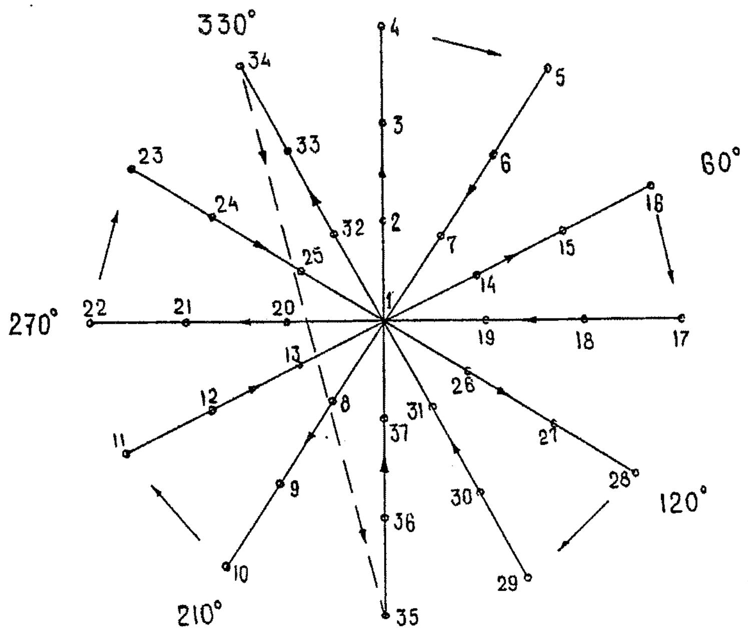


Fig. 3. Scheme of polygon SPIDER made by R/V Lev Titov in the vicinity of st. T3, 10.06.90-11.06.90

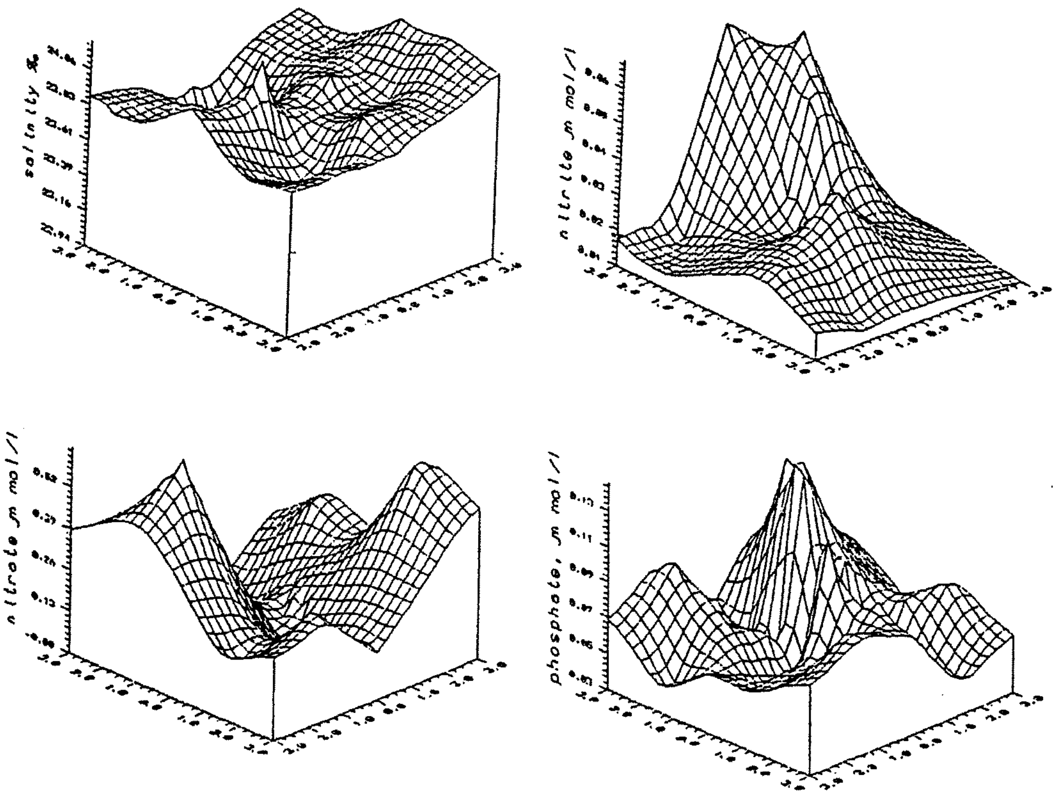


Fig. 4 a, b, c, d. Distribution of slainity, nitrite, nitrate and phosphate on the surface of the Skagerrak at polygon SPIDER.

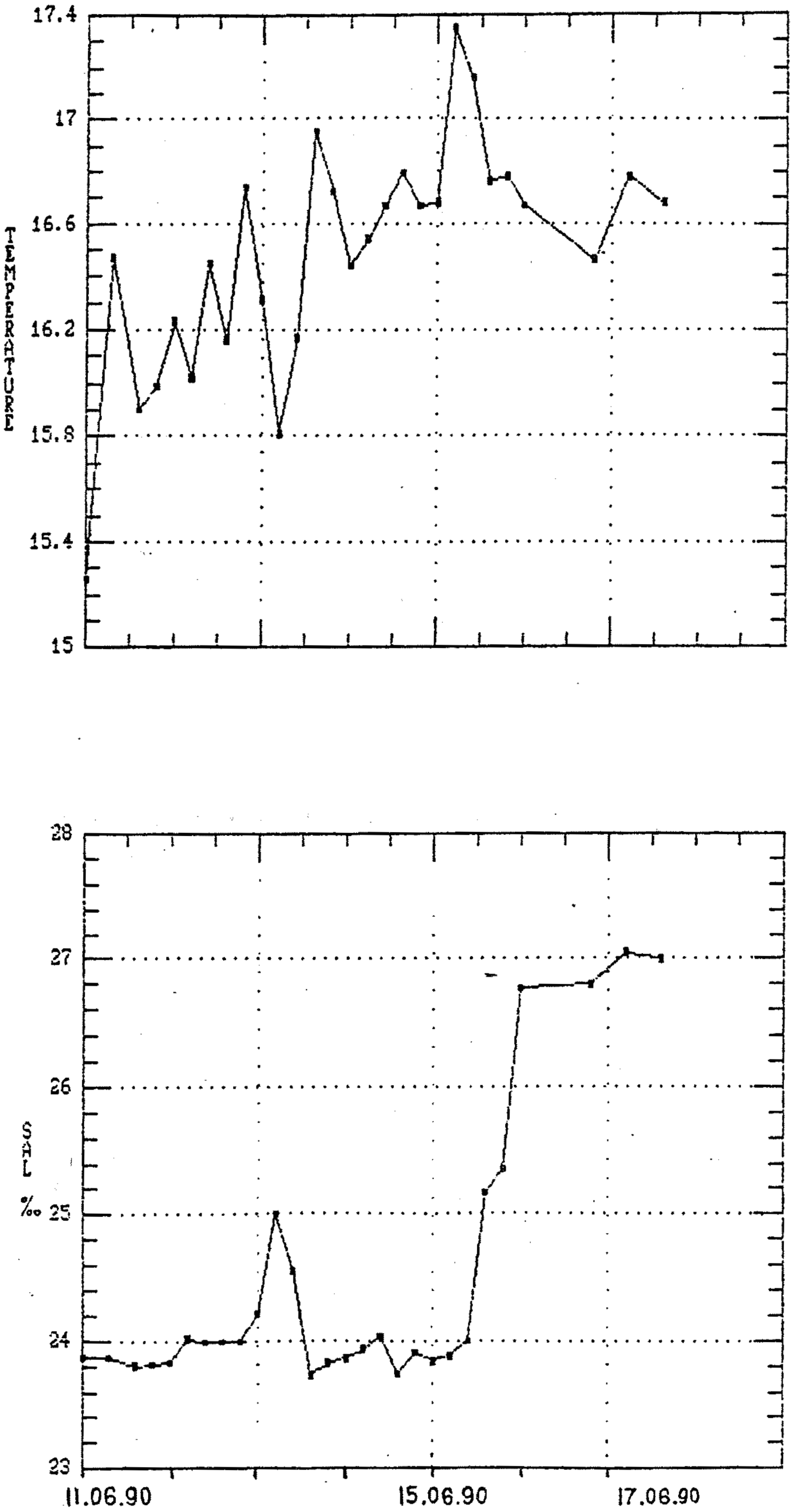


Fig. 5 a and b. Time variability of surface temperature and salinity near the drifter.

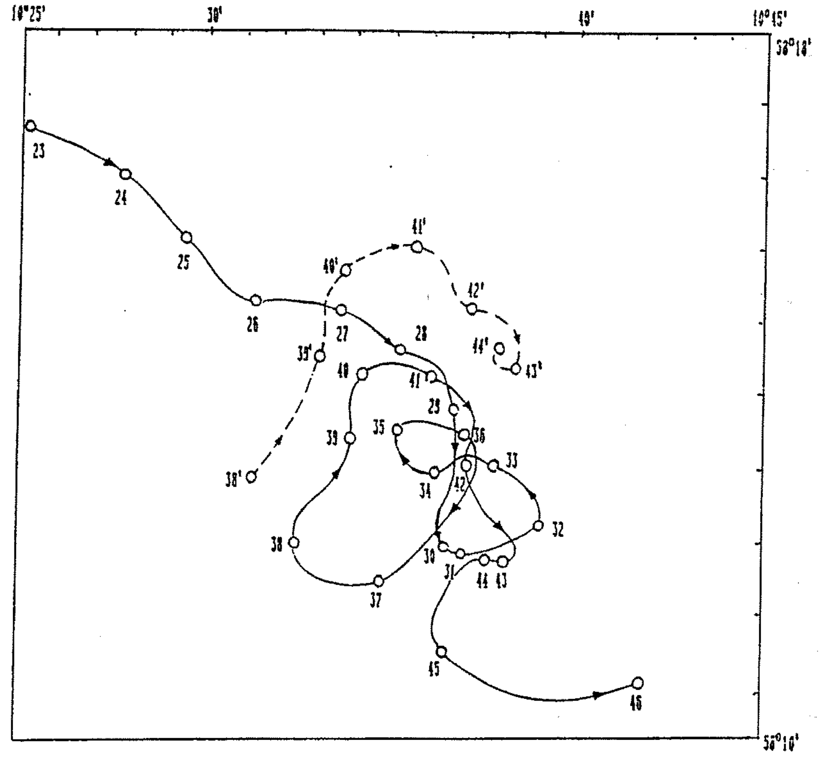


Fig. 6. Trajectories of two drifters in the frontal zone during 14-15 of June 1990. Dash line belongs to the second drifter.

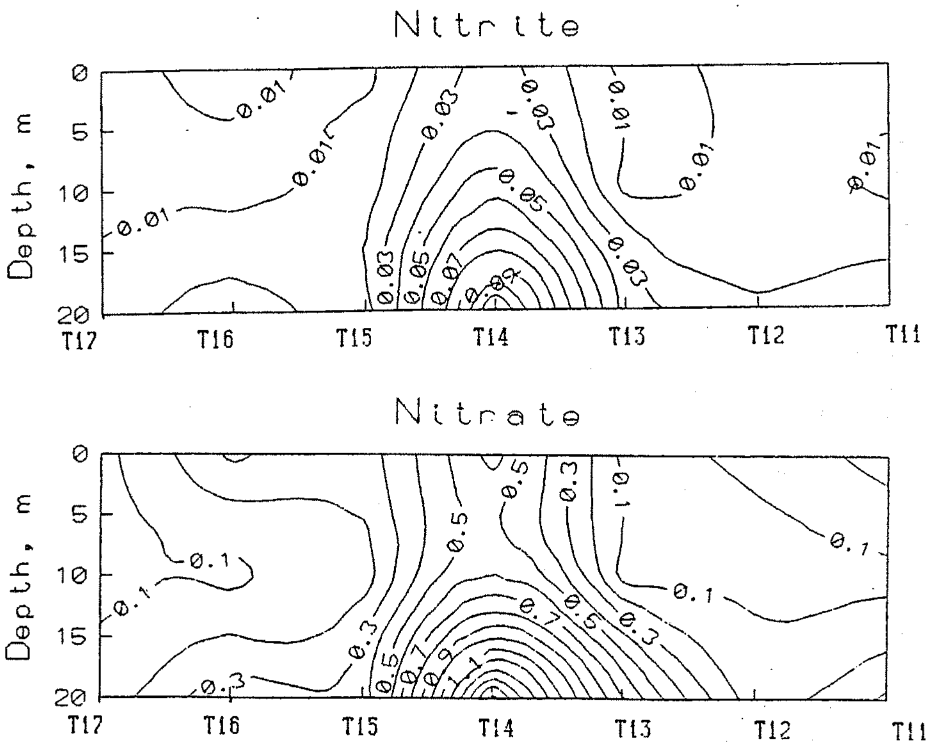


Fig. 7 a and b. Nitrite and nitrate concentrations (µmol/l) at transect T11-T17.

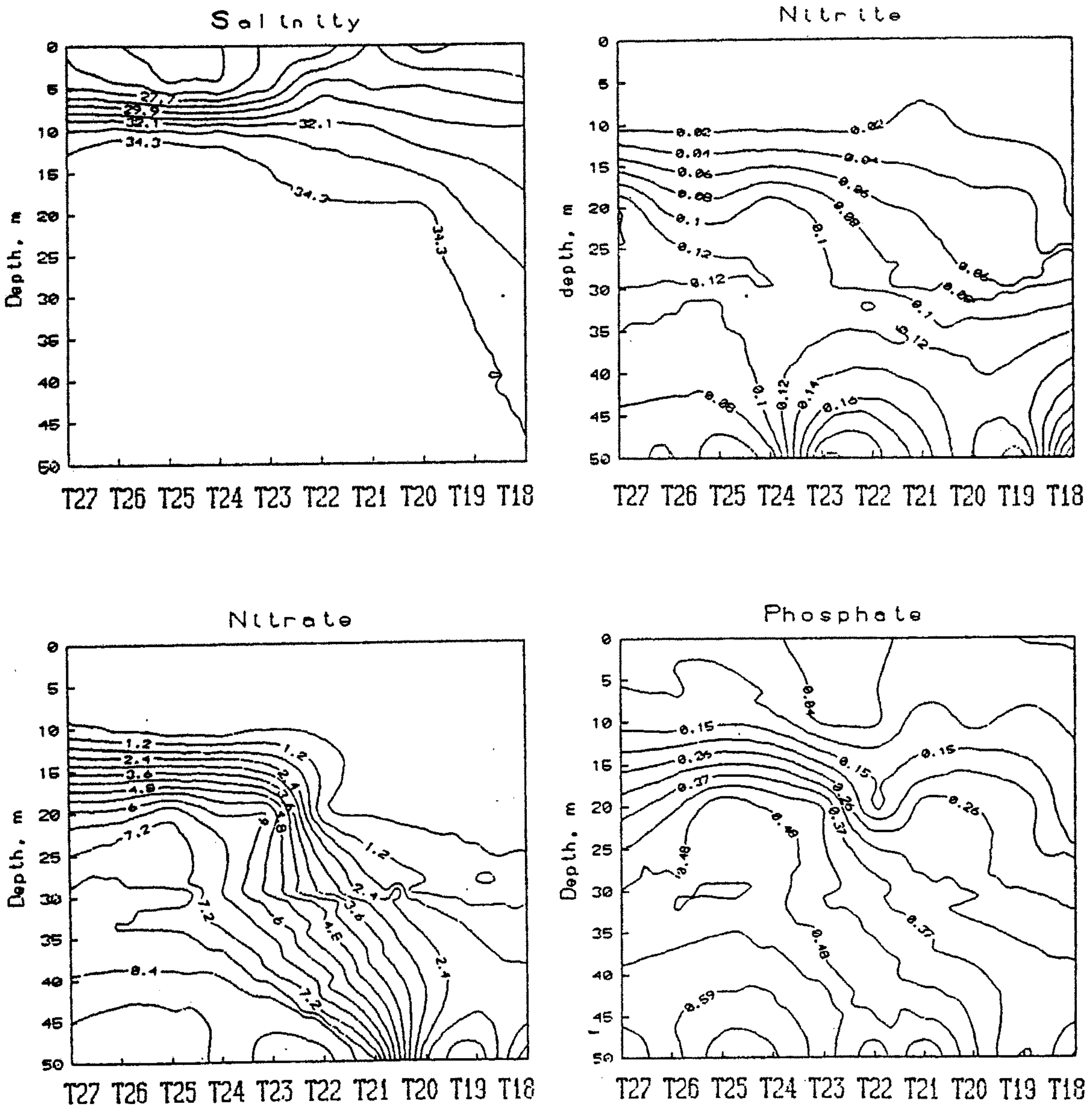


Fig. 8 a, b, c, d. Distribution of salinity (‰), nitrite, nitrate and phosphate (µmol/l) at trensect T18-T27, 18.06.90.

Presentation no 17.

Isolation of homogeneous water masses by the data of the Skagerrak experiment using cluster-analysis.

by

V. N. Maximov and V. V. Andrjuschenko

ISOLATION OF HOMOGENEOUS WATER MASSES BY THE DATA OF THE SKAGERRAK EXPERIMENT USING CLUSTER-ANALYSIS

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Introduction

By tradition water masses in the Skagerrak are isolated on the basis of hydrological data about their origin and by common oceanological parameters, like temperature and salinity, to which presently nitrate concentration is added in addition (Danielssen et al., 1991; Danielssen et al., 1992). The purpose of this work is to show, that the given problem may be solved using as a powerful method of multivariate statistics as cluster-analysis by K-means (Hartigan, 1975; Hartigan, Wong, 1979). The advantage of this method is a possibility to use all available hydrochemical data for identification and classification of water masses, to decide between them the most informative data and based on them to obtain more reliable and objective findings. Furthermore, analysis by K-means facilitates the estimation of statistical relationships between hydrochemical regime of particular water masses and their hydrobiological characteristics, that is one of a number of objectives specified by ICES in the SKAGEX project.

Preliminary analysis of basic data

The data collected at the obligatory stations of the transects C and E and kindly provided to us by Dr. M. Ostrowski in database form that he set up in the Institute of Oceanology of PAS in Sopot. As indices of the state of water masses were selected temperature, salinity, phosphate, nitrate, nitrite, silicate, oxygen and chlorophyll concentrations which were the most complete materials of SKAGEX I, SKAGEX II and SKAGEX IV.

First the estimation of the distribution character of all these variables with help of so called "stem-and-leaf plots" was carried out (Turkey, 1977). On these plots the marked asymmetry of nitrite, oxygen, chlorophyll distribution and bimodal distribution of nitrate, phosphate, salinity, temperature and silicate have been found.

On these plots quartiles of distributions and maximum and minimum values have been defined with taking account of strays (Table 1). The obtained findings show clearly that for using of multivariate statistical analysis of the collected material the methods based on the notions of normal distribution are completely unsuitable, in particular, such popular methods as factor analysis or principal component method. On the other hand, one can bargain for that the most pronounced classification of water masses will be gained with the use of parameters with bimodal or even polymodal distribution.

At the same time it was rational to choose between all above numerated variables only such ones, the character of variations of which has been more or less alike in all three experiments. In this case one can expect that the different types of water masses, found in every experiment, one can correlate with each other not to correct for seasonal or any random variations. Based on the data from Table 1, we have selected salinity, nitrate and phosphate concentrations for further analysis.

General remarks on the K-means method and its application to the classification of water masses

The peculiarity of the K-means method is that in accordance with its algorithm the objects under investigation are clustered in such way, that for all selected variables (features) within groups variance is a minimum, But between groups variance is a maximum. Therewith distance or similarity matrix between all its objects is not warranted to calculate as it is needed in common agglomerative hierarchical methods. For our task this advantage is of critical importance because values on 236 water samples collected at all depths of C1-C8 and E8-E12 stations for two days of work belonging to the SKAGEX IV data file to be of minimal body lied ahead. For this 27730 Euclidean distance or other metrics could calculate and then analyze the structure of resulting matrix. As for the SKAGESX I data file where the material have been collected for five days, these metrics could exceed 150000 in number. The extent of the corresponding computations is far in excess of ability of up-to-date programs on applied statistics and so warrants seeking help of supercomputers. Cluster-analysis by the K-means method for the same data takes not more than five minutes even using PC/XT.

It is well to bear in mind that the final result of clusteranalysis depends on choice of the scale of variables in use. This leads to certain problems when we need to deal with variables of different origin as in case of our task. To match the scales by different variable it is usually recommend to make their standardization that is substraction of arithmetic mean from all magnitudes of given variable and then a finding is divided by a standard deviation for the variable in given file. We consider that this procedure is poorly adequate for our task as arithmetic mean and standard deviation are an estimation of the parameters of normal distribution, and as pointed out above, distribution of our variables differ noticeably from normal one. In addition, as values of arthmetic means and standard deviations for every variables differ somewhat in three data files such standardization makes further correlation of results of clusterization difficult for alternative experiments.

In this work we chose the scale for every variable so that ten units of scale were in the limits of its maximum variations. Such rearrangement is equivalent to standard practice in the construction of two-dimensional scatter plots, when both axes are uniform in length and with 10 ticks on each axis. To illustrate, it is known in the Skagerrak salinity may be changed from about 35,5‰ (in waters from Atlantic Ocean) to 15 - 15,5 ‰ in surface waters from the Kattegat (Kattegat Surface Waters - KWSW). So for salinity the rearrangement was X_{--1} = 0,5 (SALINITY - 15,5), in accordance with which salinity of 15,5 ‰ corresponds to the initial point of the scale and salinity of 35,5 ‰ is at the terminal point of this scale with ticks of 10. For phosphate concentration the rearrangement was Xphos = 10*[PO_4] and for nitrates it was decided to use that data without rearrangement because the great bulk of measurements has provided the values [NO_3] in the range from 0 to 10 µmol/l.

The specific feature of the K-means method is that a quantity of groups (clusters) are defined not under analysis, but it is given beforehand. Therewith there is no criterion to determine this number, if it is unknown a priori. Quality of clusterization could be inferred after running cluster-analysis by the size of distance between the centres of the clusters to be found and by the character of distribution of classified samples within every cluster due to their individual distance from its centre. We have tried to estimate the sizes of these distance that are typical for custom water masses in order to determine on their basis of a number of clusters. The latter value will be optimum in the sense that it corresponds to a number of water masses which actually existed in the sea area studied.

To do this we have taken advantage of available data of well known experiment devoted to patchiness investigation in the Baltic sea (Patchiness experiment - PEX). In this experiment, at the SLOPE GRID polygon all stations were located in homogeneous space by hydrology and essential differences by hydrological water composition are seen only above and below the pycnocline. So a priori we can expect that a number of cluster corresponding to distinct water masses must be equal to 2 or not more than 3 if we isolate discontinuity layer as a separate water body.

For example, in Table 2 values of distances between three clusters are given. They were isolated for SLOPE 2 and SLOPE 4 data files by salinity, nitrate and phosphate values, that were rearranged on the same principle as for SKAGEX data file. In Fig 1 distribution histograms of distances from the centre of clusters are shown. They are determined for the samples that were included in these clusters. We can conclude that the distance between the centres must be not less than 2.5 - 3.0 for clusters relevant to the different water masses. With this the maximum distance from the centre within each cluster must be not more than 1,8 - 2,0. These magnitudes were adopted as critical values for the choice of optional number of clusters on analysis of the SKAGEX data. Thus the PEX materials served us as the reference for the estimation of optimal clusterization of the SKAGEX data.

Results of cluster-analysis

K-means clustering carried out for three experiments each (SKAGEX I, SKAGEX II and SKAGEX IV), enhancing successively the given number of clusters. The process of clusterization was stopped when 1 - 2 values less than 2.5 appeared in distance matrix. The value from previous clusterization was adopted as optimum number of clusters. So it was found that in SKAGEX I and SKAGEX II it was isolated by 5 different water bodies whereas in SKAGEX IV six was isolated.

In Table 3 mean concentrations of salinity, nitrate and phosphate are given for isolated clusters as well as a quantity of samples to be related to each of clusters. In Fig. 2 distribution of these clusters in "Salinity - nitrate concentration" coordinates are shown. Correlation of clusters to be found by us with types of water masses that were described for the Skagerrak hitherto was made possible in these coordinates. We can state with assurance that A4, B2 and D5 clusters coincide virtually in between and they are nearest to the Norwegian Coastal Waterd (NCW) by the relationship of salinity and nitrate content. Also we can assign with certainty A5, B5 and D6 clusters to the type of Atlantic Waters low (AW_1). We can identify with less assurance three other groups of clusters that are closely related but occupied an intermediate position as to "classic" types of waters. A3, B3 and D2 clusters are nearest to the Southern North Sea Waters (SNSW), althoug its salinity is well below (in average). B4 cluster is closer to that for SNSW by salinity and nitrate content. As for phosphate concentration, and especially by distance in three-dimensional space (in salinity-nitrate-phosphate coordinates) it is undoubtedly in one group with A2 and D3 clusters which are near to the Central North Sea Waters (CNSW). So identified arbitrarily the group of A3-B4-D3 clusters as SNS (?) we denoted equally arbitrarily the group of as CNS (?). The group of A1-B1-D4 clusters that belongs without doubts to the same water body in all three SKAGEX experiments occupied intermediate position between Atlantic Waters high and Atlantic low, so we specified it as AW (?). At last D1 cluster integrating only 15 samples from the whole SKAGEX IV data file being reasonably distinct from other clusters, is brought nearest to the Jutland Coastal Waters (JCW) by salinity and nitrate content.

Discussion and perspectives

Along with any classification the isolation of distinct types of water masses must be considered as some intermediate stage of data working out following by more deep analysis of resulting material. In this case, for instance, we can deal with vertical distribution of isolated water masses, showing it in such way, as it did in Fig. 3. As it seems to us, the procedure like this is more clear than traditional vertical sections with isolines for each parameter. In addition it is more effective in terms of methodology because it provides multivariate instead of univariate approach to analysis of multidimentional phenomenon as in case of hydrochemical state of water body.

In addition there is no question that the information about distribution of all samples in the data file by isolated clusters to be obtained in the process of cluster-analysis is of great interest (Table 3). It is quite evident, that during SKAGEX II at C - E transect homogeneity of water masses was higher than during SKAGEX I and SKAGEX IV. We can suggest simple quantitative index of this homogeneity by type of indices of ecological diversity. As for instance, let us calculate for every cluster which fraction of the total quantity of N samples comprise n_2 samples in i-cluster. In this case the value $d = \sum pi^2$ will characterize theextent of homogeneity of water bodies in the same manner as the well known Simpson' index (Simpson, 1949) describes the species diversity of ecological community. We will get its maximum value equal to "1" when all samples belong to one type of water, namely to absolutely homogeneous water mass.

Naturally under further analysis we can also calculate mean values of the parameters for each separate water body that weren't used on clusterization. The detection of dynamics of these parameters is the most important both in time and in space in the limits of isolated water body. In Table 4 such data are given for chlorophyll, calculated for those water masses in which its concentration were determined during the experiment.

REFERENCES

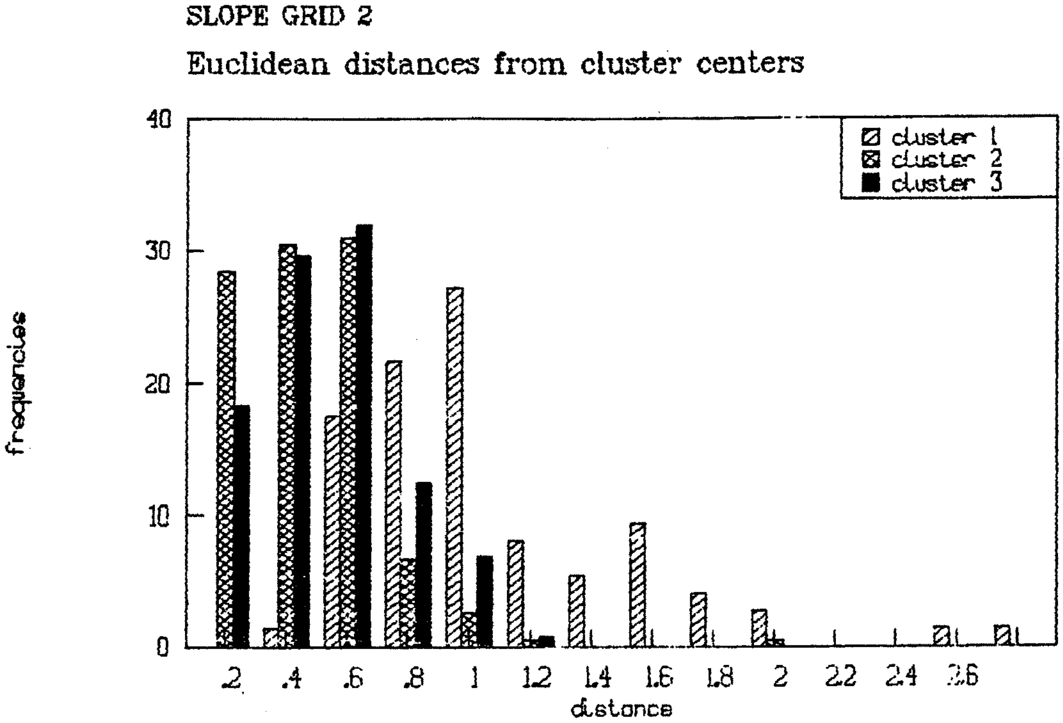
Danielssen, D.S., Davidsson L., Edler L., Fogelquist E., Fonselius S.H., Føyn L., Hernroth L., Hakansson B., Olsson I., Svendsen E. (1991): SKAGEX: Some preliminary results, ICES C.M. C:2.

Danielssen D.S., Edler L., Fonselius S.H., Hernroth L., Ostrowski M., Svendsen E., Talpsepp L. (1992): Oceanographic variability in Skagerrak/Northern Kattegat, May-June, 1990. Report from the SKAGEX Workshop. ICES. A.4.

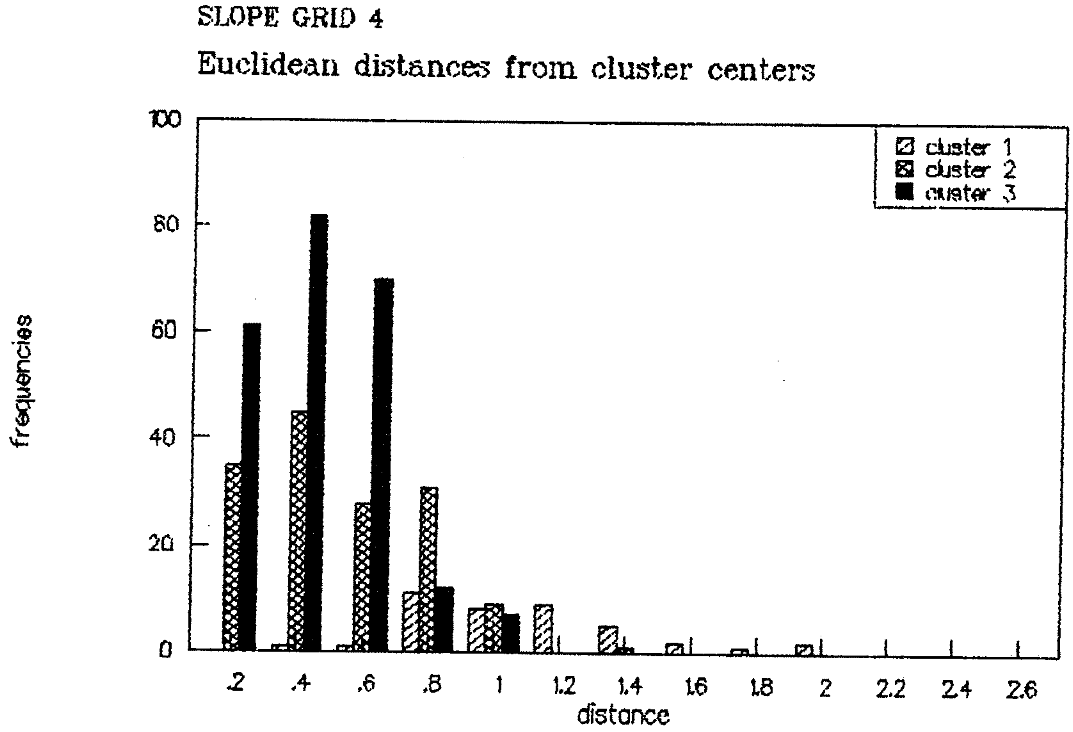
Hartigan J.A. (1975): Clustering algoriths N.Y. John Wiley & Sons.

Simpson E.H. (1949): Measurement of diversity. Nature, 163, 688.

Tukey J.W. (1977): Exploratory data analysis. Reading, Mas


SLOPE GRID 2

Euclidean distances from cluster centers


SLOPE GRID 4

Euclidean distances from cluster centers

Fig. 1 Frequency hystograms for single cases distance from cluster center in Patchiness Experiment (PEX).

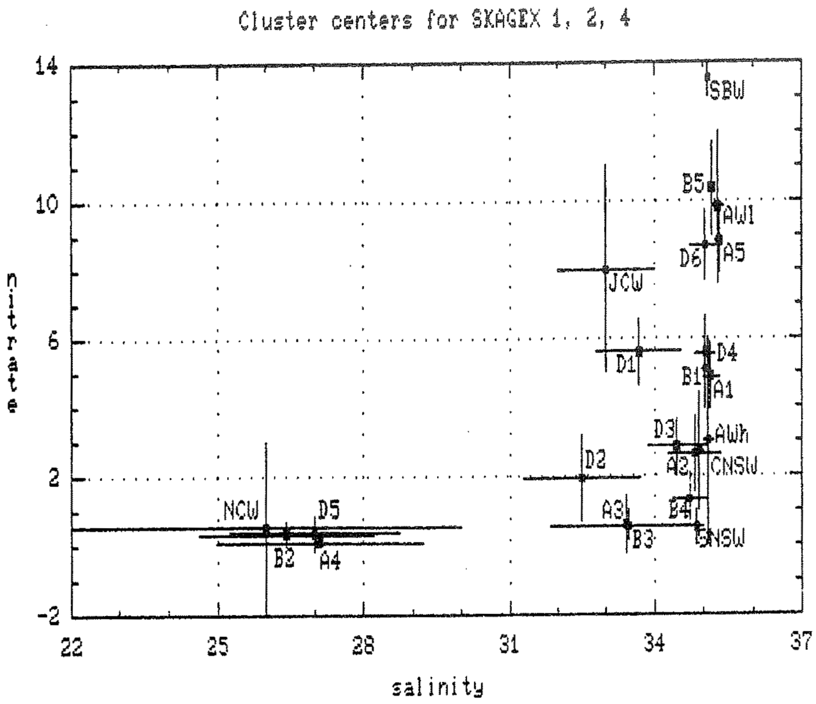


Fig. 2 Nitrate-salinity relations between different water masses (explanations see text).

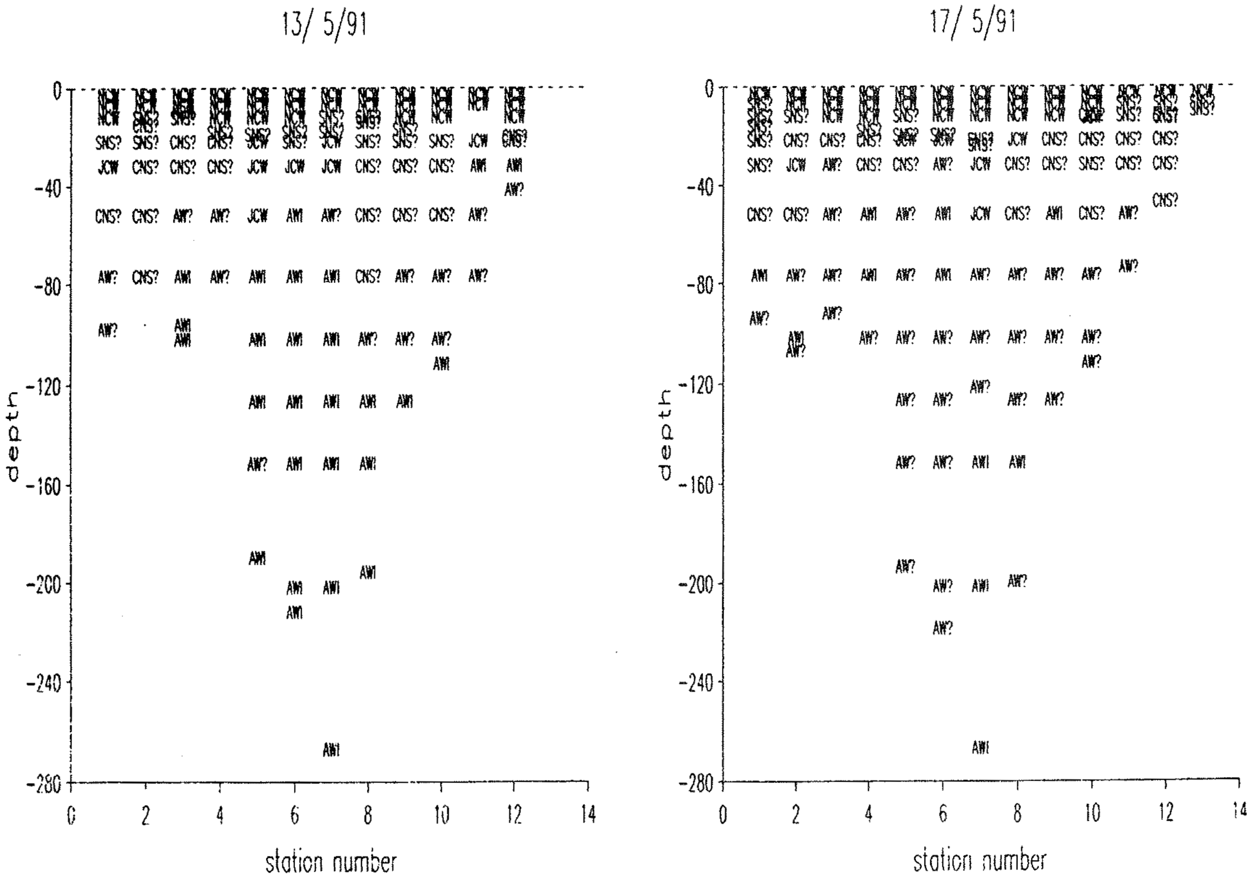


Fig. 3 Spatial distribution of water masses isolate by K-means clustering. Stations: 1-E12; 2-E11:; 3-E10, 4-E9; 5-E8; 6-C8; 7-C7; 8-C6; 9-C5; 10-C4; 11-C3; 12-C2; 13-C1.

Table 1.

Distribution parameters for hydrochemical variables

Variable	Experiment	min. stray	min	lower hinge	median	upper hinge	max	max. stray
Temperature	SKAGEX 1	-	7.35	7.67	8.06	11.01	14.23	-
	SKAGEX 2	-	7.58	9.40	14.75	15.56	16.79	-
	SKAGEX 4	-	5.27	6.18	6.55	7.43	9.10	10.31
Salinity	SKAGEX 1	18.37	25.90	31.48	35.08	35.23	35.42	-
	SKAGEX 2	24.19	31.10	33.43	33.97	34.99	35.26	-
	SKAGEX 4	-	23.79	30.21	34.35	35.06	35.28	-
Silicate	SKAGEX 1	-	.10	1.00	2.30	3.50	6.20	-
	SKAGEX 2	-	.00	.80	1.80	3.60	7.30	72.30
	SKAGEX 4	-	.16	.60	2.03	4.35	8.70	-
Phosphate	SKAGEX 1	-	.01	.05	.37	.58	.92	-
	SKAGEX 2	-	.01	.07	.13	.57	1.13	-
	SKAGEX 4	-	.01	.07	.39	.69	1.01	-
Nitrite	SKAGEX 1	-	.01	.02	.09	.21	.48	.84
	SKAGEX 2	-	.00	.01	.04	.21	.51	.66
	SKAGEX 4	-	.00	.02	.14	.22	.37	-
Nitrate	SKAGEX 1	-	.00	.10	2.90	5.80	10.30	-
	SKAGEX 2	-	.00	.30	.80	2.35	5.30	12.90
	SKAGEX 4	-	.00	.70	3.20	6.30	11.50	-
Oxygen	SKAGEX 1	-	5.82	6.33	6.51	6.80	7.50	8.06
	SKAGEX 2	-	4.91	5.39	5.69	5.96	6.55	-
	SKAGEX 4	-	5.34	6.42	6.93	7.30	8.20	8.70
Chlorophyll	SKAGEX 1	-	.15	.61	.85	1.24	2.14	5.16
	SKAGEX 2	-	.01	.66	.93	1.28	2.13	6.61
	SKAGEX 4	-	.04	.66	.96	1.50	2.70	8.83

Table 2.

Euclidean distances between cluster centers in Slope Grids of PEX

Distance	Slope 2	Slope 4
D_{1-2}	7.693	7.439
D_{1-3}	9.480	9.857
D_{2-3}	2.189	2.914

Table 3.

Cluster means and standard deviations

Clusters	Salinity		Nitrate		Phosphate		Number of cases
	Means	STD	Means	STD	Means	STD	
A1	35.16	.16	4.90	.96	.532	.069	107
A2	34.82	.53	2.60	1.08	.348	.101	118
A3	33.42	1.57	.60	.84	.098	.066	90
A4	27.10	2.11	.10	.11	.025	.016	127
A5	35.32	.07	8.80	.88	.679	.068	121
B1	35.04	.09	5.10	1.20	.648	.090	32
B2	26.42	1.78	.30	.33	.089	.055	28
B3	33.48	.96	.60	.43	.094	.055	195
B4	34.72	.36	1.30	.78	.457	.129	47
B5	35.18	.06	10.30	1.32	.832	.085	49
D1	33.68	.88	5.60	.99	.399	.083	15
D2	32.50	1.22	1.90	1.22	.135	.083	35
D3	34.46	.60	2.80	.83	.445	.102	38
D4	35.04	.21	5.60	1.06	.724	.091	50
D5	27.00	1.74	.40	.48	.041	.024	60
D6	35.04	.31	8.70	.99	.739	.099	38

Note: A1-A5 - SKAGEX1; B1-B5 - SKAGEX2; D1-D6 - SKAGEX4.

Table 4.

Mean depths and Chlorophyll contents in isolated water masses.

Water Mass	Experiment	Mean Depth	Chlorophyll		Number of Cases
			Mean	Standard Deviation	
NCW	SKAGEX 1	4	.951	.656	127
	SKAGEX 2	3	1.044	.443	27
	SKAGEX 4	4	1.254	.912	58
SNS?	SKAGEX 1	13	1.263	.726	83
	SKAGEX 2	15	1.013	.653	180
	SKAGEX 4	14	2.006	1.965	33
CNS?	SKAGEX 1	22	1.043	.586	52
	SKAGEX 2	38	.806	.650	5
	SKAGEX 4	21	1.533	2.183	18
JCW	SKAGEX 4	20	.863	.645	7

Presentation no 18.

