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BALTIC SEA PATCHINESS EXPERIMENT

-- PEX '86 --

PART I: GENERAL REPORT

VOL.1: TEXT

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Baltic Sea Patchiness Experiment
Part I: General Report
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Errata:

page 25 line 2 :
change: Fig. 3-9 to **Fig. 3-5**

page 25 para 2 last line :
change: Fig. 3-9 to **Fig. 3-6**

page 33 para 4 line 3 :
correct : April transect the **center of** the elevation ..

page 42 after para 2 :
add: **(Figs. 4-54 to 4-57).**

page 59 last para :
correct first two lines : A weak but rather clear indication of inertial wave activity **was found on 27 April.** According to the

page 63 last line from bottom:
correct: This variability **decreased** with increasing depth, ...

page 82 para 2 line 4 :
change: (c.f. 4.1.4) to **(c.f. 5.1.4)**

Appendix A6:

change:

Inst.of Oceanology
Pol.Acad.of Sciences
Pl **Sopot**

Add Institutes:

Dept.of Oceanography, Univ.of Gothenburg
S Gothenburg

Institute of Marine Research
S Lysekil

Preface

At a meeting of the ICES Study Group on Patchiness in the Baltic Sea in Wustrow, German Democratic Republic, in April 1988, it was decided to request ICES to publish the proceedings from the Baltic Sea Patchiness Experiment in April-May 1986 (PEX-86).

This General Report is the first part of the proceedings. It is, for practical reasons, divided into two volumes, the first one containing the text and the second one the figures. It should be considered as a summery of the findings during PEX-86.

In addition to the General Report, several papers containing data and results from PEX-86 have been published and a great number of scientific papers are expected to be published. They will later form Part II, III, etc of the proceedings.

The Editors want to stress that the General Report is the result of the work of approximately 150 scientific personal and the crews of 14 vessels and one aeroplane participating in the field investigation, as well as scientists in different institutes taking part in the working up of the results. The leader of PEX-86 has been Dr Bernt I Dybern.

The scientists who have been directly involved in the writing of different parts of the General Report are listed in the Appendix at the end of this volume.

We want to thank all the people, institutes and authorities involved in PEX 86, as well as ICES, especially its Hydrographer, Dr Harry Dooley, for all work and assistance during the planning stage, the field expedition and the working up of the results. The cooperation has been excellent and an extraordinary potential for further joint international work in the Baltic Sea area has been formed.

Bernt I Dybern Hans Peter Hansen

Lysekil and Kiel, January 1989

BALTIC SEA PATCHINESS EXPERIMENT
-- PEX '86 --

Part I: General Report
I (1) Text

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1 Introduction

1.1 Aims

Since the advent of high resolution measurements in space and time in the middle of this century, it has become more and more apparent that not only physical, but also chemical and biological parameters in the sea show a more or less spatial structure which changes with time; this is referred to as patchiness.

This phenomenon is controlled by physical and biological processes but it does practically not influence the physical dynamics. The Baltic Sea is an especially interesting area for such studies since it is an enclosed sea with special hydrographic features. Recent discoveries e.g. by means of satellite images of complex systems of fronts, eddies etc. enhance this.

The subject was raised in the former ICES/SCOR Working Group on the Study of Pollution in the Baltic (former SCOR WG 42) in 1979 - 1982 then under the chairmanship of Professor Gunnar Kullenberg, Denmark. Since a patchy distribution of parameters in different ways is very interesting from the scientific viewpoint and since it may have practical implications for the fish distribution and results from monitoring it was considered important to elucidate the phenomenon further. It would then be necessary to study in detail physical, chemical, and biological parameters in order to get adequate pictures of spatial structures and their temporal changes.

A Workshop on Patchiness was arranged in Tallinn on 22 - 23 March 1983 to review what was known about patchiness in the Baltic (ICES 1983). To complete the information a Study Group on Patchiness Investigations in the Baltic was set up under the chairmanship of Dr. Bernt I. Dybern, Sweden, at the ICES Statutory Meeting in October 1983. The main aim was to make an international study of the patchiness phenomenon.

The Study Group reviewed the knowledge on patchiness and recommended a field investigation in the Baltic Sea with the main objectives

- to observe the spatial and temporal scales of the biological and chemical fields in the Baltic Proper

- to understand the processes generating the observed patchiness in terms of physical and biological processes.

This investigation was carried out in April-May 1986 and is called PEX-86. It was preceeded by a four-ship investigation in 1985, called PRE-PEX, during which valuable information and training for the definitive PEX were obtained.

A large quantity of data were collected during PEX-86 and this General Report summarizes the findings. More detailed information will be published as a Data Atlas and as individual contributions.

1.2 Previous patchiness investigations

Inhomogeneous (patchy) species distribution of marine benthic animals has been described and discussed since long ago. Holme (1953, 1964) made extensive studies of the phenomenon and Gärdefors & Orrhage (1968) were among the first scientists to use the term patchiness for the uneven distribution of benthic organisms. During the last two decades a great number of benthos researchers have made studies on the spatial and temporal variability of bottom organisms.

Marine planktologists have investigated the spatial and temporal variability of phytoplankton and zooplankton (and later also microorganisms). Steele (e.g. 1976, 1978) summarized the problems and discussed different causes for the variability, among other things pointing out the importance of inhomogenously distributed physical and chemical factors.

Especially during the 1970s scientists concerned with the latter factors increasingly became interested in the spatial and temporal variability shown, see e.g. Pickard and Emery (1982) and Pond & Pickard (1983). Several international expeditions touched in different ways upon the patchiness phenomenon, e.g. the North Sea Fladen Experiment (FLEX) in 1976, the UK/USA/USSR POLYMODE experiment, completed in 1978, and the Second Multiship Experiment of the Joint Air-Sea Interaction Experiment (JASIN) in 1978.

In the Baltic Sea the spatial and temporal variability of physical, chemical and biological parameters had also been observed for a long time, but it was only recently that investigations began directly aimed at an understanding of the phenomena belonging to this category, cf e.g. Grasshoff and Hansen (1980), Renk (1983), Aitsam et al. (1984), Gidhagen (1984), Kahru et al. (1984), Blomqvist and Bonsdorff (1986) and Fennel et al. (1986).

2 The experiment

From the beginning it was clear that an investigation of the patchiness phenomenon must concentrate on a localized water body during a certain time. In this way it would be possible to (1) make detailed maps of the distribution of different parameters and (2) understand some of the dynamics by following changes from day to day. The Study Group decided to perform the experiment during two weeks in the period of the spring algal bloom since an optimal signal to noise ratio was expected in this season. The area under investigation should be such that the water body was exposed to both shallow water and deep water processes. It was decided to make the measurements in two nested grids whose sizes were determined to cover the scales of the governing physical processes. The chosen sampling scheme in space and time was a compromise between minimizing the aliasing, covering the expected scales, and logistic requirements.

Such an investigation can only be carried out by several ships operating simultaneously over a time in the chosen area.

All Baltic countries except Denmark took part in the investigation 21 April - 10 May 1986 with altogether 14 ships. The project was also formally supported by other scientific organizations working in the Baltic and by SCOR, in addition to ICES.

The period from the end of April to the beginning of May was considered suitable because weather conditions then generally are rather stable. Moreover, it is usually the end of the algal spring bloom and one could expect to find both algae and remaining nutrients at the same time.