Current measurements in the northern Kattegat during SKAGEX in May - June 1990.

by

L. Rydberg

CURRENT MEASUREMENTS IN THE NORTHERN KATTEGAT DURING SKAGEX IN MAY-JUNE 1990.

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ABSTRACT

Current measurements were made in May - June 1990 along a cross-section in the northern Kattegat. The measurements were undertaken as a part of the international Skagerrak expedition, SKAGEX. Totally 18 current were meters deployed in six different moorings. The results are compared to other measurements during SKAGEX and to earlier current measurements in the area.

INTRODUCTION

The SKAGEX1 was a multiship, interdisciplinary expedition, undertaken in Skagerrak from 24 May - 21 June 1990. It was followed by another three short expeditions in 1990 and 1991. Some preliminary results from SKAGEX1 have been presented by Danielsson et al. (1991; 1992). Recording current meters were deployed in two cross-sections, one between Hanstholm and Kristiansand in the outer part of Skagerrak and another in the northern part of Kattegat, between Denmark and Sweden. The cross-section in Kattegat (see Fig 1), was chosen near to the Danish island Läsö, a short distance south of the current meter section used by Svansson (1984) but some few km north of the cross-section used by Andersson and Rydberg (1993). Here, some results from the cross-section at Läsö are presented and discussed in relation to other SKAGEX1 (hereafter SKAGEX) data.

Except for the current meter sections mentioned above, current measurements in the northern Kattegat are sparse. Svansson (1975) presented data from the joint Skagerrak expedition in 1966 and Dietrich (1951) summarized lightvessel data (surface currents, only) from Kattegat in relation to the wind. Results from single moorings at different sites near Läsö are also presented by Gustafsson and Otterstedt (1931), by Svansson (1984) and by Rossiter (1968), who reworked old measurements from the lightvessel Läsö Rende, west of Läsö.

CURRENT MEASUREMENTS

Six current meter moorings (Stns A1, A2, A4, A5, A6, A7) with totally 18 instruments (Aanderaa, RCM-4) were deployed in a cross-section on both sides of the island Läsö in the northern Kattegat (see Figs 1, 2). The deployment was made from 22-23 May and recovery from 19-20 June 1990. The maximum depth in this section is less than 100 m, the total width about 60 km and the cross-sectional area approx. $2*10^6$ km^2, of which less than 1/10 is in Läsö Rende on the west side of Läsö. A mooring on Stn A3 was to be deployed by another participant in SKAGEX. This was never done, however. Positions of each mooring including depths and working period for each instrument are shown in Table 1. Three instruments failed totally, and for another few, the working period was shortened for different reasons.

Most of the instruments were of an older type and did not have a salinity sensor. Moreover, for some of the instruments, the temperature and salinity sensors were not calibrated. Thus, decoding of data was done for velocity and direction, only. From these original data (measured in 10 min intervals), we calculated hourly mean velocity components in the N-S and the E-W direction. The results from this calculation are shown in Figs 3 a-f. For comparison with other data from SKAGEX, the corresponding daily mean velocities are shown in Table 2 a-b.

RESULTS

Figs 3a-c show the N-S velocity components and Figs 3d-f the E-W components. The tidal amplitude varies from 10 - 30 cm/s with negligible phase differences between the moorings. The amplitudes are larger in Läsö Rende where the depth is smaller and the tidal heights are also larger (see Svansson, 1975). The maximum volume flux due to tides is of the order of $10^5 m^3/s$.

In general, there are few prominent features in our measurements. The period from 29 May-4 June is characterized by an outflow on the Swedish side (Stn A1 and A2) with mean velocities of 10-30 cm/s in the upper 15 m. On Stn 4, on the other hand, near Läsö, the flow is inwards during this period indicating a cyclonic gyre east of Läsö. In Läsö Rende the mean flow is near zero in May. From 1-16 June the current is northgoing with mean velocities of 10-40 cm/s, mainly on Stn 6. On Stn 7, the currents are weaker or sometimes even southwards.

From 8-13 June there are high northward velocities on Stn A5, particularly at 15 m depth. In the beginning of that period the flow is northward also on Stn A1 and A2 (including Stn A6). After 10 June, the current on the Swedish side changes direction, giving rise to an anticyclonic gyre in the surface water.

In the deep water, represented by three current meters at 25 and 50 m, only the velocities are generally very small.

DISCUSSION

The mean circulation in Kattegat is dominated by an outflow of low saline water from the Baltic in the upper layer and an inflow of high saline deep water from the Skagerrak in the lower. Andersson and Rydberg (1993) measured, a few km south of our section, a yearly mean outflow of 55000 m^3/s (S=24 PSU) and an inflow of 40000 m^3/s (S=33 PSU) at deeper levels. Even though measurements from the central parts of our cross-section are missing (particularly Stn A3, but later also Stn A4), it is obvious that the mean circulation during SKAGEX is small compared to their results. This is particularly true for the deep water, where the inflow was very small. On the other hand, SKAGEX coincided with long periods of calm weather (see below) and thus low entrainment fluxes. An integration of the cross-section volume flux above 15m (i.e. the halocline depth) for the whole period indicate an ouflow of less than 10000 m^3/s east of Läsö, mainly in the vicinity of Stn A1. In Läsö Rende, the mean flow integrates to approx. 7000 m^3/s.

Tides, wind-driven motions and sea level differences between the Baltic Sea and the Kattegat imply large variations in the momentaneous volume fluxes, however. These fluxes are also related to the circulation in Skagerrak.

The sea level variations were moderate during SKAGEX. Daily mean sea levels in Kattegat and in the Baltic communicated by Lars Andersson at The Swedish Meteorological and Hydrological Institute, are shown in Fig 4. As mentioned, the winds were weak most of the time during SKAGEX (Danielsson et al, 1992) except for a NW near gale from 25 and 27 May, S near gale on 4 June and W near gale on 17 June.

According to the current measurements in the Hanstholm-Kristiansand section (Danielsson et al., 1991), the cyclonic circulation in Skagerrak was relatively weak (or possibly of normal strength, but somewhat variable) in the end of May. From 1 June the circulation increased to a maximum, occuring from 3-10 June. This period coincides with a period of large outflow from the Kattegat with maximum in the surface layer from 7-10 June. During these days, the surface water outflow in Kattegat may have approached 50000 m^3/s. After 10 June, the currents at Stn 1 changes direction to inwards, and the outflow decreases. This period also coincides with a decrease in the Baltic Sea water level of 10 cm (Fig 4).

The volume flux in Läsö Rende was near zero in May, but increased to northward, approx. 20000 m^3/s in the beginning of June. After 10 June there is a decrease again. Thus, it seems as if there is a coupling between a stronger Skagerrak circulation and increasing volume fluxes on the Danish side of Kattegat, including Stn A5, east of Läsö. On the other hand, a less strong Skagerrak circulation may be coupled to an outflow on the Swedish side of Kattegat, as is the case in the beginning of the SKAGEX period.

Danielsson et al. (1991) also shows vector plots from a drifter (ARGOS buoy) in the northern Kattegat. Except for the last few days, however during which the buoy was moving right through our cross-section the correlation between the movements of the Argos buoy and the currents observed at the cross-section is surprisingly weak, indicating that the frontal area in the northern Kattegat is very dynamic and that results from current observations are difficult to evaluate.

Finally, it must be noted that it is of greatest interest to understand how the circulation in Kattegat is related to the circulation in Skagerrak and to the outflow of low saline water from the Baltic. It is possible that the full SKAGEX dataset on currents and hydrography offers a much better insight into that kind of problem than given here. I believe that future quantitative approaches on the SKAGEX data, involving flux calculations based on salinity, is the proper step forward.

ACKNOWLEDGEMENT

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REFERENCES

Andersson, L. and Rydberg, L. 1993 Exchange of water and nutrients between the Skagerrak and the Kattegat. Est. Coast. Shelf Science. 36:159-181.

- 1988 Trends in nutrient and oxygen conditions within the Kattegat; Effects of local nutrient supply. Est. Coast. Shelf Science. 26:559-79.

Danielsson, D.S., Davidsson, L., Edler, L., Fogelquist, E., Fonselius, S., Föyn, L., Hernroth, L., Håkansson, B., Olsson, I. and Svendsen, E. 1991 SKAGEX: Some preliminary results. I.C.E.S. C.M. 1991/C:2. Hydrography Comm. Ref. E. 14 pp

Danielsson, D.S., Edler, L., Fonselius, S., Hernroth, L., Ostrowski, M., Svendsen, E. and Talpsepp, L. 1992 Oceanographic variability in Skagerrak / Northern Kattegat, May-June 1990. (manuscript). 12pp.

Dietrich, G. 1951 Oberflächenströmungen im Kattegatt, im Sund und in der Beltsee. Deut. Hydr. Z. 4:129-150.

Gustafsson, T. and Otterstedt, B. 1931 Strömmätningar i Kattegatt 1930. Sv. Hydr.-Biol. Komm. Skrift. Hydr. X. ..pp.

Rossiter, J.R. 1968 The analyses of tidal streams - Läsö Rende. Tidal Institute Internal Rep. 12:1-3.

Stigebrandt, A. 1983 A model for the exchange of water and salt between the Baltic and the Skagerrak. Journ. Phys. Ocean., 13:411-27.

Svansson, A. 1984 Hydrographic features of the Kattegat. Rapp.P.-v. Reun. Cons. int. Explor. Mer., 185:78-90.

Svansson, A., 1975 Physical and chemical oceanography of the Skagerrak and the Kattegat. Inst. of Marine Research, Lysekil, Sweden. Rep. no 1. 72 pp.

TABLE 1. Mooring positions, depth of current meters and working time for the instruments.

A1	57.20.7 N 11.49.5 E	
	8 m	22 May - 20 June
	16 m	22 May - 20 June
	25 m	22 May - 20 June
A2	57.19,8 N 11.42,6 E	
	8 m	22 May - 14 June
	15 m	22 May - 14 June
	25 m	-
	50 m	-
A4	57.18,0 N 11.26,2 E	
	8 m	22 May - 8 June
	15 m	22 May - 8 June
	25 m	22 May - 8 June
	50 m	22 May - 20 June
A5	57.17,2 N 11.18,0 E	
	8 m	22 May - 20 June
	15 m	22 May - 20 June
	25 m	-
A6	57.15,4 N 10.45,2 E	
	6 m	23 May - 19 June
	10 m	23 May - 14 June
A7	57.15,6 N 10.40.0 E	
	6 m	23 May - 19 June
	10 m	23 May - 19 June

Table 2 a. North(+)/south daily mean velocity components

DATE	A1-8	A1-16	A1-25	A2-8	A2-15	A4-8	A4-15	A4-25	A4-50	A5-8	A5-15	A6-6	A6-10	A7-6	A7-10
22/5	9.1*	1.7*	-.4*	-7.2*	2.7*	6.9*	-4.3*	-3.8*	-.1*	-9.2*	-20.9*	.0*	.0*	.0*	.0*
23/5	14.3	4.4	1.4	-2.9	.9	2.2	-4.3	-3.9	1.5	-3.6	-13.4	30.6*	-12.8*	-6.8*	-5.9*
24/5	12.9	-.5	.7	-10.5	.3	-1.2	-6.8	-6.0	-1.3	-6.7	-3.9	-19.4	-24.2	-17.3	-15.3
25/5	-9.2	-2.7	-6.2	-9.2	-7.9	-3.0	-7.6	-4.6	-.4	-16.2	-16.7	-1.6	4.5	-10.7	-2.7
26/5	-10.2	2.9	1.5	-12.5	-4.8	-2.3	-3.5	-2.7	3.7	-5.4	-18.3	5.6	3.7	-7.4	-2.4
27/5	-2.1	8.8	2.3	-8.3	-5.1	-5.6	-10.1	-10.8	-2.0	-4.5	-10.3	-10.9	-1.4	-19.6	-10.5
28/5	7.2	7.5	5.4	-1.0	.9	-14.5	-9.3	-9.4	-1.0	6.5	-6.3	9.0	13.2	-7.4	4.1
29/5	21.2	20.3	6.5	10.0	9.3	-26.2	-15.1	-11.4	-1.3	10.8	-4.4	8.9	4.3	-4.7	-1.5
30/5	26.8	12.7	4.0	9.2	7.9	-27.1	-12.0	-9.4	3.0	10.1	.5	5.9	1.3	13.3	7.8
31/5	30.9	8.5	4.0	9.7	7.2	-28.6	-24.1	-11.1	1.5	-5.9	-4.4	-6.2	-6.2	-4.1	-11.1
1/6	20.9	-.5	6.2	11.7	7.6	-13.1	-11.9	-7.9	4.2	-2.9	-7.4	10.3	7.2	-.9	.0
2/6	35.2	13.2	5.4	13.5	3.9	-15.5	-2.3	-4.7	.8	.5	-5.4	24.8	11.1	7.9	.5
3/6	36.6	7.0	3.2	8.1	-.4	4.2	3.3	4.6	4.1	-2.0	-5.3	21.7	.0	2.0	-8.0
4/6	18.2	-5.1	1.6	12.0	-8.1	-3.0	.9	1.4	4.2	-6.9	2.3	12.7	-5.1	4.4	-2.1
5/6	14.6	-1.8	-1.5	7.1	-8.4	-.2	4.1	2.0	5.2	-7.2	5.0	24.5	13.2	2.4	-5.6
6/6	6.4	-20.4	.0	1.6	-7.7	6.0	6.8	2.0	4.8	-9.4	-8.2	25.7	18.5	9.5	1.7
7/6	6.5	-18.0	5.5	5.6	-2.8	-5.4	-.1	1.8	2.8	-4.1	2.2	29.8	16.4	16.4	-.7
8/6	13.0	-17.9	5.9	1.1	-6.4	-21.5*	-8.7*	-5.2*	-2.5	3.2	14.9	40.2	23.3	19.1	-6.0
9/6	12.4	-17.6	5.0	12.2	-2.6	.0*	.0*	.0*	-2.5	10.5	15.6	21.0	12.7	15.8	-8.8
10/6	10.0	-11.2	.8	11.7	.5	.0*	.0*	.0*	-1.4	6.3	19.5	6.9	2.8	-3.7	-9.5
11/6	1.1	-1.0	-2.1	13.1	-5.2	.0*	.0*	.0*	-2.3	13.9	25.8	16.4	7.5	14.1	-.5
12/6	-11.7	-2.6	-3.0	1.4	-10.6	.0*	.0*	.0*	-2.4	-4.4	31.2	15.0	8.0	6.5	-3.4
13/6	-19.6	-4.7	-2.3	-10.2*	-12.4*	.0*	.0*	.0*	1.8	-1.4	18.4	21.6	10.4*	12.3	1.3
14/6	-19.2	-5.6	-3.2	.0*	.0*	.0*	.0*	.0*	6.0	-1.1	-1.2	29.9	.0*	7.2	-3.3
15/6	-1.3	-5.8	1.6	.0*	.0*	.0*	.0*	.0*	6.5	2.3	-10.7	28.6	.0*	9.4	-1.6
16/6	7.9	-1.6	4.6	.0*	.0*	.0*	.0*	.0*	4.8	3.3	-2.0	12.9	.0*	-9.5	-14.4
17/6	.6	4.2	3.3	.0*	.0*	.0*	.0*	.0*	.2	6.9	1.5	7.9	.0*	-8.7	-7.4
18/6	13.2	-6.6	2.3	.0*	.0*	.0*	.0*	.0*	1.2	6.0	.9	8.4	.0*	2.5	-1.5
19/6	20.0	-7.4	5.7	.0*	.0*	.0*	.0*	.0*	2.4	9.5	3.0	15.0*	.0*	-2.8*	-5.4*
20/6	23.6*	-9.1*	3.8*	.0*	.0*	.0*	.0*	.0*	1.5*	1.1*	1.8*	.0*	.0*	.0*	.0*

Table 2 b. East(+)/west daily mean velocity components

DATE	A1-8	A1-16	A1-25	A2-8	A2-15	A4-8	A4-15	A4-25	A4-50	A5-8	A5-15	A6-6	A6-10	A7-6	A7-10
22/5	-5.9*	-3.5*	2.3*	2.6*	3.8*	3.3*	5.3*	9.3*	2.8*	-1.0*	10.6*	.0*	.0*	.0*	.0*
23/5	-10.1	-1.0	1.3	-4.1	.4	-1.0	4.6	4.9	.5	-3.6	1.2	-.9*	-2.4*	1.4*	.3*
24/5	-9.7	3.4	3.3	.0	2.8	10.7	6.5	.2	2.3	-5.1	1.7	6.2	5.6	4.2	2.0
25/5	11.2	1.9	7.9	7.2	5.2	2.7	6.8	7.5	2.7	2.6	3.5	.8	7.3	6.8	1.2
26/5	-2.5	-.8	.5	-1.0	-1.6	-11.7	-5.9	-.3	-1.1	-6.8	3.0	-.9	3.4	1.7	2.6
27/5	-4.3	1.4	-3.0	3.6	-2.5	-.5	-4.1	-.4	-2.0	-8.8	-4.6	6.6	7.2	6.2	2.2
28/5	-2.4	-7.1	-5.5	1.7	-6.7	-7.3	-11.6	-4.4	-2.7	-.2	-1.1	4.6	.6	6.3	.8
29/5	-12.1	-7.9	-8.9	2.8	-2.5	-8.3	-6.9	-.6	-2.4	-1.3	.0	3.5	.5	2.5	-.4
30/5	-14.4	-7.3	-5.1	-4.0	-5.3	-1.7	-1.8	.5	.9	2.0	.4	-4.2	-3.1	-5.7	-3.9
31/5	-18.3	-2.2	-1.4	-2.2	-3.6	8.5	1.0	2.0	-3.5	1.4	1.0	5.8	.9	4.2	3.9
1/6	-16.2	-.4	-.2	-1.0	-2.0	8.4	3.1	4.0	-2.9	4.5	1.2	-6.2	-.6	1.6	.4
2/6	6.8	-3.3	4.9	5.8	1.0	12.1	2.5	4.4	-.3	6.7	2.9	-5.3	-7.8	-3.2	-.2
3/6	-2.4	-1.1	8.6	11.3	4.9	11.0	2.8	2.5	-.3	-7.7	-2.8	-2.2	-5.0	-4.7	2.1
4/6	3.0	6.8	7.5	17.4	17.6	11.1	3.5	-.3	-.1	-3.6	-5.7	-6.5	-2.4	-.4	1.3
5/6	8.5	8.1	9.5	9.3	13.5	2.7	3.2	.2	1.9	-.1	.9	5.9	-1.7	6.5	1.5
6/6	5.6	3.9	.2	7.3	11.8	8.9	6.5	.8	2.5	2.1	-.3	-4.6	.0	-1.0	-.4
7/6	1.7	1.9	1.2	5.9	7.8	6.2	.5	1.3	-2.3	1.3	-1.1	-17.7	-1.0	-1.5	.5
8/6	2.2	5.0	4.3	3.9	4.8	13.1*	.5*	-6.6*	.1	2.3	-1.2	-1.9	1.1	7.1	1.4
9/6	-7.0	4.6	1.7	2.1	9.5	.0*	.0*	.0*	-.6	3.4	.6	5.4	1.7	5.2	3.1
10/6	-2.3	3.8	-.6	-1.0	6.1	.0*	.0*	.0*	.5	.3	-1.4	8.0	.9	1.0	.4
11/6	-.3	-1.4	-1.2	-2.4	.8	.0*	.0*	.0*	1.6	-2.8	-.8	-4.6	-2.6	-1.5	-.1
12/6	9.4	.3	1.8	.7	.1	.0*	.0*	.0*	3.6	-2.5	-1.2	4.4	-1.2	-.6	.8
13/6	7.1	1.2	3.8	5.5*	3.6*	.0*	.0*	.0*	1.7	-4.1	-1.0	-3.5	-2.1*	-1.3	-.2
14/6	6.6	-.4	3.0	.0*	.0*	.0*	.0*	.0*	-1.9	-1.6	4.3	2.6	.0*	3.1	.7
15/6	5.9	.2	-.9	.0*	.0*	.0*	.0*	.0*	-3.8	-1.5	-1.6	.3	.0*	3.4	.3
16/6	.2	1.0	-.5	.0*	.0*	.0*	.0*	.0*	-.2	1.1	1.0	3.8	.0*	5.6	4.8
17/6	12.7	.0	.6	.0*	.0*	.0*	.0*	.0*	.9	5.2	.1	-.6	.0*	2.6	2.4
18/6	3.0	3.3	.5	.0*	.0*	.0*	.0*	.0*	.2	-2.5	-1.7	-2.3	.0*	.9	2.6
19/6	-1.1	5.7	1.0	.0*	.0*	.0*	.0*	.0*	-.6	4.0	5.3	-4.4*	.0*	-.8*	1.2*
20/6	-3.9*	9.4*	4.2*	.0*	.0*	.0*	.0*	.0*	1.8*	6.6*	2.5*	.0*	.0*	.0*	.0*

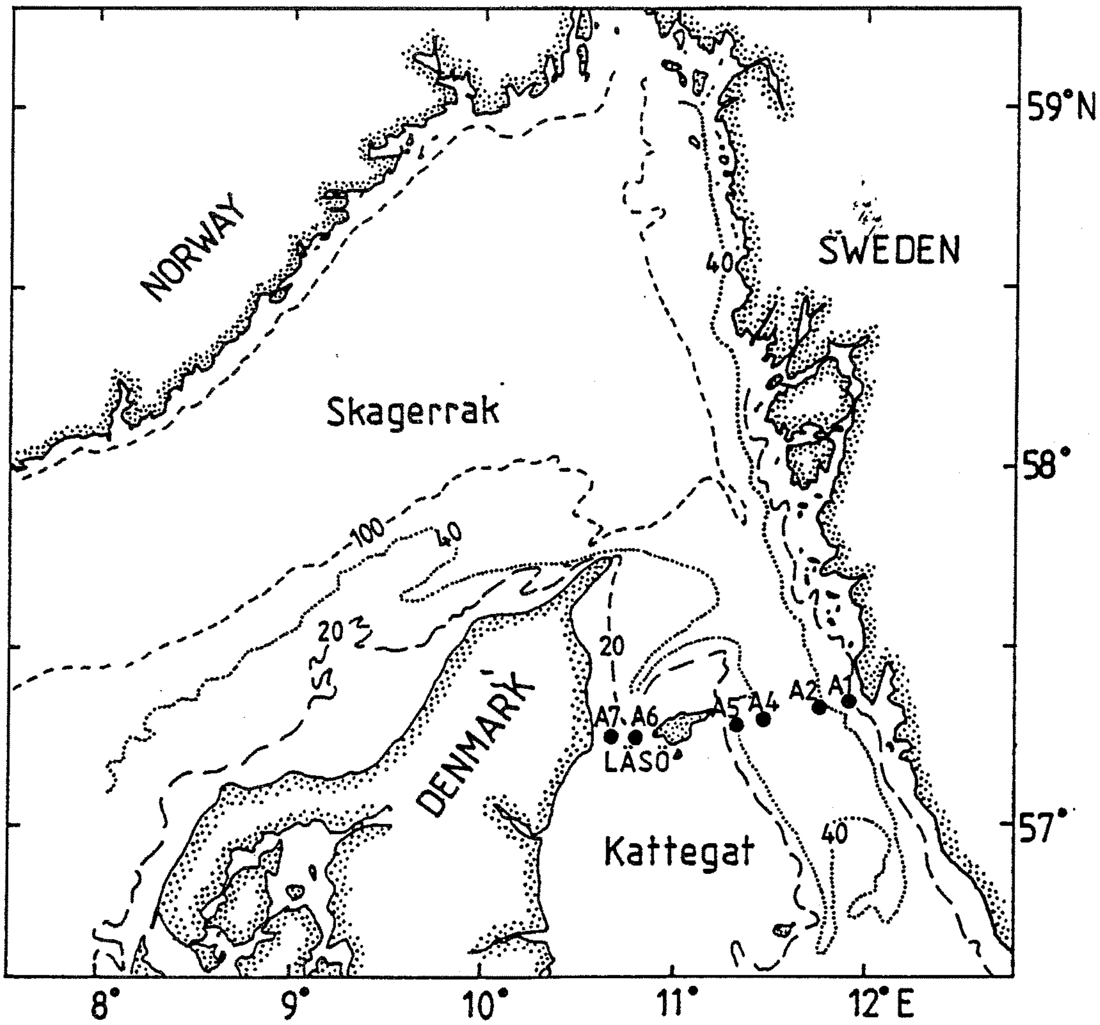

Fig 1. Map over the study area.

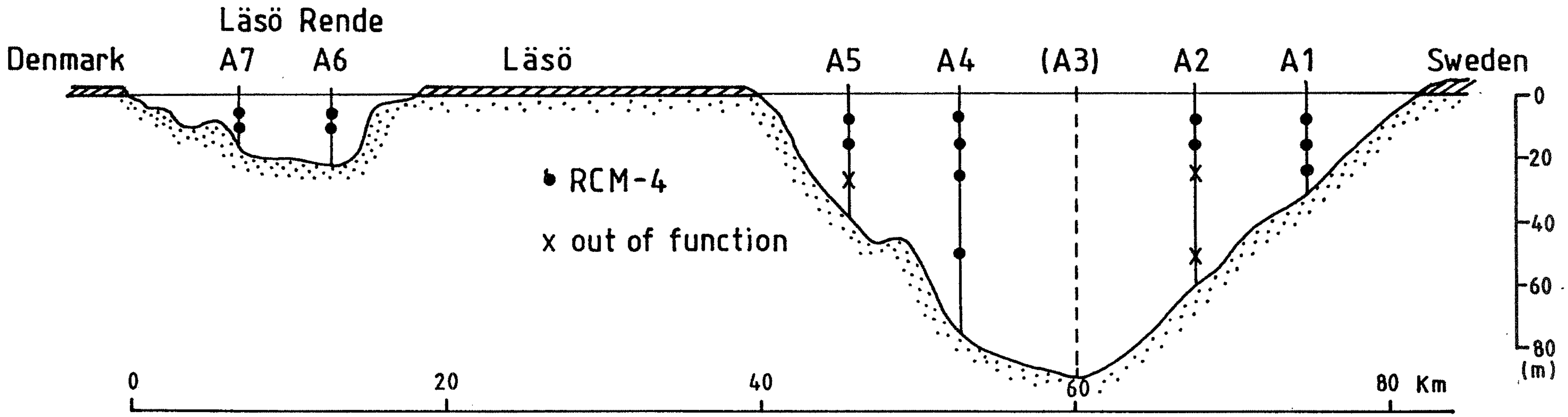

Fig 2. The cross-section between Denmark and Sweden.

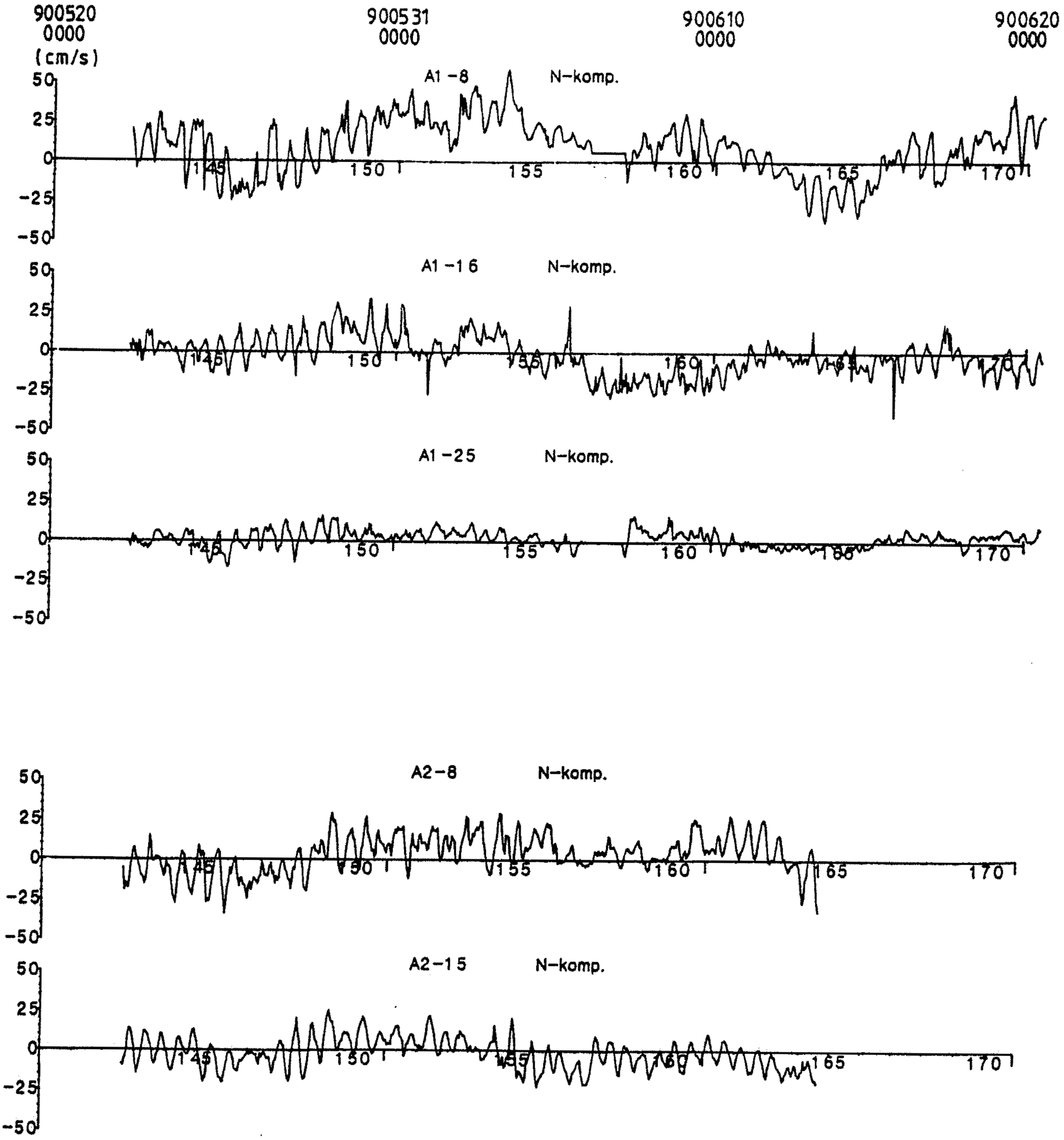

Fig 3a. N-S (E-W) hourly mean components of velocities.

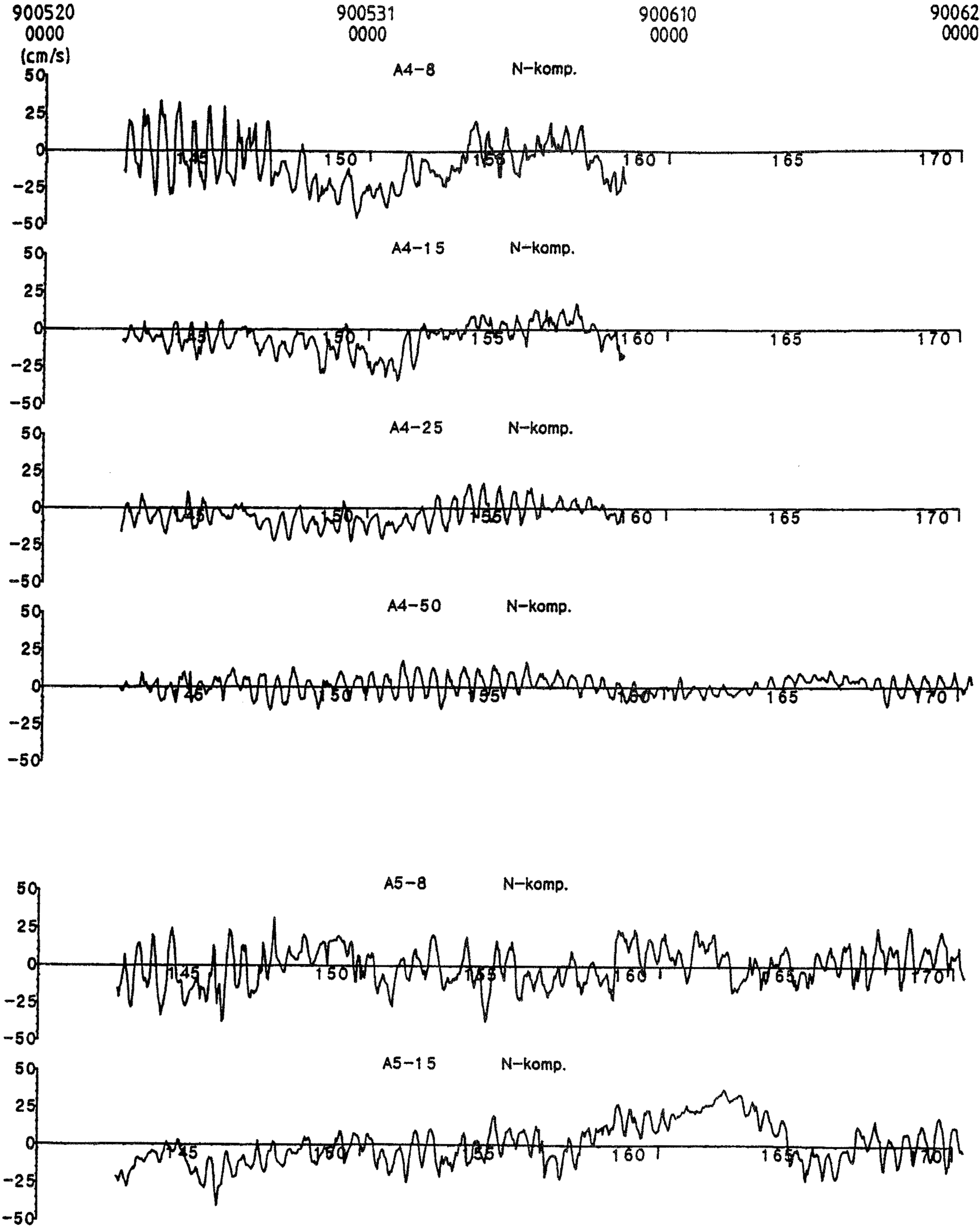

Fig 3b. N-S (E-W) hourly mean components of velocities.

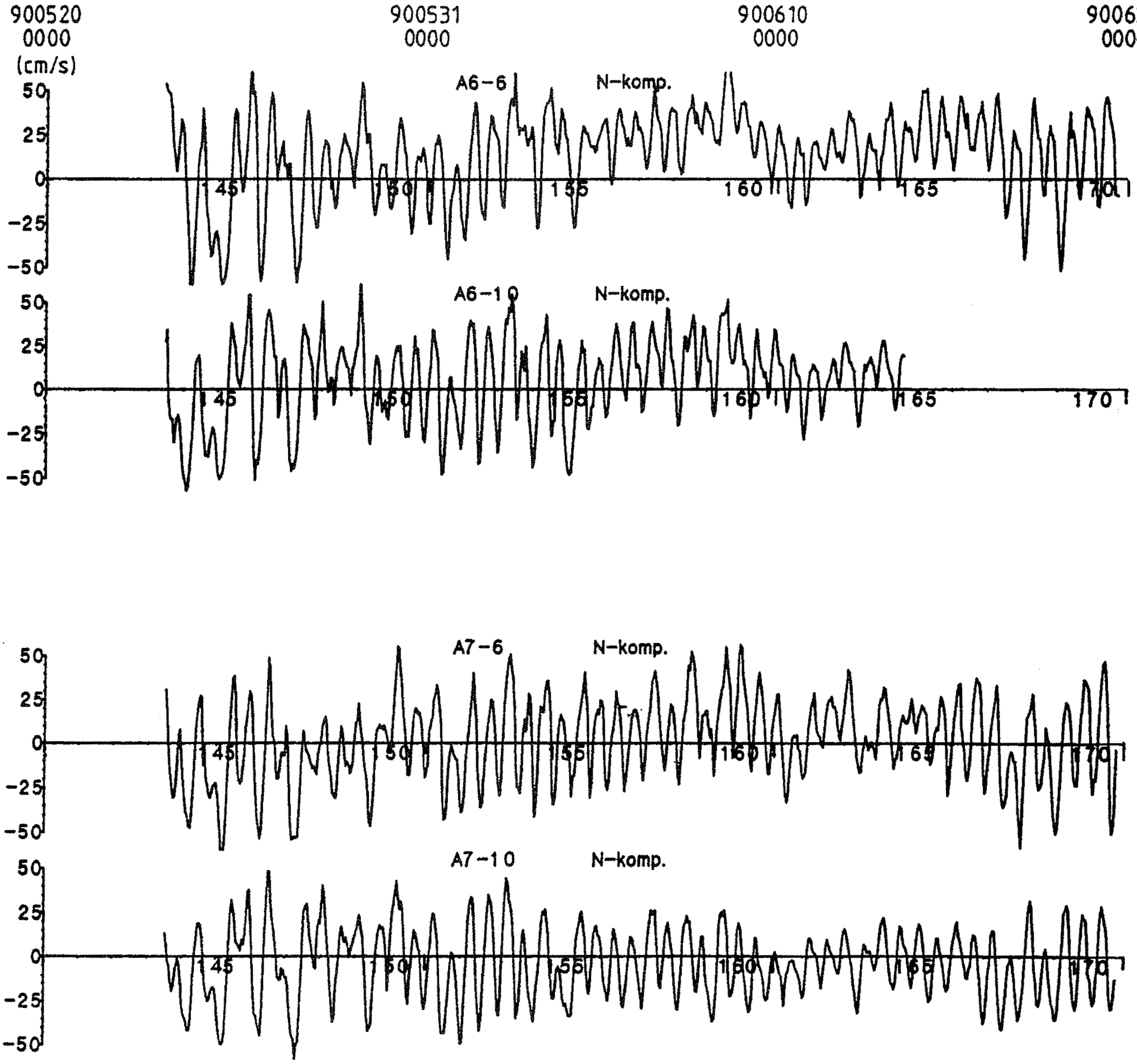

Fig 3c. N-S (E-W) hourly mean components of velocities.

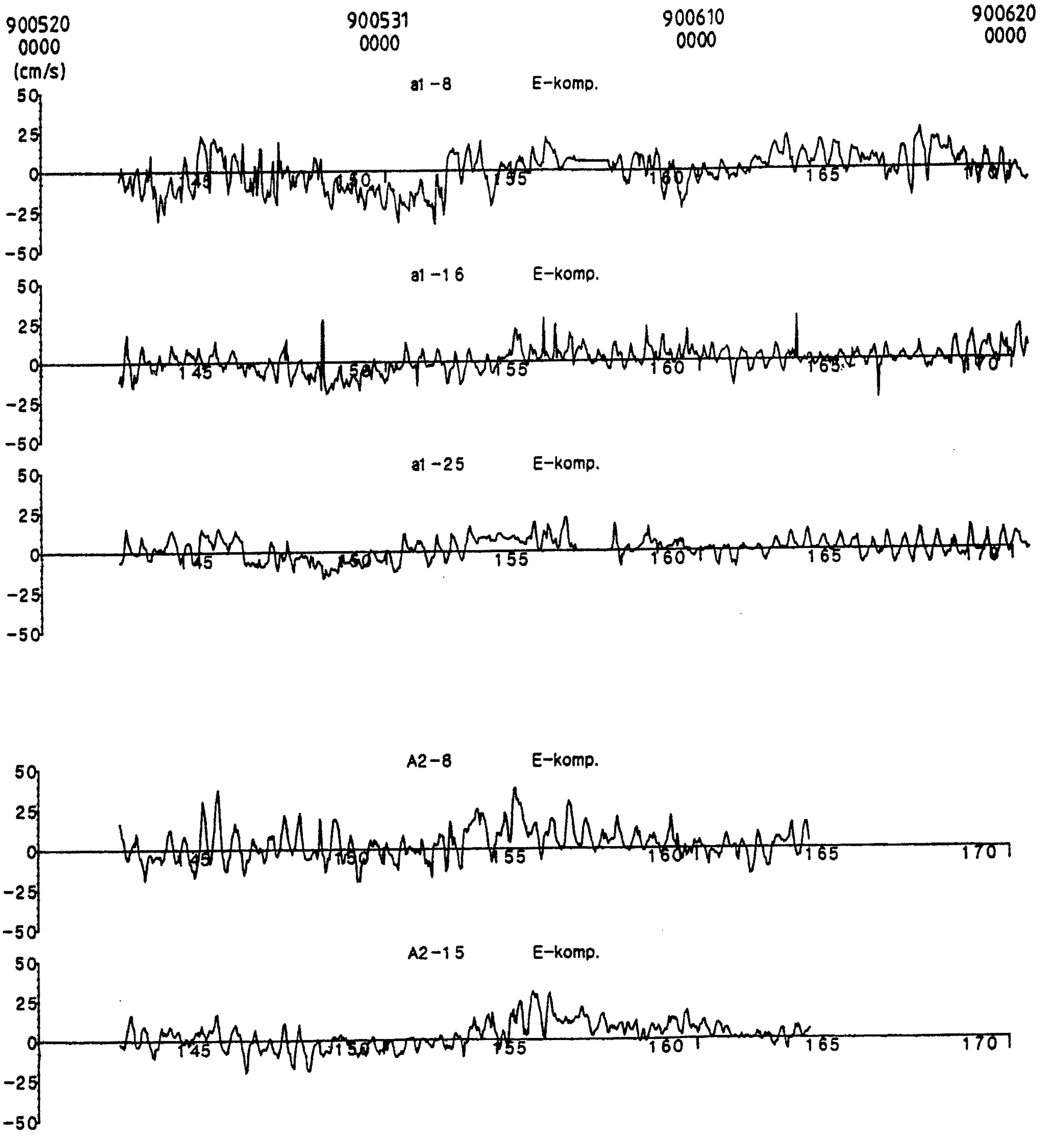

Fig 3d. N-S (E-W) hourly mean components of velocities.

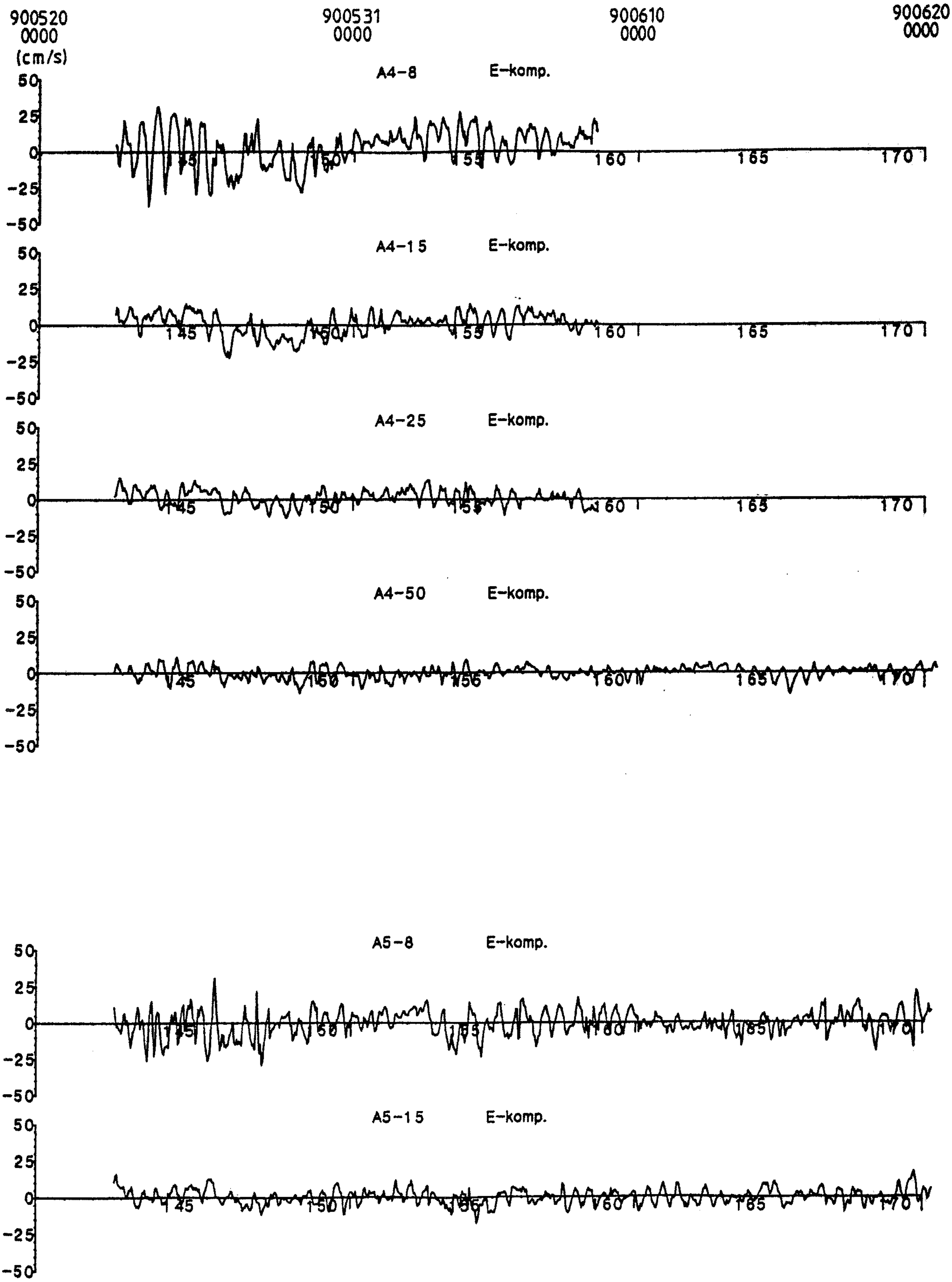

Fig 3e. N-S (E-W) hourly mean components of velocities.

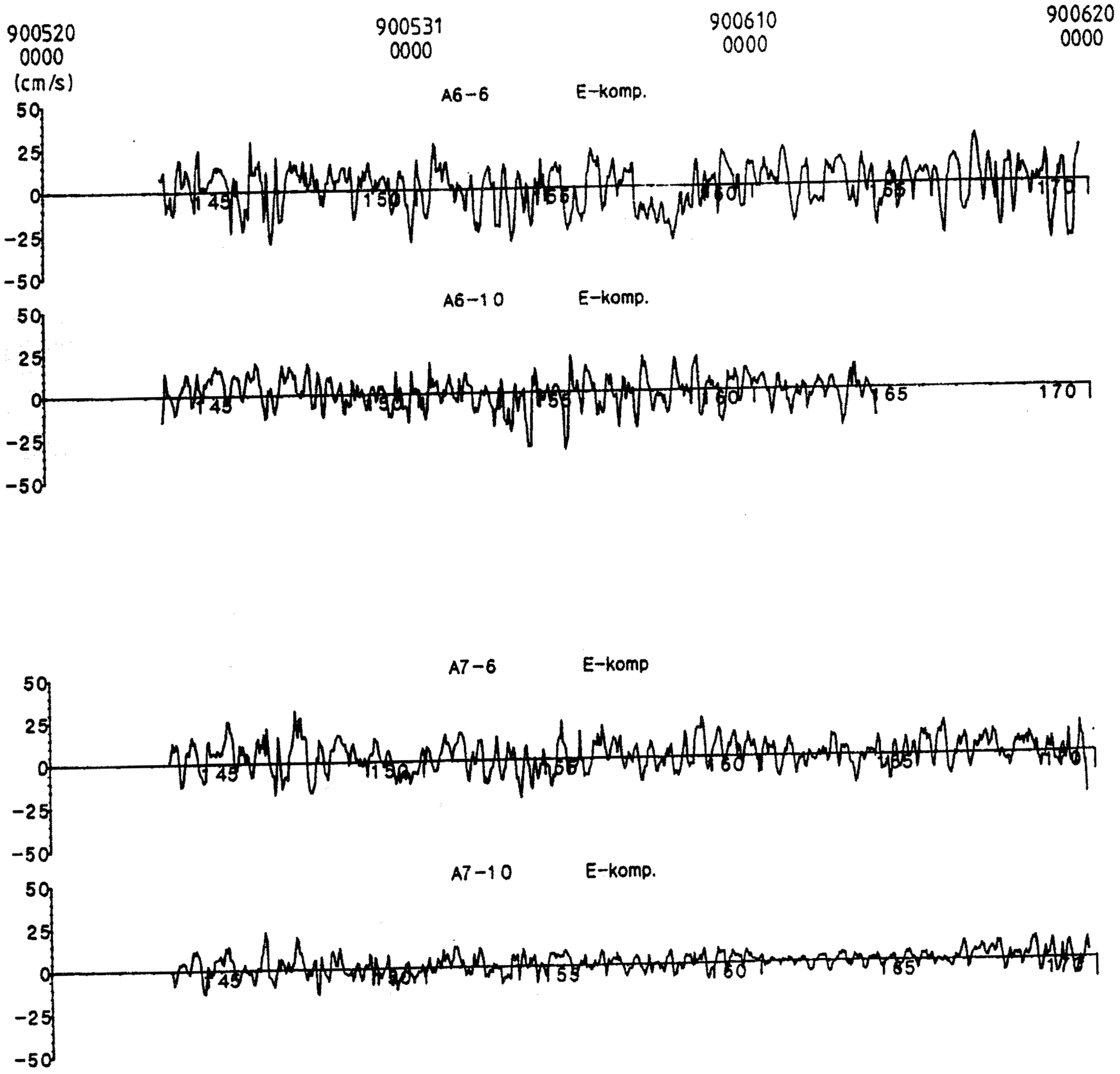

Fig 3f. N-S (E-W) hourly mean components of velocities.

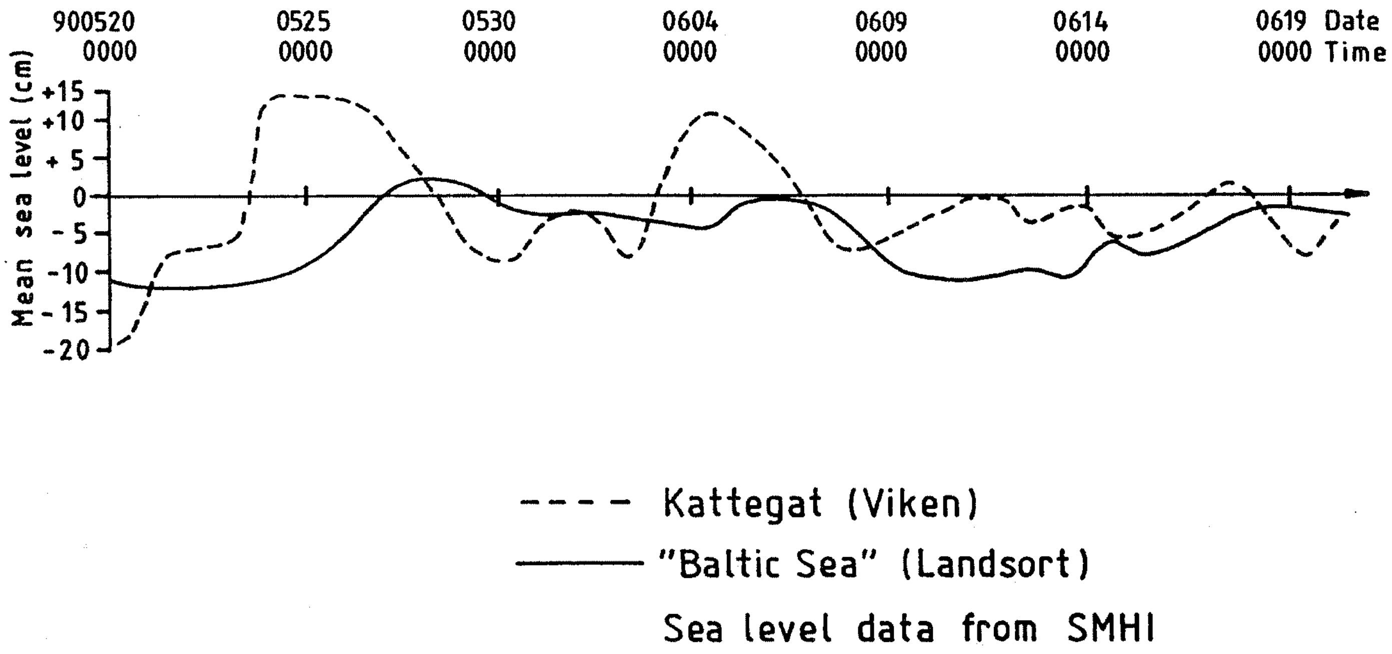

Fig 4. Daily mean sea level observations from Kattegat (Stn Viken) and from the Baltic Sea (Landsort).

Presentation no 19.

Variability of biological parameters during SKAGEX I at the C/E - transect.

by

S. Schulz and G. Breuel

Variability of biological parameters during SKAGEX I at the C/E - transect.

by

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One of the aims of the SKAGEX was " to identify and quantify the various water masses entering and leaving the Skagerrak area and their variation over time". For this purpose the programme was designed in such way that with repeated surveys at certain transects and with the observation of comparatively easy measurable determinands such alterations in the environment could be monitored.
In a first attempt to quantify this processes as they are reflected in some biological parameters , information obtained by fluorescence profiles and secchi disc readings as well as the analysis of chlorophyll, potential primary production and mesozoplankton biomass, were used. The biological results were related to physical and chemical features as far as this was possible at the present stage of data availability.
The analysis is restricted to the transects surveyed by RV"Alexander von Humboldt", that means the splitted E/C-transect (see Fig.1).

Material and Methods

Generally all methods used in SKAGEX were agreed upon in the preparation of the programme and followed accepted international standards. For the fluorescence measurements a Variosens (Impulsphysik, Hamburg) probe was used. All data are given in "arbitrary units" that means in this paper no transformation of fluorescence to chlorophyll was done. Chlorophyll was estimated after the procedure described by Jeffrey and Humphrey (1975) and Lorenzen (1961), referred to in the "Guidelines for the Baltic Monitoring Programme", HELCOM, 1988. Samples were taken from

0,5 ; 5; 10; 20; the fluorescence maximum depth and 30m. An intercomparison was executed before the experiment.

Potential primary production was measured in a standard tank (dutch/ICES type), provided by the organizer for all participating ships. Triplicate samples were prepared for the layer 0-10 m by mixing aliquots from 0,5 ; 5; and 10 m and from the fluorescence maximum depth. From the same mixed sample also subsamples for the determination of chlorophyll and phytoplankton species composition were taken. Zooplankton hauls were performed from the pycnocline to the surface and bottom/150 m to the pycnocline. As standard net the WP II- net supplied with 200μm gauze was used. The samples were splitted by using a FOLSOM- splitter and conserved in buffered formol. One half was used for the qualitative analysis, the other part for a gravimetric determination. For this purpose the sample was filtered on 100μm gauze, the zooplankton dried for 2h at 60° C and weighted. The zooplankton biomass was expressed as dryweight mg/m3 for the haul/station.

Brief environmental assessment

As expected from the position of the transect, the area under investigation was oceanographically influenced at least by three dynamic systems and the corresponding water masses, the Jutland current, the Baltic current and the central eddy above the dome area. This is reflected clearly in the distribution patterns of the physical and chemical parameters, since the three systems are characterized by specific properties. The features of the water masses are compiled in DANIELSSEN et al.,(1991).

The southermost stations of the E-transect were occupied over most of the time by water of the Jutland current. This coastal water showed very often a barotropic structure, as examplified by diverging and sinking isopycnals. The striking feature of this water type in relation to the biology was its low nutrient content and the downward tendency of the nutrient horizon in comparison to the northward following dome-region.

In contrast to the JCW-region the area above the dome was characterized by a strong stratification. In this region the pycnocline was identical with the nutricline. The warm surface water was exhausted from nutrients over most of the investigation time . Only from 18 June on till the end of the observation, intrusions of nutrientrich water or entrainment to the surface layer could be detected.

The eastermost part of the C-transect was influenced by the Baltic water or a mixture of Kattegat water and the corresponding northward current. Again, as in the case of the JCW, the isopycnals went down or disappeared completely. The nutrients showed the same tendency.

Distribution patterns of the biological parameters

Fluorescence and chlorophyll content

Generally both parameters, used here with all known shortcomings as an indication for the phytoplankton biomass, showed low values in the JCW (fig.2.) At the 3-4 southermost stations of the E-section , which ought to be positioned in the JCW, no or only weak indication of a subsurface maximum were detected. This maximum was well developed over the investigation time in the dome region. Fig.3 can be considered as a typical example over the observation time. Although the subsurface maximum was a persistent feature, the chlorophyll content was at the E and C - transect much lower than reported from the more westerly region of the Skagerrak (DANIELSEN, et al.,1991). In the dome area of our transects higher chlorophyll values could be stated in comparison to the JCW, they were, however, lower than in the BW region (fig. 2). This fact is not expressed in the figure with the means, but better in that of the single day values. From this figure it is clearly shown that the average is very much influenced by two exceptional high values. Thus it can be assumed that the highest biomasses were detected in the water observed at the eastermost stations. The vertical distribution of the fluorescence indicated higher values as close to the danish coast and again a weakening of the stratification (fig.3).

As could be seen from fig.2 (lower part), the variability, expressed by the coefficient of variation, decreased from Skagen in direction to the dome region and increased again in direction to the swedish coast.

Potential primary production

The figures for the potential primary production at light saturation level are generally very low and show a pronounced day -to-day variability (fig.4 upper part). Only slight differences, however, exist for the mean values over the time and the transect (fig.4 lower part). The JCW and the water in the central part vary at the same level. Only the values from the eastern stations are slightly elevated. This is again an indication for the higher productivity of the water near the swedish coast. In this water type also the highest variability could be detected.

In fig.4 (upper part) from the single day measurements it is obvious that at june 8 and 20 at most sites the highest rates were measured . Whereas for 8 june no clear indication for the causes are visible, at 20 june the maxima coincided with elevated nitrate values .

Mesozooplankton biomass

The distribution pattern for the mesozooplankton biomass from the mixed surface layer and the layer down to the bottom or to 150m are fairly similar (fig.5). In both cases the dome region showed the lowest values. The figure examplifies also that the biomass in the surface layer was about 4 times higher than in water below the pycnocline. In the surface layer the variability showed a clear maximum for the boundary zone between Baltic current and the central gyre (fig.6). In the depth haul , however, a different pattern could be discerned . Here the boundary between the Jutland current and the central gyre showed the highest variability.

Secchi disc readings

The secchi disc readings increased from both coastal sides of the transect in direction to the central gyre (fig.7). The lowest values were recorded in the water close to the swedish coast. During the investigation period at all sites a tendency to higher visibility ocurred. This was most pronounced at 17 and 20 June . The amplitude of the values amounted at 8 june only 4m, at 20 june, however , 10m. This clear tendency is also supported by partly higher production rates and can be caused by stronger entrainment or transport of Central Northsea water into the area. In contrast to all the other parameters the variability of the results was rather uniform and showed the same patterns. This might indicate, that the changes which have taken place, had the same causes and were similar for all stations.

Discussion

The observation time of our SKAGEX (second period of SKAGEX I) contribution was oceanographically characterized by post springbloom conditions. Bright, silent weather warmed up the surface water increasingly. The surface water was up to some exceptions stripped off from nutrients. Higher nutrient concentrations could be found only below the pycnocline. According to the Secchi disk readings the light penetration depth (˜2,6 x Secchi depth = 1 % incident light level) would mean that during the observation time the penetration depth increased from ˜18-26 m in the beginning to ˜20-33 m (see also fig.7) at the end of our period. This increase in the light penetration is also characteristic for the production condititons during this time of the year, showing that with proceeding season light penetration becomes more and more important especially for the deep phytoplankton maximum. This decrease of turbidity might be caused by either sedimentation of phytoplankton and feeding by zooplankton or the transport of water masses with other features into the area. Probably the first argument is more important because the tendency of clearance was evident for the whole transect and therefore more a seasonal process than a

stochastic event. Also the low variance of the variation coefficient (fig.7, lower part) hint to this fact.
The distribution of the subsurface chlorophyll maximum showed a specific pattern which was persistent over the whole observation time. A typical example is given in Fig.3. No or only slight indications of a maximum are reflected in the JCW. Highest values could be discerned in the southern dome region and towards the swedish coast. Here an ascending tendency of the maximum was detectable which could be related to the decreasing light penetration towards the coast. If the mean Secchi depth (Fig. 7) is compared to the distribution of the subsurface maximum than just in the zone with the highest light penetration the most pronounced maxima are found.

The phytoplankton biomass, expressed by the chlorophyll content, exhibited for the surface layer low values, according to the season. Significant differences existed between the JCW and the other stations of the transect (see fig.2).

The potential primary production showed very low values which are in relation to the described low nutrient content in the surface water. In comparison to the other here considered determinands no significant differences between the different watermasses seems to exist. This again shows that during this season light was the decisive factor for phytoplankton activity in this area. Higher photosynthetical activity was evident for the phytoplankton from the subsurface maximum. This higher activity is related to the higher nutrient potential present in that water layer. Unfortunately no in situ measurement have been conducted at our area in this depth. For the Kattegat area LINDAHL et. al(this volume) could show that also in situ, although the light intensity was reduced to some 10% or less, the yield is still higher than in the nutrient impoverished surface water.

The mesozooplankton biomass showed in direction to both coasts significantly higher biomasses and a minimum in the southern boundary to the ridge region in the central Skagerrak. Obviously both the JCW and the water masses close to the swedish coast had a higher zooplankton biomass compared to the southern dome region. According to DANIELSSEN et al., (1997) was the outflow off the Kattegatt/Baltic water more or less blocked during SKAGEX I (second lag) by the strong JCW current and the water transported towards the swedish coast. Here the water was mixed with BW/Kattegat water and moved northward. This would explain why the zooplankton biomasses are nearly similar in both coastal areas. Unfortunately at the moment we do not have the species composition to our disposal, which should give clearly answer on this question.

The variability of the different parameters was expressed here as the coefficient of variation (standard dev./ mean x 100). It was calculated for the different parameters and for the stations using the results of the various turns. Generally the coefficient, because calculated from only five values, is very sensitive already for one outlayer. This is in some cases very obvious and therefore the value for interpretation shall be considered critically and may only underline features already discerned.
For both phytoplankton parameters the core stations of the distinguished dynamical areas show the highest variability (see fig.2+4). This is somewhat surprising because one should expect that the boundary zones display the maxima.
In case of the mesozooplankton for the surface layer there is an indication that the station situated in the boundary zone between BW and central waters shows the highest value. This high coefficient is, however, very much influenced by one extrem value. Generally the coefficient for the mesozooplankton varies between 10 and 35%. This is considerably lower than for the phytoplankton parameters , where it ranged between 20 and 60 %. Much more even is the course of the coefficient for the secchi disc readings (fig.7). The amplitude was in this case only 10%, ranging between 15 and 25%. The differences in the variability of the considered parameters indicate that various reasons are responsible for them. For the phytoplankton e.g. light and nutrients might be decisive , whereas for the zooplankton , not able to respond in short time scale to changes, the current system might be more important.

Conclusions

- The considered biological parameters underline the existence of three different current systems, respectively water masses
- The features of the water masses are determined by different biomasses of phytoplankton and also zooplankton as well as by differences of the potential primary production.
- The visibility of the water masses indicates at least differences between the coastal current zones and the central gyre
- The variability of the results from the single days was different for the considered parameters. Highest coefficients of variation were observed for the phytoplankton parameters.
- Spatially the variability was highest for the plankton parameters at the stations close to the danish and the swedish coast.

Reference

Danielssen, D.S., L. Davidson, L. Edler, E. Fogelquist, S. Fonselius, L. Foyn, B. Hakansson, I. Olsson and E. Svendsen. 1991:SKAGEX: Some preliminary results. C.M.1991/C:2, Hydrography Comm.

Danielssen, D.S., L. Edler, S. Fonselius, L. Hernroth, M. Ostrowski, E. Svendsen and L. Talpsepp. 1997. Oceanographic variability in the Skagerrak and Northern Kattegat, May-June 1990. ICES Journal of Marine Science, 54.

Helcom, 1998. Guidelines for the Baltic Monitoring Programme for the third stage. Part D. Biological determinants. Baltic Sea Environment Proceedings 27 D:1-161.

Lindahl, O., B. Andersson, D. Danielssen and L. Hernroth. 1992. High subsurface phytoplankton primary production east of Skagen, Northern Kattegat in May 1991. Paper 1. SKAGEX Symposium, Lysekil, 3-6 November 1992.

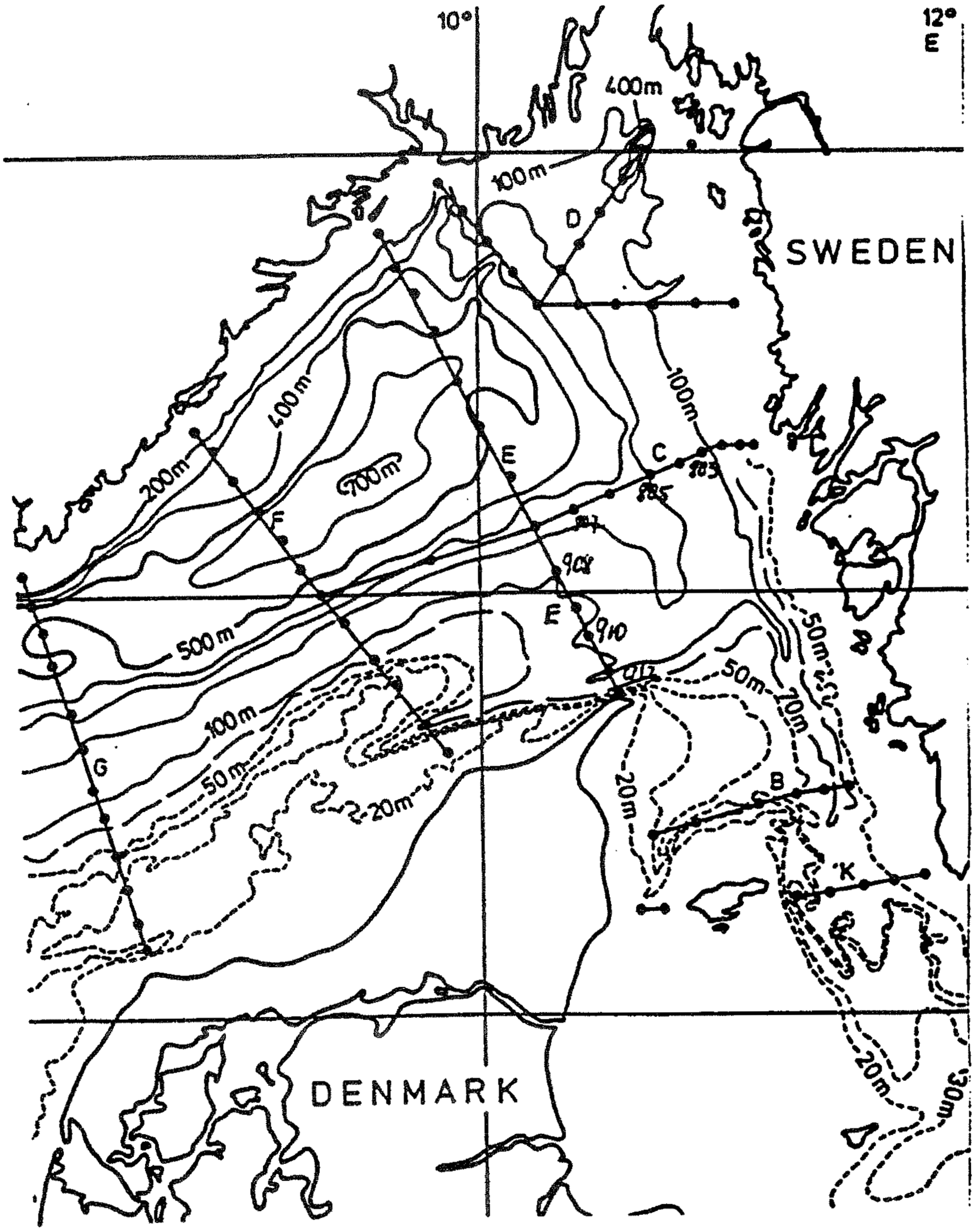
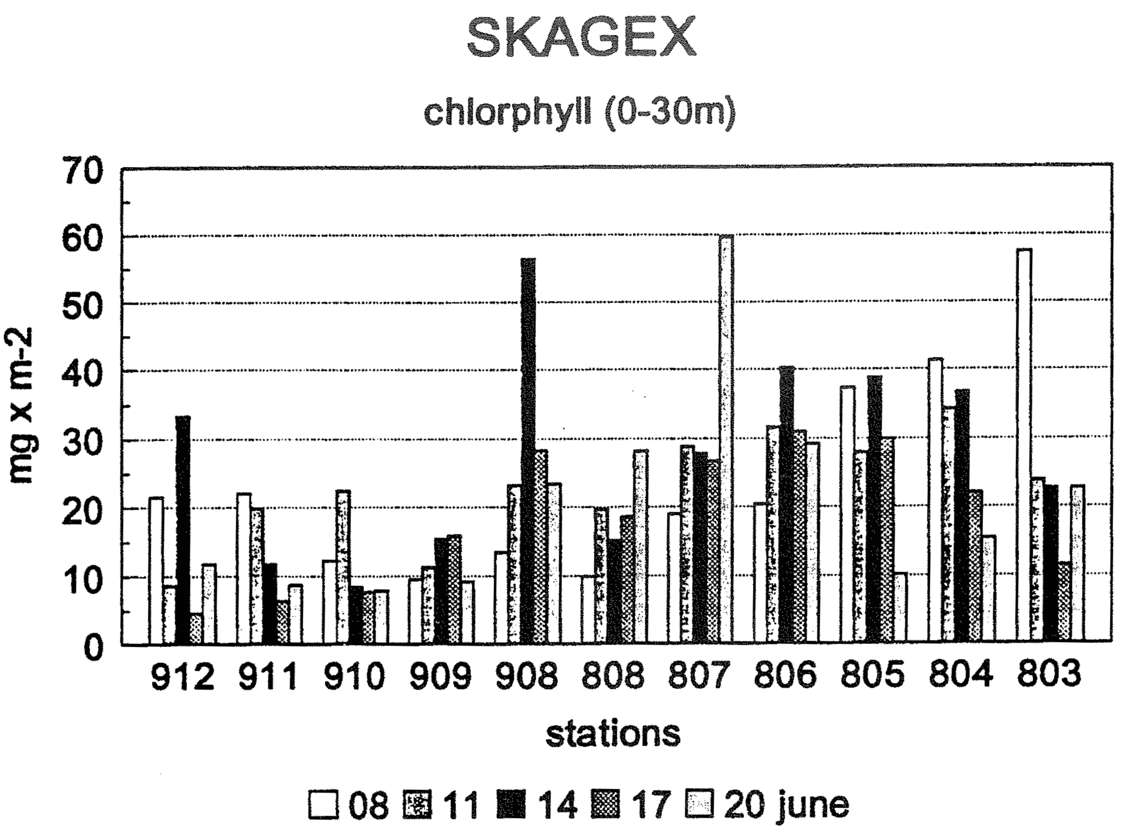


Fig. 1 Map of the Skagerrak



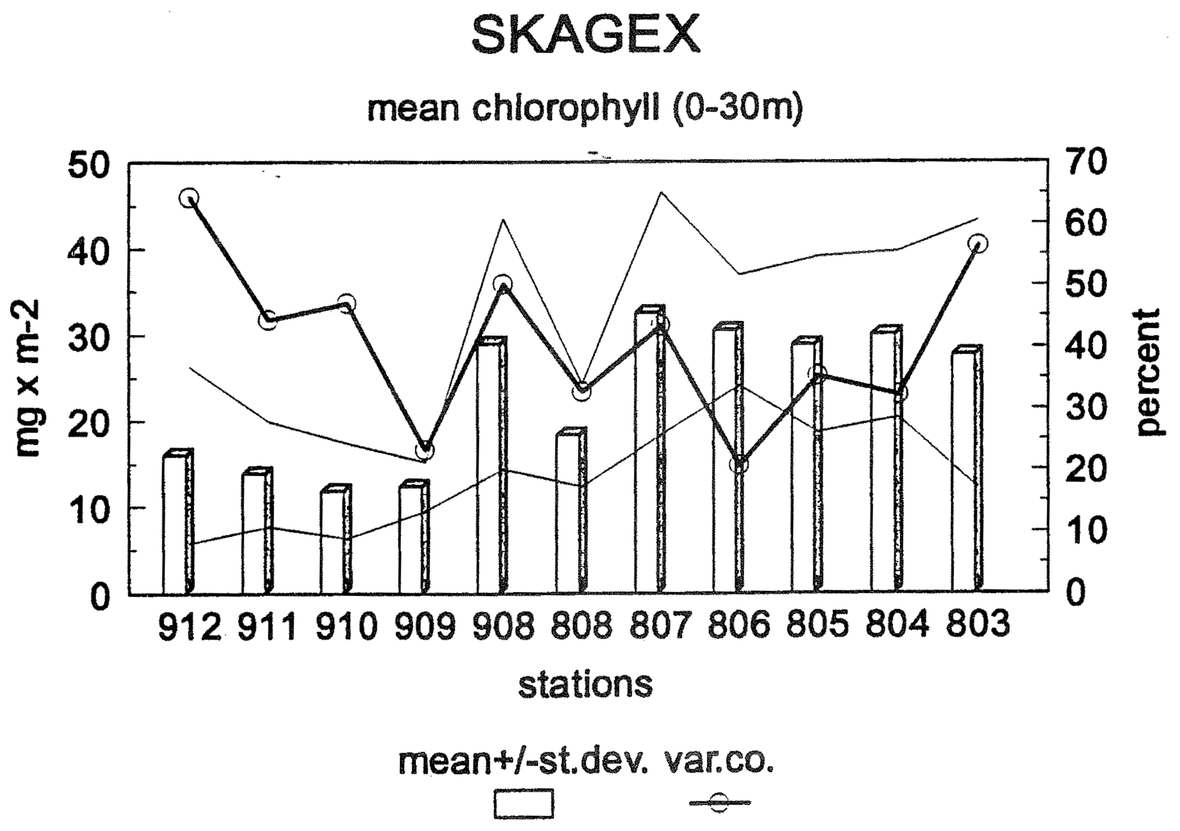


Fig. 2 Chlorophyll concentration below a m^2 (0-30m) for all stations at the obligatory turns (upper part). Mean values for the stations over the observation period (lower part).

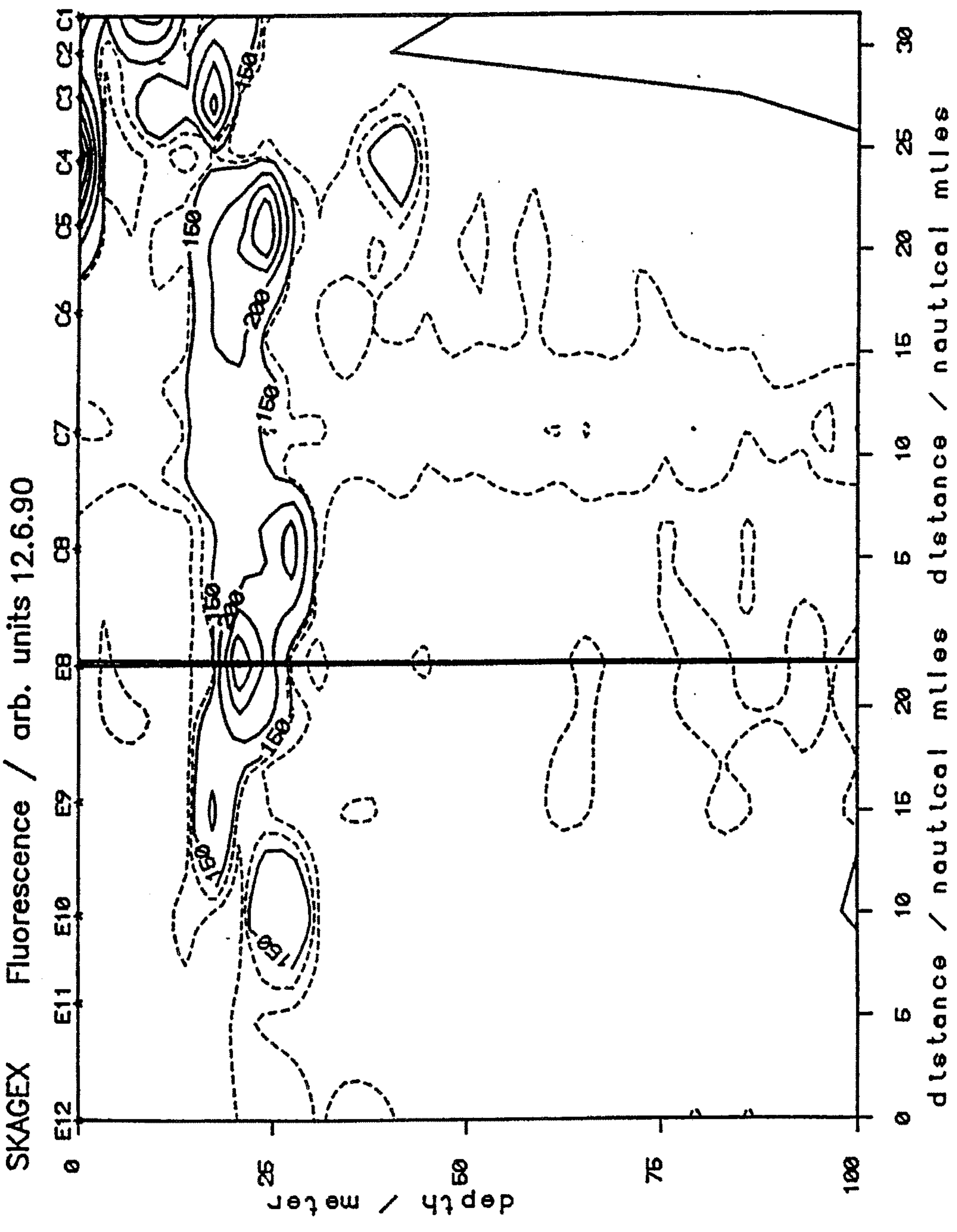


Fig. 3 Isopleth diagram for fluorescence.

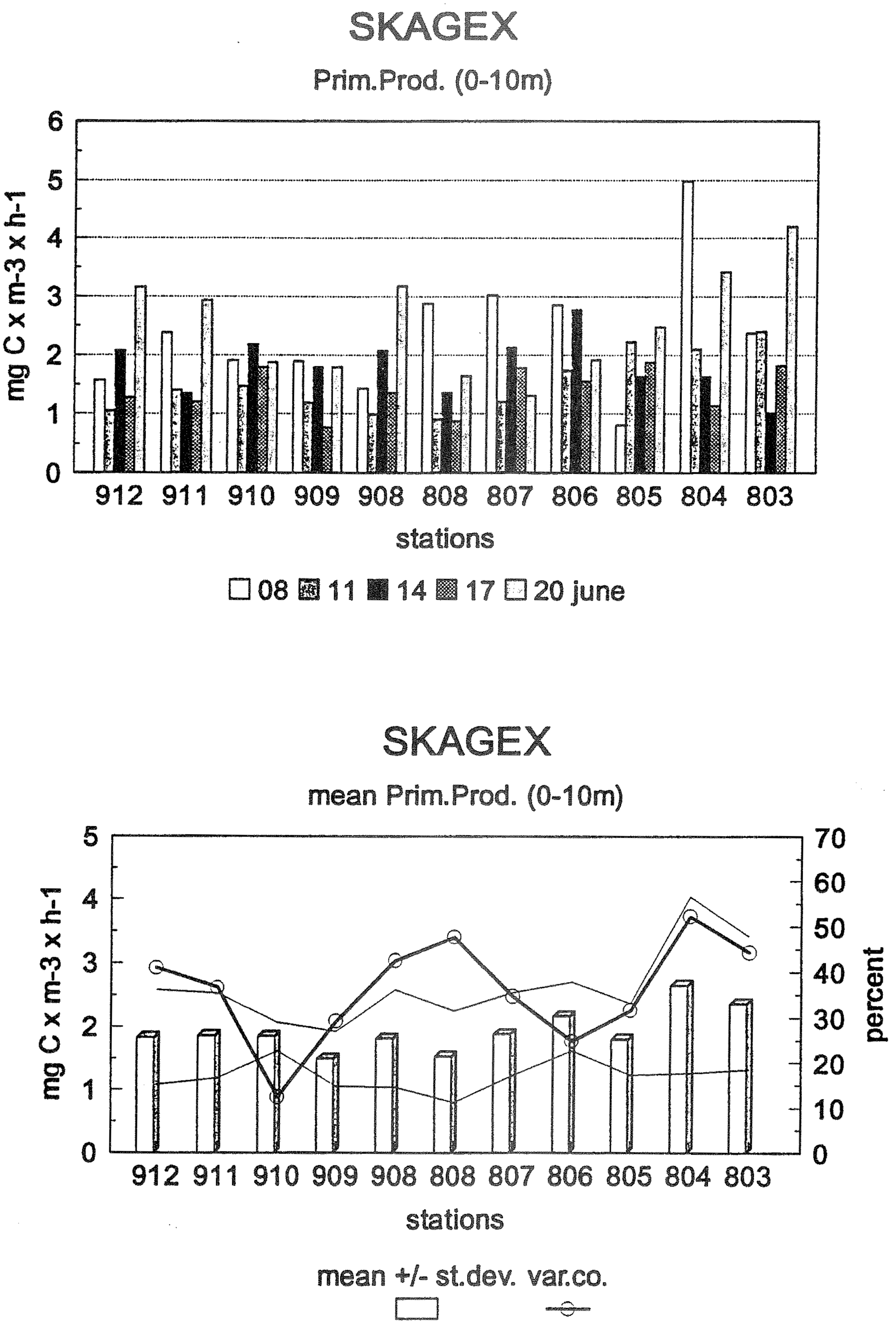
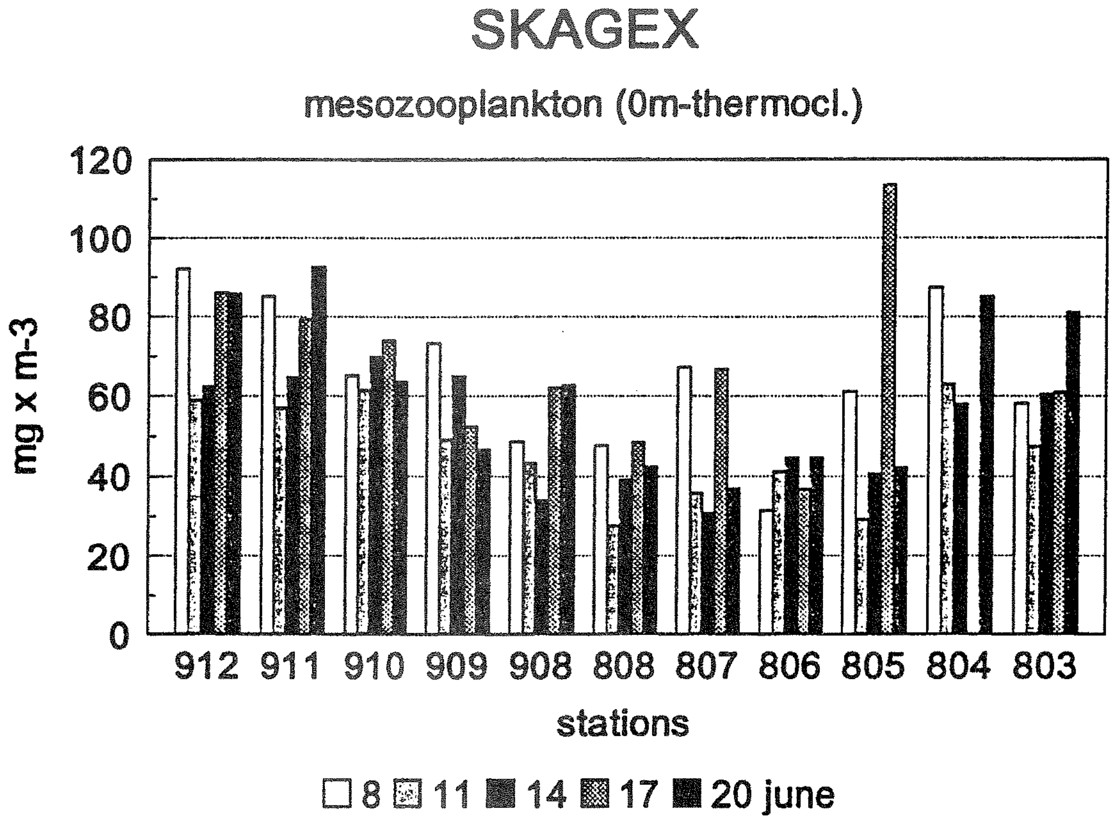


Fig. 4 Avergage potential primary production (0-10m) for all stations at the obligatory turns (upper part). Mean values for the stations over the observation period (lower part).