Following HELCOM recommendations all times are given in GMT. As the mean longitude of the PEX area was 19°, 1 h 16 min have to be added to convert GMT into true local time (GMT + 2 hrs = local standard summer time).

2.1 Description of the area

The field investigation took place from 25 April to 8 May in the open parts of the Baltic Sea Proper in the southern part of the eastern Gotland Basin between 55° 59'and 56° 36'N and 18° 18'and 19° 39'E (Fig. 2-1). The investigated area crossed a channel with a slope from about 20 m on the Hoburg Bank on the NW side down to about 120 m and up to 80 m on the SE slope. Within the deepest part there was a small ridge with a minimum depth of 90 m (Fig. 2-2).

2.2 Ships

A list of the participating research ships and their main data is presented in Table A-1 (after the text). The small SONDA was used as liaison vessel. In addition to the 13 ships in the table also a vessel (TV-171) and an aeroplane from the Swedish Coastguard took part.

The total number of scientific personnel on board the ships was about 150 and the ship crews amounted to about 190 persons. Thus in total about 340 persons took part in the exercise. On land about 15 marine institutes were involved.

Radio communication between the ships also included daily "radio meetings" between the chief scientists in which common problems as well as latest measurements results were discussed. These "meetings" were chaired by the expedition leader on board ARGOS.

2.3 Actual parameters

It was clear from the beginning that restrictions had to be imposed on the number of obligatory parameters to be measured because of the limited capacity of some ships.

Table A-1 shows the parameters which were obligatory and those which were investigated on a voluntary basis by ships having enough capacity. In addition ARGOS carried out acoustic soundings for fish, LITTORINA and TV-171 used drifters to study water movements, Arnold Veimer and Oceania carried out additional physical measurements and LITTORINA made studies with sediment traps.

12 current meter stations, deployed by different ships, were set out according to the pattern shown in Fig.2-3.

Besides the data obtained during the seagoing expedition meteorological and satellite-image data have been used for the working up of the PEX results.

All obligatory and some of the non-obligatory data were submitted to the ICES Data Center after the experiment.

2.4 Grids, anchor stations, transects

Before the field experiment started most ships gathered in the harbour of Karlskrona for intercalibrations from 21 to 23 April. Other intercalibrations were made at sea during PEX.

The investigated area was divided into one grids with a distance between stations of 4 nautical miles (called the Eddy grid) and one smaller grid with a distance of 2 nautical miles between the stations (called the Slope grid) nested within the Eddy grid, cf. Fig. 2-2. The grid coordinates are given in Table 2-1. The number of stations was the same in each grid.

Each grid contained 6 transects with 11 stations. 7 ships operated transects A - F in Fig. 2-2 and took parallel stations from west to east simultaneously at a number of depths. In this way 11 simultaneous cross-sections were obtained daily, either in the Eddy grid or in the Slope grid. The first cross-section was taken at 0300 GMT and the last at 1800 GMT. Time spacing between stations was thus 1.5 hours. The Eddy grid was measured 4 times (25, 29 April, 3, 7 May) and the Slope grid 8 times (26, 27, 28, 30 April, 2, 4, 5, 6 May) (see Table 2-2). Some of the ships made additional measurements. Note that for practical reasons the investigated windows are shown as horizontal rectangles in this report. The following ships took part in the Eddy and Slope grid measurements: LEV TITOV, SVANIC, ARANDA, ARNOLD VEIMER, ARGOS, GAUSS and PROFESSOR ALBRECHT PENCK (c.f. Table A-1, in the appendix). Table 2-3 shows the arrangement of the ships in the grids.

Table 2-1 Grid coordinates

Slope grid

transect	start (N	E)	end (N	E)
APS-AZS	56°30.70'	18°30.80'	56°21.30'	19°02.70'
BPS-BZS	56°29.00'	18°29.10'	56°19.50'	19°00.90'
CPS-CZS	56°27.20'	18°27.40'	56°17.80'	18°59.30'
DPS-DZS	56°25.40'	18°25.70'	56°15.90'	18°57.50'
EPS-EZS	56°23.80'	18°23.90'	56°14.30'	18°55.60'
FPS-FZS	56°21.90'	18°22.20'	56°12.40'	18°54.00'

Eddy grid

transect	start (N	E)	end (N	E)
AP-AZ	56°36.00'	18°36.00'	56°17.00'	19°39.70'
BP-BZ	56°32.50'	18°32.60'	56°13.50'	19°36.30'
CP-CZ	56°29.00'	18°29.10'	56°10.00'	19°32.80'
DP-DZ	56°25.40'	18°25.70'	56°06.40'	19°29.40'
EP-EZ	56°21.90'	18°22.20'	56°02.90'	19°25.90'
FP-FZ	56°18.30'	18°19.00'	55°59.40'	19°22.60'

Table 2-2 Grids and dates

Date	Eddy grid		Slope grid
25.04.86	E I		
26.04.86			S 1
27.04.86			S 2
28.04.86			S 3
29.04.86	E II		
30.04.86			S 4
01.05.86	---	break	---
02.05.86			S 5
03.05.86	E III		
04.05.86			S 6
05.05.86			S 7
06.05.86			S 8
07.05.86	E IV		

Table 2-3 Arrangement of the ships in the grids

Slope grids

transect	ships name
APS-AZS	LEV TITOV / SVANIC alternate stations
BPS-BZS	ARNOLD VEIMER
CPS-CZS	ARANDA
DPS-DZS	ARGOS
EPS-EZS	GAUSS
FPS-FZS	PROFESSOR ALBRECHT PENCK

Eddy grids

transect	ships name
AP-AZ	LEV TITOV / SVANIC alternate stations
BP-BZ	ARANDA
CP-CZ	ARNOLD VEIMER
DP-DZ	ARGOS
EP-EZ	PROFESSOR ALBRECHT PENCK
FP-FZ	GAUSS

Four ships were anchored at two stations in the western half of the Slope grid (AN1 and AN2 respectively in Fig. 2-2) where they made simultaneous measurements during the whole period with an interruption for 1 May. The two anchor stations were located within the PEX grids at the following positions:

AN1: 56°25.30' N / 18°37.00' E
Ships: OCEANIA and HYDROMET
Bottom depth : 65 - 70 m

AN2: 56°24.50' N / 18°41.60' E
Ships: WIECZNO and ALKOR
Bottom depth : 89 - 92 m

The coordinates were chosen to meet the following criteria:

- the anchor stations should as much as possible represent the center of the PEX Slope grid,

- one of the anchor stations (AN1) should be located at a position where the halocline just touched the slope, while

- the other one (AN2) should be located at a position where the halocline was well pronounced and situated above some layer of bottom water

- the positions of AN1 and AN2 should be between the eddy and Slope grid transects to avoid any interference from the ships conducting the measurements at the transects.

The two ships forming one anchor station were put as close together as permitted by nautical safety (i.e. varying from

500 to 900 m due to swaying). The mean distance between AN1 an AN2 was about 5 km.

The two AN2-ships ALKOR and WIECZNO were anchored on a slope with a difference of about 3 m in mean depths (ALKOR= 92 m, WIECZNO= 89 m). This depth difference resulted, with few exceptions, in higher salinities and nutrient concentrations and lower oxygen contents in the bottom samples.