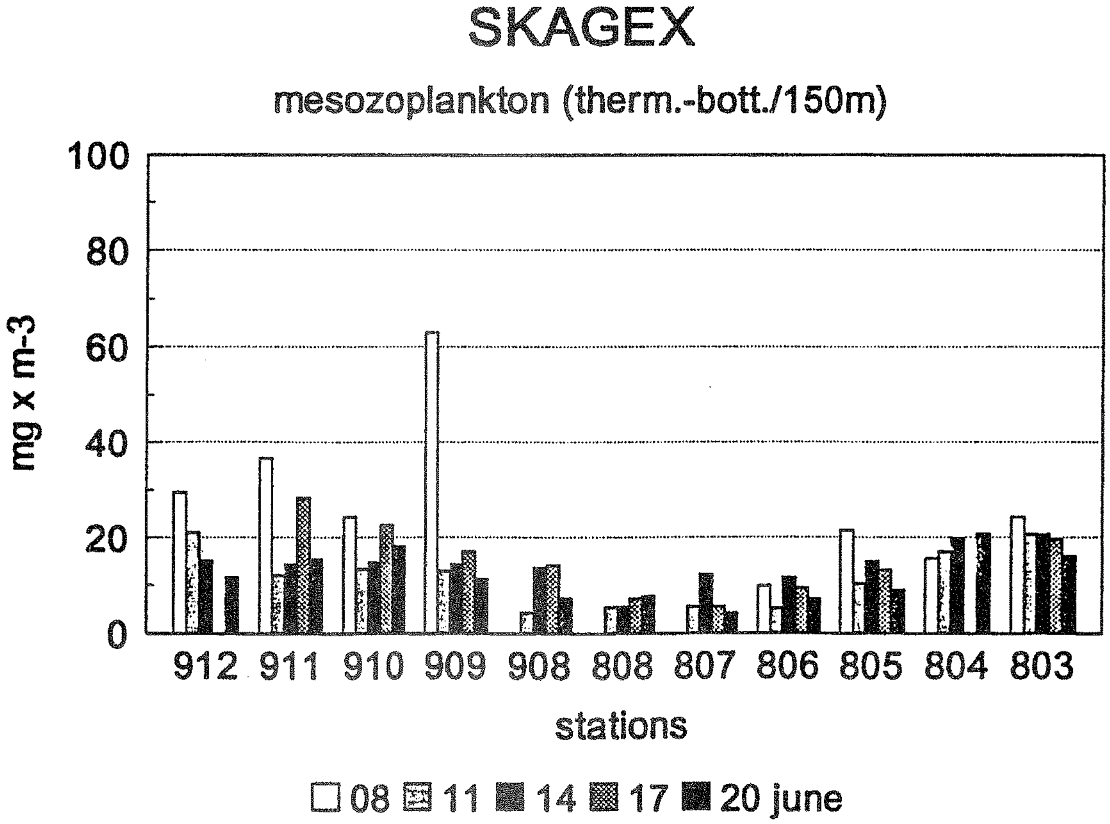
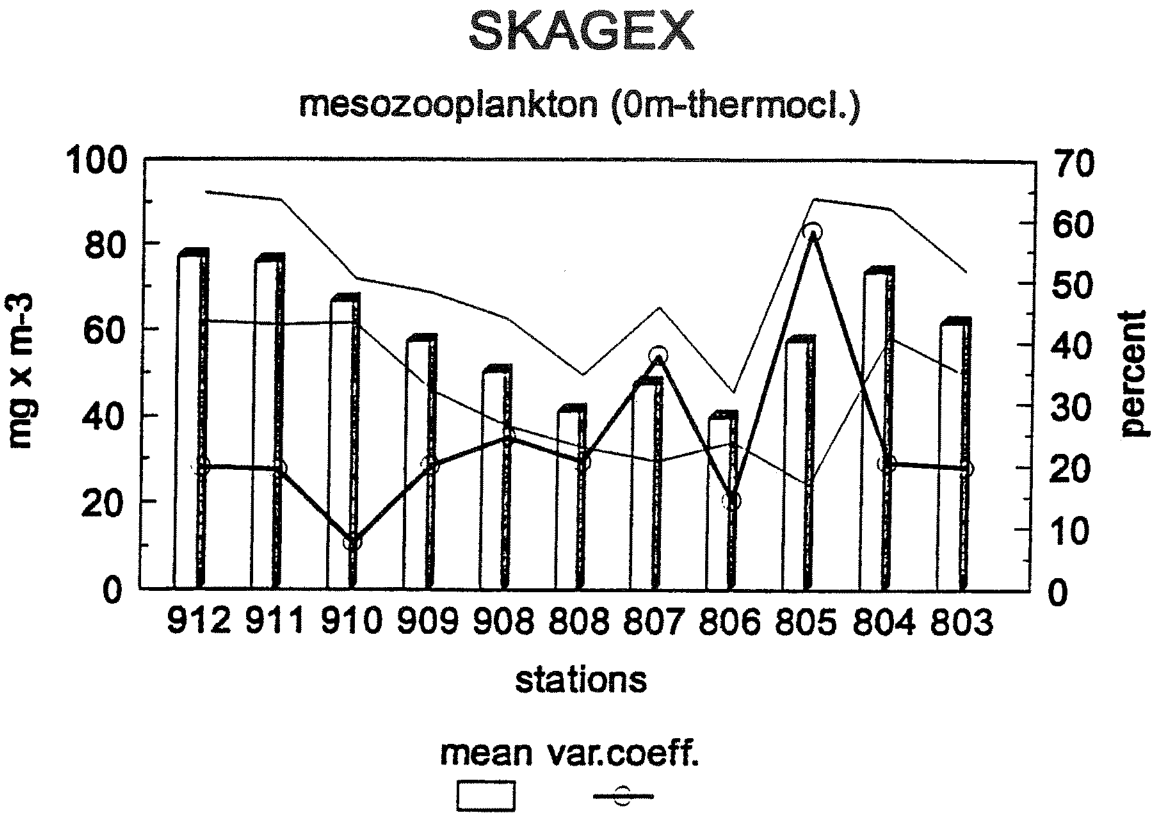


Fig. 5 Mesozooplankton biomass (dryweight mg x m3) in the surface layer (upper part) and in the layer below the thermocline to the bottom/150m (lower part) for all stations at the obligatory turns.



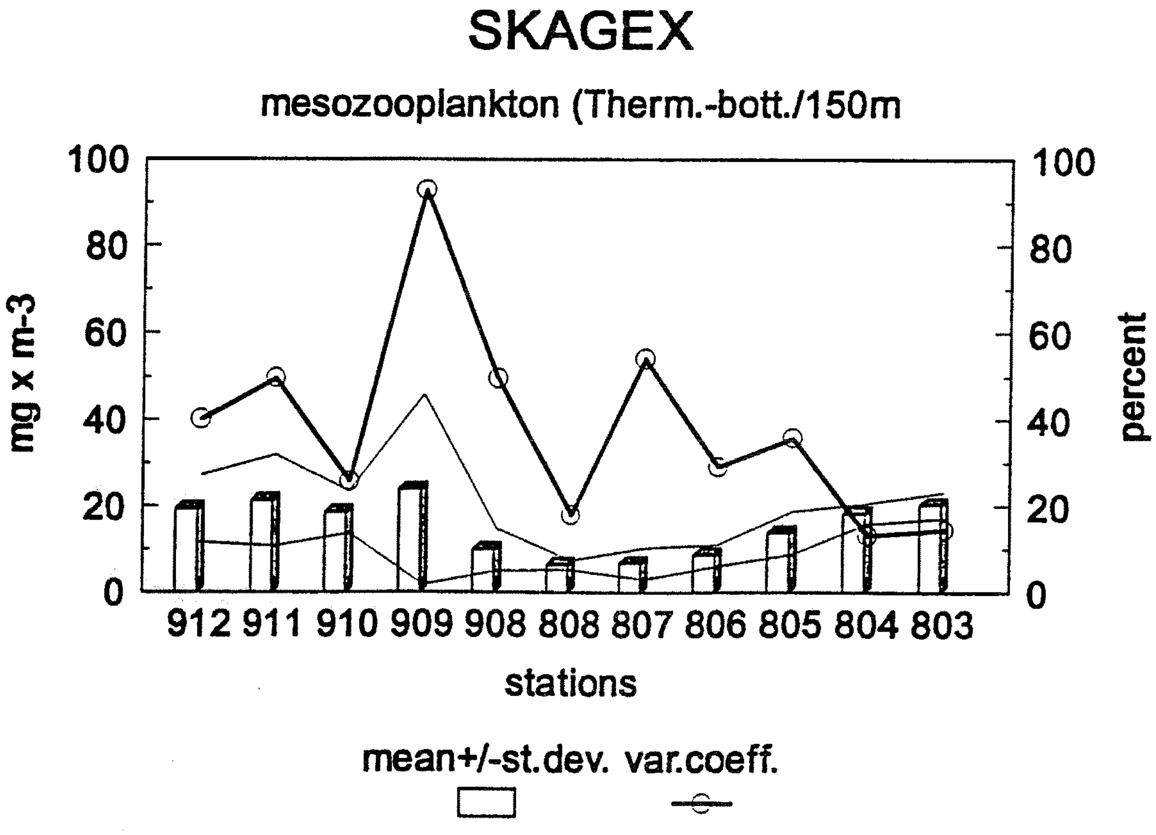


Fig. 6 Mean mesozooplankton biomass in the surface layer (upper part) and in the layer below the thermocline to the bottom/150m (lower part) for all stations at the obligatory turns.

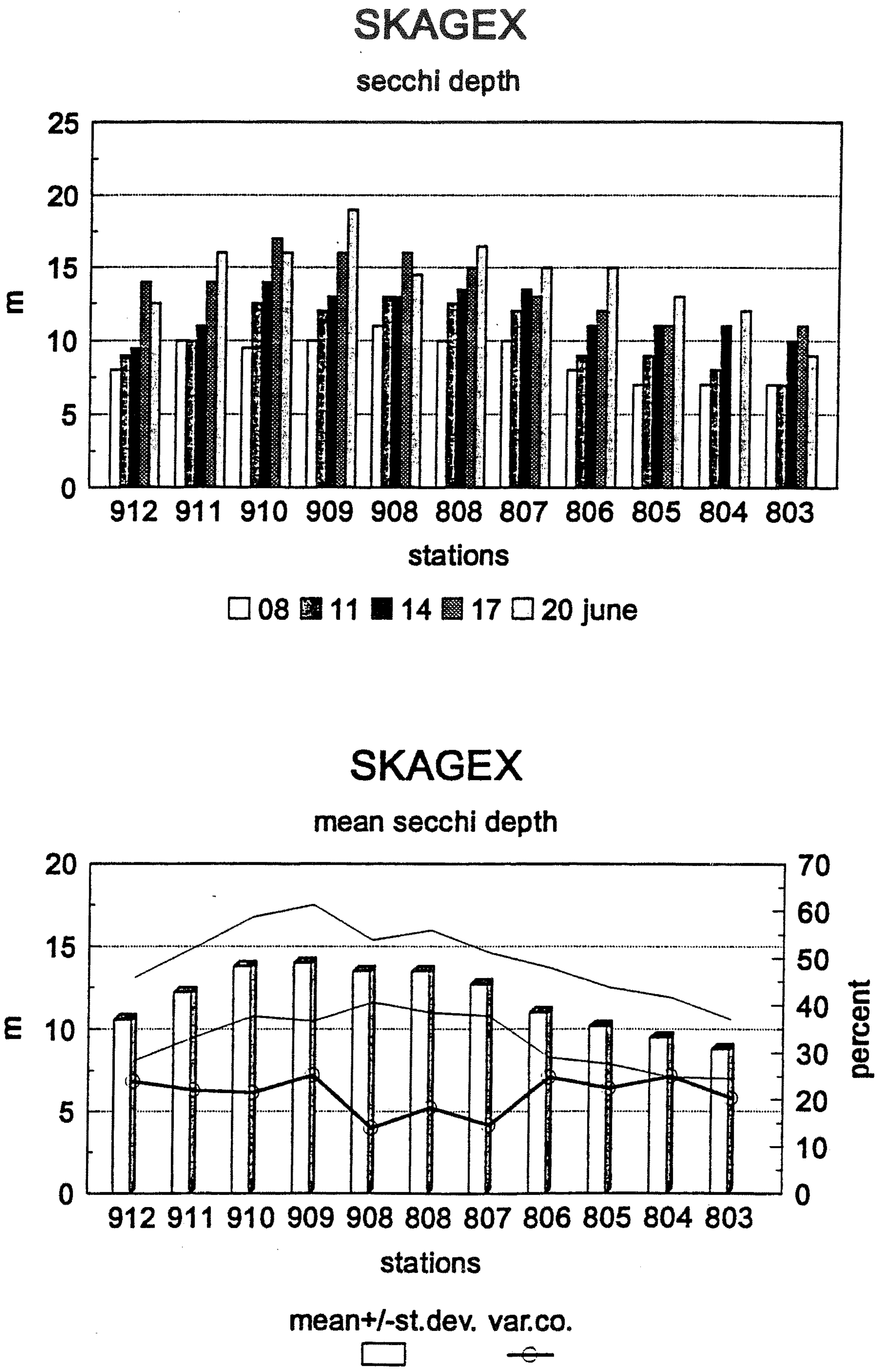


Fig. 7 Secchi disc readings for all stations at the obligatory turns (upper part). Mean values for the stations over the observation period (lower part).

Presentation no 20.

The distribution of planktivorous seabirds in relation to surface fronts and pycnocline topography in the Skagerrak.

by

H. Skov, J. Durinck and P. Andell

"THE DISTRIBUTION OF PLANKTIVOROUS SEABIRDS IN RELATION TO SURFACE FRONTS AND PYCNOCLINE TOPOGRAPHY IN THE SKAGERRAK

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INTRODUCTION

The Skagerrak marks the outer part of the transitional area between the Baltic and the North Sea. The area is characterized by a complex hydrography created by the dynamic circulation and mixing of up to six different water masses (Danielssen et al. 1991). During the period from May 1990 to May 1991 four synoptic investigations ("SKAGEX") coordinated by ICES were carried out in the Skagerrak with the main objective to obtain base-line information regarding circulation patterns and key processes in the whole area.

One of the main questions adressed was the reasons for the unusually high productivity of the Skagerrak. Fish production in the Skagerrak is almost the double of that of the North Sea (70 kg/ha/y), and the area functions as the main nursery area for North Sea Herring (Bøhle 1989). Although high rates of primary and secondary production have frequently been reported at fronts and at the pycnocline in the Skagerrak (e.g. Pingree et al. 1982, Richardsson 1985), the links between lower and higher trophic levels are poorly known.

Skagerrak is the most important feeding area for several species of seabirds occurring in the northeastern part of the North Sea outside their breeding seasons (Skov et al. 1990). SKAGEX provided an excellent opportunity to study the relationship between individual hydrographical structures and concentrations of seabirds. A number of recent studies indicate that seabirds can be used as indicators of gradients in physical oceanographical structures, such as fronts, likely to concentrate plankton and fish (Schneider & Hunt 1982, Haney & McGillivary 1985, Briggs et al. 1987) and as indicators of increased productivity in general (Springer & Roseneau 1985, Haney 1986, Brown 1988a, Schneider et al. 1988, Hunt & Harrison 1990).

The bird fauna of the Skagerrak is dominated by two planktivorous species from the North Atlantic ; Fulmar Fulmarus glacialis and Little Auk Alle alle (Laursen et al. in prep.), which both have been estimated at several hundred thousands in the area. The Little Auk is known to favour the larger species of zooplankton of high caloric value (Bradstreet 1982, Brown 1988a), while the Fulmar exploits a wider range of food items (Cramp & Simmons 1977), and may in some areas take offal from working trawlers during daylight hours, when plankton availability is low (Furness & Todd 1984). There is growing evidence that planktivorous seabirds concentrate in areas with strong horizontal and/or vertical property gradients (Schneider 1982, Schneider & Hunt 1982, Haney 1985, Follestad 1990, Haney 1991). Such concentrations may both reflect productivity and availability of prey in the upper water column, as many of the planktivorous species, incl. Fulmar and Little Auk, have reduced capacity for diving. Therefore, by attaching seabird studies to oceanographical investigations, we hoped to be able to gain insight into processes and structures of potential importance to higher trophic levels in the Skagerrak.

METHODS

During the SKAGEX II and III expeditions in September 1990 and January 1991 seabird counts were performed concurrently with oceanographical sampling from R/V Argos along a 100 km transect from Oksoy (58°02' N, 08°30' E) to Hanstholm (57°14' N, 08°33' E) (Fig. 1). The hydrogrographical data were collected by the Oceanographical Laboratory of the Swedish Meteorological & Hydrological Institute. During Skagex II birds were counted on three crossings: 10 September, 12 September and 14 September, while during Skagex III birds were counted on the 14 January, 16 January and 18 January. Due to fog insufficient bird data were gathered on the 18 January, hence only data from five crossings have been retained for analysis.

Profiles of CTD were taken for each 5-10 m over the whole water column at 12 stations using a Rosette multibottle-array system or a 30 l Niskin bottle in conjunction with CTD analysis (Neil Brown). Most samples were obtained from stations during daylight, when birds could also be observed.

Birds were counted continously in a 300 m wide strip transect within a 90° sector ahead of the ship, while steaming between stations at a speed of approximately 10 knots/hour. The observer worked from the bridge-wing of R/V Argos and used binoculars to locate and count the number of birds present within the transect. We used the suggested standard for strip transects of seabirds (Tasker et al. 1984), which includes interval-counting of flying birds in order to reduce overestimation of flying birds in the transect. As we wished to focus on birds seemingly related to natural food sources, birds seen in the vicinity of trawlers were not included in the analysis. The bird counts showed that Fulmar predominated the bird fauna in September and Little Auk in January.
To compare bird data with hydrographical data it was necessary to aggregate bird count periods into segments with one sampling station located centrally in each segment, as bird data were split into time periods equaling 3 nautical miles of cruising distance and oceanographical data were sampled at distance intervals of approximately 6 nautical miles. The bird data were evened due to variations in the distances between stations.

Due to the skewness of bird data (several zero counts), we chosed to base tests of relationships between birds and oceanographical features on robust and distribution-free statistics. Utilization tests (Bonferroni z-tests) give a statistical indication of habitat preference based on individual comparisons of observed proportions to expected proportions within different habitat categories (e.g. water masses) , allowing for control of the experiment-wise error rate (α) during testing (several chi-square tests, Neu et al. (1974), Haney & Solow (1992)). The following formula provides confidence limits on observed probabilities for each oceanographical category:

$$p \pm Z_{(\alpha k)} \sqrt{(p(1-p)/n)},$$

p is observed proportion, $Z_{(\alpha 2k)}$ is the upper standard normal table value corresponding to a probability tail area of (0.05/2k), k is the number of habitat categories. The important assumption of no correlated samples between categories (e.g. birds following the research ship from one water mass to the next) could be met, as ship-following birds were excluded from analyses.

We first tested the null hypothesis that planktivorous birds were distributed independently of water masses. If rejected, five different models of bird-oceanography relationships were tested, each assuming greater use than expected of areas with maximum mixing, strongest surface fronts and shallowest pycnocline/halocline:
1. Bird distributions related to the mixed surface water masses (32-34 psu). The following four water mass categories were used: a/ surface salinity < 32 psu, b/ 32-33 psu, c/ 33-34 psu and d/ > 34 psu.
2. Distributions related to convergense zone created by the gross circulation of surface currents. In the study area inflowing water masses were determined as water > 32 psu, and outflowing water masses as water < 32 psu. The convergense between these two major surface water movements was chosen as the middle section (approximately 1/3 of transect) around 32 psu.

3. Distributions related to particular mesoscale fronts in the convergense zone (descriptive).
4. Distributions related to areas with strongest surface gradient (psu) in convergense zone.
5. Distributions related to areas with the shallowest pycnocline measured from the surface to the middle inflection point and to areas with the strongest vertical gradient (psu) of the upper water column (upper 20 m).

We finally tested the application of the best models for the whole Skagerrak by comparing maps showing average distribution of Fulmar and Little Auk gathered during large scale surveys of the whole Skagerrak (bird densities) with maps showing general oceanographical knowledge of the lateral distribution of important oceanographical features.

RESULTS

The distributions of salinity in the upper 50 m on each of the five crossings are illustrated on Fig. 3. During SKAGEX II salinities were in the range 25.0 to 35.0 psu, while during SKAGEX III salinities were in the range 30.5-34.5 psu. During each crossing a gradual increase in surface salinity was found from station 1 at the Norwegian coast to station 12 near Denmark. During the anticyclonic weather, which prevailed throughout both study periods with relatively calm conditions, the Norwegian Coastal Water (< 32 psu) was running close to the Norwegian coast. Strong horizontal changes in surface salinity took place from station 1 in the Norwegian Coastal Water to station 8 in water of North Sea origin (33.5-34.5 psu). Station 6 generally marked the border (convergense) between the Norwegian Coastal Water and inflowing surface waters of higher salinities. In general, the depth of the pycnocline decreased from at least 30 m to around 10 m at the central segments of the transect (shallowest during SKAGEX II). The stations closest to Denmark were characterized by a mixed or almost mixed water column with salinities above 34 psu.

The distribution of both planktivorous seabird species was not uniform along the transect. Both Fulmar and Little Auk were highly aggregated on one segment of the transect over the edge of the Norwegian Trench around stations 5 and/or 6 (Fig. 2). Up to 1500 Fulmar and 130 Little Auk were recorded per crossing. In general, no birds were recorded in mixed North Sea water close to Denmark and more than 90 % were seen in the central parts, with at least 75 % recorded around stations 5 and 6. The null hypotheses that the two bird species were distributed independently from water masses was rejected (χ^2, $p < 0.01$).

We first tested the affinity of the birds for mixed surface waters (32.0-34.0 psu). The results (Tab. 1, Tab. 2) show that both Fulmar and Little Auk preferred the mixed water masses between inflowing high saline and outflowing low saline waters. On the other hand, the confidence interval for the observed proportion of Little Auk in water of salinities below 32 psu could not completely roule out the possibility of affinity for the Norwegian Coastal Water for this species.

The next model (Tab. 1, Tab. 2), which tested the bird's use of mixed waters of the convergense zone as opposed to the centers of inflowing and outflowing surface water masses, strongly indicated that the distribution of the two planktivorous was indeed related to the convergense zone. Both species clearly avoided the core of the Norwegian Coastal Water as well as the core of inflowing surface water from the North Sea. As the distribution of mixed surface waters of the convergense zone varied between days, the peak abundances of both species, which occupied segments smaller than 10 km transect distance, did not seem to be related to any specific water mass within the 32.0-34.0 psu category.

Although some of the bird aggregations were recorded in areas with surface fronts, neither species seemed to use particular fronts (mesoscale) between water masses occurring in the convergense zone. The 75%-quartile of birds seen on the five crossings were found along the following salinity gradients (surface): Fulmar 10/9 31.0-33.5 psu, 12/9 33.0-34.4 psu, 14/9 32.6-32.8 psu and Little Auk 14/1 32.0-33.5 psu, 16/1 31.0-33.4 psu.

Utilization tests (Tab. 1, Tab. 2) further showed that bird distributions did not relate to surface gradients (psu) in the convergense zone, as they failed to indicate any trend in significanse when comparing observations between weak and strong fronts (Tab. 1, Tab. 2).

Pycnocline characteristics, on the other hand, clearly affected the distribution of both species on all five crossings (Tab. 1, Tab. 2). Surprisingly, both species showed strong affinity for areas with a shallow pycnocline and a strong vertical gradient (psu) of the upper 20 m of the water column. The results of tests indicate Fulmar use of areas with a pycnocline shallower than 15 m (78-88% of birds) and Little Auk use of areas with a pycnocline shallower than 20 m (92-98% of birds). The results indicate an abrupt change in preference from significant use to non-significant use around 15 m (Fulmar) and 20 m (Little Auk). Further, a trend towards gradually fewer birds with increasing pycnocline depth is indicated, and both species avoided waters with a pycnocline deeper than 30 m or a mixed water column.

It was not possible to test the general application of the bird's affinity for areas with a shallow pycnocline, as lateral extension of the shallow pycnocline through Skagerrak is only poorly known. As the seasonal lateral oscillations of Norwegian Coastal Water have been investigated by Sætre et al. (1988), it was possible to indicate the application of the bird's use of the convergense zone between inflowing/outflowing surface waters. Sætre et al. (1988) found a mean annual displacement of the 34 isohaline of 80-100 km, the winter location being approximately along 200 m depth contour on the southern edge of the Norwegian Trench and in midd summer south of the 100 m contour. We therefore chosed to compare the average distribution of Fulmar and Little Auk over the whole of Skagerrak, as obtained during former surveys (1987-1990), with the approximate distribution of the convergense area between Norwegian Coastal Water and North Sea Water. As the outflow of the Norwegian Coastal Water is often blocked during strong westerly winds (Aure & Sætre 1983), this comparison only reflects the relationship during calm or easterly wind conditions. Fig. 4. shows the wide ranges of Fulmar and Little Auk in the Skagerrak, and the striking overlap between the location of their concentration area and the predicted location of the convergense zone south of the Norwegian Trench along the 100 m and 200 m depth contours.

DISCUSSION

Our work adds to the number of studies, which have underlined the extreme heterogeneity and patchiness of the Skagerrak. Due to the spatial and temporal dynamics of the area, especially the wind-driven oscillations of the outflow (Aure & Sætre 1983, Danielssen et al. 1991), one should be carefull to use the results obtained from single transects to make general statements concerning the whole of Skagerrak.

Taking these considerations into account, we still find that the study of associations between planktivorous birds and hydrography in the Skagerrak generated pertinent results, which have elucidated important relationships. Both studied species were definitely associated with the convergense zone between inflowing and outflowing surface water masses in the central part of the Skagerrak, whereas both species seemed to avoid the core of these water masses. In spite of the fact that the location of the interface between outflowing and inflowing surface water masses was dynamic and changed position within 25 nautical miles, the location of bird aggregations always coincided with this zone.

The finding of significantly more birds of both species in areas with a shallow pycnocline is in agreement with their relation to the convergense zone, and may actually be the reason for the significant use of this area. It is not likely, however, that Fulmar and Little Auk are associated with the areas of the Skagerrak supporting the shallowest pycnocline. The doming of the pycnocline, which is created by the anti-clockwise circulation pattern, has been found by Pingree et al. (1982) and Danielsen et al. (1991) to be generally centered in the deepest part of the Skagerrak, whereas the main concentrations of planktivorous birds are normally found at the shelf break or rather over the southern area of the dome (Fig. 4).

The relationship of Little Auks to the dome is not surprising. Little Auks wintering on the Scotian Shelf were found by Brown (1988b) to concentrate above a shallow scattering layer (15 m) containing dense swarms of mesozooplankton. Least Auklet Aethia pusilla, a small auk species with a similar diet, has been found within stratified water in the Bering Sea to forage, where the pycnocline is most shallow (Hunt et al. 1990, Haney 1991). Unlike small-bodied, planktivorous auks, the Fulmar is only able to make very shallow dives. It is possible that Fulmars utilize zooplankton, which migrate through the pycnocline during night, as found by e.g. Rosenberg et al. (1990). Unfortunately, the few investigations of the biological processes related to the Skagerrak pycnocline make interpretations of the nature of this relationship very difficult. Several studies, including SKAGEX, have documented the importance of the shallow pycnocline to sub-surface concentrations of phytoplankton (Dahl, E. & Danielssen, D.S. (1981), Pingree et al. (1982), Richardson (1985), Danielssen et al. 1991). Fulmars may receive additional food from working trawlers (Furness & Todd 1984), yet studies of the distribution of Fulmars in relation to trawling activities in the Skagerrak have documented that during winter only trawling within the convergense zone attracts the species, trawling outside this area using similar gear does not attract birds (Skov et al. in prepp). Therefore, natural food sources seem to form the stable food for the species in Skagerrak.

Very limited information seems to be available on the lateral distribution of mesozooplankton, which might be the food for the populations of Fulmar and Little Auk in the Skagerrak. Pingree et al. (1982) and Rosenberg et al. (1990) found aggregations of the abundant Calanus finmarchicus at the sub-surface chlorophyl maximum during night only. Bøhle & Moksness (1991) and Ulmestrand & Hagström (1992) analysed krill catches throughout most of Skagerrak using ICES standard trawls, and found the highest abundance over much of the deep area and single large patches in the transition zone to the Kattegat. Some studies have underlined the general importance of mixing processes to secondary production in the Skagerrak (Richardson 1985, Tiselius et al. 1991). Other studies, such as Kiørboe et al. (1990) seem to indicate variable structures of food webs, which might influence the abundance of mesozooplankton in different areas of Skagerrak. Kiørboe et al. (1990) found during a 5-day cruise indications of a microbial loop type food chain in the central, stratified part of the Skagerrak, while a more "traditional" herbivorous food chain dominated at the periphery.

Future studies relating zooplankton abundance and distribution to the dome, should take into account the considerable heterogeneity and dynamics of the Skagerrak. Shallow scattered layers and vertical migrations make sampling of zooplankton abundance difficult. Supplementing such studies with research on planktivorous seabirds may assist in locating single patches and in determination of the lateral distribution of zooplankton.

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REFERENCES

Aure, J. & Sætre,R. 1983: Wind effects on the Skagerrak outflow. pp. 263-280 in: The Norwegian Coastal Current, R. Sætre & M. Mork (Eds.). - Univ. of Bergen.

Bradstreet, M.S.W. 1982: Pelagic Feeding Ecology of Dovekies, Alle alle, in Lancaster Sound and Western Baffin Bay. Arctic 35 (1): 126-140.

Briggs, K.T., Tyler, W.B., Lewis, D.B. & Carslon, D.R. 1987: Bird communities at sea off California: 1975-83. Stud. Avin. Biol. 11: 1-74.

Brown, R. G. B. 1988a: Zooplankton patchiness and seabird distributions. Pp. 1001-1009 in Oulette, H. (ed.): Proc. XIX Int. Orn. Congr. Ottawa, 1986.

Brown, R.G.B. 1988b: Oceanographic factors as determinants of the winter range of the dovekie (Alle alle) off Atlantic Canada. Colon. Waterbirds 11: 176-180.

Bøhle, B. 1989: Ressurcer av fisk, krebsdyr og sel i Skagerrak. Flødevigen meldinger nr. 3 - 1989. 116 pp. Fiskeridirektoratets Havforskningsinstitutt.

Bøhle, B. & Moksness, E. 1991: On the distribution of Euphasiids in Skagerrak. ICES - C.M. 1991/L:4.

Cramp, S. & Simmons, K.E.L. 1977: Handbook of the Birds of Europe, the Middle East,and North Africa: the Birds of the Western Palearctic. Vol. 1. Oxford University Press.

Dahl, E. & Danielssen, D.S. 1981: Hydrography, nutrients and phytoplankton in the Skagerrak along the section Torungen-Hirthals, January-June 1980. Pp. 294-310 in: R. Sætre & M. Mork (Eds.): The Norwegian Coastal Current. University of Bergen.

Danielssen, D.S., Edler, L., Fonselius, S., Hernroth, L., Ostrowski, M., Svendsen, E. & Talpsepp, L. 1991: Oceanographic variability in Skagerrak/Northern Kattegat, May-June, 1990. Report to the Skagex Workshop, Lysekil, Sweden, 3-6 November 1992.

Durinck, J., Skov, H. & Danielsen, F. in press. (Proceedings 7. Nordic Orn. Congress): Factors determining the distribution of seabirds in the North Sea.

Follestad, A. 1990: The pelagic distribution of Little Auk Alle alle in relation to a frontal system off central Norway, March/April 1988. Polar Research 8: 23-28.

Furness, R.W. & Todd, C.M. 1984: Diets and feeding of Fulmars Fulmarus glacialis during the breeding season: a comparison between ST. Kilda and Shetland colonies. Ibis 126: 379-84.

Haney, J.C. 1985: Wintering phalaropes off the southeastern United States: application of remote sensing imagery to seabird habitat analysis at oceanic fronts. J. Field. Ornith. 56: 321-333.

Haney, J.C. 1986: Seabird affinities for Gulf Stream frontal eddies: Responses of mobile marine consumers to episodic upwelling. Journal of Marine Research 44: 361-384.

Haney, J.C. 1991: Influence of pycnocline topography and water-column structure on marine distributions of alcids (Aves: Alcidae) in Andyr Strait, Northern Bering Sea, Alaska. Marine Bioloy 110: 419-435.

Haney, J.C. & McGillivary, P.A. 1985: Midshelf fronts in the South Atlantic Bight and their influence on seabird distribution and seasonal abundance. Biol. Oceanogr. 3: 401-430.

Haney, J.C. & Solow, A.R. 1992: Testing for resource use and selection by marine birds. J. Field Ornithol. 63 (1): 43-52.

Hunt, G.L. Jr. 1990: Foraging habitat and prey taken by least auklets at King Island, Alaska. Mar. Ecol. Prog. Ser. 65: 141-150.

Hunt, G.L., Jr., Harrison, N.M. & Cooney, R.T. 1990: The influence of hydrographic structure and prey abundance on foraging least auklets. Stud. Avian. Biol. 14: 7-22.

Kiørboe, T., Kaas, H., Kruse, B., Møhlenberg, F.,Tiselius, P. & Ærtebjerg, G. 1990: The structure of the pelagic food web in relation to water column structure in the Skagerrak. Mar. Ecol. prog. Ser. 59: 19-32.

Laursen, K., Pihl, S., Skov, H., Durinck, J., Danielsen, F., Frikke, J. & Hansen, M. in prepp. (Dan. Review of Game Biol.): The distribution and numbers of non-breeding waterbirds in Danish waters 1987-89.

Neu, C.W., Byers, C.R. & Peek, J.M. 1974: A technique for analysis of utilization-availability data. J. Wild. Mgmt. 38: 541-545.

Pingree, R.D., Holligan, P.M., Mardell, G.T & R.P. Harris 1982: Vertical distribution of plankton in the Skagerrak in relation to doming of the seasonal thermocline. Cont. Shelf Res. 1 (2): 209-219.

Richardson, K. 1985: Plankton distribution and activity in the North Sea/Skagerrak-Kattegat frontal area in April 1984. Mar. Ecol. Prog. Ser. 26: 233-244.

Richardson, K. 1989: Phytoplankton distribution and activity in the Skagerrak: a review. ICES CM 1989/L:24.

Rosenberg, R., Dahl, E., Edler, L., Fyrberg, L., Granéli, E., Granéli, W., Hagström, Å., Lindahl, O., Matos, M.O., Petterson, K., Sahlsten, E., Tiselius, P., Turk, V. & Wilkner, J. 1990: Pelagic nutrient and energy transfer during spring in the open and coastal Skagerrak. Mar. Ecol. Prog. Ser. 61: 215-231.

Schneider, D.C. 1982: Fronts and seabird aggregations in the southeastern Bering Sea. Mar. Ecol. Prog. Ser. 25: 211-218.

Schneider, D.C. & Hunt, G.L. 1982: Carbon flux to seabirds in water with different mixing regimes in the southeastern Bering Sea. Mar. Biol. 67: 337-344.

Schneider,D.C., Duffy, D.C. & Hunt G.L., Jr. 1988. Cross-shelf gradients in the abundance of pelagic birds. Pp. 976-981 in Oulette, H. (ed.): Proc. XIX Int. Orn. Congr. Ottawa, 1986.

Skov, H., Andell, P., Danielsen, F. & Durinck, J. 1990: Hvordan kan man forebygge olieforureningsskader på havfugle i Kattegat och Skagerrak?. Fauna och Flora 3-4-1990: 153-161.

Skov, H., Andell, P. & Durinck, J. (in prepp.): The effects of trawling activities on the distribution of seabirds in the North Sea-Baltic Sea transitional area.

Springer, A.M. & Roseneau, D.G. 1985: Copepod-based food webs: auklets and oceanography in the Bering Sea. Mar. Ecol. Prog. Ser. 21: 229-237.

Sætre, R., Aure, J. & Ljøen, R. 1988: Wind effects on the lateral extension of the Norwegian Coastal Water. Cont. Shelf Res. 8 (3): 239-253.

Tasker, M.L., Jones, P.H., Dixon, T., & Blake, B.F. 1984: Counting seabirds at sea from ships: A review of methods employed and a suggestion for a standardized approach. - Auk 101: 567-577.

Tiselius, P., Nielsen, T.G., Breuel, G., Jaanus, A., Korshenko, A. & Witek, Z. 1991: Copepod egg production in the Skagerrak during SKAGEX, May- June 1990. Marine Biology 111: 445-453.

Ulmestrand, L. & Hagström, O. 1992: Abundance and Distribution of Euphasiids (krill) in Skagerrak and Kattegat in February 1984-1992. ICES - C.M. 1992/L:16.

Table 1. Utilisation tests of differential use of surface water masses, fronts and pycnocline characters (see Methods section) by Fulmar Fulmarus glacialis in the Skagerrak. Observed proportions (p) compared to expected proportion (pe). * marks significantly lower use than expected (Bonferroni z-statistic), ** marks significantly higher use than expected (Bonferroni z-statistic).

Hydrographical Significans category	Census effort (pe)	Proportion of Fulmars observed (p)	95 % CI	
Surface water mass (salinity)				
25-32 psu	0.323	0.025	$0.018 \leq p \geq 0.033$	*
32-33 psu	0.194	0.692	$0.669 \leq p \geq 0.714$	**
33-34 psu	0.323	0.238	$0.218 \leq p \geq 0.259$	*
> 34 psu	0.160	0.045	$0.035 \leq p \geq 0.055$	*
Surface flow (salinity)				
inflow (> 32 psu)	0.290	0.064	$0.053 \leq p \geq 0.075$	*
outflow (< 32 psu)	0.291	0.018	$0.012 \leq p \geq 0.024$	*
convergense zone	0.419	0.918	$0.906 \leq p \geq 0.930$	**
Surface gradient (salinity)				
0-1 psu	0.455	0.722	$0.700 \leq p \geq 0.740$	**
1-2 psu	0.182	0.080	$0.066 \leq p \geq 0.093$	*
2-3 psu	0.182	0.180	$0.161 \leq p \geq 0.200$	NS
3+ psu	0.181	0.018	$0.011 \leq p \geq 0.025$	*
Pycnocline depth (m)				
mixed column	0.100	0.000	$0.000 \leq p \geq 0.000$	*
5-10 m	0.033	0.396	$0.370 \leq p \geq 0.422$	**
10-15 m	0.133	0.441	$0.416 \leq p \geq 0.467$	**
15-20 m	0.267	0.090	$0.075 \leq p \geq 0.104$	*
20-25 m	0.267	0.053	$0.042 \leq p \geq 0.065$	*
25-30 m	0.133	0.020	$0.013 \leq p \geq 0.027$	*
30-35 m	0.067	0.000	$0.000 \leq p \geq 0.000$	*
Pycnocline gradient (psu - 0-20 m)				
0-1 psu	0.385	0.062	$0.051 \leq p \geq 0.073$	*
1-2 psu	0.384	0.317	$0.296 \leq p \geq 0.338$	*
2-3 psu	0.231	0.621	$0.599 \leq p \geq 0.643$	**

Table 2. Utilisation tests of differential use of surface water masses, fronts and pycnocline characters (see Methods section) by Little Auk Alle alle in the Skagerrak. Observed proportions (p) compared to expected proportion (pe). * marks significantly lower use than expected (Bonferroni z-statistic), ** marks significantly higher use than expected (Bonferroni z-statistic).

Hydrographical category	Census effort (pe)	Proportion of Little Auks observed (p)	95 % CI	Significans
Surface water mass (salinity)				
25-32 psu	0.400	0.458	$0.385 \leq p \geq 0.530$	NS
32-33 psu	0.133	0.396	$0.325 \leq p \geq 0.468$	**
33-34 psu	0.200	0.146	$0.094 \leq p \geq 0.197$	*
> 34 psu	0.267	0.000	$0.000 \leq p \geq 0.000$	*
Surface flow (salinity)				
inflow (> 32 psu)	0.267	0.000	$0.000 \leq p \geq 0.000$	*
outflow (< 32 psu)	0.267	0.010	$0.000 \leq p \geq 0.031$	*
convergense zone	0.467	0.990	$0.976 \leq p \geq 1.000$	**
Surface gradient (salinity)				
0-1 psu	0.429	0.594	$0.531 \leq p \geq 0.658$	**
1-2 psu	0.428	0.351	$0.289 \leq p \geq 0.412$	*
2-3 psu	0.143	0.055	$0.025 \leq p \geq 0.085$	*
Pycnocline depth (m)				
mixed column	0.267	0.000	$0.000 \leq p \geq 0.000$	*
10-15 m	0.200	0.650	$0.580 \leq p \geq 0.722$	**
15-20 m	0.200	0.336	$0.265 \leq p \geq 0.407$	**
20-25 m	0.133	0.014	$0.000 \leq p \geq 0.031$	*
25-30 m	0.200	0.000	$0.000 \leq p \geq 0.000$	*
Pycnocline gradient (psu - 0-20 m)				
1-2 psu	0.429	0.144	$0.104 \leq p \geq 0.184$	*
2-3 psu	0.571	0.856	$0.816 \leq p \geq 0.896$	**

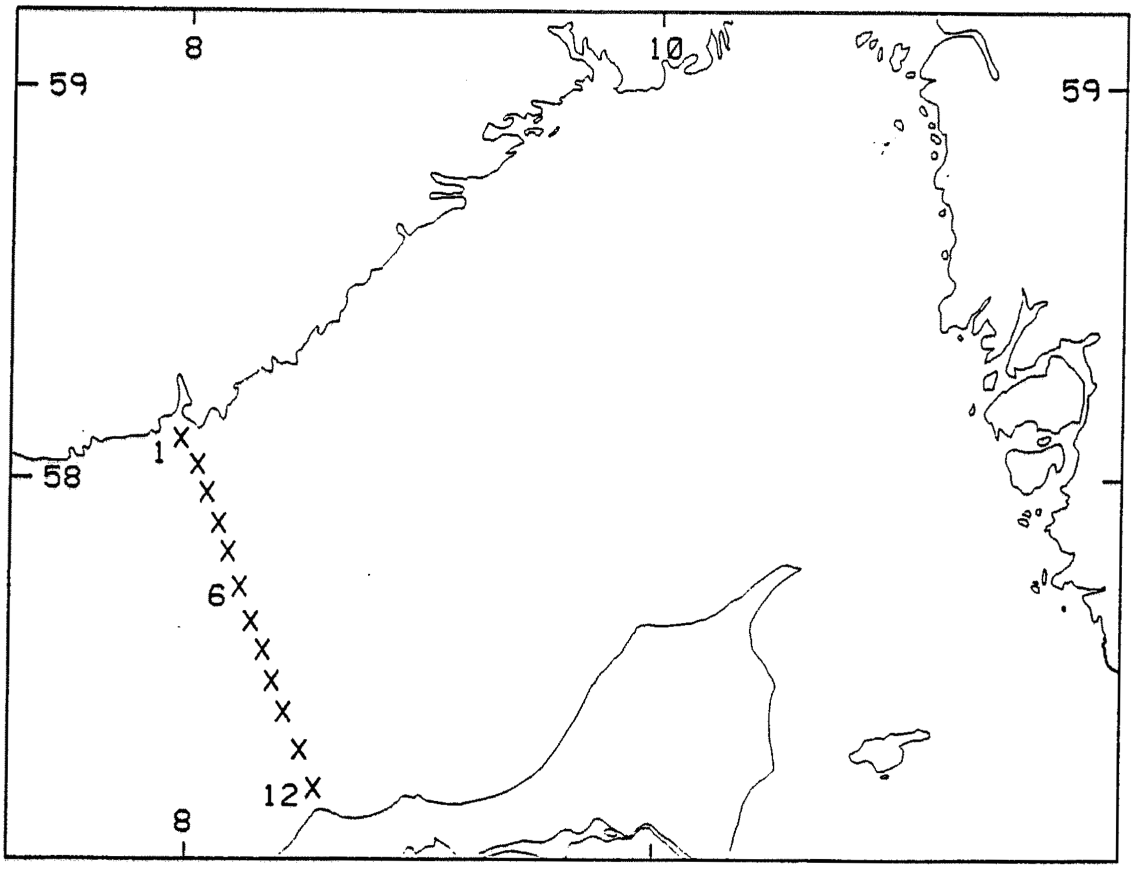

Fig. 1. The location of the study transect in the Skagerrak. Stations 1, 6 and 12 are indicated.

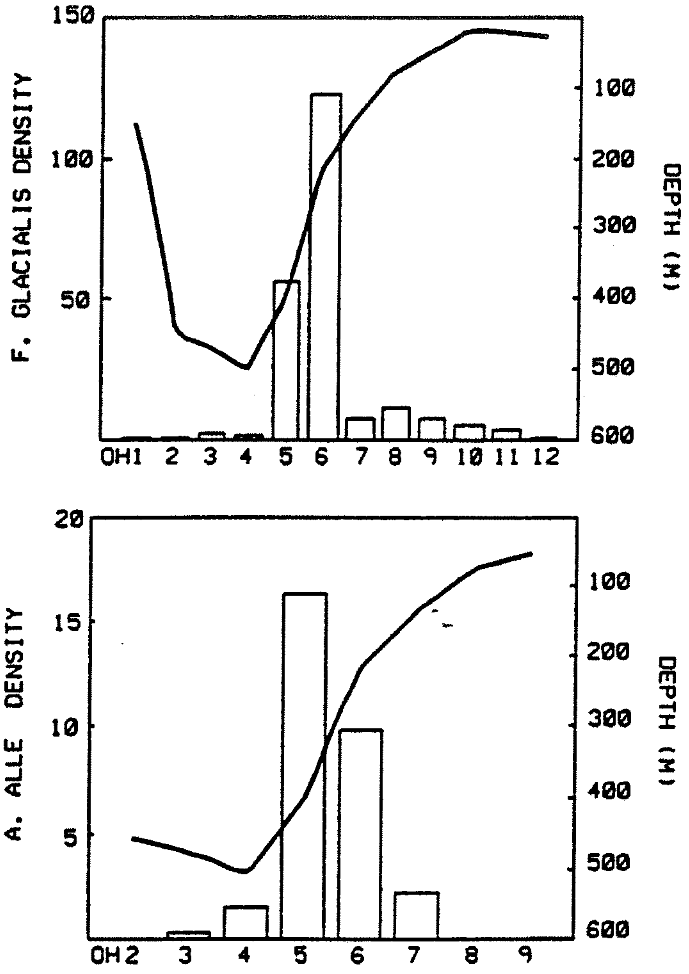

Fig. 2. The average density of Fulmar Fulmarus glacialis recorded during SKAGEX II and Little Auk Alle alle recorded during SKAGEX III. Densities are birds/km^2 per station segment. The water depth is indicated.

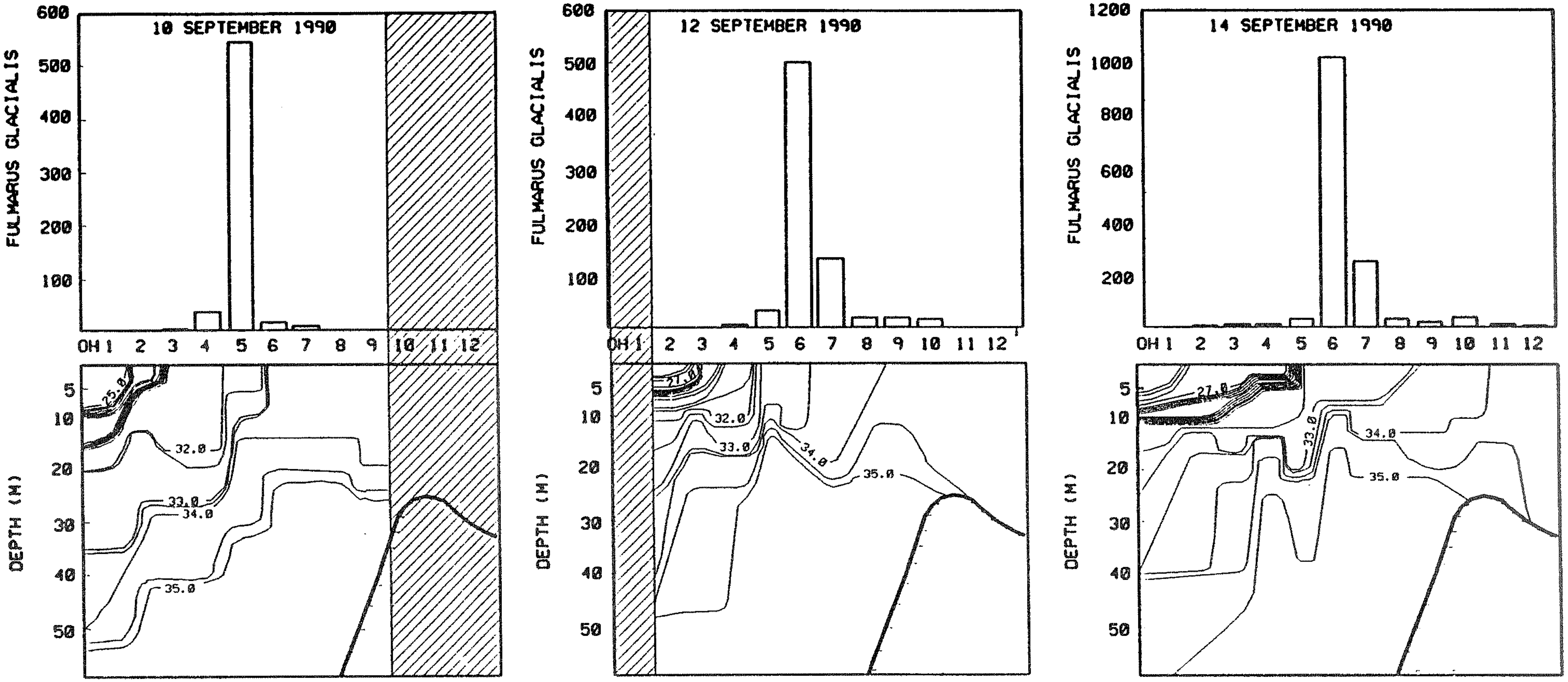

Fig. 3. The distribution of Fulmar Fulmarus glacialis (SKAGEX II) and Little Auk Alle alle (SKAGEX III) in relation to the distribution of water masses (0.5 psu isohalines) in the upper 50 m water column along the study transect. Numbers refer to hydrographical stations (see Fig. 1). Segments worked during darkness are indicated by hatched area.

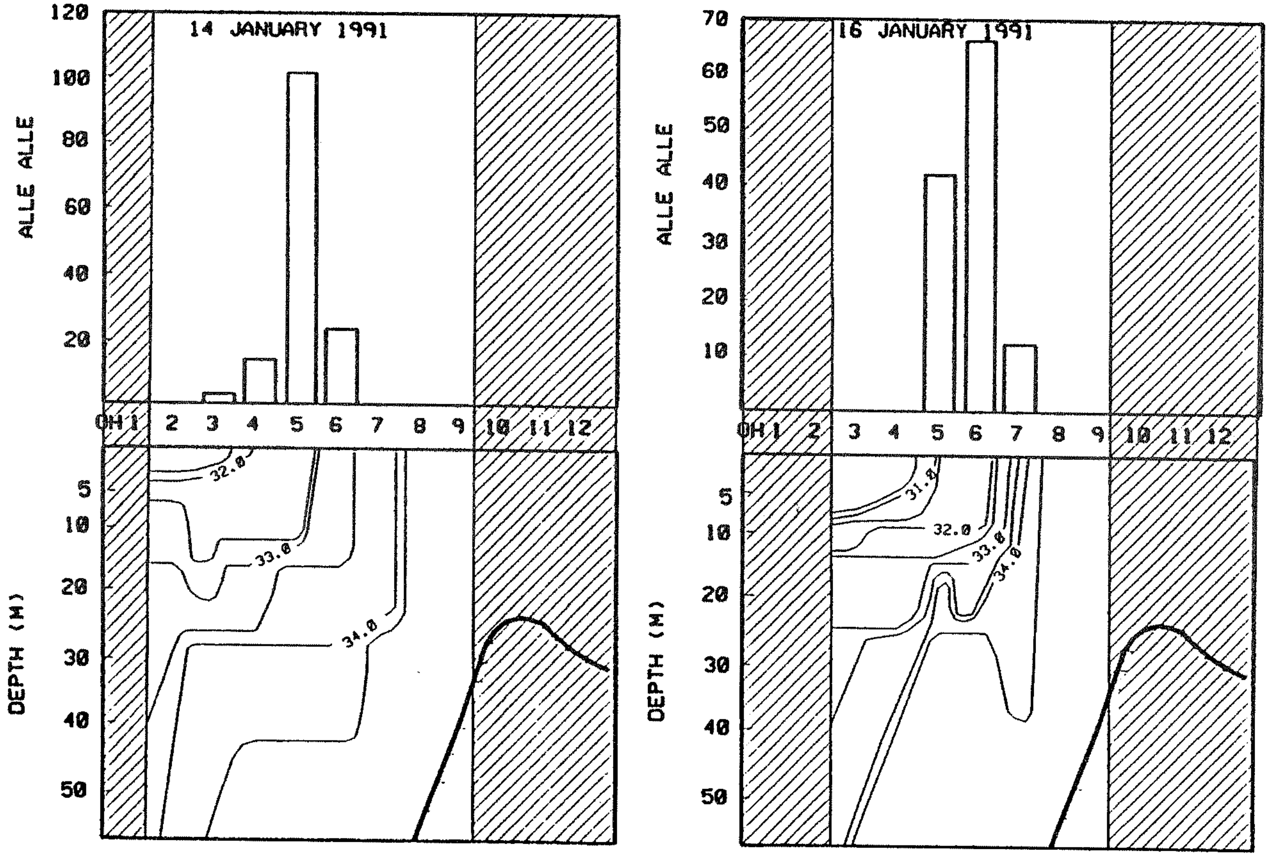
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Fig. 3. Cont.

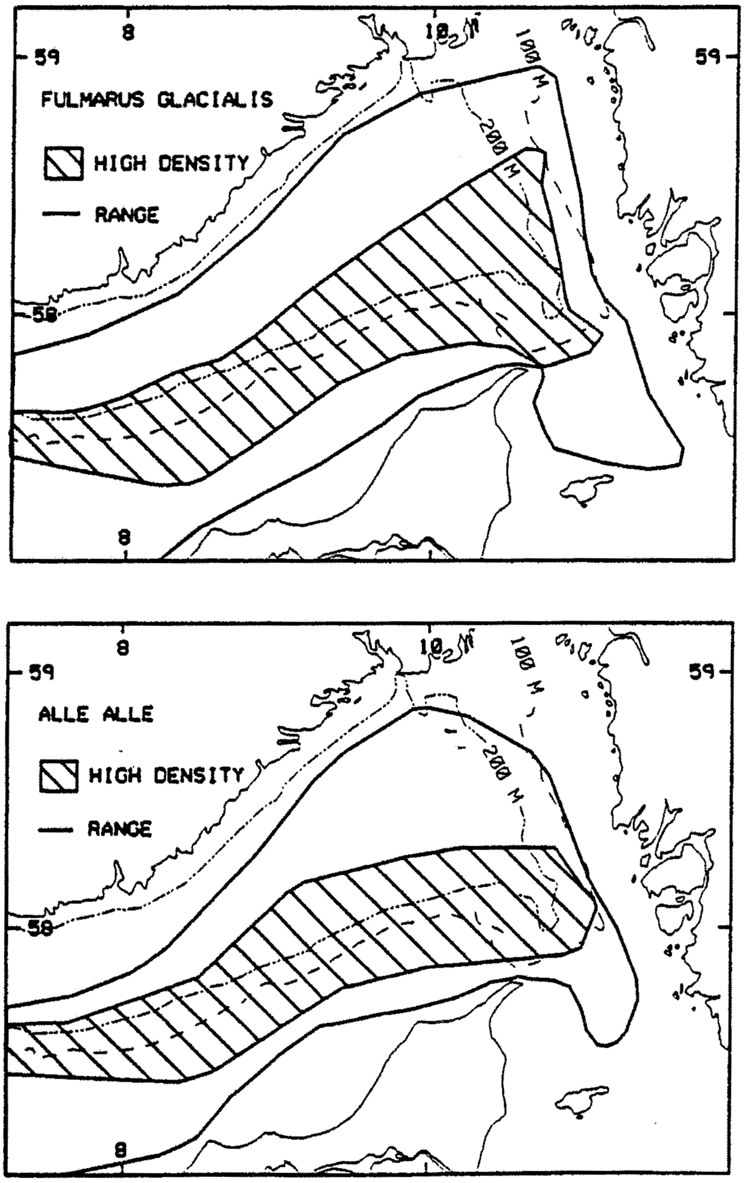

Fig. 4. The average geographical distribution of Fulmar Fulmarus glacialis and Little Auk Alle alle obtained during surveys in the Skagerrak autumn and winter 1987-1990 compared to the predicted location of the convergense zone between inflowing and outflowing surface waters along the southern edges of the Norwegian Trench (see text). The thick contour indicates the range of the species, the hatched area indicates the area of average high densities (≥ 5.0 birds/km²).

Presentation no 21.

Suspended matter and minor elements distribution in the Danish straits.

by

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SUSPENDED MATTER AND MINOR ELEMENTS DISTRIBUTION IN THE DANISH STRAITS

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Methods of sampling and processing of samples

Water sampling for suspended matter was carried out by using 5 litre waterbottles attached to a cable which had a fluorometer at the bottom. Usually the samples at all stations were taken from 0.5 and 10 m depth asaccording to the SKAGEX manual. At individual stations in the Kattegat samples were collected according to light dispersion intensity extreme at right angle to the water. At some stations in the Kattegat samples were also taken at near-bottom depth (about 2 metres above the bottom) by a special waterbottle which closed when the fluorometer touched the bottom.

The collected water was immediately transfered into polyethylene bottles and suspension was extracted on a filter appliance under vacuum conditions of 0.3 atmosphere through nuclear filters, 35 mm diameter, pore diameter 0.45 µm. The volume of filtered water varied between 0.5-1 litre.

Presentation of results

Table 1 shows the concentration of suspended matter (mg/l) according to the results of the 13th cruise of research vessel "Shelf" (April-May 1990) and table 2 shows the results of the 15th cruise of research vessel "Shelf" (September 1990). Table 3 provides the calculated average concentrations of suspended matter with root-mean-square deviations on cruises, regions and depths. Table 4 reflected concentration and content of suspended and dissolved minor elements across A section in the 13th cruise.

Preliminary scientific results

The number of samples appeared to be insufficient for compiling representative maps of areal distribution of suspension that is why the average values of suspended matter concentration were calculated depending on cruises, regions, horizons and time. Qualitative analysis of the distribution of suspended matter throughout the profiles was performed as well. This enabled us to compile a generalized picture of the distribution of suspended matter to make a comparative analysis of suspension concentration for two seasonal surveys, to examine the distribution of suspended and dissolved forms of Fe, Mn, Zn and Cu at profile A (according to data of the 13th cruise) and to draw the following preliminary conclusions:

1. According to the data of the 13th cruise suspension concentration in the Kattegat made up 1.0 mg/l at of 0.5 m depth and 1.1 mg/l at 10 m. In the Skagerrak the values of suspension concentration were insignificantly lower: 0.9 mg/l at 0.5 m depth and 1.0 mg/l insignificantly lower: In the Kattegat in the near-bottom layerthe suspension concentration increased sharply: up to 2.0 mg/l as an average and at an individual stations it mounted to 6.8 mg/l (station L-4).

2. The average concentration of suspension in Kattegat decreased from 1.2 mg/l to 1.0 mg/l (9-10.06) during the survey between 27.05 - 04.06 and to 0.8 mg/l (17-18.06), this could be related to the termination of a phytoplankton bloom.

3. There was a notable increase in suspension concentration at the depth of 10 m in the northern part of E transect in the Skagerrak.

4. The average concentrations of suspended forms at transect A profile in the Kattegat were for Fe - 44.6 µg/l, for Mn - 1.5 µg/l, for Zn - 1.2 µg/l and for Cu - 0.7 µg/l.

5. The average concentrations of dissolved forms inthe same transects were: for Fe - 13.6 µg/l, Mn - 1.2 µg/l, Zn - 6,2 µg/l and Cu - 0.9 µg/l. The data on Fe and Zn correlate well with the results of Magnusson and Westerlund, (1983), while our data on Cu are lower. The investigations were carried out approximately in the same region (north of transect A), but it should be noted that the elements were determined by an other method.

6. One should also mark a considerable increase of suspended Fe in the near-bottom layer which was twice higher, and at station 4A thirteen times higher as compared to the surface one.

7. It seems an interesting fact that high concentrations of dissolved Mn were registered in the near-bottom layer at stations 5A and 4A (1.7 and 8.0 µg/l respectively) that testifies indirectly to oxygen deficit and even hydrogen sulphide presence.

8. According to the 15th cruise data the average concentration of suspended matter in the Kattegat Strait made up 0.4 mg/l at 0.5 m depth and 0.6 mg/l at 10 depth. In the Skagerrak the average concentration of suspended matter was 0.6 mg/l at 0,5 m and 0.5 mg/l at 10 m depth. These values were at average twice lower than the results of the 13th cruise that could be explained by a phytoplankton bloom and may be by river drainage and store abrasion during spring storms.

9. The concentration of suspended matter in Skagerrak at depth of 150 m (stations 7 and 5), where transparency of water is comparable with deep open sea one, made up 0.1 mg/l, that is lower than the concentration of suspension on the surface layer of the open sea.

REFERENCES

Magnusson, B. and Westerlund, S. 1983. Trace metal levels in sea water from the Skagerrak and the Kattegat. In: Trace metals in sea water. NATO Conf. Ser., 1983, 9, pp. 467-473.

Table 3

THE CALCULATED AVERADE CONCENTRATIONS OF SUSPENDED MATTER (mg/l) WITH ROOT-MEAN-SQUARE DEVIATIONS ON CRUISES, REGIONS AND HORIZONS

horizon, m	13th cruise		15th cruise	
	number	the averade concentrations	number	the averade concentrations
THE KATTEGAT STRAIT				
0.5	64	1.0 ± 0.4	15	0.4 ± 0.1
10	24	1.1 ± 0.4	15	0.6 ± 0.3
near-bottom	26	2.0 ± 1.3	-	- -
all sample	126	1.3 ± 0.8	30	0.5 ± 0.3
THE SKAGERRAK STRAIT				
0.5	30	0.9 ± 0.3	26	0.6 ± 0.3
10	30	1.0 ± 0.5	26	0.5 ± 0.2
all sample	60	0.9 ± 0.4	52	0.5 ± 0.3
THE BOTH STRAIT				
all sample	188	1.1 ± 0.7	86	0.5 ± 0.3

1	2	3	4	5	6	7	8
		10	0.2	7E-1	450	150	0.1
40	113	0.5	0.6	5E-1	500	150	0.1
		10	0.6				

1	2	3	4	5	6	7	8
		10	0.5	3S	51	0.5	0.7
2E	260	0.5	0.8			10	0.4
		10	0.4	2S	54	0.5	0.3
1E	178	0.5	1.0			10	0.2
		10	0.5	1S	28	0.5	0.4
		07.09.90				10	0.6
2D	170	0.5	1.1	1A	28	0.5	0.4
		10	0.7			10	0.6
3D	230	0.5	0.4			12.09.90	
		10	0.4	6B	27	0.5	0.2
4D	270	0.5	0.5			10	1.5
		10	0.6	5B	41	0.5	0.5
5D	270	0.5	0.6			10	0.6
		10	0.2	4B	40	0.5	0.4
6D	200	0.5	0.7			10	0.8
		10	0.7	3B	46	0.5	0.4
7D	138	0.5	0.6			10	0.6
		10	1.1	2B	52	0.5	0.4
8D	94	0.5	1.2			10	0.5
		10	0.7	1B	77	0.5	0.3
9D	63	0.5	1.2			10	0.2
		10	0.8	0B	50	0.5	0.4
		08.09.90				10	0.6
1C	45	0.5	0.6			13.09.90	
		10	0.7	6C-1	210	200	0.5
3C	94	0.5	0.8	8C-1	230	200	0.3

Table 2

THE CONCENTRATION OF SUSPENDED MATTER (mg/l) ACCORDING TO THE RESULTS OF THE 15th CRUISE OF RESEARCH VESSEL "SHELF" (SEPTEMBER 1990)

number	depth m	horizon m	concentration mg/l	number	depth m	horizon m	concentration mg/l
1	2	3	4	5	6	7	8
		06.06.90					
11E	112	0.5	0.2	5C	139	0.5	0.6
		10	0.3			10	0.5
10E	101	0.5	0.1	6C	209	0.5	0.4
		10	0.3			10	0.2
8E	200	0.5	0.4	7C	270	0.5	0.2
		10	0.4			10	0.2
7E	472	0.5	0.1	8C	223	0.5	0.2
		10	0.4			10	0.2
6E	486	0.5	0.4		09.09.90		
		10	0.6	6S	23	0.5	0.3
5E	500	0.5	0.4			10	0.6
		10	0.4	5S	70	0.5	0.2
4E	470	0.5	0.2			10	0.9
		10	0.8	4S	71	0.5	0.6
3E	470	0.5	0.4			10	1.0

1	2	3	4	5	6	7	8
4B-1	42	17	1.4	5L-2	37	0.5	0.9
		35	2.0	6L-2	29	0.5	0.7
3B-1	47	17	1.2		19.06.90		
		44	1.2	7T	126	123	1.1
2B-1	52	17	1.1				
		49	1.5				

1	2	3	4	5	6	7	8
3E	470	0.5	1.3			100	1.3
		10	2.0		17.06.90		
2E	270	0.5	1.2	5A-2	50	0.5	0.6
		10	1.5			15	0.8
1E	236	0.5	0.9			47	1.5
		10	2.2	4A-3	86	0.5	0.2
		01.06.90				15	0.4
2D	175	0.5	1.0			83	1.9
		10	0.9	3A-2	65	0.5	0.6
3D	232	0.5	0.6			11	0.6
		10	1.0			62	1.8
		229	0.9	2A-2	57	0.5	0.4
4D	270	0.5	0.8			10	0.8
		10	0.8	1A-2	32	0.5	0.9
5D	270	0.5	0.8			15	0.9
		10	1.5			29	1.4
6D	161	0.5	0.8		18.06.90		
		10	0.6	6B-2	29	0.5	1.3
7D	115	0.5	1.3	5B-3	41	0.5	0.8
		10	0.8	4B-3	40	0.5	0.7
8D	106	0.5	0.5	3B-3	45	0.5	0.9
9D	57	0.5	0.4	1B-3	72	0.5	1.0
		10	1.1	1L-2	53	0.5	1.2
		02.06.90		2L-2	102	0.5	1.7
5B-1	40	16	1.0	3L-3	51	0.5	0.6
		30	1.0	4L-2	42	0.5	0.8

1	2	3	4	5	6	7	8
4L	44	0.5	0.9			36	3.0
		10	1.0	5B-2	41	0.5	1.6
3L	54	0.5	1.0			37	2.3
		10	0.8	6B-1	29	0.5	0.5
		52	21.0			27	1.4
2L	100	0.5	1.1		10.06.90		
		10	0.9	6S-1	21	0.5	0.9
1L	52	0.5	1.1	5S-1	110	0.5	0.6
		10	1.0			107	1.2
		31.05.90		4S-1	73	0.5	0.6
11E	112	0.5	1.4			71	0.5
		10	0.7	3S-1	52	0.5	0.6
10E	107	0.5	0.6			50	2.4
		10	0.5	2S-1	54	0.5	0.6
9E	110	0.5	1.2			52	1.7
		10	0.4	1S-1	28	0.5	0.6
8E	192	0.5	0.9			26	2.4
		10	1.2	1A-1	19	0.5	0.8
7E	470	0.5	0.8			17	0.9
		10	1.2	2A-1	56	0.5	0.9
6E	490	0.5	1.3			54	2.1
		10	1.8	3A-1	66	0.5	0.9
5E	550	0.5	1.0			64	1.2
		10	1.4	5A-1	38	0.5	1.1
4E	470	0.5	1.1			36	1.5
		10	1.3	4A-1	102	0.5	0.7

1	2	3	4	5	6	7	8
		10	1.3			10	0.5
4A	77	0.5	0.4	5F	640	0.5	0.7
		10	1.3			10	0.5
3A	67	0.5	0.5	4F	410	0.5	0.6
		10	1.5			10	0.5
2A	64	0.5	1.7	3F	410	0.5	0.5
		10	0.9			10	0.8
1A	31	0.5	1.6	2F	270	0.5	0.3
		10	0.8			10	0.5
1B	78	0.5	1.3			09.06.90	
		10	1.3	6L-1	30	0.5	0.6
2B	49	0.5	1.1	5L-1	39	0.5	1.1
		10	1.4	4L-1	42	0.5	1.5
3B	46	0.5	1.3			40	6.8
		10	0.9	3L-1	52	0.5	2.2
4B	40	0.5	1.1			50	1.6
		10	1.3	2L-1	100	0.5	1.2
5B	39	0.5	1.2			98	4.5
		10	2.0	1L-1	50	0.5	0.5
6B	30	0.5	1.6			48	2.5
		10	1.4	1B-2	82	0.5	1.3
		29.05.90				80	1.1
6L	27	0.5	1.0	2B-2	52	0.5	1.4
		10	1.1			50	4.2
5L	39	0.5	1.5	3B-2	42	0.5	1.2
		10	0.8	4B-2	39	0.5	0.5

Table 1

THE CONCENTRATION OF SUSPENDED MATTER (mg/l) ACCORDING TO THE RESULTS OF THE 13th CRUISE OF RESEARCH VESSEL "SHELF" (MAY-JUNE 1990)

number	depth m	horizon m	concentration mg/l	number	depth m	horizon m	concentration mg/l
1	2	3	4	5	6	7	8
		27.05.90		1B-1	71	50	1.2
6S	16	0.5	1.4			68	1.1
		10	1.0		04.06.90		
5S	92	0.5	1.0	12F	28	0.5	1.1
		10	0.9			10	0.6
		89	0.6	11F	61	0.5	0.8
4S	79	0.5	1.6			10	0.6
		10	0.6	10F	40	0.5	0.8
3S	40	0.5	1.5			10	1.5
		10	1.6	9F	83	0.5	0.9
2S	48	0.5	1.5			10	0.8
		10	1.7	8F	180	0.5	0.8
1S	24	0.5	1.6			10	0.8
		10	0.8	7F	450	0.5	0.6
		28.05.90				10	0.8
5A	42	0.5	1.7	6F	400	0.5	0.7

Table 4

CONCENTRATION AND CONTENT OF SUSPENDED AND DISSOLVED MINOR ELEMENTS ON THE KATTEGAT ACCROSS A SECTION
(13th CRUISE OF RESEARCH VESSEL "SHELF")

N st.	horizon m	Fe			Mn			Zn			Cu		
		1	2	3	1	2	3	1	2	3	1	2	3
5A	0.5	23.6	3.93	16.0	0.8	0.13	0.5	1.1	0.18	6.4	0.4	0.07	1.0
	15	44.0	4.89	-	0.8	0.13	-	1.3	0.14	-	0.9	0.10	-
	47	73.2	4.56	14.8	6.0	0.38	1.7	2.0	0.12	17.5	0.9	0.06	0.9
4A	0.5	14.8	7.40	16.0	0.4	0.20	0.7	1.0	0.50	5.1	0.7	0.35	1.2
	15	17.6	4.40	20.4	0.8	0.20	0.3	1.4	0.35	5.4	0.7	0.18	0.8
	83	190.0	10.0	29.6	4.3	0.23	8.0	1.5	0.08	3.7	0.9	0.05	0.7
3A	0.5	22.6	3.77	11.3	0.3	0.05	0.3	1.2	0.20	3.2	0.4	0.07	1.3
	11	19.6	3.27	19.6	0.4	0.07	0.5	1.6	0.27	4.8	0.4	0.07	1.2
	62	46.9	3.91	12.2	0.7	0.06	0.8	1.0	0.08	4.9	1.1	0.09	0.7
2A	0.5	38.8	9.70	9.0	0.4	0.10	0.7	0.9	0.33	4.5	0.4	0.10	0.7
	10	35.0	4.38	18.2	0.5	0.06	0.7	0.9	0.11	3.9	0.4	0.05	1.2
	54	-	-	10.8	-	-	0.7	-	-	15.0	-	-	0.6
1A	0.5	27.4	3.04	0.3	0.7	0.08	0.7	1.0	0.11	3.8	0.8	0.09	0.7
	15	16.1	1.79	9.8	0.5	0.06	0.5	0.8	0.09	5.0	0.9	0.10	0.7
	29	54.3	3.88	3.2	3.9	0.28	0.5	0.7	0.05	4.2	0.8	0.06	0.4
averade		44.6	4.92	13.6	1.5	0.14	1.2	1.2	0.18	6.2	0.7	0.10	0.9

1 - the suspended form minor elements (mkg/l)
2 - the suspended form minor elements (%)
3 - the dissolved form minor elements (mkg/l)

Presentation no 22.

On water masses and biological variability in the central and eastern Skagerrak during SKAGEX - 90: Inflow of the Atlantic water.

by

L. Talpsepp, J. Pavelson, T. Põder, K. Künnis,
K. Piirsoo and V. Porgasaar

ON WATER MASSES AND BIOLOGICAL VARIABILITY IN THE CENTRAL AND EASTERN SKAGERRAK DURING SKAGEX-90: INFLOW OF THE ATLANTIC WATER

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Abstract

This paper is based on the hydrophysical, hydrochemical and hydrobiological data gathered on board of R/V Arnold Veimer in the central and eastern Skagerrak during the international experiment SKAGEX-90 in May-June 1990.

Synoptic hydrological surveys expose the large-scale circulation and mesoscale hydrological processes as follows. The Jutland Current (JC) is not present during the first surveys of the experiment in May. The saline water appearance near the Danish coast in the central Skagerrak at the beginning of June can be interpreted as the start of the JC in spite of that the N:P ratio does not correspond to that for the JC water. Most of the biological parameters except the number of heterotrophic bacteria (NHB) do not explain the origin of the water. The high NHB (due to the increased organic matter content) showed that this saline water was pushed to north-east by the JC after it started and consisted of a mixture of the former JC water and the North Sea water. Near the Norwegian coast two upwelling events bringing saline nutrient-rich water to the surface layer were observed. The less-saline Norwegian Coastal Water (NCW) was extending over the surface of the central and also southern part of the Skagerrak. The spreading of the NCW southward was confirmed by the content of some phytoplankton species. The start of the increased salinity Atlantic Water inflow was observed in the central Skagerrak near the southern slope of the Norwegian Trench in two cores - between the 20-100 m with about 100 m deep seafloor, where the maximal daily mean speed exceeded 80 cm/s, and near bottom with the 300-450 m deep seafloor. During the inflow the two cores widened creating inflow region over all depths. T-S analyses of deeper water generally confirms the cyclonic circulation in the Skagerrak. However, a part of the saline water formed a branch not observed earlier that turned in

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the central Skagerrak to the northwest not following the isobaths and left the Skagerrak. The current speed up to 30 cm/s was estimated in the deep layers. This anomalously saline water inflow seems to be related to the increased salinity water appearence into the NE Atlantic and the northern North Sea observed in late 1989 and early 1990.

INTRODUCTION

The Skagerrak is the very important transition area between the North and the Baltic Seas, which considerably influences the water and matter exchange in these seas being at the same time an area under considerable anthropogenic load. Therefore, under the aegis of ICES, the joint expedition SKAGEX-90 was organized, the first stage of which took place in May-June, 1990.

The present paper is based on the results of R/V Arnold Veimer which was one of the 17 research vessels working in the eastern and central parts of the Skagerrak. The aim of the paperis to present the new experimental data giving new scientific knowledge about water circulation and their connection with biological processes, but also to give some new interpretations concerning the Atlantic Water Inflow and the behaviour of the Jutland Current. The historical data to which these results are compared are Joint Skagerrak Expedition 1966 (1970), Svansson (1975), Rodhe (1987) and Fonselius (1989). The Three latter form the basis for the interpretation of the data.

The paper contains the analysis of the unique SKAGEX microbiological measurements and also the analysis of the phytoplankton data. The biological data are analysed from the point of view of their possible with circulation and hydrophysical processes. Less attention is paid to their statistical analysis. Most of the phenomena described in the latest works (Danielssen et al.,1991 and Danielssen et al., 1994 (in this issue)) can be observed in the data of R/V Arnold Veimer. Moreover, many results presented in this paper give valuable contribution to the mentioned overview papers.

MATERIAL AND METHODS.

R/V Arnold Veimer worked in the central and eastern part of the Skagerrak from 24 May till 5 June. The work was divided into obligatory and the so-called voluntary program. The obligatory parameters measured were water temperature, salinity, *in situ* fluorescence, nitrates, nitrites, ortophosphates, chlorophyll *a*, primary production, composition and amount of phytoplankton, zooplankton and its production. The measurements were performed on definite transects (Fig. 1), started every third day and lasted for a day and a half. R/V

Arnold Veimer carried out measurements five times on transect F containing 12 stations, and four times on transect E having 6-13 stations. A mooring station with five "Aanderaa" current meters was deployed on 25 of May in the southern part of transect F (Fig.1). Current meters were placed at 20, 40, 60, 80 and 90 m level, while recording interval was 10 minutes. The mooring station was recovered on 14 July.

CTD-casts were carried out using Neil Brown (NBIS) Mark III profiler. Calibration of temperature and conductivity probes was realized in the thermobasin using NBIS calibration equipment directly before and after the experiment. Also 118 water samples were regularly collected and analysed in laboratory with the salinometer "Autosal" to compare their salinities with corresponding *in situ* CTD values. As a result, a correction factor -0.091 was calculated over the whole ensemble of water samples and salinity data were corrected according to it.

Meteorological parameters were measured by the ship's automatic weather station "Midas".

Water samples for nutrient (NO_3 +NO_2, PO_4) analyses were collected with 1.7 l Niskin bottles on the General Oceanic's rosette sampler attached to the CTD profiler. Analysis were performed immediately after sampling with the DATEX autoanalyser according to the methods supplied by the manufacturer.

Chlorophyll a (chl a) was analysed according to the recommendations by Edler (1979). The filtration of water was performed with the Whatman GF/C type filters, chlorophyll was extracted with 90% acetone. Measurements were made on the spectrophotometer Yanacco-2000, *chl a* concentration was calculated according to the equation of Jeffrey and Humpfrey.

Microbiological measurements as a part of the voluntary program were carried out three times on transect F. The distribution of heterotrophic bacteria was studied and in some samples the total number of microorganisms was estimated. For that purpose ZoBell agar medium 2216 E with two different salinities (7 and 34 psu) and the spread-plate technique were used.

RESULTS

1. The wind data.

The wind speed and direction, measured on board of R/V Arnold Veimer are presented in Fig. 2. During the first days of the experiment the speed of westerly winds was reaching up to 15 m/s. Since 27 May the wind weakened to 6-8 m/s and turned SW. After 2 June easterly and southerly winds were fluctuating mainly below 10 m/s. Thus, moderate westerly winds during the first half and weaker variable winds during the second half of the measurement period dominated.

2. Water masses and currents

2a. Historical knowledge. The main circulation scheme in the Skagerrak according to Svansson (1975) is as follows. In the upper layer the Jutland Current (JC) and its continuation flows along the Danish coast to the north-east and the Norwegian Coastal Current (near the Norwegian coast) in the opposite direction. The Baltic Current (BC) carries the Kattegat's water to the north along the Swedish coast, then mixes with the JC water and farther with the Oslo fjord water and turns into the Norwegian Coastal Current (NCC). In this way the cyclonic circulation is predominantly formed. The upper layer of the Skagerrak is "sensitive" to the wind and essential deviations from cyclonic circulation may occur (Fonselius,1989). For example, strong westerly and northwesterly winds prevent the BC from entering into the Skagerrak. Strong northerly and easterly winds allow the BC to spread over the central part of the Skagerrak, while the JC can't enter into it. In the deeper layers the flow pattern is also cyclonical, at which the increase of current speed towards the bottom was sometimes observed on the Danish side of the Skagerrak (Rodhe,1987).

2b. Norwegian Coastal Water. In Figs.3-5 the salinity and temperature distributions on transect F over the Skagerrak on 24, 27, 30 May, 2 and 5 June and in Figs.6-7 these on transect E (Fig.1) on 25, 28, 31 May and 3 June are presented. During the observation period the upper mixed layer of 5-10 m had relatively low salinities on the whole survey area except for the Danish coastal zone (see transect F) at the end of the experiment. The freshest water - 18.6 psu was observed on the transect E at two nearest to the Norwegian coast stations on 25 May. During the next surveys the salinity of the NCW continuosly increased near the Norwegian coast having the minimal salinity 21.7 psu on 3 June in the fresher water region. A deflection from this tendency was observed on 31 May due to an upwelling event. The existence of the NCW on transect E is clearly seen also from the bowl-like isotherms and isohalines (Figs.6-7), which enables an estimation of the extent of the NCW down to 25 m. On transect F which is located 65 km downstream the narrow fresher water core near the coast comparable to that on the transect E, was observed only on 27 May. Just before (24 May) and after (30 May) it was shifted approximately 30 km from the coast (station 4) due to the influence of upwelling events in the upper layer. The salinity in the core on transect F is always higher, obviously as a result of the lateral and vertical mixing of the NCW with more saline water. For example, the salinity increase of 2 psu was estimated on transect E on 25 May and on transect F on 27 May, which was assumed to be quite a reasonable motion (about 30 cm/s) for the

NCC water in that area. The temperature of the NCC water of low salinity was always approximately 0.5 °C higher than in other regions. Besides, the overall warming of the upper layer by 2 °C took place during the whole survey period.

2c. Upwelling. Two upwelling events occured in the coastal zone of Norway. The first of them on 24 May was in the central (transect F) and western (transect G) parts of the Skagerrak. The second upwelling was observed on both transects F and E on 30 and 31 May respectively. The upwelled water was registered at one or two closest to the coast stations, which shows that the width of the colder and saline water-band was roughly 6-12 km. These upwellings didn't occur in the whole water column, but only in the upper 15-20 m layer, while the rising water was compensated by the inflow of the NCC water into the subsurface layers (Fig.4). During the most prominent case (on 30 May, section F) the salinity - 33.7 psu and temperature - 8.1 °C were observed in the surface layer. The upwelling event was evidently caused by the moderate W to SW winds that blew over the basin starting from 28 May.

2d. The Jutland Current. In the southern part of the Skagerrak the JC is expected to be one of the main transporters of the North Sea water to north-east. Inspection of the sections shows that during the first part of the experiment there were no signs of the presence of the JC water. Until 31 May the upper layer west of Denmark had the salinity between 25 and 30 psu, at the same time with the tendency of continuos increase towards the coast. Besides, temperatures in the range of 11-12 °C were typical without any noticeable horizontal variations. On 2 June the inflow of more saline water at station 10 on transect F was observed. Three days later, on 5 June, the area covered with more saline water became wider, embracing the stations 9-11. Salinity had increased up to 32.4 psu and temperature was more than 9.5 °C in the upper 20 m layer. Also, a strong front that separated the saline water and the fresher (warmer) central Skagerrak water had been formed. According to the widening of the saline water band near the Danish coast, the front shifted about 15 km offshore to the station 8 on 5 June. The overall increase of salinity 6 psu through the front was accompanied by the change in temperature of about 2 °C.

2e. The Atlantic Water inflow. A relatively strong inflow of the saline Atlantic Water (AW) occured during the whole period of observations along the southern slope of the Norwegian Trench. It clearly appeared mainly in two depth intervals - between 20-100 m with about 100 m deep seafloor and near bottom with 300-450 m deep seafloor. The upper inflow region in the vicinity of the station 8 on transect F is relatively narrow (8-12 km) and characterized by drastically lifted isohalines. At the same time continuous increase of salinity took place in the whole column of the AW until 2 June. The maximum salinity of 35.317 psu (with the temperature of 8.15 °C) was registered in the core which was situated in the 50-65 m layer on 2 June. An existence of a current is confirmed by the velocity data obtained from the mooring station located between the stations 8 and 9. In Fig.8, where the daily mean current vectors are presented, we see that the current was directed parallel to the isobaths into the north-east. The daily mean speed of the current at 20, 40 and 80 m levels was mainly in the range of 20-40 cm/s. Nevertheless, on some days the speed reached up to 50 cm/s at the 20 m level. So it may be concluded that the whole column of the AW moved nearly with the same speed except the near-bottom layer (90 m level), where the speed was considerabely lower - 5-10 cm/s. During the last two weeks of operation of the mooring station, the speed at the upper levels increased and for example at the 20 m level sometimes exceeded 80 cm/s.