Two ships (LITTORINA and TV-171) performed special investigations in the area. Some ships carried out special tasks during nights.

On passage to and from the PEX area some ships took a number of stations along transects in order to get a picture of the general conditions in the Baltic.

2.5 Sampling depths

Observation depths in the grids and at the anchor stations were for most parameters (where possible due to bottom depth) 1, 5, 10, 20, 30, 40, 50, 80 m and bottom.

For chlorophyll a and phytoplankton standard depths were 1, 5, 10, 20 and 30 m, and for primary production capacity 1, 5, 10 and 20 m (with dark bottles on 1 and 20 m).

Mesozooplankton was collected by net-towing (1) from 5 m above the bottom to the upper layer of the halocline and from (2) the upper layer of the halocline to the surface with a velocity of 0.5 ms^{-1}. A WP-2 net with mesh size 100 µm was used.

Some ships made samplings also on other depths for special purposes.

3 Methodology

3.1 Parameters

3.1.1 Meteorology

Meteorological observations were made with standard instruments according to the recommendations of the World Meteorological Organization.

Components of heat exchange at the air-sea interface were calculated or determined by the following methods:

evaporative heat flux - Friehe and Schmitt (1976)
sensible heat flux - Friehe and Schmitt (1976)

3.1.2 Physical parameters

3.1.2.1 Temperature and salinity

At grid and anchor stations profiles of temperature and salinity were obtained by means of CTD probes except for HYDROMET, WIECZNO and LEV TITOV, which used water bottles and reversing thermometers at the standard depths (c.f. 2.5).

The CTD probes used were mainly NBIS Mark III systems, but PROFESSOR ALBRECHT PENCK and OCEANIA used probes constructed in their own institutes and ALKOR used ME-OTS-3.

From temperature, conductivity and pressure values measured by CTD probes lowered from the surface down to near-bottom layers profiles of temperature and salinity with a 1 dbar (in some cases 2 dbar) interval were calculated. Conductivity values were converted to practical salinity using the UNESCO formula (Fofonoff, 1985). Salinity values measured by means of CTD were calibrated against salinometer values (determined under laboratory conditions) from water samples taken from the same station.

3.1.2.2 Towed CTD

In order to get higher resolution in space than possible by the obligatory CTD surveys, measurements with towed, undulating CTD were made by ARNOLD VEIMER and GAUSS (Table 3-1).

Table 3-1 Towed CTD transects (c.f. Fig. 2-2).

No.	Date	Start (GMT)	Transect from:	to:
R/V ARNOLD VEIMER :				
1.	25.04.86	22.30	CY-CZ	CR
2.	26.04.86	21.30	CY	CR
3.	27.04.86	23.00	CX	CR
4.	28.04.86	22.00	CY	CR
5.	29.04.86	22.00	CY-CZ	CR
6.	02.05.86	22.00	CY-CZ	CR
7.	03.05.86	21.50	CY-CZ	CR
8.	04.05.86	22.00	CY-CZ	CR
9.	05.05.86	21.50	CY-CZ	CR
10.	06.05.86	22.00	CY	CT-CU
11.	07.05.86	22.00	CY	CS-CT
12.	08.05.86	00.50	CS-CT	CY
13.	08.05.86	03.30	CY	CS-CT
R/V GAUSS :				
1.	24.04.86	04.40	FP	FZ
2.	24.04.86	08.47	FZ	AZ
3.	24.04.86	10.52	AZ	AP
4.	24.04.86	21.09	AP	FP
5.	29.04.86	20.48	FZ	AP
6.	02.05.86	22.25	EUS	EPS
7.	02.05.86	23.20	EPS	EUS
8.	03.05.86	00.11	EUS	EPS

The towed CTD consist of a depth controllable body (fish), in depth, which is equipped with a standard CTD and additional sensors (e.g. fluorimeter). ARNOLD VEIMER used a NBIS Mark III CTD system, GAUSS used a CTD, type ME. The accuracy of both instruments is in the order of 0.01 (or better) in temperature and in salinity. The horizontal resolution (distance between successive descents or ascents of the fish) is about 1 to 2 km, depending on water depth, the ship speed and the selected vertical velocity of the fish. The fish is towed about 500 to 1000 m behind the ship. The data are treated like "normal" CTD data, the pressure is converted into depth and the horizontal coordinates added to the data points.

ARNOLD VEIMER every night after the obligatory grid work towed CTD sections along transect C from half-way between stations CY,CZ to CR covering the upper 80-m layer with a horizontal resolution (distance between successive ascents or descents of the towed body) of about 0.77 n.m.

3.1.2.3 Currents

During PEX, currents were measured at 12 positions within the PEX area by means of moored instruments (Fig. 2-3). At stations 1, 2 and 4 they were of the type LSK (GDR - Poland production), the rest were Aanderaa instruments. Most of them worked satisfactorily, some, however, delivered doubtful data or no data at all.

On the map, Fig. 2-3, the mooring positions are depicted with stars, with their numbers and the sampling depths for which current data are available. All institutes sent hourly means of their reliable current measurements to ICES for collection and distribution among the PEX participants.

The Swedish Coast Guard ship TV-171 carried out a drifter experiment from 28 April to 1 May . Twenty drifters were released forming a cross, with a distance of 1 km between them. Each drifter (constructed in SMHI) consisted of a sail with an approximate area of 1 m^2 projected perpendicular to the current. The sail was suspended at a depth of 10 m, with a floating, disc-shaped buoy at the surface. The buoys were all equipped with flags, but during the experiment it was found necessary to put radar reflectors on them. The buoys were tracked by the radar aboard TV-171.

During the three-day period 5 to 7 observations of each drifter were performed, all of them during daytime.

LITTORINA colected sediment by means of drifting sediment traps. The tracks of the drifting traps were analyzed to produce additional information about currents.

3.1.2.4 Optical Methods

Solar radiation and its transmittance into the sea was measured by means of a pyranometer in the air and a spectral irradiance integrator underwater. The light attenuation was measured _in situ_ using a beam transmittance meter according to Jerlov (1976). Heat exchange at the air/sea interface and evaporative heat flux were calculated according to Friehe and Schmitt (1976).

The fluorescence of the sea water was measured in situ using a Hundahl and Holk (1980) fluorimeter which mainly gave the fluorescence of chlorophyll _a_.

3.1.2.5 Particle Counting

On the grids water samples were collected by ARGOS for particle counting from depths of1-2, 5, 10 and 20 m. Particles in the size range of 4-50 μm (equivalent spherical diameter) were counted with a Coulter Counter (Coulter Electronics Ltd), using a 140 μm orific tube. Three replicate measurements were made on each sample, usually within one hour of collection. Results are presented as ppm/vol. For particle counting according to the "on-track" sampling mode see 3.1.6.

3.1.3 Chemical Parameters

The sampling and analysis were in principle carried out following the Guidelines for the Baltic Monitoring Programme for the Baltic Sea (HELCOM 1983 a), in some cases with minor modifications. Table 3-2 (below) gives an overview of the methods used during the PEX programme.

Ships using automated chemical analysis (AUTO ANALYZERS™) applied the standard methods (Hansen & Grasshoff 1986) or slightly modified versions. ALKOR used a continuously profiling system which combines CTD measurements and continuous flow analysis of sample water from a pumping device attached to the CTD (Chemical-Profiler).