The deeper AW inflow occured near the bottom with 300-450 m deep seafloor and was characterized by continuously increasing salinity over the period of observations. This tendency was evident on the transect F, where the salinity in the core was 35.20-35.23 psu on 24 May, 35.25-35.27 psu on 27 May (Fig.3), 35.27-35.29 psu on 30 May (Fig.4) and exceeded 35.30 psu on 5 June (Fig.5) when the maximum observed salinity was 35.321 psu. The similar saline core was observed on transect E (Figs.6,7) some days later, where first the water with salinity 35.20-35.22 psu near both slopes appeared, then the saline water inflow continued (for example, the distance between the upper and lower 35.20 psu isohalines and the maximum salinity in the core increased). On 2 and 5 June (Figs.4,5) we notice the water with the salinity exceeding 35.27 psu and 35.30 psu, respectively, on the transect F near the northern slope of the Norwegian Trench, thus the spreading of the AW over the whole Skagerrak can be expected.

3. Nutrients

At the beginning of the study the surface layer of the Skagerrak was already depleated of inorganic nutrient. The typical nitrate and phosphate concentrations did not exceed 1.0 and 0.1 µM/l respectively. The mean concentration of phosphates in water at different depths changed in narrower limits than that of nitrates and was the following: 1m - 2 µM/l, 10 m - 3 µM/l, 20 m - 7 µM/l and 30 m - 12 µM/l. The average phosphate content of the water with the salinity 34 psu decreased somewhat in the upper layers, being 8 µM/l at the depth of 20...30 m and 4 µM/l at the depth of 1...10 m. Local differences from the situation where nutrients were depleated were observed in two areas at different time:

On 24 May and 2 June enhanced nutrient concentrations were recorded in the surface layer near the Danish coast (Figs.9-10). On 24 and 30 May the drastic increase of nitrate and phosphate concentration was detected close to the Norwegian coast (Fig.9-10). It is possible to identify three relatively persistent areas on transect F across the Skagerrak according to the vertical nutrient distribution pattern:

1) The coastal zone of Denmark; 2) the so-called Domain area in the middle of the transect; 3) the Norwegian coastal slope.

In the coastal zone of Denmark the vertical distribution of NO_3 and PO_4 was rather uniform during most of the study period. The nutrient depleated surface layer reached down to the bottom at 40 - 60 m. The sligth vertical stratification of phosphate content occured on 24 May and more expressive one on 2 June. The vertical stratification of nitrate was observed on 24 and 27 May, and also on 2 June.

In the domain area the vertical distribition of nitrate and phosphate had clearly a two layer structure. The shallow, nutrient depleated upper layer reached down to 10 - 15 m. Within the nutricline in the 15 - 25 m layer the concentration of nitrate jumped up to 7 - 8 µM/l, the concentration of phosohate up to 0.5 - 0.6 µM/l.

The variability of the nutrient content below the nutricline was relatively small except on 24 May, when it was probably related to errors in sampling depths. Nevertheless, the tendency of increase with depth is obvious in both nitrate and phosphate concentration. Compared to the domain area, the slope water near the Norwegian coast had a more complicated nutrient stratification structure. Twice, on 24 and 30 May, the enhanced phosphate and nitrate concentrations were detected in the surface layer close to the Norwegian coast. The nutricline was less defined and generally the concentrations were somewhat lower than at the same depth in the domain region.

The spatio-temporal pattern of the phosphate and nitrate distribution is related to biological and physical processes in the Skagerrak and in adjacent basins. In the context of the present study the nutrient data will be considered as an additional source helping to identify water masses and make decisions about their genesis.

The low nutrient concentration recorded in the Skagerrak surface layer is to be attributed to vernal phytoplankton growth. The low chlorophyll a content confirms that at the beginning of the observations the vernal phytoplankton bloom had already decreased. It can be assumed that at this time the postbloom situation was prevailing in the adjacent North Sea and Baltic areas, too. Thus, it is impossible to assess on the basis of the available nutrient data to what extent the low nutrient concetration in the Skagerrak was related to biological processes in situ or, to what extent it was influenced by inflows of nutrint depleated water outside the Skagerrak, especially by the Baltic current.

5. Composition of species and abundance of phytoplankton

On 24 May phytoplankton samples were taken at 11 station and from 27 May to 5 June at 7 stations. Most numerous were small flagellates (smaller than about 10 um) both in the surface water and at 20 and 30 m. The following diatoms occurred frequently: *Cerataulina pelagica*, *Chaetoceros spp.*, *Guinardia flaccida*, *Rhizosolenia alata*, *Rhizosolenia delicatula*, *Rhizosolenia fragilissima*, *Skeletonema costatum*, *Thalassiosira sp.*, *Nitzschia longissima*, *Nitzschia seriata*.

There were essential temporal and spatial differences in the phytoplankton structure during the whole period of observations. In the surface water (1-10 m) the most numerous diatom was mainly *Rhizosolenia fragilissima*.Lower values of the mean abundance of this species were registered at stations 8, 10 and 11. At two stations (10 and 11) the most numerous diatoms were *Thalassiosira sp* (27 May) and *Nitzschia seriata* (2 June). In station 5 the most numerous diatom was *Eucampia zodiacus* (27 May).

At the depth of 20 m *Rhizosolenia delicatula* was often the most numerous diatom. Its mean abundance was higher at stations 1-8. At station 10 the most numerous diatom was *Thalassiosira sp* (24 May-2 Yune). *Nitzschia seriata* was the most numerous diatom in stations 11 (30 May) and 12 (2-5 June), *Rhizosolenia fragilissima* in station 12 (27-30 May).

At the depth of 30 m the most numerous diatom was mainly *Rhizosolenia delicatula*. *Thalassiosira sp.* was most abundantly represented at stations 10 (27.05) and 11 (30.05).

Data on the phytoplankton abundance are given in Fig. 11. The correlation between the phytoplankton abundance and chlorophyll a in the surface water was 0.65, P>0.95.

At the depth of 20 m the chlorophyll content often increased while the phytoplankton abundance decreased (excl. at station 12 on 2 June and at station 11 on 5 June when the phytoplankton abundance at the depth of 20 m was greater than in the surface water). The contradiction between the phytoplankton abundance and chlorophyll content at the depth of 20 m was caused by changes in the phytoplankton structure: the rich chlorophyll content discovered at the depth of 20 m was caused by large diatoms (for instance: *Eucampia zodiacus* at station 7 on 24 May, *Cerataulina pelagica* at the depth of 17 m at station 12 on 30 May).

The temporal and spatial distribution of some phytoplankton species:

1. *Dinobryon cfr. balticum*. The species occurred only in the surface water: on 24 May at stations 1-7, on 27 May the species occurred at stations 1-11, on 30 May at stations 10 and 11, and on 2 June only at station 11.

2. *Thalassiosira sp*. On 24 May the species occurred in the whole transect in the surface water as well as at 20 m and 30 m. The highest abundance of the species was observed in the surface water of stations 11 and 12. By 27 May the abundance had increased in the surface layer of Danish coastal waters (max 132 000 at station 10). On 30 May the maximum abundance (151 500) was ob stations 1 and 12 the situation where abundance in the surface water was greater than in 20 and 30 m remained the same. On 2 June the abundance of the species at the depth of 20 m and 30 m was higher than in the surface water. On June 5 the situation also remained the same: abundance at 20 m was mostly greater than in the surface water.

3. *Torodinium robustum*.On 24 and 27 May the species occurred at 20 m and 30 m.On 30 May the species was observed in the surface water of station 2. On 2 June the species occurred in the surface water of stations 10 and 11; at the same time the species occurred at 20 m and 30 m in the other stations. On 5 June the species occurred both in the surface water and at 20 m.

4. *Gonyaulax sp*. occurred only at 20 m and 30 m during the experiment.

5. *Scrippsiella cfr. trochoidea* was observed only at 20 m and 30 m (excl. on 2 June, when the species occurred in the surface water of station 8.

6. *Distephanus speculum* was observed at 20 m and 30 m, but from 30 May to 5 June the species occurred in the surface water of stations 1 and 2.

The water of the surface layer at the depth of 1 to 5m was mixed and poor in chl a. The horizontal variation of the chl a content in the surface water was within the range 0.6...3.8 ug/l, while lower values (often below 1 ug/l) were observed in the central part of the section on all days of the experiment. Water at the depth of 10 m showed a variable chl *a* content both in the range of the transect and on different days. The mean chl a concentration of the section exceeded that of the surface water. Chl a concentrations at the depth of 20 m were very scattered, varying from 0.8 up to 17.3 ug/l during the experiment. The mean chl a contents per section were higher than in the upper layers on all days. (The maximum chl a concentration, 20.8 ug/l, was recorded at the depth of the fluorescence peak, at 17 m at station 7 on 30 May). At the depth of 30 m the chl a content of the water decreased, being less than 1 ug/l in many cases.

The maximum concentrations of chl a in water along the vertical profile were different in various stations and on different days. In two stations near the Norwegian coast the highest chl a concentrations were observed in the surface water on May 24 and May 30. In the central part of the section the maximum values of chl awere recorded at the depth of 10...20 m.

Such a distribution of chl a seems to be more or less typical of the water of the Skagerrak during the season. A similar vertical distribution of chl a in the same section was observed in May and June 1989, although the values of maximum concentration were lower, up to 7 ug/l on May 18 (Dahl et al., 1990). The formation of the subsurface populations of some phytoplankton species and an intense chl a maximum above the pycnocline at the depth of 15 m in the central part of the Skagerrak have been reported by several investigators (Dahl, 1989; Lindahl, Dahl, 1990).

6. Microbiological investigations.

The distribution of the heterotrophic bacteria on 27 May was quite even near the Danish coast, having maximum in the 10 m layer (in pycnocline) and mimimum in the 20 m layer, where an inflow was observed according to hydrophysical data. In the central and nothern part the number of the heterotrophic bacteria (NHB) is greater in the surface layer, decreasing rapidly in the 20 m layer (25..70 b/ml), incresing again in the 30 m layer (500 b/ml) and having minimum below the 300 m layer (30..60 b/ml), where a saline water patch was observed. Some higher values of heterotrophic bacteria (at 200 m at station F7, at 400 m at F5 and at 30 m at station F1 near the Norvegian coast) coincided with higher values of dissolved oxygen there.

The distribution of heterotrophic bacteria on 2 June is presented in Fig.12. The number of HB near Danish coast is about 8 times higher over the water column. The number of HB is higher over the section in the surface layer. Comparing the results of the heterotrophic bacteria on 27 May and 2 June it is seen that the NHB is higher on 2 June, which in the surface layer may be the result of water warming, but near the Danish coast where the most rapid increase occurs over the whole water column, the result of the more trophic water mass inflow. In both cases the minimum of NHB coincided with fluorescence maximum in 20-30 m layer and then again increasing with the depth. Near the Norwegian coast the HBN has a maximum at 10 and a minimum at 20 m depth, indicating the inflow into the 10 m layer.

On 5 of June the HBN was nearly the same in the surface layer and everywhere near the Danish coast (the inflow of trophic water goes on). The remarkable increase (more than 3 times) occurs at 30 m depth.

DISCUSSION AND CONCLUSIONS

The circulation in the central and eastern Skagerrak differed from the classical scheme. Due to the strong inflow of the AW the gyre-like stratification that was observed by many investigators (Rodhe,1987, Dahl et al.,1990, Joint Skagerrak Expedition 1966, 1970), was disturbed during this experiment.

The Norwegian Coastal Current.

The classical narrow NCC was not observed on the section F since 2 June. The observed wide fresher water region (22.5-24.5 psu) extending to the central Skagerrak seemed to be the "track" of the NCC. This interpretation is supported by the main features of thermohaline stratification and the lowest salinities in the upper mixed layer. The spreading of the NCC water over the Skagerrak was also indicated by the distribution of some phytoplankton species.

The Jutland Current.

The absence of the JC in May was easily established. More difficult was the identification of water masses at the beginning of June. New water flowing along the Danish coast to the north-east after 2 June on the basis of salinity and temperature values might be interpreted as the JC water. To identify the origin of this water the nitrate to phosphate ratio (N:P) was studied. According to Kōnig and Becker (1988) the nitrate concentration in the JC several times exceeds the typical postbloom values in the upper layer of the North Sea and the Skagerrak, but there is no significant difference in the concentration of phosphates. This results in shift in N:P ratio which provides the possibility of identifying the JC water among the other water masses having significantly lower N:P ratio. The NO_3 versus PO_4 plots for the Danish coastal area and the Domain area at the end of May and at the beginning of June are rather similar (Fig. 13). In fact, the N:P ratio at stations near the Danish coast was even less than the average over all stations. There was no remarkable change in the chlorophyll contents and in the phytoplankton community, except for *Torodinium robustum* the abundance of which increased in the surface layer since 2 June. A remarkable increase (5-8 times) took place in the abundance of heterotrophic bacteria, showing the inflow of trophic water. The possible explanation of the water origin is as follows. During a stagnant period, most of the nitrates were used and water was deluted by mixing with the North Sea water. This water still having some special features like heterotrophic bacteria content, started to propagate to north-east after 30 of May.

Upwellings.

Two upwellings that occured near the Norwegian coast were of different extent. The upwelling on 24 of May was of greater extent when upwelling front was observed up to 10 - 12 km from the coastline on transect F. This upwelling took place in the outer Skagerrak, the extent of it was well seen on satellite images, and was not observed on transect E in the eastern part of the Skagerrak. The wind influencing the upwelling (probably northely or north-westerly) was blowing before the SKAGEX and was therefore not fixed in the data. An upwelling of a smaller extent on transects F and E on 30 and 31 of May was caused by westerly wind blowing up to 15 m/s for two days. The main conclusion about these upwellings (well defined in the nutrient data) is that these upwellings do not influence the whole water column but only the upper 20 m layer. Thus, the upwellings in the intensive flow region do not upwell the deeper layer water. From the biological point of view these upwellings do not bring the most nutrient-rich water (anyway nutrient-rich) to the surface and this water is not so poor in phytoplankton as the deeper layer, thus the primary production in this water must be quicker and continue for a shorter time when nutrients get depleated from the water.

The Atlantic Water inflow.

During the observation period the AW inflow that appeared in two cores was one of the main sources of new water into the Skagerrak. We haven't found any references to such high salinity of the AW in earlier investigations in the upper 100 m layer of the Skagerrak. A very strong jet-like saline water inflow there seemed to carry the AW without essential lateral mixing, maintaining the salinity gradients. A current with nearly the same direction was maintained during at least a month after the experiment. As seen from Fig.8 the daily mean currents are varying mainly from 20 to 40 cm/s in the upper layer. Weak disturbances in currents with the period of about 7-10 days could be detected. This not very "strong" signal may be the evidence of coastal shelf waves which propagate having shallower water to the right. The propagating character of these oscillations can not be established using the current measurements at one mooring station. We expect that changes of the current speed are due to varying transport from the North Sea and due to the meandering of the jet having the highest speeds in the core. On transect E it appears that this subsurface saline AW band became wider and situated in the region of the stations 8-10. In the approximately 30 km wide band salinity slightly exceeded 35.15 psu. We suggest that the AW on the transect E reflects the continuation of a narrow current on the transect F. Obviously, due to the changing bottom topography between the transects, the AW band became wider and consequently, the currents changed for weaker.

One remarkable phenomenon observed was the deep AW inflow near the bottom with the 300 and 450 m depth with the tendency of salinity increase in time. The salinity of the AW core (maximum salinity) on transect F increased continuously except on

2 June, when the lower salinity was accompanied by the lower temperature thus showing the variability within the "saline" AW (Fig.14a). Analogical scenario of increasing salinity occured on transect E, but also on the opposite slope of the Trench. It is summarized in Fig.15 where AW maximum salinity variation in time for stations F7, E7, E3 and F3 (the stations with seafloor between 350-450 m depth) are presented. In general, all the salinity variation lines are quasiparallel with similar slopes indicating quasi-uniform increase of maximum salinity. In the following we will use the increasing salinity of the AW within the salinity range 35.22-35.28 psu as a tracer and we can estimate that after approximately 50 hours the inflowing AW had shifted from transect F to transect E. As the distance between the stations F7 and E7 was 55 km, the corresponding mean current speed was 30 cm/s. Further AW with similar properties appeared again at the station E3 after 80 hours. Assuming the flow of the AW along isobaths or over the distance 70-75 km, the mean current speed of 25 cm/s was estimated. More complicated problem was to fit the salinity variation line for the station F3 into cyclonic circulation scheme. While it is placed in Fig.15 "earlier" than the line for station E3, but 85-90 hours later than the line for station F7 (Fig.15), the only explanation seems to be the branching of the current in the way that a part of the inflowed saline water turned towards the Norwegian coast in between transects F and E, not following the isodepths, and then flowed out from the Skagerrak. Having only sparse CTD data set it was impossible to estimate the exact current speed within this supposed AW branch. Different presumed pathways of the branching water gave the following estimations: the minimal estimation (semicircle-like road) of the current speed - 15 cm/s, in case of a longer pathway - up to 30 cm/s.

All the estimated current velocities seem to be somewhat high in comparison with most of the earlier observations for the deeper layers of the Skagerrak. However, the current speed reported by Rodhe (1987) for the years 1975-77 (transect G) and the episodic ADCP current measurements carried out during this experiment (L.Rydberg, personal communication)were of the same order in the bottom layer.

The overall spatio-temporal distributions of the AW maximum salinity (Fig. 16) show the following pecularities. The inflow of the AW took place very close to the southern slope of the Norwegian Trench. As it embraced only station 7 on both transects the width didn't exceed 10 km.The outflow of the AW occured over the wider region above the opposite slope of the Trench. The flow passed two stations (F3, F4 and E3, E4) and the corresponding width was 20-25 km. We expect that the widening of the AW band reflects the redistribution of the current on the way as it became wider and weaker.In the central part of the Trench the salinity increased too, but considerably slower than at it's edges. This indicates the mixing of the inflowing saline AW and the less saltier central basin water. An example of these complicated processes are the split T-S diagrams for the stations F6 and E6 (Fig. 14b) which located at the interface area.

The AW inflow into the Skagerrak is a regular phenomenon. It is stressed here that the observed inflow was anomalous by its extremely high salinity. The appearance of this anomalously saline water in the Skagerrak is obviously related to the increased salinity level in the North Atlantic in the Rockall Trough in late 1989 and early 1990 (Ellet and Turell, 1992) and unusually high surface water salinity observed in the North Sea in January 1990 (Heath et al., 1991). According to Ellet and Turell (1992) the salinities in the NE Atlantic were the highest since the high-salinity period of late 1960s. If so, the data obtained during SKAGEX in May-June 1990 are unique for studying the spreading and mixing of the AW in the North Sea and the Skagerrak, enabling us to explain the current branching in the central Skagerrak, described above.

The spatial and temporal distribution of different phytoplankton species and the correlation with chlorophyll a data was given in Results. The remarkable variability in phytoplankton was not always explained by hydrodynamics, therefore we conclude that the variability of phytoplankton species in most cases does not coincide with the variability of hydrophysical fields , convincing us that the hydrophysical variability was not the main source of all hydrobiological variability cases in the Skagerrak during SKAGEX. On the other hand, in many cases the hydrobiological and chemical parameters gave additional very valuable information to explain the hydrodynamics, as the established relations between hydrophysical and hydrobiological fields convinced us once more of the need to continue the complex approach in marine science.

References

Dahl, E. (1989) Monitoring of toxic phytoplankton causing fish mortality and mussel toxicity in Norwegian waters. In: N. De Pauw, E. Jaspers, H. Ackefors and N. Wilkins (Eds.): Aquaculture Biotechnology in Progress, European Aquaculture Society, Bredene, p.19-28.

Dahl, E., D.S. Danielssen and P.T. Hognestad (1990) Hydrografisk snitt Torungen-Hirtshals 1989. - Flodevigen, Meldinger, 1, 28 pp.

Danielssen, D.S., L. Davidsson, L. Edler, E. Fogelqwist, S. Fonselius, L. Föyn, L. Hernroth, B. Håkansson, I. Olsson and E. Svendsen (1991) SKAGEX: Some preliminary results. - ICES CM 1991/C:2, 33 pp.

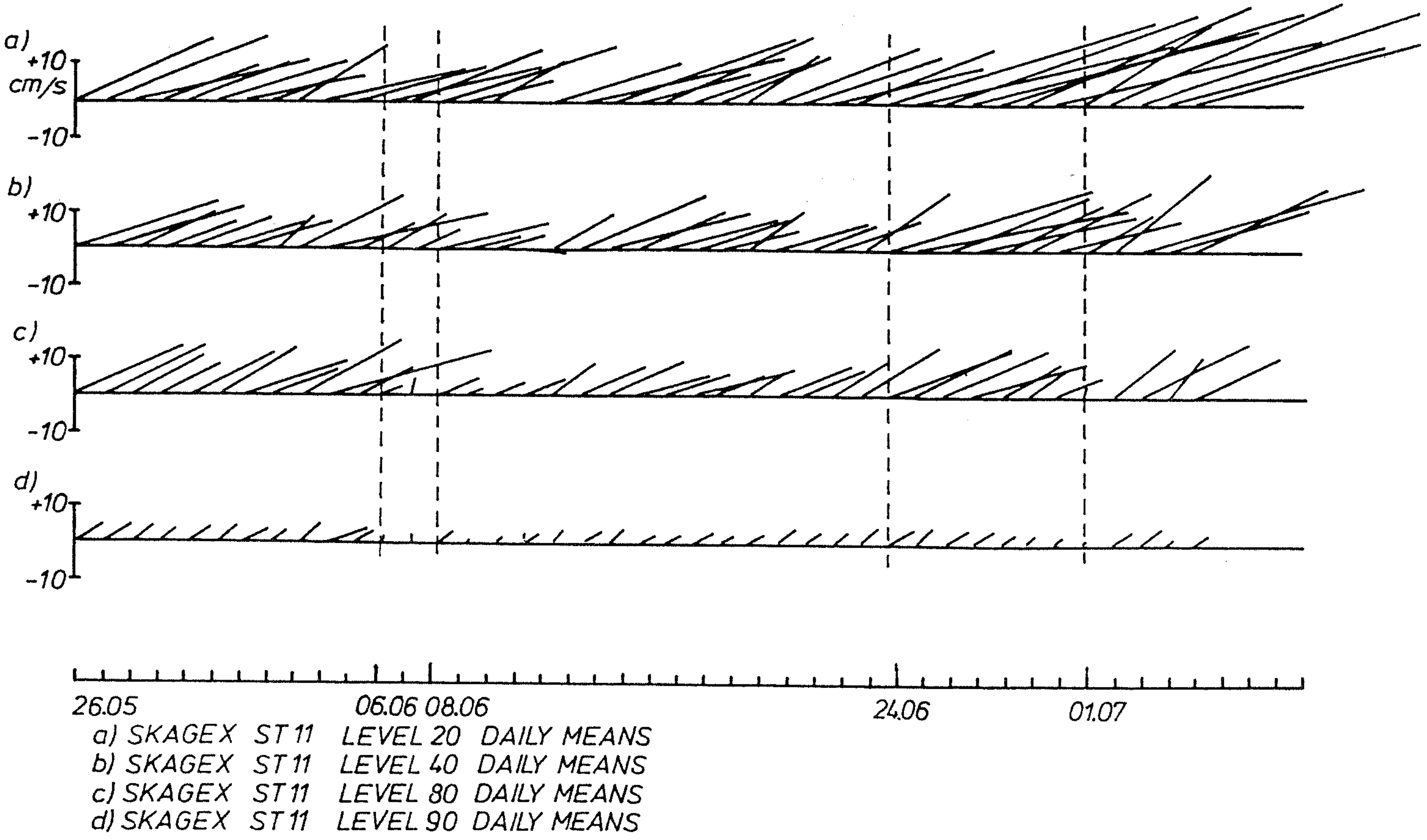


Fig.8. The daily mean current vectors at 20, 40, 80 and 90 m levels at the mooring station 11 (sea bottom 100 m) on transect F (see Figs.1 and 3).

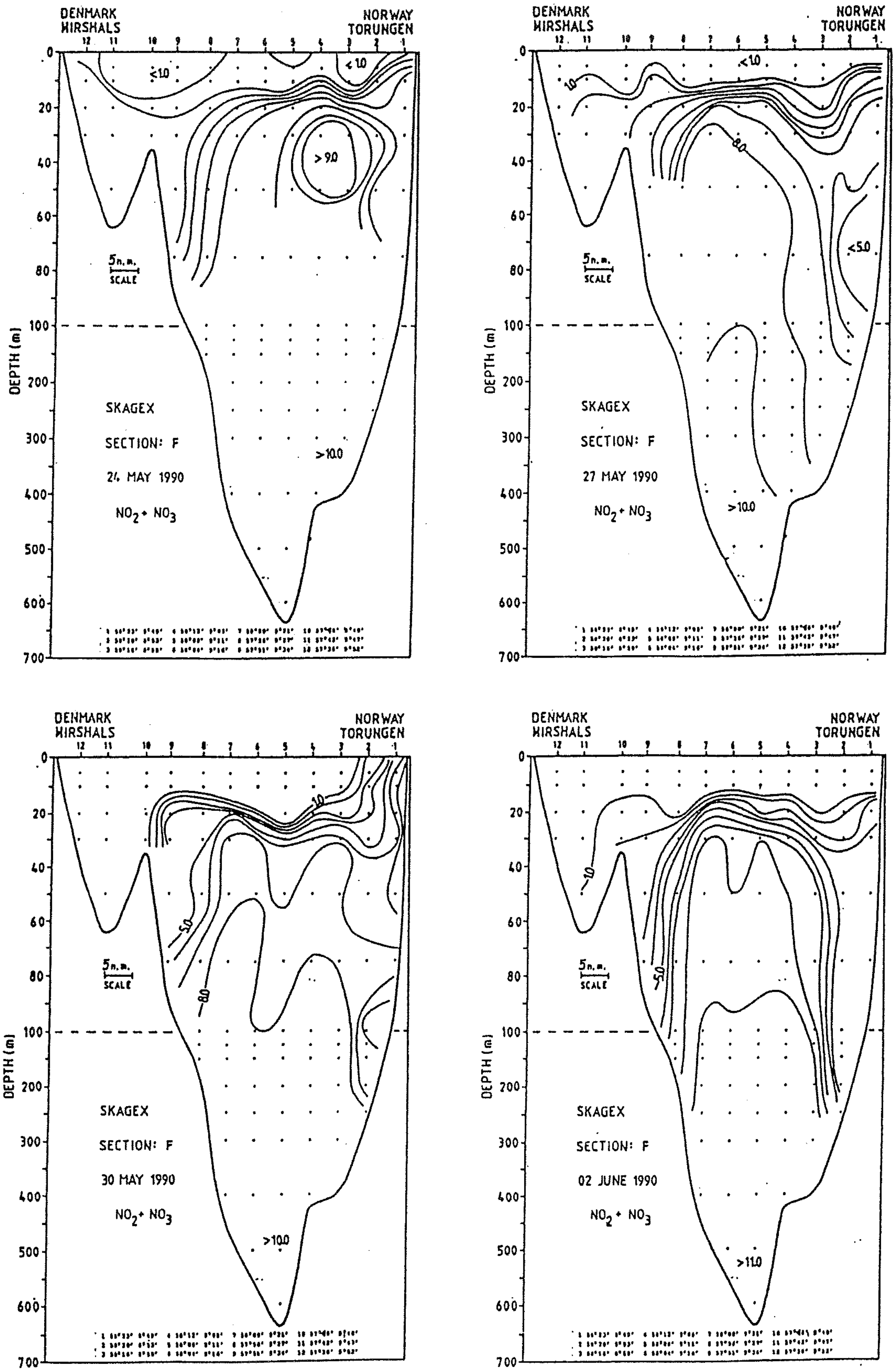


Fig.9. Vertical distributions of nitrates-nitrites on 24, 27, 30 May and 2 June on transect F.

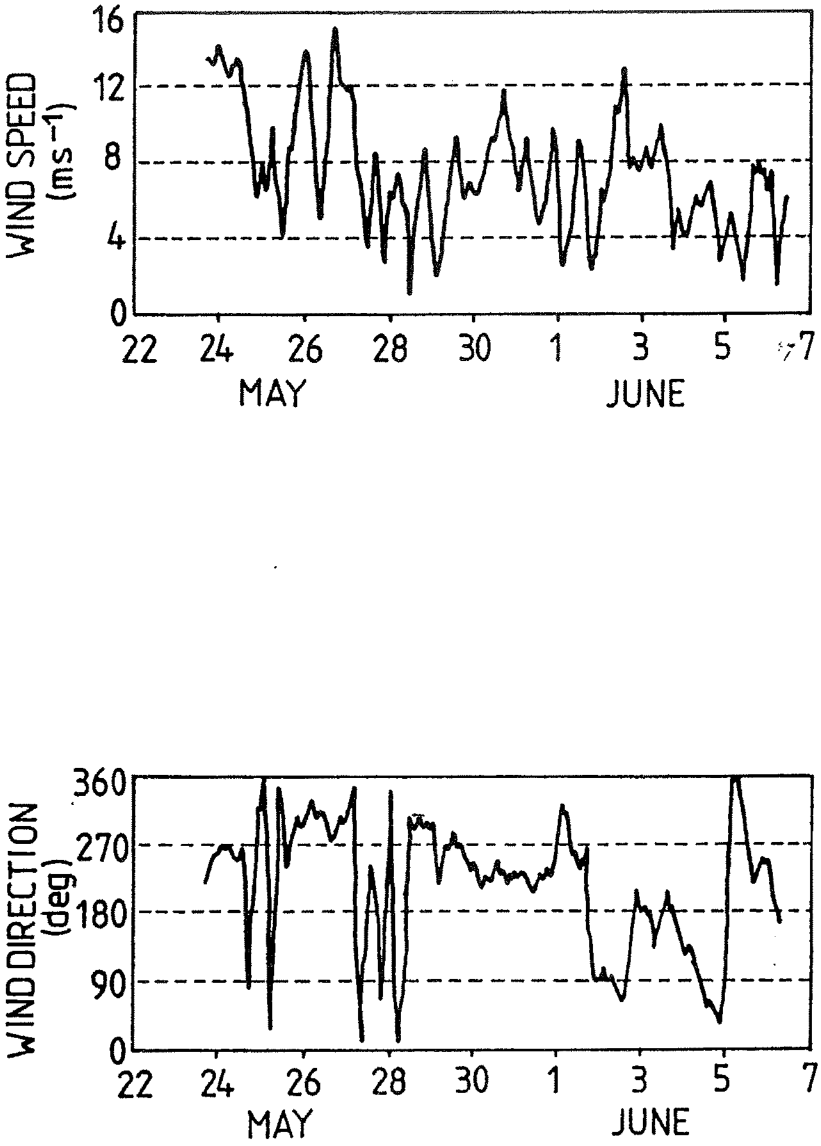


Fig.2. The wind speed (a) and wind direction (b) measured on the board of the R/V Arnold Veimer in the eastern Skagerrak during SKAGEX.

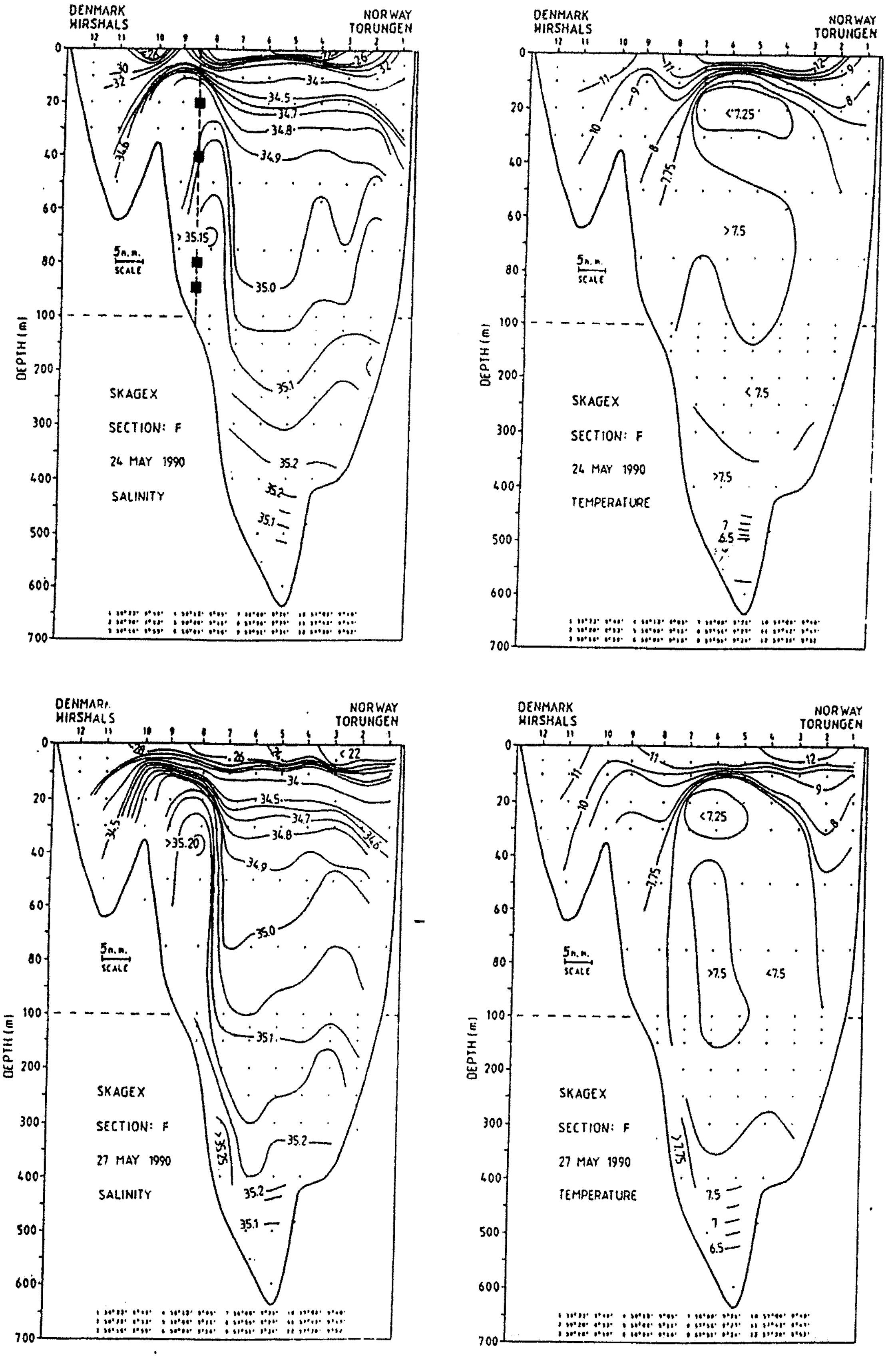


Fig.3. The salinity and temperature distributions along transect F on 24 and 27 May. The position of mooring station (dashed line) and locations of current meters at 20, 40, 80 and 90 m levels (squares) are shown in the upper-left panel.

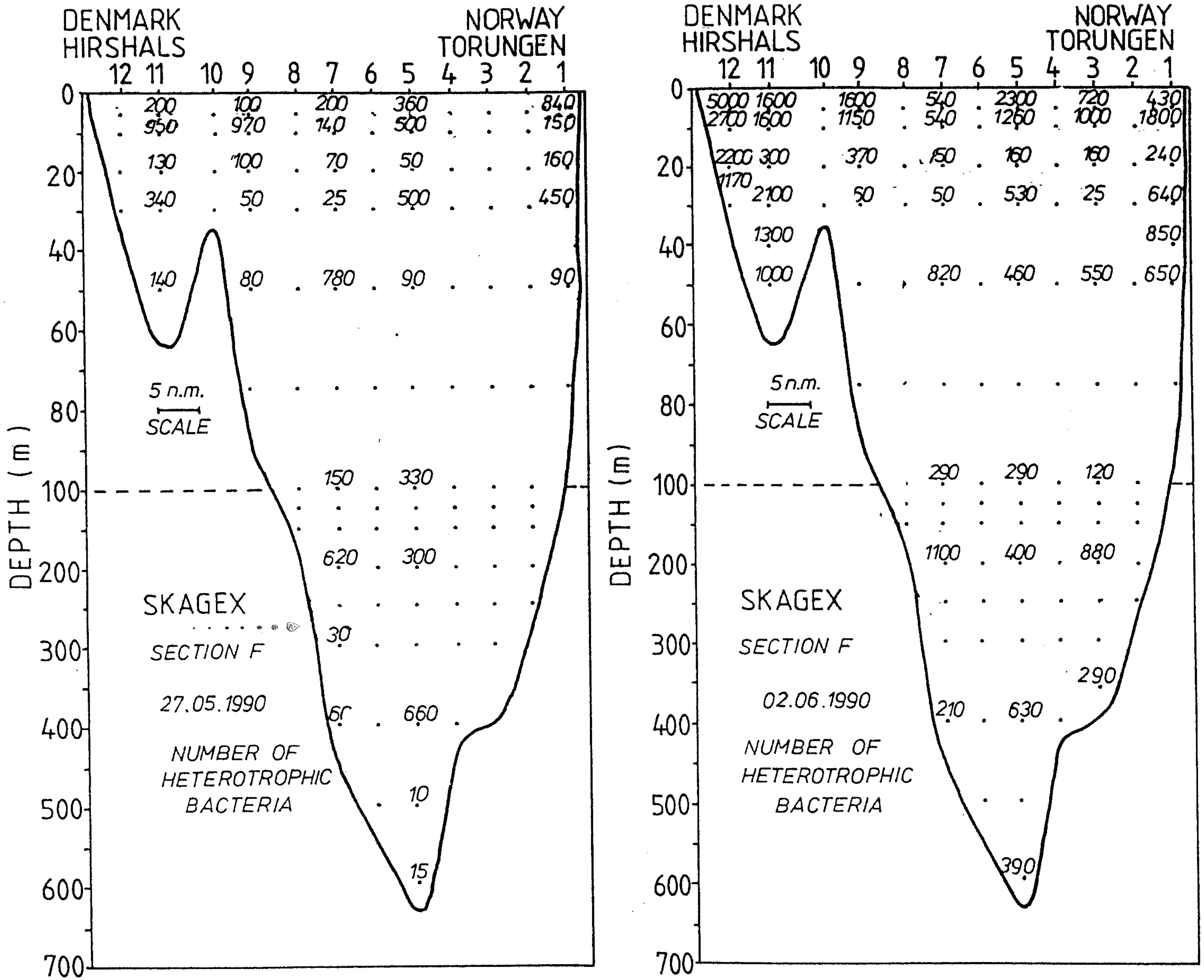
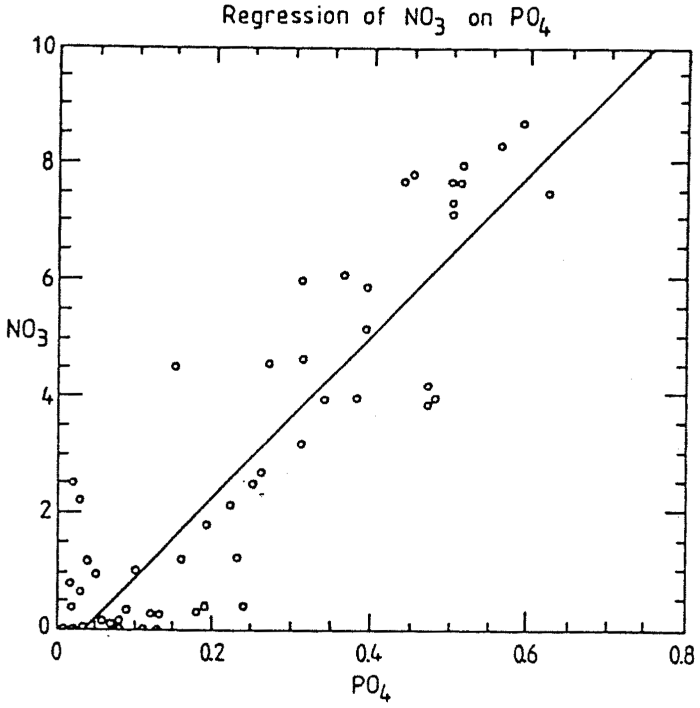


Fig.12. The number of heterotrophic bacteria (bacteria/ml) on 30 May and 2 June on transect F.



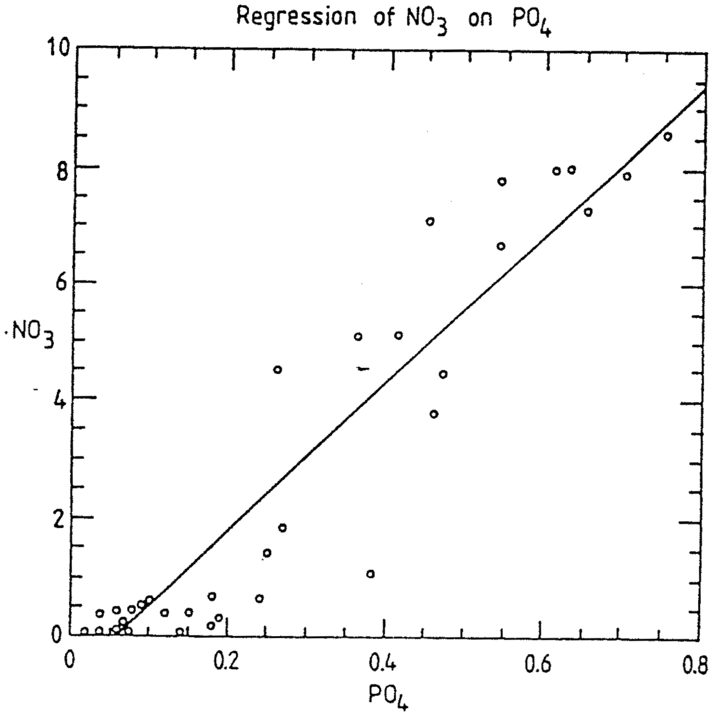


Fig.13. Nitrate-phosphate ratio in the Danish coastal area on transect F on 30 May and 2 June 1990.