The following chemical parameters were measured during the experiment by all ships: oxygen, phosphate, and the sum of nitrate and nitrite. The data have been corrected as explained in section 3.2.2. Phosphate is the most accurately measured chemical parameter.

During the experiment the sum of nitrate and nitrite was used to describe the nitrate distributions. In addition, nitrite, alkalinity, pH and total phosphorus were measured by some ships.

Table 3-2 Methods and equipment used for the chemical investigations

Ship	O2	pH	Alk	PO4	NO3 +NO2	NO2	SiO4	TotP
ALKOR	1,2			7	7	7	7	
ARANDA	1			5	5			
ARGOS	1			6	6		6	8
ARNOLD VEIMER	2			5	5	5	5	
GAUSS	1	3	4	6	9			
HYDROMET	1			6	6	6	6	8
LEV TITOV	1	3		6	6	6	6	
LITTORINA				9	9		9	
PROFESSOR ALBRECHT PENCK	2			6	6			
SVANIC	1			6	6			
WIECZNO	1			6	6			

1 = Winkler titration
2 = Oxygen sensor
3 = Glass electrode
4 = pH method
5 = Autoanalyser
6 = Spectrophotometer, manually
7 = Chemical profiling, autoanalyser
8 = Persulphate oxydation
9 = Deep-freeze preservation, autoanalyser

With respect to the chemical parameters, the surface layer was quite homogeneously mixed down to well below 10m (c.f. 4.2). In the following account, the 10 dbar level is used for the horizontal distributions in order to minimize ship-generated disturbances. In addition to horizontal isopleth maps, cross sections and longitudinal sections have been constructed for study of the vertical extention of the patches.

3.1.4. Biological parameters

The subsamples for chlorophyll a, phytoplankton and primary production capacity were taken from the same water samples as for the chemical analyses. Zooplankton was collected by net-towing as described in 2.5.

At grid stations chlorophyll, phyto- and zooplankton were sampled from every station while water for primary production capacity investigations was collected from every second station. At the anchor stations all biological sampling was made every 3 hours. Primary production was, however, measured only between 0300 and 1500 GMT.

All the analyses were performed according to the Guidelines for the Baltic Monitoring Programme (HELCOM 1983 a).

For the purpose of this report phytoplankton samples were counted from the depths of 5, 10 and 30 m for the period of April 25 - April 28 and only from 1 m on 7 May. Additionally, 4 ships counted samples from 4 May to 6 May. However, at AN1 the samples were counted for the whole period.

Zooplankton from the Eddy grids was analysed only from eddy grid 1 (25 April) from one transect and eddy grid 4 (7 May) from two transects. Zooplankton from the Slope grids and AN2 was analysed for two periods, 26 - 28 April (Slope grid 1-3) and 4 - 6 May (Slope grid 6-8) for both layers (except for transect B , where no samples were taken from the subhalocline layer). For AN1 a continuous data set from 25 April to 9 May was analysed.

Samples for chlorophyll a were filtered on Whatman GF/C glass fiber filter, extracted with 90% acetone and measured either spectro- or fluorimetrically.

Primary production capacity was measured with the ^{14}C method by incubating water samples under constant artificial light in incubators where the temperature was adjusted according to the mean temperature of the 0-20 m layer. One ship AN2 (ALKOR) measured primary production in situ parallel to the incubator measurements by the second ship (WIECZNO).

All laboratories used their own ^{14}C batches for primary production capacity measurements but the activities were determined by ARANDA as well as the activities of all the samples collected during the investigation period. The liquid scintillation counter (Rackbeta) and the scintillation cocktail (LUMAGEL™) were provided by Wallac Oy, Finland.

Seven phytoplankton species were selected to be counted on the basis of their dominance and their easy identification: the dinoflagellate Gonyaulax catenata, the diatoms Achnanthes taeniata, Chaetoceros holsaticus, C. wighamii, Skeletonema costatum, Thalassiosira baltica and T. levanderi.

The data were used to identify patchiness at species level. In addition to these selected species other species with varying, sometimes high abundances (e.g. an unarmored, unidentified dinoflagellate, nannoflagellates and an autotrophic ciliate, Mesodinium rubrum) were found to be present in big quantities. The phytoplankton species were, except one case, counted using inverted microscope technique (Utermöhl 1958). One ship used a different method (The water sample of 500 ml was sedimented in a glass cylinder for 48 h. The upper water layer was discarded and the sample was made homogenous. Quantitative aliquots were counted using direct microscope technique).

All the ships counted at least 200 cells and 50 chains of each species in a single sample.

Seven zooplankton species were selected to be counted: the copepods Pseudocalanus minutus elongatus, Temora longicornis, Acartia spp. (with stages and sex for the adults), Centropages hamatus (copepodid stages CIV-V), the cladoceran species Evadne nordmanni, the larvae of the polychaet Harmothoe sarsi, and the appendicularia Fritillaria borealis. It was recommended that least 5oo individuals per sample should be counted.

3.1.5 Remote sensing

3.1.5.1 Satellite image interpretation

Remotely sensed data gave information on the distribution of sea surface temperature and sea surface roughness. From time-series of temperature distribution it was possible to make conclusions of the advection in the surface layer.

Two satellite systems carrying sensors for sea surface information were been used for the Patchiness Experiment:

1. The NOAA Advanced Very High Resolution Radiometer (AVHRR) for sea surface temperature information. The NOAA satellites covered the investigation area twice within 24 hours and there were additional consecutive passes.

2. The Thematic Mapper (TM) on the LANDSAT 5 satellite which passed the investigation area only on 7 May.

An overview of the quality of the remotely sensed data is given in Table 3-3.

Table 3-3 Overview of the quality of the remotely sensed data

Month			April							May							
Date	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10
AVHRR								T	t	Tt	n	TN	xN	XN	XN	xN	X
LANDSAT-TM														X			
SLAR	X		X	X								X		X			

T = day images, N = night images, X = Aircraft recordings
(small letters indicate moderate quality)

The major part of the NOAA data were received in Dundee from where some contrast enhanced images as well as the raw data were obtained. A few scenes, analyzed in Norrköping, were received from Tromsö, Norway.

Images of the contrast enhanced NOAA-AVHRR data give an informative overview over the general sea surface temperature distribution of the PEX area and its surrounding. Due to the limited ground resolution (1100 m per pixel in the nadir) and radiometric resolution images of temperature pattern in the PEX grid, with its few greysteps can hardly be reproduced. Therefore an alternative reproduction program has been developed to draw isolines of grey steps of the different NOAA images. The greystep isolines were then transformed to isothermes through a calibration with one or two simultaneous ship measurements.

Time series of the plotted grey step distribution can also be used to demonstrate general advection as well as the movement of fronts and eddies. In order to understand the frontal movements, a quick motion video was produced by connecting the different consecutive NOAA images. The transport processes observed are described in section 4.5.

The data of the Thematic Mapper of the LANDSAT 5 satellite were received in Kiruna, Sweden, and distributed via Italy, from where also some contrast enhanced images have been obtained. Additional data sets have been received from the Swedish Space Corporation. The data were partly processed at the SMHI in Norrkoeping and partly at the IFM in Kiel.

The TM IR data were transformed to isotherms by assuming a linear relationship between the radiation levels and the temperature (0.5 K per level). In situ measurements of sea surface temperature (bulk temperature of the uppermost 2 m) have been used to calibrate the temperature scale. As the PEX research ships were resolved on the visible bands of the TM sensor (channel 4), a rather exact positioning of the Eddy grid was obtained.

TM channel 2 data were used to map the horizontal distribution of particles. As the differences in reflected radiation energy was very small and did not exceed the strong background noise, hardcopy products were too poor to be reproduced but some information is presented in the text.

3.1.5.2 SLAR-Measurements

In collaboration with the Swedish Coastguard and the Swedish Space Corporation six aeroplane overflights with a Sidelooking Airborne Radar (SLAR) were organized (c.f. Table 3-3).

The SLAR emitts electromagnetic energy in the microwave (9,4 GHz) part of the spectrum which coresponds to a wavelength of approximately 4 cm. The ground resolution is 70 m which is of the same order as LANDSAT TM. When the radar energy reaches the sea a resonant type of reflection occurs. The reflected energy depends on the amount of sea surface waves with almost the same wavelength as the radar beam. These surface waves are located at the short part of the gravity wave spectrum where the capillary force becomes important, and they are mainly driven by the wind. The windgenerated 4-cm wave-pattern can be modified by naturally occurring oil as well as oil-spill caused by man.

The microwave radar is not sensitive to atmospheric disturbances (like clouds and fog) in the same way as the passive satellite sensors are.

The SLAR data from the PEX overflights were very low in contrast . It was found that the real time link between the airplane and the R/V ARGOS considerably reduced the quality of the radar images. The data presented here have been visualized on a special tape recorder/monitor afterwards.

3.1.6. On-track particle and fluorescence measurements

ARNOLD VEIMER measured particle concentrations and chlorophyll a *in vivo* fluorescence in the "on-track" (quasi-continuous) sampling mode. The water was continuously pumped into the ship laboratory from an intake below the ship's hull at the depth of 5 m. The instrumentation package consisted of an "on-line" particle size analyzer HIAC-ROYCO™-320, a TURNER DESIGNS™ flow-through fluorimeter, and a computer/data logger. The corresponding water temperature data were retrieved from the automatic ship weather station MIDAS files.

The horizontal distributions of particles were obtained for 12 size classes with the equivalent spherical diameter from 1 to 1000 µm (Table 3-4).

The measurements were conducted on tracks from the Northern Baltic to the PEX area and back as well as together with the towed CTD ("fish") on the C-line of the Eddy grid.

Table 3-4 Channel settings for the Hiac Model PC 320 particle counter in equivalent spherical diameters

Sensor	Channel	Diameter range (µm)
CMH-60	1	1-2
	2	2-4
	3	4-6
	4	6-10
	5	10-20
	6	20-60
E-1000	7	28-42
	8	42-73
	9	73-105
	10	105-163
	11	163-305
	12	305-1000

3.1.7 Sediment trapping

Vertical fluxes of particulates were measured by means of free drifting sediment traps deployed at 30 and 60m depth respectively between 4 April and 4 May within the PEX window. The "Kiel" sediment trap (see Fig. 3-1) has a funnel-shaped collection jar (surface area 0.42 m^2). *In situ* preservatives were not used during deployment. Table 3-5 summarizes deployment times and Fig. 3-2 shows trajectories of the drifters. Trap samples were analyzed for chlorophyll *a* content and phytoplankton cells were counted under an inverted microscope.

In the vicinity of one drifter array (called main trap in Fig. 3-2) water samples were collected at 10-12 depths every three hours. Chlorophyll *a* content was determined for all samples and cell counts were made for 1-2 stations every day. Of the various phytoplankton species present, the following ones were counted: *Thalassiosira levanderi*, *Chaetoceros spp.* (<10 µm), *Gonyaulax catenata*. In addition the ciliate *Mesodinium rubrum* was counted.

Table 3-5 Deployment of free drifting traps

Drifter and depth of trap	sampling periods and intervals 25 - 29 April	30 April - 4 May
main array, trap at 30m	daily sampling (24h)	no data
main array, traps at 30+60m	no data	daily sampling (24h)
multi trap array, trap at 60m	6 hours sampling interval	6 hours sampling interval

3.2 Data quality and correction factors

3.2.1 Intercalibration

3.2.1.1 CTD and salinity

A field CTD intercalibration was undertaken on 24 April. All the ships came as close to each other as possible and made CTD registrations at 40 m depth in a vertically homogeneous layer. However, the water was horizontally so inhomogeneous that possible instrumental errors were overmasked by natural heterogeneity. Salinity samples, taken from the depth of CTD measurements by different ships were analyzed on one salinometer in order to avoid possible systematic errors. The salinities of the water samples differed more than 0.03. At the same time salinity differences between CTD and salinometer were generally less than 0.01. CTD to salinometer comparison made later yielded the same deviation. Therefore we can conclude that salinity was measured during the PEX with an accuracy of 0.01 or better. For the future it is necessary to work out other ways of field testing of CTD probes.

3.2.1.2 Chemical factors

For the chemical intercalibration during the port call in Karlskrona two different sets of samples were distibuted to the ships laboratories for analysis. One set of subsamples was taken from a large-volume sample previously collected by ARGOS. In addition, a set of standards was distributed.

While the analyses results of the standards were in reasonable agreement (except few outliers which could be identified as instrumental errors and thus be eliminated) the results of the "natural" samples showed considerable deviations. The disagreement of results exceeded the range expected with respect to former intercalibration execises and seemed to be of more or less random nature. Field intercalibration carried out during the experiment showed better - though not quite satisfying - agreement.

The reasons of the disagreement in intercalibration results were discussed but could not be clearly identified. However, it seemed that the intense biological activity (especially in the coastal areas where the Karlskrona samples were taken) caused a considerable inhomogeneity of subsamples to be distributed.

Analysis of the results from the experiment indicated that the actual accuracy of chemical data was much better than suggested by the intercalibrations. Thus correction factors established by statistical procedures (c.f. 3.2.2.2) were used instead of those from the intercalibrations.

3.2.1.3 Biological factors

During the investigation period 3 intercalibration exercises for chlorophyll and primary production, and one for phyto- and zooplankton were carried out. Even though the differences between the ships in the intercalibration samples were statistically signifiant the differences found in nature during the field experiment were clearly higher. The 95% confidence limits for the means of all ships were ca. ±0.5 $mg \cdot m^{-3}$ for chlorophyll. For primary production capacity the corresponding figure was ±3 $mg\ C \cdot m^{-3} \cdot h^{-1}$ during the first intercalibration when the production level was high. In the two other exercises the 95% confidence limits were ±0.5 $mg\ C \cdot m^{-3} \cdot h^{-1}$. On the basis of the intercalibration results and the field observations it was decided to adjust the primary production capacity values of two ships. The diurnal rhythm in the primary production capacity and the possible diurnal migration of phytoplankton can bias the spatial interpretation of patchiness based on the layer 0-10 m. The data from anchor station 2 indicate that there was diurnal rhythm in the production capacity values. This was, however, not recognizable in the grid data.

For all phytoplankton species the counting error was generally higher than 13 % as estimated theoretically by Lund et al. (1958) (c.f. Table 3-6).

Table 3-6: Statistical confidence limits for counts of different species at 95 % level

species	mean	confidence limit
G. catenata	1060	± 227
A. taeniata	631152	± 73997
C. hols. + wigh.	405836	± 73800
S. costatum	49427	± 8367
T. baltica	15600	± 1034
T. levanderii	127342	± 12684

No correction factors were used for any species.