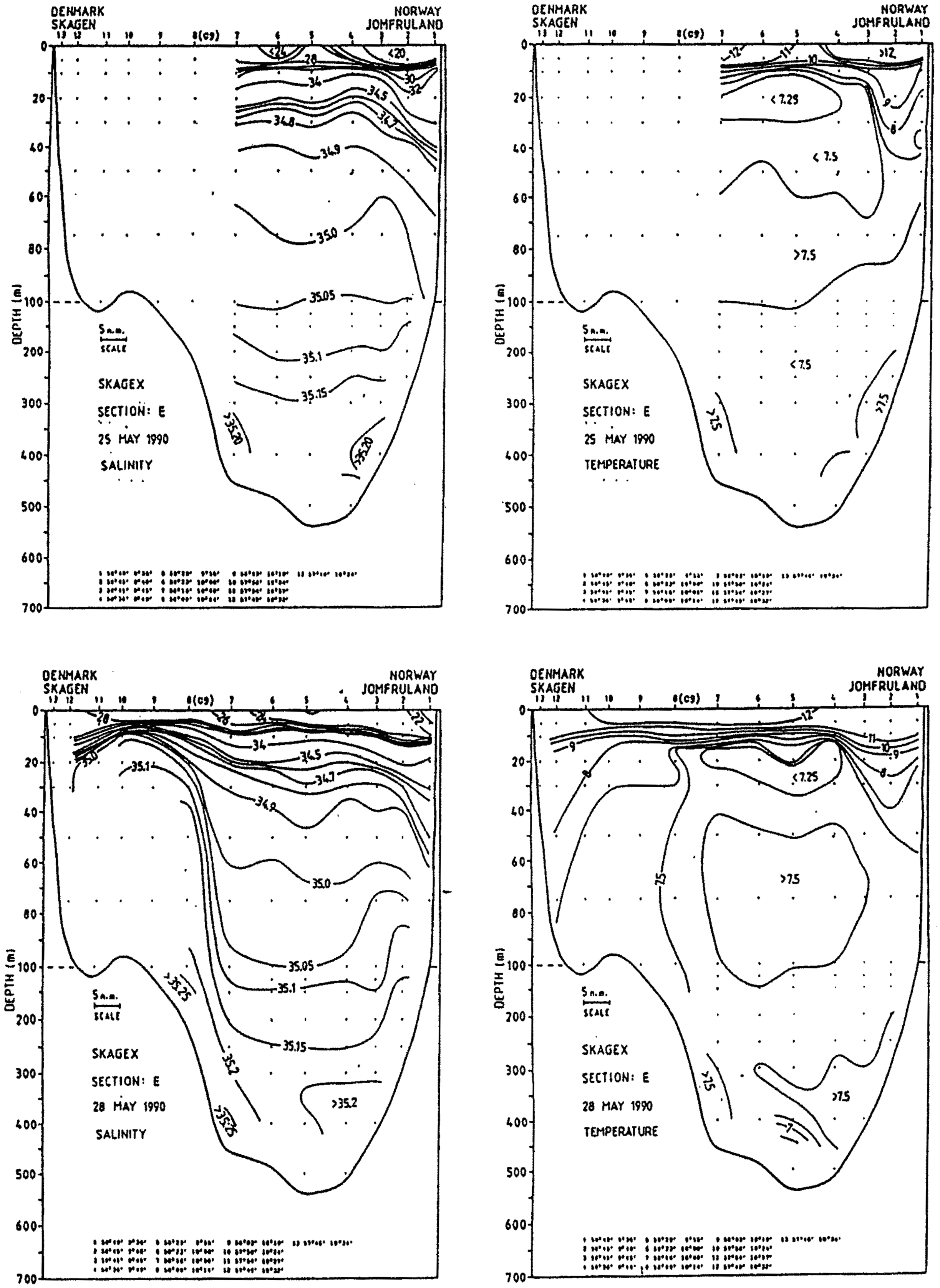


Fig.6. The salinity and temperature distribution along transect E on 25 and 28 May.

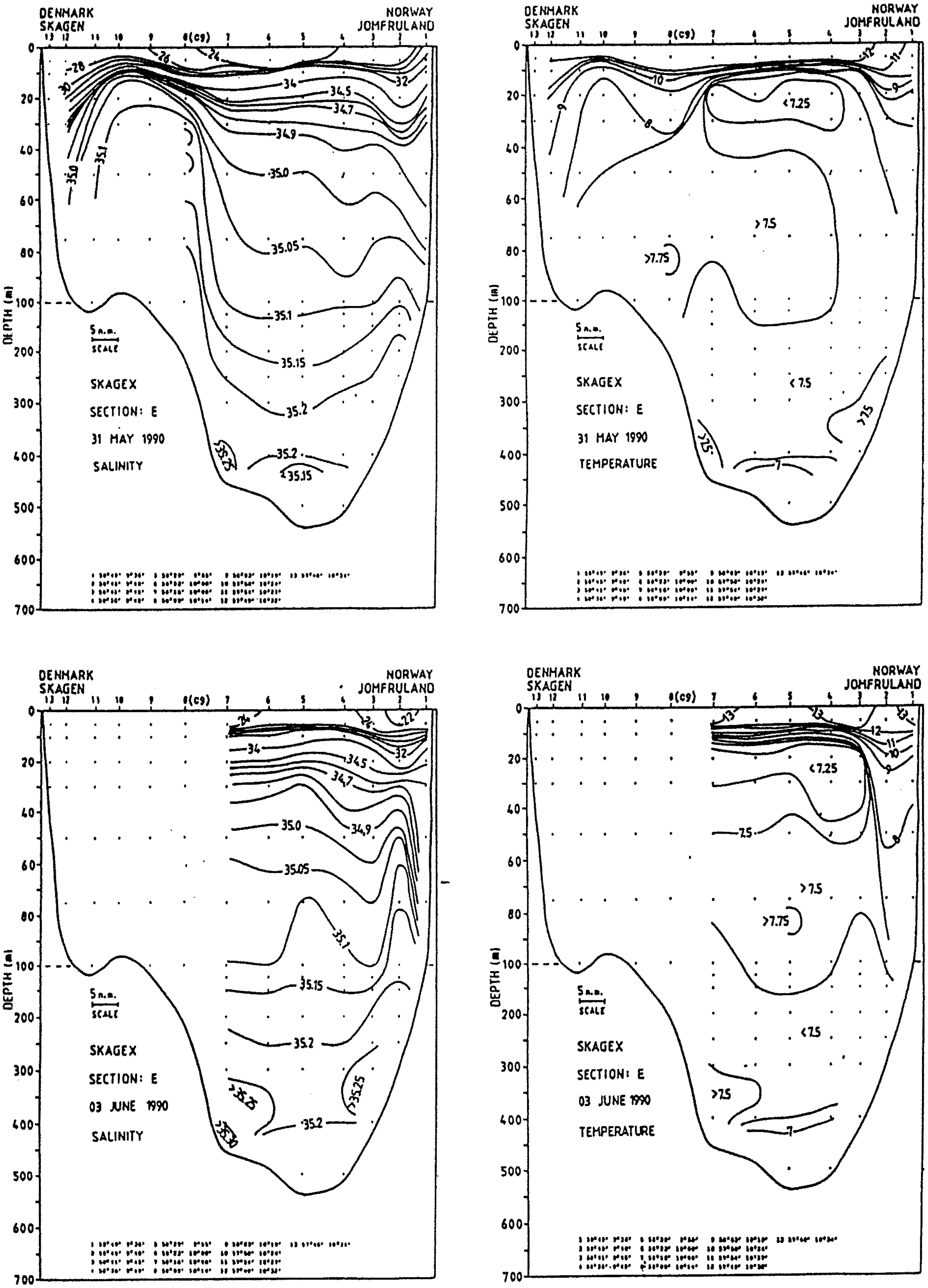


Fig.7. The salinity and temperature distribution along transect E on 31 May and 3 June.

Danielssen, D.S., L.Edler, S.Fonselius, L.Hernroth, M.Ostrowski, E.Svendsen, L.Talpsepp (1994) Oceanographic variability in Skagerrak and Kattegat in May-June 1990, in this issue.

Edler, L.(Ed.) (1979) Recommendations for marine biological studies in the Baltic Sea. Baltic Marine Biologists, 5, 38 pp.

Ellet, D.J. and W.R Turell (1992) Increased salinity levels in the NE Atlantic. ICES CM1992/C:20, 12 pp.

Fonselius, S. (1989) Hydrographic variabilities in the Skagerrak surface water. - ICES C.M.1989/C:35, 19 pp.

Heath, M.R., E.W.Henderson, G. Slesser and E.M.S. Woodward (1991) High salinity in the North Sea. Nature, 352, p.116.

Joint Skagerrak Expedition 1966 (1970) , vol.5, Atlas, Copenhagen.

König, P. and G. A. Becker (1988) ZISCH - circulation and pollutant transfer in the North Sea. First survey results. Coop. Res. Rept. Int. Counc. Explor. Sea, No 156, 35-66.

Kiorboe, T., F. Mohlenberg and H.U. Riisgard (1985) *In situ* feeding rates of planktonic copepods: A comparison of four methods. Exp. Mar. Biol. Ecol., 88, 67-81.

Lindahl, O. and E. Dahl (1990) On the development of the Chrysochromulina polylepis bloom in the Skagerrak in May-June 1988. In: E.Granely et al. (Eds.): Toxic Marine Phytoplankton, Elsevier Science Publishing Co., 189-194.

Rodhe, J. (1987) The large-scale circulation in the Skagerrak; interpretation of some observation. Tellus, 39A, 245-253.

Rosenberg, R. (Ed.) (1986) Eutrophication in marine waters surrounding Sweden. In: National Swedish Environmental Protection Board, Report 3054, Solna, 137 pp.

Svansson, A. (1975) Physical and chemical oceanograhy of the Skagerrak and the Kattegat. Fish. Bd. Sweden, Institute of Marine Research, Report No.1.

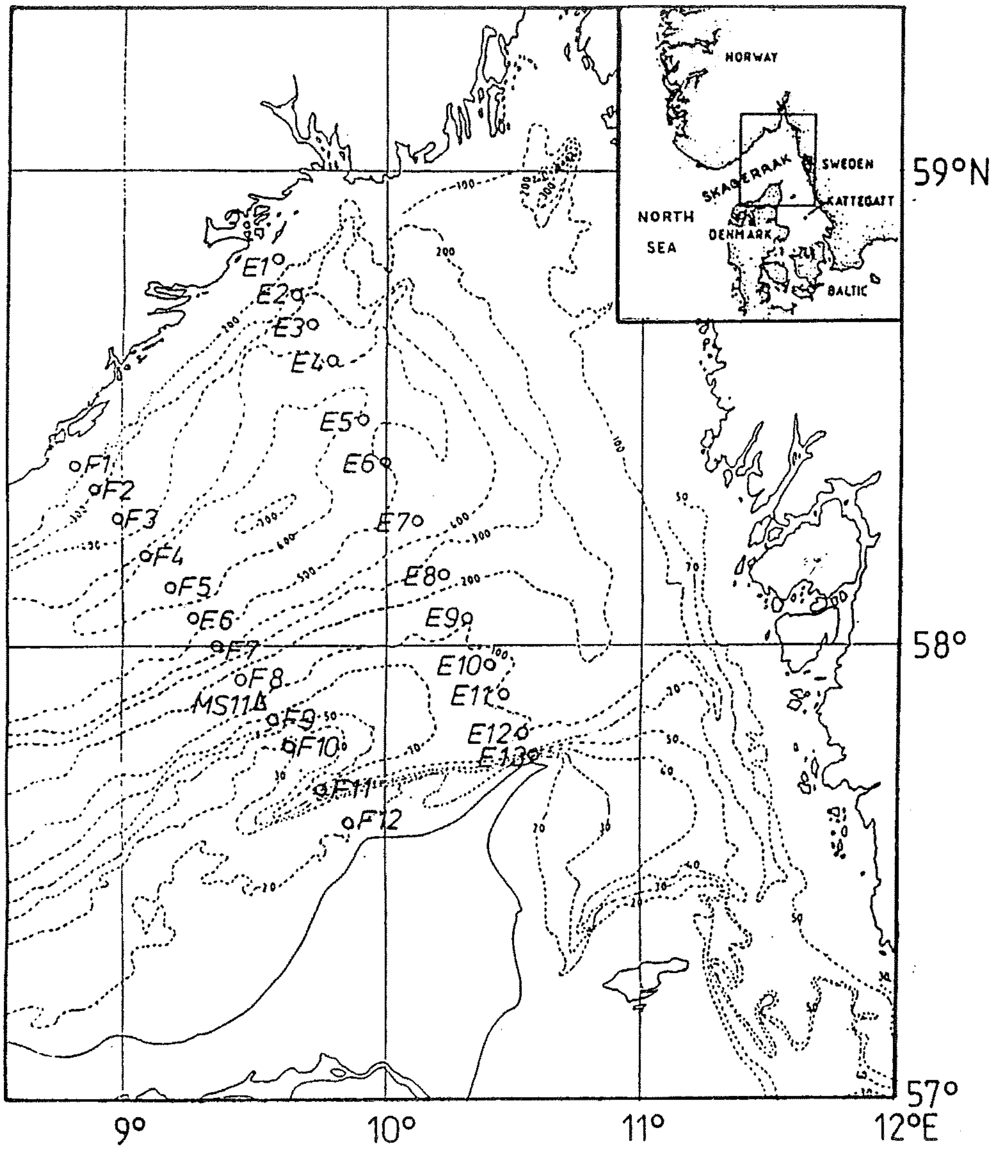


Fig.1. Map of the SKAGEX region showing locations of hydrological stations (circles) on the transects F and E and current meter mooring (triangle).

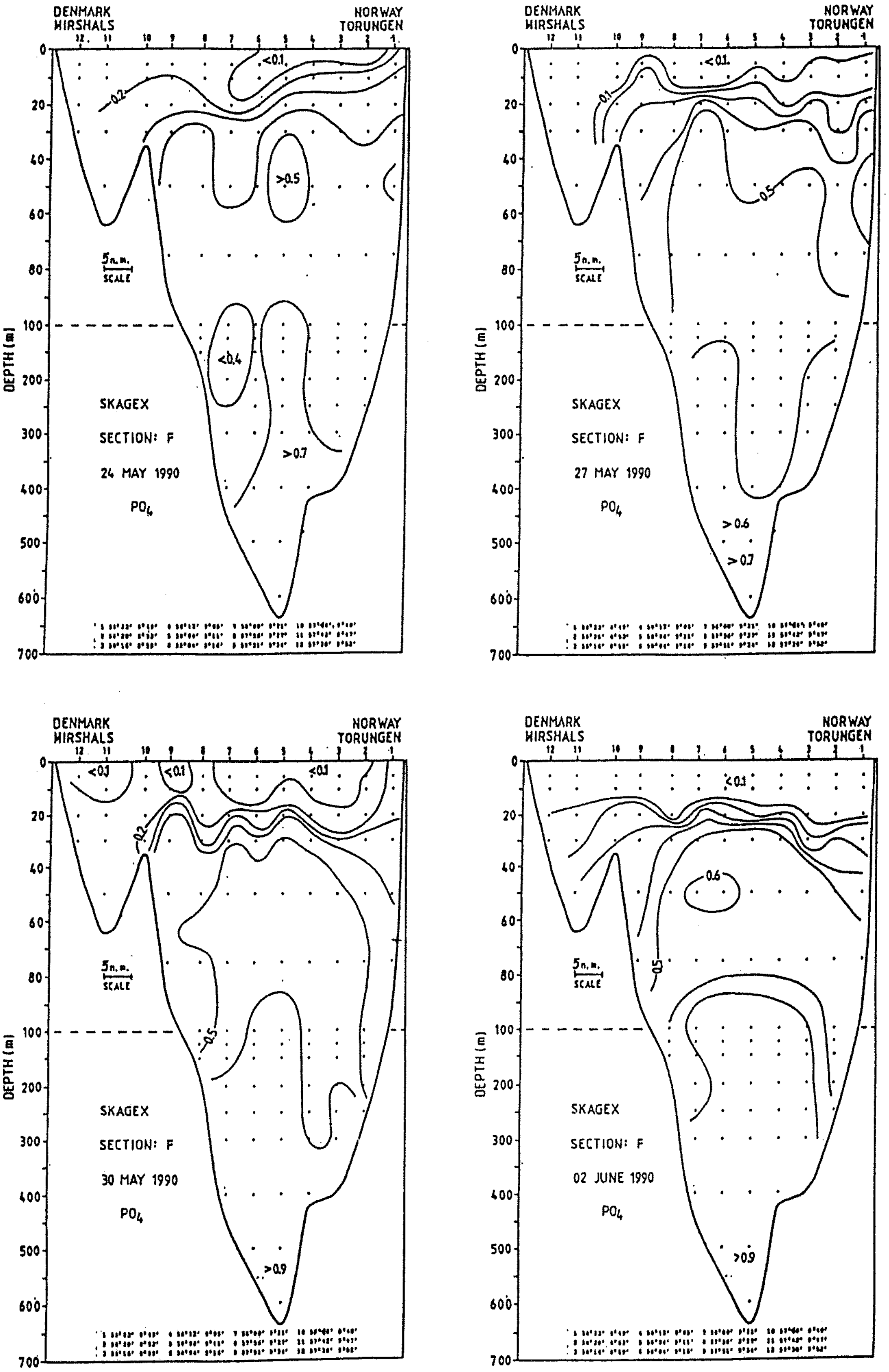


Fig.10. Vertical distributions of phosphates on 24, 27, 30 May and 2 June on transect F.

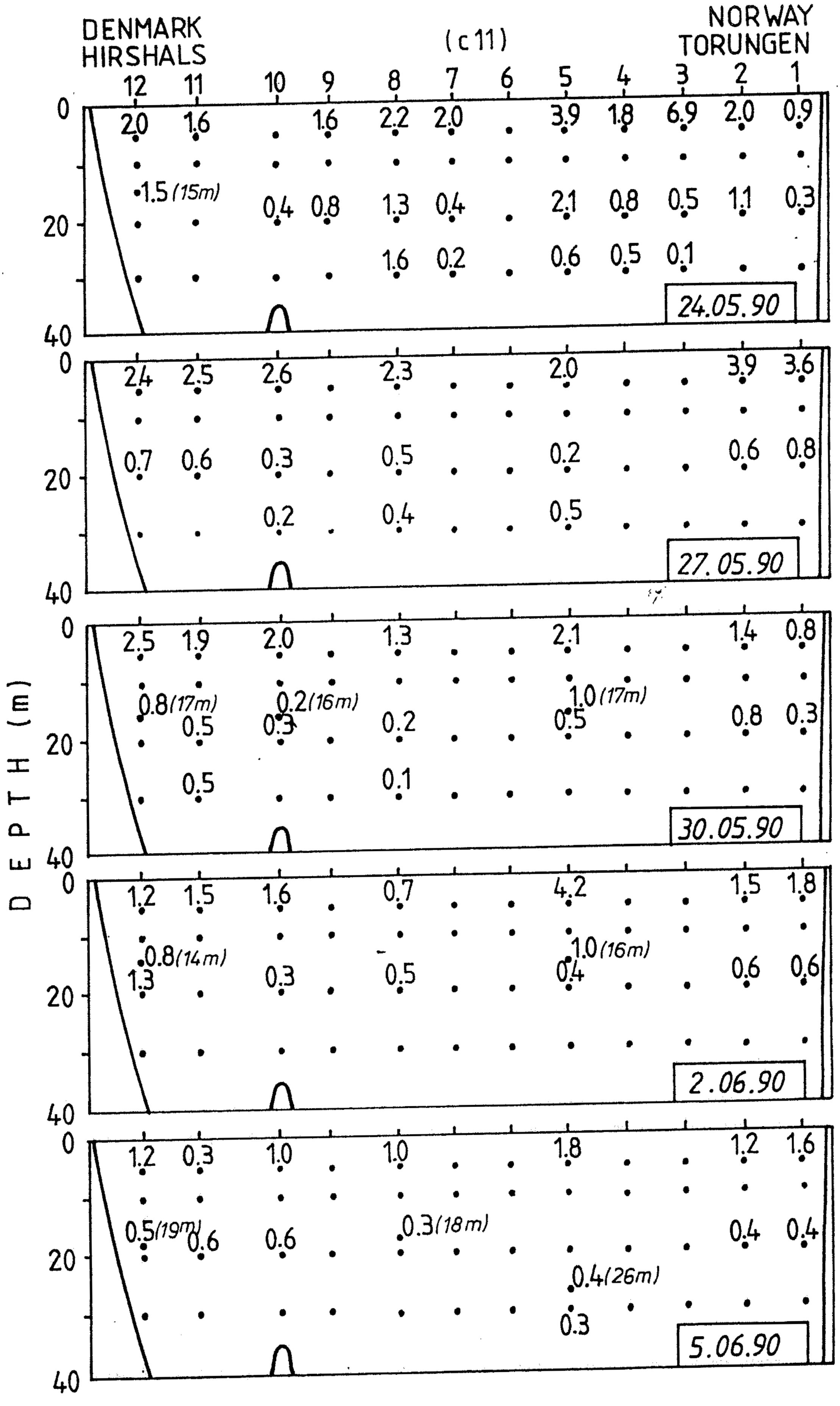


Fig.11. The abundance of phytoplankton (million per liter) from 24 May to 5 June on transect F.

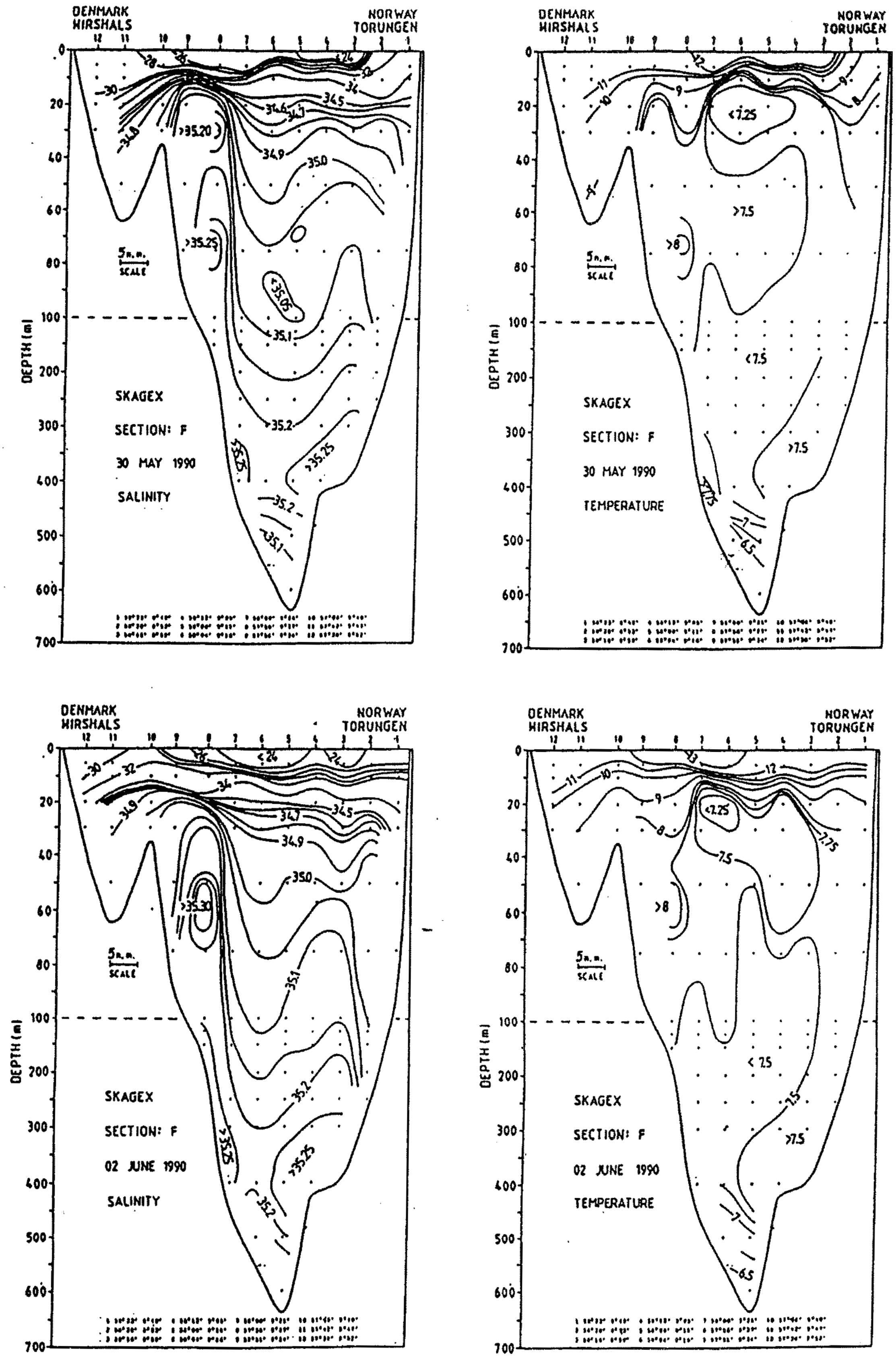


Fig.4. The salinity and temperature distributions along transect F on 30 May and 2 June.

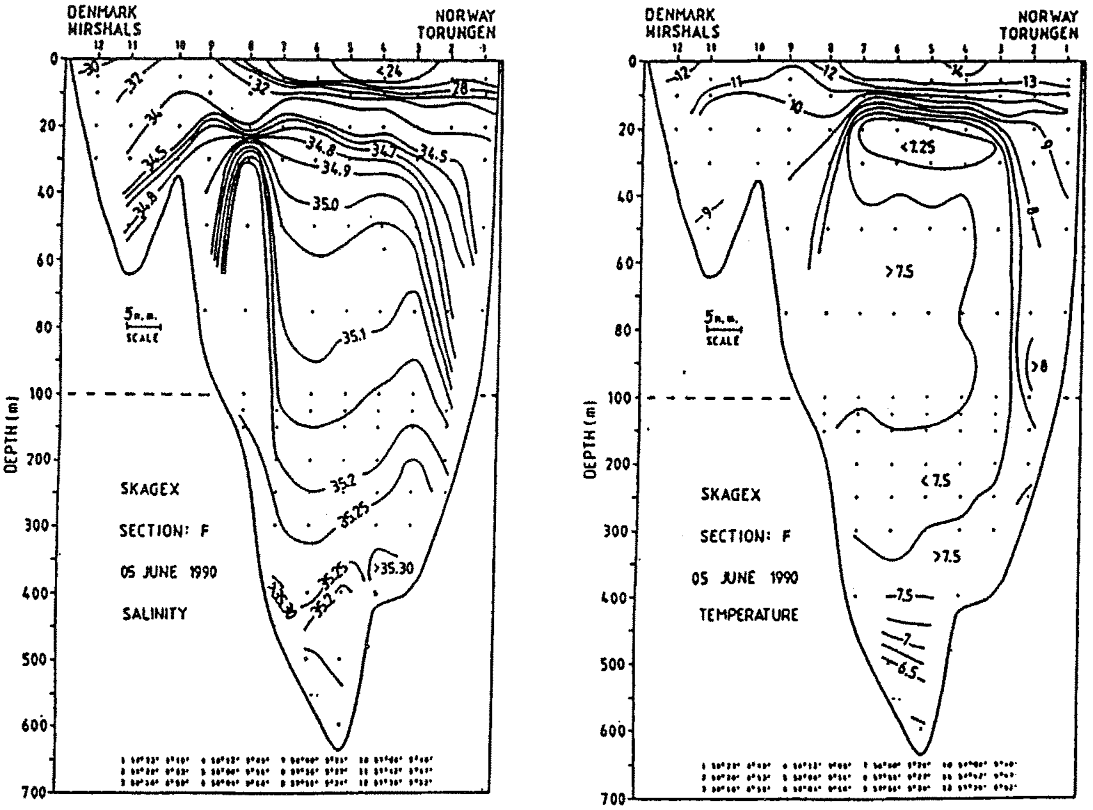


Fig.5. The salinity and temperature distributions along transect F on 5 June.

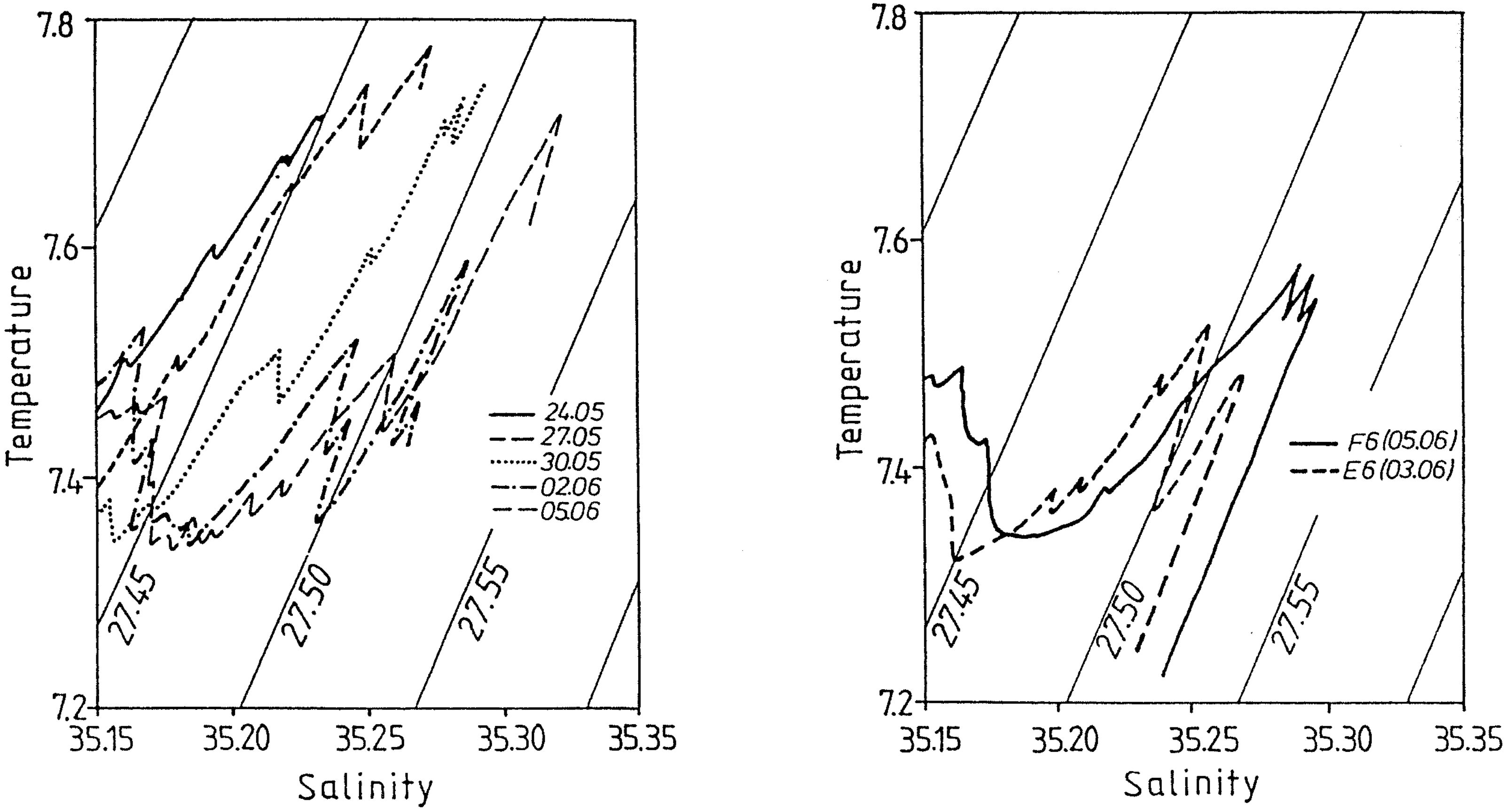


Fig.14. T-S diagrams of Atlantic Water for station F7 at Danish slope of the Norwegian Trench (a) and these for stations F6 on 5 June (——) and station E6 on 3 June (– – –) (b).

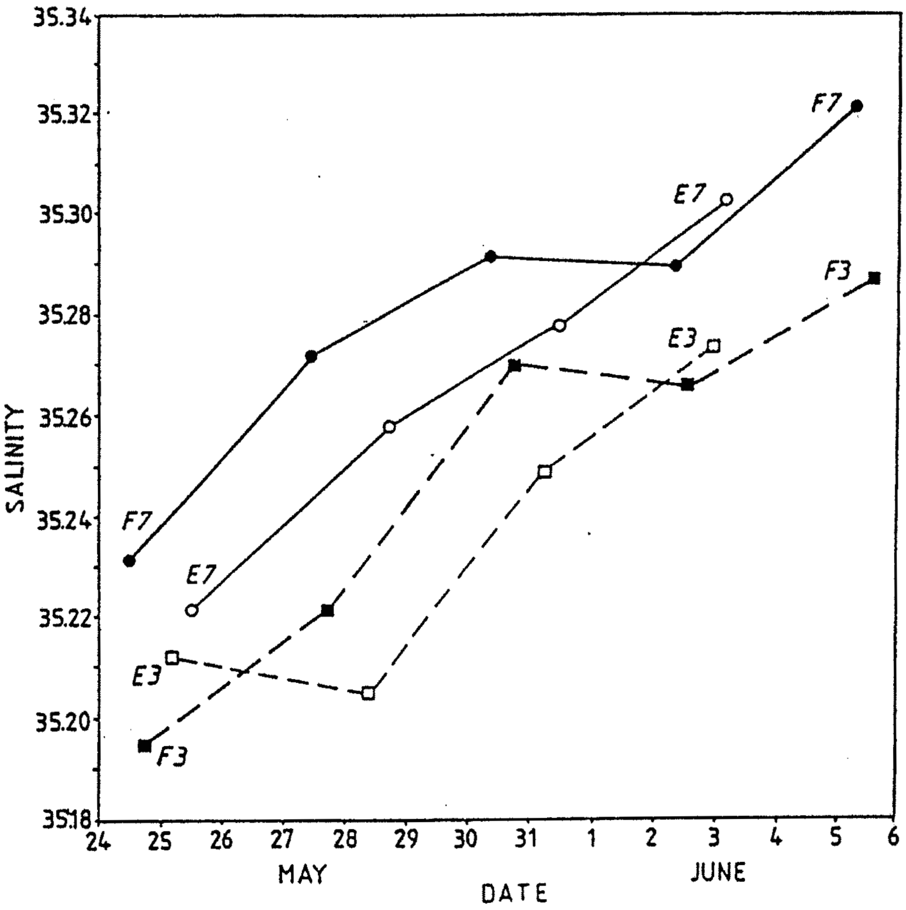


Fig. 15. Variation of Atlantic Water maximum salinity at different stations during the period of observations.
Legend: ——— station F7, — — — station F3,
——— station E7, - - - - station E3.

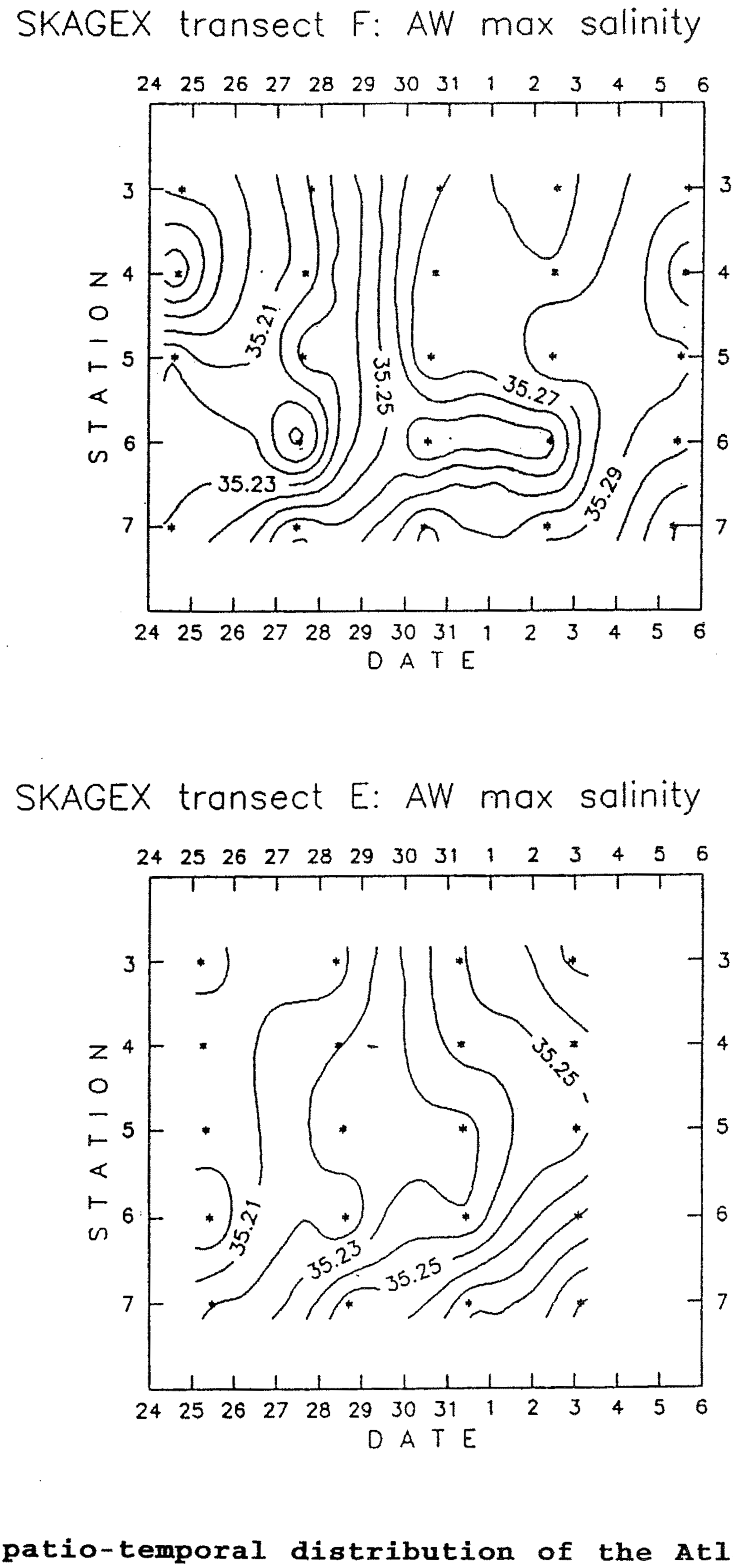


Fig. 16. Spatio-temporal distribution of the Atlantic Water maximum salinity on transects F (a) and E (b).

Presentation no 23.

Measurement of ocean current, waves and turbulence using a matched illumination multifrequency forward scatter sonar system.

by

S. Wickerts

MEASUREMENT OF OCEAN CURRENT, WAVES AND TURBULENCE USING A MATCHED ILLUMINATION MULTIFREQUENCY FORWARD SCATTER SONAR SYSTEM.

Sture Wickerts
TRIAD as
Postboks 89
N-2001 Lillestrøm
NORGE

Introduction.

Modern technology opens new avenues in the field of ocean acoustics. Among which measurement of ocean current is one.

- We possess broad band acoustic transmitters with beam steering capability and likewise long phased array receivers.

- Frequency synthesizers synchronized through the satellite GPS system at receiving as well as on transmitting site allow us to measure phase and amplitude at the receiving end relative to the transmitter.

- Modern communication systems enable us to communicate theappropriate message to remote transmitting site and receive the the data characterizing the ocean structure in great degree of detail.

- Our knowledge regarding interaction mechanims between ocean phenomena and the acoustic wave field allows us to characterize the ocean structure in great detail.

- Powerful processing algorithms allow us to perform real time analyses of the ocean structure.

Illustration of concept.

The challenge is one of monitoring continously the motion pattern (and vertical mixing capability, the 3-D turbulence field) of Skagerrak area between Norway, Sweden and Denmark. As an example, the transmitter is placed in Arendal, Norway and the line-of-sight receiver in Hirtshals, Denmark. See figure 1.

Playing on the transmitting organ in Aredal with one finger (with a PC) putting one frequency at the time in the water between 300 Hz and 6 KHz, gives us information about the available channels (frequency bands) in the geographical area of interest. (Detailed models based on the knowledge about the spatial profiles of sound velocity enable us to calculate the acoustic modes that will propagate between transmitter and receiver).

Having established the available frequency band for the actual day, the attention is directed towards receivers in the shadow zone. These measure the forward scatter signal from the common volume, which is that illuminated by the transmitter and "seen" by the receiver. (Note that both the transmitting and the receiving beams are steerable).

Transmitting a suitable tune (or simultaneous combination of 6 frequencies from 300 Hz to 6 KHz), we can measure the following parmeters, describing the ocean structure: See figure 2.

- Doppler shift, f, giving information about mean current speed.

- Doppler broadening gives information about mean mean current and also about the current fluctuations (variance of current in space and time - the turbulence).

- Spatial correlation distance of acoustic field giving information about the shape of the turbulence spectrum.

Presentation of a typical hardware configuration.

The hardware developed is shown in figure 3. The direction of the transmitting beam is remotely controlled through a standard modem and a telephone or mobile telephone.

The homdyned received signal is transmitted back to the operator via telephone or mobile telephone. The frequency synthesizers at the transmittring and receiving end are synchronized through the GPS satellite system.

Other applications with the same configuration.

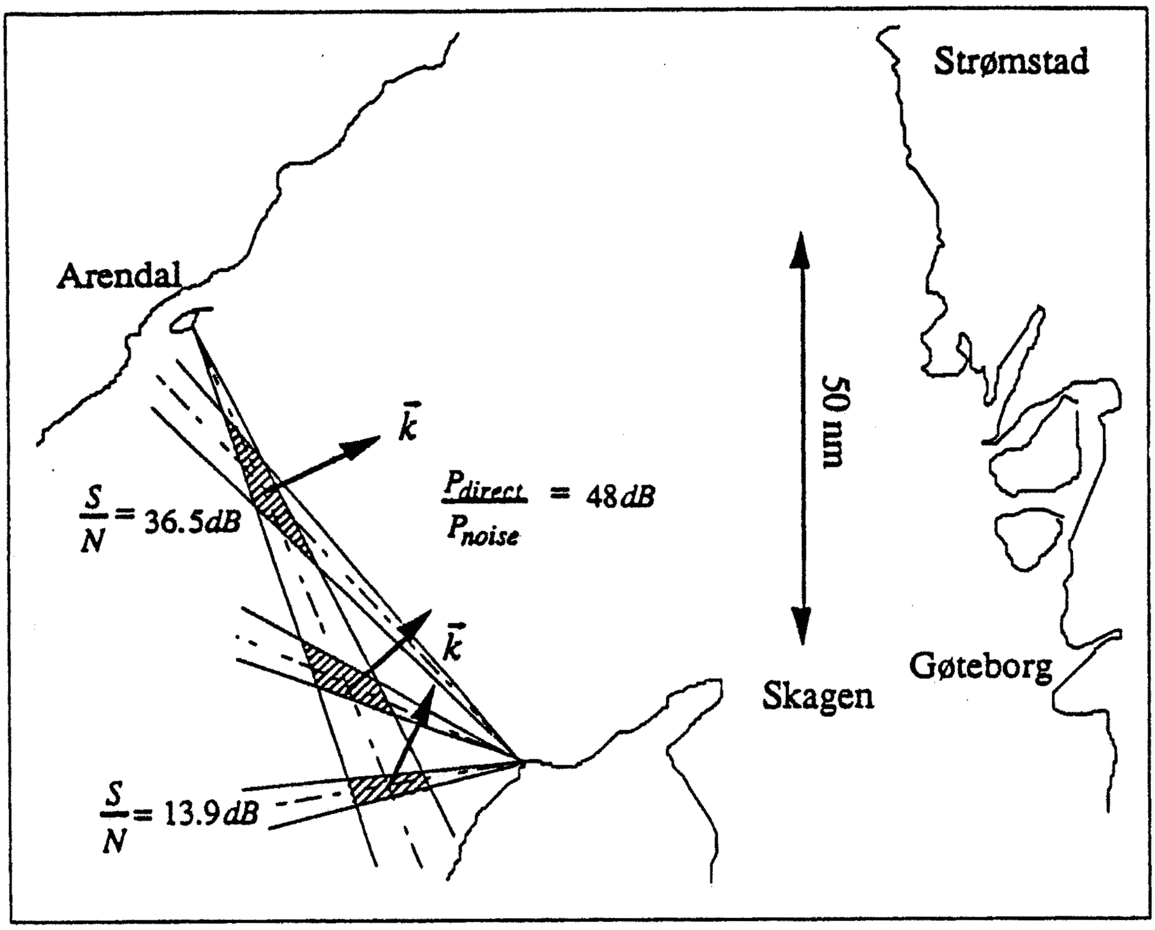
When performing measurements of ocean current the forward scattered signal is coased by fluctuations in the sound speed field within the common volume. Also fish schools constitute scattered signals. That allow us to detect and trace fish schools, though at other frequencies. In figure 4 is presented an example with school of herring.
In the case of whales it is possible to detect them one by one, only choosing the optimal frequency.

Conclusions.

The described hydroacoustic method to measure the ocean current and turbulence has been experimentally tested with very good results within a relatively small testarea, 5 km large. Fullscale measurements are planned and will be done late 1993. Theoretical attenuation calculation show that it shoud be possible to fulfill the experiment shown in figure 1.

Reference.

D. Gjessing, J Hjelmstad, A Tonning, R Hansen and S Wickerts: "Characterization of ocean current, waves and turbulence using matched illumination multifrequency foreward scatter acoustic system"
TRIAD report 22/92. October 1992.

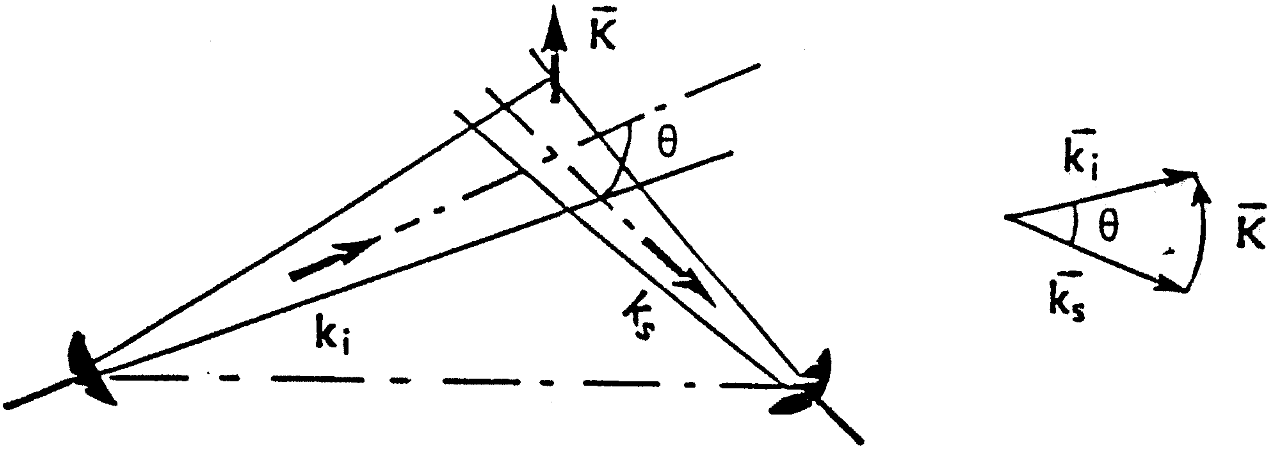


$$\text{Doppler} \quad f = \frac{1}{2\pi}\vec{K}\cdot\vec{V}$$

$$\vec{K} = \vec{k}_{in} - \vec{k}_{sc}$$

$$\vec{V} = \text{velocity of water within the common scattering volume}$$

Figure 1. An example of the basic scenario in Skagerrak. The power received in Hirtshal in the line-of-sight mode is considerable (S/N=48 dB)
The forward scatter mode is less intense, but substantially above noise level.



$$\vec{K} = \vec{k}_i - \vec{k}_s$$

$$|\vec{K}| = \frac{4\pi}{\lambda} \sin \theta/2$$

$$\omega = \vec{K} \cdot \vec{V}$$

Doppler shift

$$f_o = \frac{1}{2\pi} \frac{4\pi \sin \theta/2}{\lambda} V$$

$$\boxed{f_o = \frac{\theta}{\lambda} V = \frac{F\theta V}{c}}$$

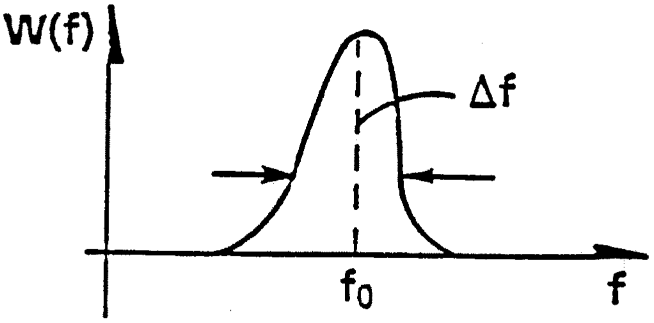


Figure 2. Forward scattered signal. Doppler shift.

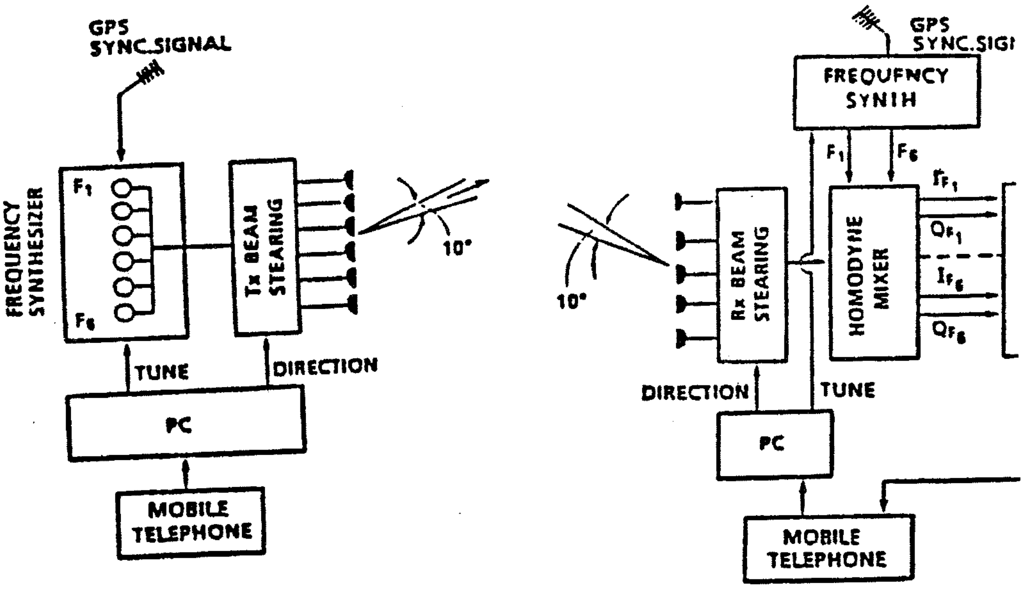
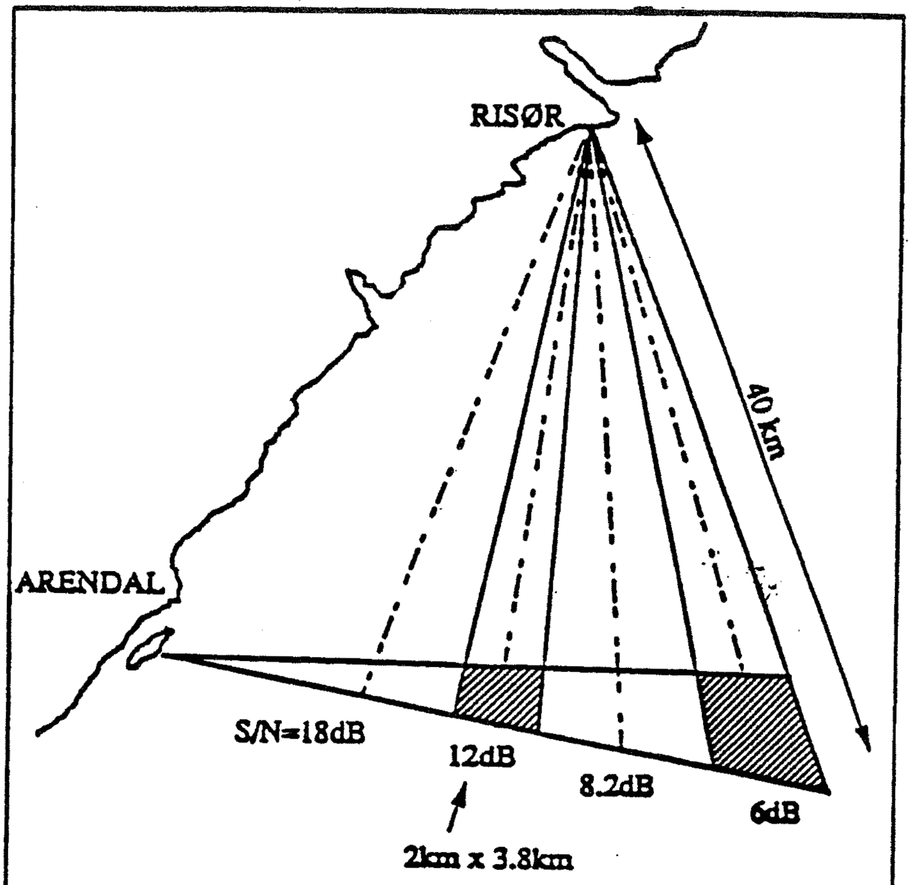


Figure 3. The bistatic acoustic system involving spaced frequencies and steerable beams



- sea state 1
- 10 sec integration time
- school of herring 100 x 100 x 50m
  (5 herrings per m3)
- frequency adjusted to resonance
- frequency 735Hz (0.3kg at 20m depth)

Figure 4. Example of signal level from a school of herring.

Annex I

Titles and summaries of papers presented elsewhere

Not to be cited without prior reference to the author

International Counsil for
the Exploration of the Sea

CM 1996/C:5
Hydrography Comittee

Validation and Sensitivity study of a Sigma-coordinate Ocean Model using the Skagex dataset

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February 1966

Abstract

Numerical ocean models are now being applied in numerous oceanographic studies. However, the qualities of the model results are often uncertain and there is a great need for standards and procedures for evaluation of the skills of numerical general circulation models. In this paper measurements from repeated hydrographical sections across Skagerrak taken in 1990, the SKAGEX dataset, are used to evaluate the skills of two σ-coordinate ocean models and to study the sensitivity of these models to model parameters. A methodology for quantification of model skills based on observations from repeated hydrographical sections in general is suggested.

The value of the SKAGEX dataset as a tool for model improvements is demonstrated. Evidence to support the importance of applying non-oscillatory, gradient preserving advection schemes in areas with sharp density fronts is given. The method is used to identify that the forcing/ initial values/ boundary values for the temperature field are inferior to the corresponding values for the salinity field. With the the present coarse resolution, 11 layers in the vertical, it is shown that it is far from obvious that the quality of the model results improve when replacing simple Richardson number formulations for vertical mixing processes with higher order turbulence closure in the Skagerrak area.

Keywords: general circulation models, evaluation, Skagerrak, sections, hydrodynamics

ICES Journal of Marine Science 54: 000–000. 1997

Oceanographic variability in the Skagerrak and Northern Kattegat, May–June, 1990

D. S. Danielssen, L. Edler, S. Fonselius, L. Hernroth,
M. Ostrowski, E. Svendsen, and L. Talpsepp

Danielssen, D. S., Edler, L., Fonselius, S., Hernroth, L., Ostrowski, M., Svendsen, E., and Talpsepp, L. 1997. Oceanographic variability in the Skagerrak and Northern Kattegat, May–June, 1990. – ICES Journal of Marine Science, 54: 000–000.

The Skagerrak Experiment (SKAGEX), was a large, international, ICES-supported joint venture, carried out in the Skagerrak–Kattegat area on four different surveys in the period 1990–1991. It involved some 20 institutes, and, at times, up to 17 research vessels. The main aim of the Experiment was to identify and quantify the different water masses entering and leaving the Skagerrak area and their variation over time. It also aimed to investigate the mechanisms that drive the circulation and to study their effects on biological processes. The aim was to be attained mostly through extensive synoptic observations.

This paper focusses on the variability in physical, chemical and biological parameters during the first part of SKAGEX, 24 May–20 June 1990. During the first half of the period of investigation, the main outflow from the Skagerrak, represented by the Norwegian Coastal Current, was barotropic with daily mean velocities varying from 10–40 cm s^{-1}. During the second half a clear baroclinic current component developed, giving rise to near surface velocities of up to 100 cm s^{-1}.

A pronounced feature in the Skagerrak during the study was the counter-clockwise circulation of the Norwegian Coastal Current at times of strong northwesterly winds. During such conditions this surface water reached as far as the Danish coast south of 57°N and upwelling along the Norwegian coast was also found. During northerly winds upwelling also occurred along the Swedish coast.

The nutrient-rich Jutland Coastal Water, originating from the German Bight, was never found to reach the inner part of the Skagerrak during this first part of SKAGEX. It was partly blocked or diluted by other water-masses.

A large "ridge" of nutrient-rich Atlantic water was found in the central Skagerrak throughout the investigation. It is shown that this elongated "ridge" was associated with the deepest (>500 m) area of the Skagerrak. Within this area, high subsurface chlorophyll concentrations were always found and, due to the persistence of the supply of nutrients, it is concluded that this phenomenon could be one of the main reasons for the high productivity of the Skagerrak.

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Key words: Skagerrak, Kattegat, circulation, upwelling, nutrients, chlorophyll, primary production.

Received 12 September 1994; accepted 4 December 1996.

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Introduction

The Skagerrak may be regarded as a part of the transitional area between the Baltic and the North Sea and is heavily influenced by both seas. It is a very productive sea area with a yearly fish production of 7 g m^{-2} (I. Olsson, pers. comm.). This is almost double that of the North Sea. The Skagerrak is thus of great economic importance to the surrounding countries and is also a nursery and feeding area for about two-thirds of the

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Model simulation of the Skagerrak circulation and hydrography during Skagex

Einar Svendsen [a], Jarle Berntsen [b], Morten Skogen [a], Bjørn Ådlandsvik [a], Eivind Martinsen [c]

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Received 8 November 1994; accepted 25 May 1995

Abstract

A 3-dimensional barotropic/baroclinic numerical circulation/transport model system is set up and run for an extended North Sea area in the period October 1989 to August 1990. The model system consists of a "large scale" model with a 20×20 km^2 horizontal resolution, coupled to a finer scale (4×4 km^2) similar model set up for the Skagerrak/Kattegat area. The performance of this model system is evaluated against the Skagex-90 data set containing several drifting buoy tracks, transport estimates from moored current meters, ship-mounted ADCP current velocities, and 10 synoptic hydrographical field data over most of the area obtained every third day in May/June 1990. The Skagex data set also contains chemical (nutrients) and biological (chlorophyll concentration, primary production etc.) data which later will be used for evaluation of this physical model system coupled to a primary production model. The model system is forced with realistic wind and atmospheric pressure fields. Although some of the outputs (after more than half a year prognostic running) still are questionable, the results so far are very promising both with respect to the simulated vertical and horizontal structure and magnitude of the circulation and the salinity distribution.

1. Introduction

The obvious limitations in space and time (and large costs) of traditional oceanographic ship sampling, and the rapid advances in computing capacity, have led to increasing efforts in 3-dimensional physical modelling. There is also an increasing demand for model results simulating the chemical and biological consequences of possible changes in anthropogenic inputs of nutrients, nuclear waists etc. to specific ocean areas (North Sea Task Force, 1993).

A coupled Physical-Chemical Biological (P–C–B) modelling activity of the whole North Sea started in 1990–1991 through close cooperation between the Institute of Marine Research (IMR) in Bergen, the Institute of Fishery- and Marine Biology (IFM) at the University of Bergen, and The Norwegian Meteorological Institute (DNMI) in Oslo. Related to the above problem areas and that the North Sea as a whole is quite a complex hydrodynamical system, it was found that to obtain any realism in the biological results, the coupled model system must be based on a sophisticated 3-dimensional physical model with good representation of vertical exchanges (Skogen et al., 1995; Aksnes et al., 1995). Therefore the physical module to be validated here is based on a model

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Quantifying volume transports during SKAGEX with the Norwegian Ecological Model system

MORTEN D. SKOGEN,*† EINAR SVENDSEN† and
MAREK OSTROWSKI†

(*Received* 16 *February* 1995; *in revised form* 21 *April* 1997; *accepted* 8 *September* 1997)

Abstract—A coupled 3-dimensional physical, chemical and biological model system, NORWECOM (the NORWegian ECOlogical Model system), is validated and used to identify and quantify the short-term variability of the different water masses being transported into and out of Skagerrak. The model system is a nesting between a coarse grid model set up for an extended North Sea, and a fine grid defined in the Skagerrak/Kattegat area.

Originating from the extensive SKAGEX (SKAGerrak EXperiment) database, several interesting events have been identified and become the focus of the modeling. Through interactive use of the SKAGEX data set and NORWECOM, it is possible to gain a new insight into a very complex hydrodynamic system, an insight that is hard to achieve based on measurements only. © 1998 Elsevier Science Ltd. All rights reserved

1. INTRODUCTION

The Skagerrak (36 000 km^2) and the Kattegat (22 000 km^2) form a transition zone between the much larger Baltic Sea and the North Sea. The Skagerrak is heavily influenced by water exchange with the North Sea, and due to its relatively deep basin reaching down to about 700 m, it acts as a "dustbin" for suspended matter (including contaminants) from major parts of the North Sea (Anon., 1993). The hydrodynamics are quite complicated due to major water exchanges with the North Sea, large supplies of freshwater (both from the Baltic and some major rivers) and strong topographic steering. Figure 1 demonstrates the general circulation of the relevant water masses. Due to normally strong vertical density stratification, sharp fronts and large supplies of both natural and anthropogenic nutrients, the area is highly productive and acts as an important feeding area for several fish species.

The inflow of different water masses from the North Sea is highly variable on time scales of a few days (Danielssen *et al.*, 1991, 1997), making realistic estimates of transport based only on measurements very difficult. The strong vertical stratification and frontal dynamics are also quite variable, and therefore 3-dimensional modeling (including baroclinic forcing) is needed if realistic averaged transports are to be achieved. The basis for this paper has been the NORWegian ECOlogical Model system (NORWECOM) (Skogen, 1993; Skogen *et al.*, 1995). The main weakness of 3-D modeling activities claiming to simulate nature is the lack of comparison with adequate real data. The model results have therefore been compared with some of the findings from the extensive SKAGEX-90 (the SKAGerrak EXperiment)

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Using the SKAGEX dataset for evaluation of ocean model skills

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Abstract

Numerical ocean models are now being applied in numerous oceanographic studies. However, the qualities of the model results are often uncertain and there is a great need for standards and procedures for evaluation of the skills of numerical general circulation models. In this paper measurements from repeated hydrographical sections across Skagerrak taken in 1990, the SKAGEX dataset, are used to evaluate the skills of two σ-coordinate ocean models and to study the sensitivity of these models to model parameters. A methodology for quantification of model skills based on observations from repeated hydrographical sections in general is suggested. Area averages of absolute differences are for Skagerrak completely dominated by the discrepancies in the upper few meters of the ocean and may not be used to assess models' abilities to reproduce the fields in the larger and deeper part of the ocean. Therefore, discrepancies between average values in time from the observed fields and time averaged values from model outputs are related to the natural variability of the fields. The numbers produced with the suggested measure are relative numbers that will be specific for each section and for each series of observation. Ideally we would therefore like to see the measures computed for a number of sections for various models and choices of model parameters in order to assess model skills. The value of the SKAGEX dataset as a tool for model improvements is demonstrated. Evidence to support the importance of applying non-oscillatory, gradient preserving advection schemes in areas with sharp density fronts is given. The method is used to identify that the forcing/initial values/boundary values for the temperature field are inferior to the corresponding values for the salinity field. With the present coarse resolution, 11 layers in the vertical, it is shown that it is far from obvious that the quality of the model results improve when replacing simple Richardson number formulations for vertical mixing processes with higher order turbulence closure in the Skagerrak area. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: general circulation models; evaluation; Skagerrak; sections; hydrodynamics

1. Introduction

A number of numerical ocean circulation models have been under development over the last decades and applied in numerous oceanographical studies. Hydrodynamical models are coupled to chemical–biological models with different degrees of complexity. The methodology for measuring the quality of the vast amount of model results being produced is, however, poorly developed. One exception appears to be root mean square errors for the evaluation of outputs from tidal models. In baroclinic studies for instance rms errors may not be appropriate as quality measures. Small shifts of eddies, meanders or fila-

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QUANTIFICATION OF TRANSPORTS TO SKAGERRAK

A modeling approach

MORTEN D. SKOGEN, GRO ERIKSRØD AND EINAR SVENDSEN
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Abstract. A coupled 3-dimensional physical, chemical and biological model system, NORWECOM (the NORWegian ECOlogical Model system), is used to identify and quantify the variability of the different water masses being transported in and out of Skagerrak. The model system consist of a fine grid for the Skagerrak/Kattegat area, embedded in a coarse grid for an extended North Sea.

The model has been run for several years, and the interannual variability in the transports has been identified and quantified. By running the model with real atmospheric forcing, it has become a tool for explaining some of the ecological characteristics in the same period.

1. Introduction

The Skagerrak ($36000 km^2$) and the Kattegat ($22000 km^2$) are a transition zone between the much larger Baltic Sea and the North Sea. Especially the Skagerrak is heavily influenced by the water exchange with the North Sea, and due to its relatively deep basin reaching down to about 700 meters, it acts as a "dustbin" for suspended matter (including contaminants) from major parts of the North Sea [4]. The inflow of different water masses from the North Sea is highly variable on time scales of a few days [10, 11], making realistic estimates of transports (based only on measurements) very difficult. The strong vertical stratification and frontal dynamics are also quite variable, and therefore 3-dimensional modeling (including baroclinic forcing) is needed if realistic averaged transports of matter shall be achieved.

The hydrodynamics are quite complicated due to the major water exchanges with the North Sea, large supplies of freshwater (both from the Baltic and some major rivers) and strong topographic steering. Figure 1 demonstrates the general circulation of the relevant water masses. Due to general strong vertical density stratification, sharp fronts and large supplies of both natural and anthropogenic nutrients, the area is highly productive and acts as an important feeding area for several fish species.

The main weakness of 3-D modeling activities is the lack of comparison with adequate real data. The present model has [32, 35] been compared with the extensive SKAGEX-90 dataset [22], focusing the attention around the simulation of the processes and variabilities in Skagerrak and northern Kattegat in May-June 1990.

E. Özsoy and A. Mikaelyan (eds.), Sensitivity to Change: Black Sea, Baltic Sea and North Sea, 327–339.
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NATURAL FERTILISATION OF THE MARINE ENVIRONMENT – MODELLING OF THE GLOMMA FLOOD 1995

MORTEN D. SKOGEN, JAN AURE, DIDRIK DANIELSSEN & EINAR SVENDSEN

SARSIA

SKOGEN, MORTEN D., JAN AURE, DIDRIK DANIELSSEN & EINAR SVENDSEN 1998 11 30. Natural fertilisation of the marine environment – Modelling of the Glomma flood 1995. – *Sarsia* 83:361-372. Bergen. ISSN 0036-4827.

The flood in the Norwegian river Glomma in May-June 1995 was among the largest ones during this century. Besides being devastating for man and buildings, it implied an extra supply of nutrients to the Skagerrak. This paper will focus on the possible effects this natural fertilisation could have had on the primary production in the receiving water.

The NORWegian ECOlogical Model system (NORWECOM) has been used to quantify this effect. The model has been run three times with different runoff scenarios to isolate the effects of the flood. To investigate the dispersion and dilution of the water from Glomma, this water has been labelled in the model. The model results have also been compared with a set of field data obtained during the period.

During the flood the model gives a significant change in primary production over large areas of the Skagerrak, and all extra nutrients added from the flooded rivers were consumed by the algae. However, the flood seems to have only a small impact on the annual production.

Morten D. Skogen (e-mail: morten@imr.no), Jan Aure & Einar Svendsen, Institute of Marine Research, PO Box 1870 Nordnes, N-5024 Bergen, Norway. – Didrik Danielssen, Institute of Marine Research, Flødevigen Marine Research Station, N-4817 His, Norway.

KEYWORDS: Skagerrak; numerical model; primary production; fertilisation; Glomma.

INTRODUCTION

Large scale artificial, but controlled, fertilising of the ocean to increase the marine production has been discussed for some years. An EU funded research project on MARIne CULTivation has been started with strong support also from industry (HOELL & al. 1995; SAKSHAUG & al. 1995). The goal of MARICULT is to establish the necessary information on environmental constraints and potentials for increased sustainable production of food, raw materials and energy from the ocean. In the first phase of the project, analysis in mesocosmos of possible consequences of different fertilisation strategies on the ecosystem are studied.

During the early summer of 1995, an extreme, but natural large scale fertilisation experiment of the eastern Skagerrak took place through an extreme river flood in southern Norway near the Swedish border. The hydrographical, nutrient and algae distributions were mapped before and during the flood (DANIELSSEN & al. 1996). The flood was among the largest ones this century, and caused large destruction of land and buildings. Besides being devastating for man and animals, the water also transported a lot of extra nutrients into the sea.

There is an increasing concern about the ecological effects of increased nutrient inputs to the sea (SALOMONS & al. 1988; LANCELOT & al. 1990; CHARNOCK & al. 1994; SÜNDERMANN 1994). The primary production is affected by the changes in nutrient inputs, and in many areas this has caused severe problems. There seems e.g. to have been an increasing trend of harmful flagellate blooms in the coastal areas of the southern North Sea (LANCELOT & al. 1991). Probably the most extreme case was the *Chrysochromolina polylepis* bloom in the spring 1988 extending as far north as the Norwegian west coast (DUNDAS & al. 1989; MAESTRINI & GRANELI 1991).

Skagerrak is a transition zone between the much larger Baltic Sea and the North Sea. Since the area is very productive with a production of fish of 70 kg/hectare/year (DANIELSSEN & al. 1997), and at the same time acts as a dustbin for most of the North Sea (EISMA & IRION 1988), it is getting the attention from many scientists. Much of the overall historic and new knowledge obtained is collected in the North Sea Subregion 8 Assessment Report (ANON. 1993) from the North Sea Task Force, and some of the major processes in physical oceanography are described in a few Ph.D. theses (POULSEN 1991; RODHE 1992). A review of the physics of the North Sea and the Skagerrak is also given by OTTO & al. (1990).

Sporadic estimates indicate in- and outflows over the boarder towards the North Sea of 0.5-1.5 Sverdrup (e.g. DANIELSSEN & al. (1997)), while model simulation (SKOGEN & al. 1997a) suggests 1-3 Sv, with a clear seasonal signal (1 Sv = 10^6 m^3 s^{-1}). This variability acts on

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20. september, 1995

Sammendrag:

For vinter/vår sesongen i årene 1987/88 til 1992/93 har vi simulert og kvantifisert variasjoner i mengdene av vannmasser fra Tyskebukta, Østersjøen og Nordsjøen som transporteres til ytre Oslofjord. Resultatene er i stor grad gitt i henhold til et vertikalt snitt mellom Larvik og Kosterøyene der det også vises til årlige variasjoner i den horisontale og vertikale fordelingen av strøm og vannmasser i april hvert år. Transportberegningene av Tyskebuktvann og Østersjøvann viser meget store korttidsvariasjoner, opp til 10.000 m3s-1 i løpet av få dager, samt store variasjoner fra måned til måned og fra år til år. Midlere maksimale konsentrasjor av Tyskebuktvann i Skagerrak ved ytre Oslofjord i april er typisk 1-2%, mens Østersjøvannet har konsentrasjoner på 3-6%.

Emneord - norsk:
1. Langtransporterte vannmasser
2. Modellering
3. Skagerrak

Emneord - engelsk:
1. Transport of watermasses
2. Modeling
3. Skagerrak

Einar Svendsen
Prosjektleder

Hein R Skjoldal
Senterleder

KVANTIFISERING av LANGTRANSPORTERTE VANNMASSER fra TYSKEBUKTA, ØSTERSJØEN og NORDSJØEN til YTRE OSLOFJORD

av

Einar Svendsen, Gro Eriksrød og Morten Skogen
Havforskningsinstituttet i Bergen

etter oppdrag fra Statens Forurensingstilsyn (SFT) tilknyttet prosjektet:

Vannutskiftning og næringssaltbudsjetter i ytre Oslofjord

Prosjektleder v/HI:	Einar Svendsen, Havforskningsinstituttet (HI)	
Medarbeidere:	Gro Eriksrød, Morten Skogen (HI)	
Samarbeidende institusjoner:		Det Norske Meteorologiske Institutt (DNMI) Norsk institutt for vannforskning (NIVA)

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For vinter/vår sesongen i årene 1987/88 til 1992/93 har vi simulert og kvantifisert variasjoner i mengdene av vannmasser fra Tyskebukta, Østersjøen og Nordsjøen som transporteres til ytre Oslofjord. Resultatene er i stor grad gitt i henhold til et vertikalt snitt mellom Larvik og Kosterøyene der det også vises til årlige variasjoner i den horisontale og vertikale fordelingen av strøm og vannmasser i april hvert år. Transportberegningene av Tyskebuktvann og Østersjøvann viser meget store korttidsvariasjoner, opp til 10.000 m^3s^{-1} i løpet av få dager, samt store variasjoner fra måned til måned og fra år til år. Midlere maksimale konsentrasjor av Tyskebuktvann i Skagerrak ved ytre Oslofjord i april er typisk 1-2%, mens Østersjøvannet har konsentrasjoner på 3-6%. De beregnede transportene er også fordelt i henhold til saltholdighet. Dette viser i hovedsak at vannet fra Østersjøen og tildels også fra Tyskebukta transporteres gjennom Larvik-Koster snittet i vann med saltholdighet mindre enn 32 psu, som her typisk forekommer i de øverste 15 til 35 metrene av vannsøylen.

HAVFORSKNINGSINSTITUTTET, September 1995

PROSJEKTRAPPORT

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(SFT) prosjekt nr. 95403

Rapport:
FISKEN OG HAVET NR. 28 - 1995

Tittel:
NUMERISK MODELLERING AV TRANSPORT AV NÆRINGSSALTER OG PRIMÆRPRODUKSJON I SKAGERRAK/KATTEGAT OG YTRE OSLOFJORD

Senter:
Marint miljø

Seksjon:
Kjemisk oseanografi

Forfatter(e):
Einar Svendsen, Gro Eriksrød og Morten Skogen

Antall sider, vedlegg ekskl.:
12

Dato:
05.12.1995

Sammendrag:

Den koblede fysisk, kjemisk, biologiske numeriske havmodellen NORWECOM er kjørt for årene 1988 og 1993 for å kvantifisere naturlige forskjeller i langtransporterte næringssalter til Oslofjorden og primærproduksjon i Skagerrak og Oslofjorden, samt å kvantifisere effekter av reduserte norske næringstilførsler.

Til tross for dobbelt så store tilførsler av Tyskebuktvann til Oslofjorden i 1988, var primærproduksjonen vesentlig større i 1993 både i fjorden og i hele Skagerrak. Dette skyldes i hovedsak kraftigere innstrømning av næringsrikt atlantisk vann i 1993 i de øvre vannlag. Innstrømningen av næringssalter var jevnere i 1993 og hadde ikke signifikant lavere verdier om sommeren som i 1988.

Kjøringer uten nitrogen- og fosfortilførsler fra de norske elvene i Skagerrak gir en nedgang i primærproduksjonen i Oslofjorden på ca. 10 gCm-2år-^{1}, og små endringer for Skagerrak som helhet. Reduksjonene gir klare effekter i det nordøstlige Skagerrak, men effekten er vesentlig mindre enn naturlige variasjoner fra år til år.

Emneord - norsk:	Emneord - engelsk:
1. Modellering	1. Modelling
2. Primærproduksjon	2. Primary production
3. Ytre Oslofjord	3. Outer Oslofjord

Prosjektleder

Senterleder

SUMMARY

A ccoupled physical, chemical and biological numerical ocean model NORWECOM has been run for two different years, 1988 and 1993 in order to quantify natural differences in nutrient transport to the Oslofjord and primary production in the Skagerrak and the Oslofjord, together with quantifying the effects of reduced nutrient supply from norwegian sources.

In spite of twice as large supply of German Bight water to the Oslofjord in 1988 , the primary production (both of diatoms and flagellates)was significantly larger during 1993 both in the fjord and the Skagerrak. This is due mainly to a stronger surface inflow of nutrient-rich atlantic water i 1993. Nutrient supply was also more steady in 1993 and did not show as low levels as in 1988.

Modelled primary production levels just about 200 gC m^{-2} yr^{-1} *in 1993 along the northwestern swedish coast fits well with similar estimates carried out during a 10 years period in the entrance to the Gullmarfjord.*

Modellruns carried out without nitrogen and phosphorus supply from the norwegian rivers showed a reduction in primary production of about 10 gC m^{-2} yr^{-1} *and only small changes for the Skagerrak as a whole.The reduction results in clear effects in the northeastern Skagerrak, but these are smaller than natural variations found from one year to another. The natural variations can be even larger if in adition consideration to the actual year to year variations in the light field are taken into account.*

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Oppdragsgiver(e):
Statens
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Oppdragsgivers referanse:
SFT prosjektnr. 95425

Rapport:
FISKEN OG HAVET NR. 4 - 1996

Tittel:
FLOMVANN FRA GLOMMA OG MILJØFORHOLDENE I SKAGERRAK SOMMREREN 1995. (The Glomma flood and the environmental conditions in the Skagerrak in the summer 1995)

Senter:

Seksjon: Forskningstasjonen Flødevigen

Forfatter(e):
D. S. Danielssen, M. Skogen, J. Aure, og E. Svendsen

Antall sider, vedlegg inkl.:
37

Dato:
05.02. 1996

Sammendrag:

Storflommen på Øslandet i mai-juni 1995 resulterte i de laveste saltholdigheter som har vært observert i overflatelaget i Skagerrak i juni måned siden 1958. Store næringssalttilførsler førte til en unormal stor blomstring av diatomeen *Skeletonema costatum* i juni i indre Skagerrak. Ubetydelige konsentrasjoner av uorganiske næringssalter i overflatelaget indikerer at de tilførte næringssaltene hurtig ble omsatt i algeproduksjon. Observasjoner av gulstoff ga et godt bilde av horisontalutbredelsen av "Glomma brakkvann" i indre Skagerrak. Obervasjoner og modellsimuleringer viste at flomvannet fra Glomma spredte seg i pulser sørvestover langs den norske Skagerrakkysten og langs den svenske vestkysten til kystområdet mellom Koster og Väderö. I samsvar med observasjoner viste modellsimuleringer at flommen hovedsakelig medførte økt produksjon av diatomeer fra begynnelsen av juni til første del av juli 1995.

Emneord - norsk:	Emneord - engelsk:
1. Hydrografi	1. Hydrography
2. Hydrokjemi	2. Hydro chemi
3. Planteplankton	3. Phytoplankton

.... Prosjektleder

.... Seksjonsleder

SUMMARY

The fresh-water influence from the flood in June, 1995 to the eastern Skagerrak created an unusual and very fresh surface layer with a strong halocline. The surface water with extremely low salinities was detected all along the Norwegian coast within Skagerrak, east to the shore between Koster and Väderö on the Swedish west-coast, and south to the coast of Denmark (northern Jutland). The surface layer in Skagerrak was probably also affected by increased freshwater supplies from the Baltic/Kattegat and the G¢ta River. Concentrations of orthophosphate and nitrate were observed close to zero in the fresh surface layer, except from some low concentrations near Koster in the middle of June and close to Jomfruland in July. Low concentrations of silicate were found in the brackish layer in the Jomfruland-Koster section in June and close to Jomfruland in Juli. In the first part of July the total phosphorous and nitrogen concentrations in the surface layer at Jomfruland were significantly above the mean from the five year period 1990-1994.

High concentrations of chlorophyll in the brackish "Glomma water" were observed along the Jomfruland-Koster section in the middle of June, and still some chlorophyll was left in the beginning of July. The chlorophyll concentrations and the estimated primary production in the Jomfruland-Koster section increased with a factor of about 3 during the flood in June. Brackish "Glomma water" were also found in the inner part of the Skagerrak and further down the coast to Ris¢r, where unusual high concentrations of the diatom Skeletonema costatum were observed. The cause for a diatom to dominate the plankton community was probably due to the excess of silicate in the surface layer. Relatively high concentrations of this algae were still present in this coastal area in the beginning of July. Insignificant amounts of potential harmful algae were found during the investigation period.

By marking of the flood-water from Glomma in the NORWECOM model system, a unique possibility to study the dispersion and dilution of this water is demonstrated, which is not possible by sporadic in situ measurements. The model shows clearly how the "Glomma" water spread in pulses from the outer Oslofjord along the Norwegian Skagerrak coast. By comparing model simulations both with and without flood water, estimates are given in space and time on how the flood also affected the primary production. In agreement with the data, the simulations show that the flood mainly led to an increased diatom production from the beginning of June to the first part of July.

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Rapport:
FISKEN OG HAVET NR. 25 - 1996

Tittel:
Numerisk modellering av primærproduksjon og transport av vannmasser og næringssalter langs Norskekysten.
Effekter av regionale og lokale næringstilførsler (NUMPTRAVANN).

Senter:
Marint miljø

Seksjon: Havmiljødata og modellering. Fysisk oseanografi og akustikk

Forfatter(e):
Henrik Søiland, Einar Svendsen, Morten Skogen og Gro Eriksrød

Antall sider, vedlegg inkl.:
37

Dato:
17.12. 1996

Sammendrag:

Den koblede fysisk, kjemisk, biologiske numeriske havmodellen NORWECOM er kjørt for 1993 for å beregne hvor langt og i hvilken grad regionale (utenlandske) og lokale (norske) tilførsler av antropogene næringssalter gjør seg gjeldende langs kysten av Sør-Norge. Ved gjentatte kjøringer med og uten de ulike tilførsler, og ved å se på differanser i modellresultatene, får vi et kvantitativt bilde av hvordan de ulike næringssalt- og algekonsentrasjonene, samt primærproduksjonen påvirkes. I denne rapporten diskuteres kun resultater fra områdene vest-Jylland, Skagerrak, Kattegat og kysten av vest-Norge, med hovedvekt på norskekysten fra Sverige til Fedje (60045'N). Modellert primærproduksjon i overkant av 200 gCm-2år-1 (i 1993) langs den nordlige svenske vestkyst, stemmer godt med tilsvarende estimater fra ti års observasjoner fra munningen av Gullmarsfjorden i Sverige.

Emneord - norsk:	Emneord - engelsk:
1. Eutrofiering	1. Eutrophication
2. Modellering	2. Modelling
3. Forvaltningsråd	3. Management advise

Einar Svendsen
Prosjektleder

Hein R Skjoldal
Senterleder

SUMMARY/CONCLUSIONS

The coupled physical, chemical, biological numerical ocean model NORWECOM was run for 1993 to estimate how far and to what degree regional (foreign) and local (Norwegian) supplies of anthropogenic nutrients effect the waters along the coast of southern Norway. By studying the differences in the model results from repeated runs with and without different supplies, a quantative view is obtained of how the different nutrient and algae concentrations and the primary production are effected. In this report only results from the areas west of Jutland, the Skagerrak, the Kattegat and the coast of western Norway is discussed, with focus on the Norwegian coast from Sweden to Fedje (60^{0}45´N). Modelled primary production just above 200 gCm^{-2}y^{-1} (in 1993) along the Swedish west coast, is in good agreement with similar estimates from 10 years of observations from the mouth of the Gullmarsfjord in Sweden.

By reducing the foreign anthropogenic nutrient supplies (N and P) with 100% (80% of total supplies distributed on 23 sources from all countries except Norway) the main reduction in primary production is found in the coastal water along western Jutland and in the Kattegat (Fig.3). Since silicate (which here is not reduced) usually is the limiting factor for diatom production, it is (as expected) mainly the production of flagellates which is reduced. However, little effects of these reductions are seen in the Skagerrak and along the coast of Norway., only a few percent in relation to the annual production. Earlier it has been shown that natural variabilities in the inflow of nutrient rich Atlantic Water gives a much stronger effect in these areas. In 1993 this inflow was quite strong and near the surface. In years with strong atlantic inflow to the Skagerrak the effect of reduced river supplies will be less than in years with weak inflow of Atlantic Water.

100% reduction in the Norwegian anthropogenic nutrient supplies only results in significantly reduced total annual primary production in the northeastern corner of the Skagerrak (outer Oslofjord area sothwest to Jomfruland) where we also have the largest river supplies. This is also the area of the Norwegian coast which is least (but still strongly) affected by the Atlantic watermasses.

By reducing the foreign anthropogenic nutrient supplies with 50% the effect is roughly half (in comparison with the 100% reduction) west of Jutland, in the Kattegat and in the Skagerrak, but only small differences are seen outside western Norway. With a 50% reduction of phosphorous (not nitrogen) the effect is even smaller. Especially in the Kattegat the effects are small, which indicate that the modelled production here to a larger extent is nitrogen limited than phosphorous limited.

NORWECOM represents a strong simplification of complex and partly unknown natural processes. This work has shown that a weakness in the model probably is connected to a too slow sinking and a too weak removal of organic material, which through the remineralization process create a surplus in the total water column of inorganic nutrients by the end of the year. Since we mainly study the differences between several model results, the possible effects of these weaknesses to a large extent cancel out. In addition the unusually high concentrations mainly become present after the primary production phase. All parameters included in the chemical-biological process formulations are taken from published litterature. No calibration/ manipulation is performed to fit the results to certain data, since the goal of the model development has been to create a general model system. To our knowledge NORWECOM is the first and probably the only model system which with some realism can simulate the varying amounts of algae and nutrients and transports throughout the North Sea and not least within the Skagerrak with its very complex circulation and watermass distribution.

Annex II

List of participants

SKAGEX - symposium,

Lysekil, Sweden, 3 - 6 November 1992

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