The results of the mesozooplankton intercalibration are shown in Fig. 3-3 and in Table 3-7. Single extremely high and low values are excluded from the calculation for Table 3-7.

The 95% confidence limits reach from 10% to 34% of the mean of all ships. (The extreme value of 73% for Centropages C IV-V stages can be explained by the sparse occurrence of this species and is not included.)

Table 3-7 Mean of all ships and 95% confidence limits (95% CL) for the counted species. (The calculations of the 95% confidence limits are based on the t-values after STUDENT.)

species	mean	95% CL
Acartia spp.		
all stages	10959	±1153
without nauplii	803	± 181
without nauplii+CI/III	214	± 44
Centropages hamatus		
C IV-V	38	± 28
Temora longicornis		
all stages	427	± 140
without nauplii	409	± 119
without nauplii+CI/III	369	± 83
Pseudocalanus minutus		
all stages	6484	± 940
without nauplii	1430	± 253
without nauplii+CI/III	1282	± 132
all nauplii	14761	±1803
all stages CI/III	749	± 117
Fritillaria borealis	1842	± 625
Polychaet larvae	160	± 47
Evadne nordmanni	78	± 19

The coefficients of variation for all mesozooplankton species which are comparable are considerably smaller than those of the intercalibration workshop in Ronne (HELCOM 1983).

As for the phytoplankton, no correction factors were used in analysing the actual PEX mesozooplankton data, because the variations in nature were higher than in the intercalibration.

3.2.2 Data collation

3.2.2.1 Data handling

Since the PEX experiment was a cooperative exercise in the strictest sense, it was recognised at a very early stage of planning that most of the data collected during the field phase would have to be pooled before any analyses of patchiness processes were possible. This task fell to the ICES Secretariat to perform and a data management schema based on well-established international procedures was developed. A detailed description of the ensuing activities is provided in Dooley & Jancke (1987).

In order that data analysis could commence as soon as possible after the start of the experiment a tight timetable for submission of information and data to ICES was agreed. Information concerning the cumulative details of the station and other sampling from each of the ships was submitted using ROSCOP (Reports of Scientific Cruises and Oceanographic Programmes) forms and physical, chemical and biological station data was submitted using a slightly modified ICES/HELCOM format.

ROSCOP forms were submitted within two months of the end of the field phase, and served as a means of tracking data beeing submitted to ICES as well as a source of information to each participant. This information, with supporting retrieval software, was also made available to the participants. Table 3-8 is a summary of the pricipal observations during PEX.

Table 3-8 Statistical summary of principal observations

		Number of ships	Number of stations
HP.	Physical		
H09	Classical stations	5	567
H10	CTD	10	1476
H11	Subsurface measurements underway	1	-
H16	Transparency	7	837
H17	Optics	3	389
HC.	Chemical		
H21	Oxygen	10	1364
H22	Phosphates	11	1251
H23	Total-P	3	211
H24	Nitrates (+nitrites)	10	1108
H25	Nitrites	5	600
H26	Silicates	5	599
H27	Alkalinity	1	131
H28	pH	4	490
D.	Dynamics		
D01	Current meters	5	12
D02	Current meters (average duration of measurement)	3	-
D03	Currents measured from ship drift	1	12
D05	Drifters (number)	2	23

Table 3-8 (cotinued)

C. <u>Biology</u>

B01	Primary productivity	10	750
B02	Phytoplankton pigments	9	1170
B03	Seston	1	36
B04	Particulate org C	1	36
B05	Particulate org N	1	36
B07	Bacterial and pelagic micro-organisms	2	287
B08	Phytoplankon	10	1273
B09	Zooplankton	10	1091

Most participants submitted station data in the agreed ICES/HELCOM formats but with slight variations with regard to detail and medium. Data was submitted on 1/2" magnetic tape (1600 and 800 bpi), 5 1/4" and 8" floppy diskettes and in manuscript form. Given that most of these data had to be submitted more than once because of errors meant that the timetable for submission slipped significantly with a resulting delay in the redistribution of data to participants.

Following the application of a number of correction factors (see next section), all hydro chemistry data was re-distributed to pre-nominated national contacts in August 1987, some 15 months after the completion of the exercise. Each contact received a computer tape containing 17 files, one for each Eddy and Slope grid, anchor station, long sections to and from the PEX area and also the full data set from the participating ship. The last file was included in order to ensure that the corrected version of the data was available in each country for transmission through the normal channels to the International data exchange network. Data was in the PEX modified ICES format. In addition, several participants who had access to MS-DOS™ compatible micro-computers received a reduced data set (chemical records only) on floppy diskettes. These records were written in free format, each value seoarated by a comma to facilitate direct import of the data to spreadsheets and databases.

Zooplankton and phytoplankton data wree handled in a somewhat different way. Allthough it had been agreed to submit species type using the Rubin Code system, few participants followed this advise precisely. However, in consultation with the participating biologists, a set of descriptors was agreed which were edited into the files. These descriptors were not 100% Rubin Codes. Following these adjustments organism densities for each sample were computed for each ship, and the results sorted into files for each grid submitted to ICES. In the case of phytoplankton, since the number of species counted was only 13, each record accommodated all the comma separated values from the same depth at each station. All plankton data was transferred to diskette and distributed to participants in January 1988, just two weeks following the receipt of the last data set.

3.2.2.2 Correction factors

Immediately prior to, and during the exercise, intercalibration exercises were performed on all obligatory parameters. These included salinity, dissolved oxygen, nitrate, phosphate, and chlorophyll a. However, because of the rather different results obtained from each of these exercises correction factors for each of these parameters could not be deduced with confidence. Consequently it was considered inappropriate to try to correct the data on the basis of these resuts and ICES was asked to examine the data sets to establish whether stable factors could be deduced from the field data.

During investigation of this matter it became apparent that data between ships was not comparable, not only because of analytical factors, but also because of the differing sampling techniques between ships. It was in particular possible to identify the physical separation (positive or negative) between rosette sampler and CTD and whether depth was being measured as a pressure or length unit. In the case of two of the ships who had been aware of potential errors arising from this, no physical separation between samplers and CTD was detectable. However, it was not possible to compensate for all of these errors in a quantifiable way and consequently all PEX data below the surface mixed layer (i.e. > 50 dbar) must be treated with some caution, especially when using data collected from more than one ship.

A similar but unrelated problem was also apparent in the ALKOR measurements who used a submersible pump system to draw in samples for nutrient analysis. In this case nutrient samples were actually sampled from a shallower depth than the CTD measurements with which they were associated. This conclusion is supported by an analysis of the BOSEX 77 data reported in Danielsson et. al. (1978) which showed that the nutrient data of the AJU DAG was collected from a depth shallower than thought. The magnitude of the error was quantified by establishing that the time needed to wash out the previous sample from the tubing was 7 minutes instead of the calculated value of 3 minutes. In the case of ALKOR, in the absence of quantifiable information, no attempt could be made to correct its data. This is probably not as serious a problem as it would have been if this ship had been part of the grids.

Because of the above difficulties with regard to sampler depths and mismatches it was concluded that reliable correction factors could only be obtained from above the main pycnocline. As it turned the choice of depth horizon was extremely limited because the upper 40 dbar or so exhibited considerable time variability during the course of the experiment, and below 50 dbar was the pycnocline. Fortunately water masses at the 50 dbar level were sufficiently uniform in both space and time to make it possible to derive sensible statistics from which correction factors could be deduced. These factors are listed in Table 3-9, alongside the factors deduced from the various intercalibration exercises (PEX1, PEX2 etc) and were applied to the data prior to dissemination to the participants. The table also lists corresponding values for the 80 dbar level; the huge difference between these values and those at 50 dbar are due primarily, but not entirely, to the depth and sensor mismatch problem already described. In the case of oxygen there is also an additional error associated with two sets of measurements related to insufficient account being made of sensor lag.

Table 3-9 Intercalibration data (PEX1-4) compared with field data (50 and 80 dbar)

Oxygen % Corrections

	PEX3	PEX4	50 dbar	80 dbar
Mean	10.18	9.26	9.00	3.45
A	-1.96	3.11	4.52	18.56
B	2.11	3.69	0.91	8.55
C	2.11	-3.23	-1.44	4.32
D	-4.89	-2.01	2.68	-32.35
E	1.80	0.43	-1.66	32.74
F	-3.04	-2.21	-2.06	-
G	-1.36	0.00	-7.02	-17.70
H	-1.45	-2.11	-4.93	5.40
I	-4.50	5.43	-1.53	31.23
J	0.00	-4.30	-	-

Phosphate % Corrections

	PEX1	PEX1	PEX2	PEX2	PEX4	50 dbar	80 dbar
Mean	0.38	1.47	0.36	1.95	0.59	0.58	1.97
A	13.63	-6.37	2.86	-1.01	-13.24	-15.35	2.15
B	17.19	-5.16	-2.70	-8.01	-3.28	3.60	-9.04
C	-8.54	-8.12	-12.19	-8.01	-4.84	-2.36	4.39
D	-6.25	-0.68	9.10	2.63	7.27	4.70	6.71
E	-8.54	-3.29	-10.00	-2.01	1.72	0.00	-3.99
F	-1.32	0.00	28.57	8.94	-7.81	-6.31	-
H	1.35	-3.92	2.86	-1.01	1.72	1.76	-2.04
I	-6.25	32.43	-	-	18.00	8.22	4.95
J	-3.84	-1.34	-14.29	-1.01	7.27	0.70	-3.33
K	7.14	-0.68	-5.26	1.56	-6.35	-	-

Table 3-9 (continued)

Nitrate (+nitrite) % Corrections

	PEX1	PEX1	PEX2	PEX2	PEX4	50 dbar	80 dbar
Mean	0.40	6.23	0.10	7.62	4.19	4.10	8.25
A	0.00	8.10	6.67	-5.34	-15.01	-3.32	-1.40
B	0.00	4.18	100.00	2.69	-2.56	-3.54	-2.14
C	-20.00	9.30	-11.11	15.45	26.97	19.31	20.93
D	-20.00	-1.73	-20.00	2.63	3.71	-0.46	-7.38
E	0.00	1.96	-5.88	-7.81	-7.10	-8.51	-20.49
F	33.33	-9.44	-	-9.29	-3.68	-2.13	-
H	0.00	-9.53	60.00	-7.81	-3.23	-4.75	2.79
I	0.00	-	-	-	47.01	34.72	18.79
J	0.00	8.73	-	6.27	5.01	-4.72	2.36
K	0.00	45.56	-70.90	117.70	52.91	-	-

Silicate % Corrections

	PEX1	PEX1	PEX2	PEX4	50 dbar	80 dbar
Mean	12.60	25.60	11.02	14.51	13.65	37.60
A	-14.22	-6.12	1.10	14.94	-3.40	11.83
C	-9.43	-4.83	-7.39	15.20	-4.34	-7.93
D	9.56	4.87	4.95	12.95	20.58	3.58
F	20.34	9.40	15.63	12.60	-3.23	-
K	-16.00	-9.86	-10.41	16.88	-	-

The reader is referred to Dooley and Jancke (1987) for a detailed discussion of the deduced correction factors.

3.3 Aliasing

An example of the on-track data (with spatial resolution of ca. 200 m) from the Eddy grid C transect is shown in Fig. 3-4. It is evident that due to the inherent plankton variability on scales below the 4-mile and 2-mile resolution of the Eddy and Slope grids, respectively, the distribution patterns as revealed by these surveys may be significantly aliased. The general impression is that the patchiness structure of phytoplankton during PEX was such that the patterns revealed by the 2-mile grid were quite similar to the full-resolution patterns whereas the patterns from the 4-mile surveys gave in some cases biased picture.

During PEX the temporal variability of the standard parameters was measured in the center of the Slope-grid on the anchor stations. An example of the temporal variability of different parameters during the performance of the PEX-sections at a depth of 10 m on 28 April is given in Fig. 3-9.

In order to estimate the amount of temporal variability during the PEX-sections the standard deviations of the obligatory parameters within the time interval between 0300 and 1800 GMT of every day have been estimated at several depth levels. The mean values of these standard deviations, taken over the whole experiment, reveal that the amount of temporal variability is largest in the surface layer, has a minimum near 40 to 50 m depth, and increases again in the halocline at 60 - 70 m (see Fig. 3-9).

From Table 3-10 we may conclude that there are significant differences in the standard deviations of the parameters between both periods of PEX. Although the amount of temporal variability during the performance of the PEX-sections varies in time and space, the figures given in Table 3-10 give us a rough estimate of the treshold above which the variability in the PEX-grid can be identified as spatial. Contour intervals in sections and in horizontal distributions of a given parameter should not be smaller than the figures given in Table 3-10.

Table 3-10 Mean values of standard deviations between 0300 and 1800 GMT on the anchor station at a depth of 10 m.

param	T	S	O2	Phos.	Nitr.	Chloro.
unit	K		$cm^3 \cdot dm^{-3}$	$\mu mol \cdot dm^{-3}$		$\mu g \cdot dm^{-3}$
April	0.16	0.01	0.19	0.11	0.67	0.17
May	0.27	0.01	0.30	0.06	0.11	0.08

4 Measurement results

4.1 Background conditions

4.1.1 Meteorological conditions

There were two main stages in the atmospheric circulation during the experiment. Typical weather patterns are presented in Fig. 4-1. In the first stage the weather was determined by a stationary high situated over Finland and the north-west Russia. From 26 April the Baltic Sea was mainly covered by cyclonic circulation with the air coming from the east. Later, from 28 April, weather conditions were influeced by an atmospheric front over the Southern Baltic (see Fig. 4-1 c) which was oscillating between the Swedish and the Estonian coast.

A "battle-field" between warm continental air from the east and cooler maritime air from the west went caused frequent changes in wind velocity, air temperature and water vapour pressure (see Fig. 4-2).

The second stage in weather conditions started at the end of April when an extending high was moving eastwards from West Europe (Fig. 4-1 d). Cool in the beginning it became gradually warmer when the center of the high moved to the east of the PEX area after 2 May (see Fig. 4-1 e). Wind directions were rather constant (east to south-east) and wind speed was slowly increasing from light to moderate (Fig. 4-3).

The stable thermal stratification of the lower layer of the atmosphere was caused by the character of the prevailing atmospheric circulation (difference between air and sea surface temperature was positive almost all the time), air humidity was high (over 80%; see Figs. 4-2 and 4-3) and fog was frequent. Sea surface temperature was rather low and almost constant until the end of April. From the beginning of May it was 1.5 °C higher with distinct diurnal variations apparently due to solar radiation.

The first stage of the experiment was mostly cloudy and it caused low quantities of incomimg solar radiation and heat flux through the sea surface (Tables A-2 to A-5 and 5-1). In the second stage both parameters had significantly higher values.

4.1.2 General conditions of the Central Baltic Sea

The Baltic Sea is a semi-enclosed sea area in the northern latitudes with narrow and shallow sections connecting it to the open ocean. Such enclosed seas have a considerable fresh water surplus due to river run-off and, as a result, have a positive water balance relative to the adjacent seas. The narrow channels and shallow sills restrict the water exchange, and make the Baltic Sea the largest real brackish water body in the world.

The outflow of low saline surface water and irregular penetrations of water with higher salinity into the deeper layers of the Central Baltic lead to a pronounced halocline between 60 and 80 m that splits the water body into surface (salinity 6 - 10) and deep waters (salinity 8 - 16). During the summer a strong thermocline is formed at a depth of 10 - 30 m in the surface water, separating the cold intermediate water (0.5 - 3 °C) between summer thermocline and halocline from the warm upper layer (15 - 20 °C). A permanent but weak cyclonic circulation in the Baltic is associated with weak horizontal salinity gradients in the surface waters.

The water below the well mixed surface layer down to the permanent halocline is mixed by thermohaline convection during fall to early spring. In the winter the interaction between atmosphere and sea may be temporarily restricted by an ice cover especially in the coastal areas. The thermo- and haloclines greatly restrict vertical exchange between surface and deep waters and lead to high nutrient concentrations and a more or less permanent dissolved oxygen deficit in the deep water, sometimes followed by the occurrence of hydrogen sulphide. Anoxic transition causes the liberation of large amounts of phosphate and ammonia from the sediments, whereas nitrate concentrations decrease to zero by denitrification.

An effective renewal of the deep water takes place only during sporadic major inflows, which transport substantial amounts of saline and oxygenated water across the sills into the Baltic deep basins.

Long-term trends show - particularly in the deep water - a mean increase in temperature (1 - 1.5 °C), salinity (0.5 - 1) and density (0.5 - 1 σ_t-units) and a decrease in oxygen concentrations (2 - 3 $cm^3 \cdot dm^{-3}$) during the present century.

Seasonal variations of nutrients caused by biological activities and vertical mixing are observed in the surface layers. The concentrations of phosphate and nitrate increase up to 0.6 - 0.7 $\mu mol \cdot dm^{-3}$ and 4 - 5 $\mu mol \cdot dm^{-3}$, respectively, in winter and decrease to the limit of detection in summer. Silicate is no limiting nutrient. The winter concentration of phosphate and nitrate have increased by the factor 2 - 3 in recent decades in the surface layer. A similar increase has been observed in the oxic deep water below the halocline in the Central Baltic.

The Baltic Sea is mainly inhabited by euryhaline marine organisms. The species diversity remains low compared with other marine areas and decreases strongly from the entrance and inwards. The salinity is the main factor determining the distribution of organisms. Because of the permanent physiological stress the productivity exhibits a decline towards the inner parts of the sea, e.g. the primary productivity of the phytoplankton being about 200 g $C \cdot m^{-2} \cdot a^{-1}$

in the Belt Sea decreased to about 150 g $C \cdot m^{-2} \cdot a^{-1}$ in the Baltic Proper and to about 50 g $C \cdot m^{-2} \cdot a^{-1}$ in the Bothnian Bay (Schulz 1985).

As typical for boreal seas the production cycles reflect pronounced seasonal features with low activity in winter and higher activity in the other seasons. Increasing trends in productivity and partly also biomass have been observed for the pelagic system of the Baltic Sea. Signs of eutrophication are also obvious for other biological compartments of the Baltic ecosystem (Schulz, 1985, HELCOM 1987).

For a more detailed description of the Baltic Sea oceanography see e.g. Voipio (1981), Melvasalo et al. (1981) and HELCOM (1987).

4.1.3 Mean hydrographic conditions of the PEX-area

To estimate the general background conditions during the PEX experiment mean vertical profiles of temperature, salinity and oxygen content of the grids were calculated and compared to the long-term trends. In the course of the experiment the thermal stratification of the surface water started (c.f. Fig. 4-5,a). During the April period the maximum density of the surface water (about 2.4 °C at the salinity of 7.6) was attained partly. Therefore the vertical convection was forced initially by the positive heat flux from the atmosphere into the sea. With increasing temperatures the maximum sea water density was exceeded, the thermal stratification started and separated the cold intermediate water layer with minimum temperatures of < 1.3 °C immediately above the halocline (c.f. Fig. 4-4,a).

During the May period the thermal stratification became more pronounced. In the near-surface layer temperatures of more than 6.5 °C were observed (c.f. Figs.4-4,a and 4-5,a).

Compared to the mean temperature profile at station BY 9, at the PEX area, calculated for the period 1924 - 1973 (Matthäus 1977), the mean temperatures of the upper 100 m were, during PEX-86, about 0.6 - 1.4 °C lower than the long-term mean values (c.f. Fig. 4-6). Only the surface temperatures showed nearly the values of the long-term mean.

The mean salinity profiles (c.f. Figs.4-4,b and 4-5,b) correspond to the long-term mean at station BY 9 (Matthäus 1978 a).

Concerning the mean oxygen conditions in the surface water there is a distinct increase in the oxygen content during the experiment (c.f. Fig. 4-5,c). Compared to the mean long-term oxygen profile at station BY 9 (Matthäus 1978 b) the oxygen content in the upper 20 m exceeds the long-term mean by about 0.2 - 0.7 $cm^3 \cdot dm^{-3}$ (c.f. Fig. 4-7). The conditions in the intermediate water layer show only small deviations from the long-term mean.

4.1.4 Annual variability of spring blooms

For the estimation of the temporal variability during PEX long-term series data from the Gotland Sea obtained during seasonal cruises of the Institute of Marine Research of the GDR for the period 1969-1987 have been used (Table 4-1).

Table 4-1: Chlorophyll a in the 0-30 m water layer ($mg \cdot m^{-2}$).

		n	x	s	cv	max	min
April	1969-87	31	18.9	12.2	64.5	76.1	7.7
May	1969-87	109	65.0	39.1	60.1	272.6	22.0
PEX		132	115.9	63.6	54.9	377.5	15.4

The April data stem mostly from the first April decade, whereas the May data were from the second May decade. As expected the April data show winter conditions. In May the mean value is much higher and the range of the data much wider, indicating spring bloom conditions. The average of the section investigated by PROFESSOR ALBRECHT PENCK during PEX fits well into the range of the long-term May data. The mean is clearly higher than the long-term average. This can be explained by the fact that there is a high interannual variability of the time of the bloom onset. An example how the start of the bloom might vary from year to year is shown for the international station BY 9A for the years 1982-87 (Table 4-2).

Table 4-2: Start of phytoplankton bloom from 1982 to 1987

time of observation	status of bloom	prod.level
18 May 1982	postbloom	medium
21 May 1983	postbloom	low
11 May 1984	starting	high
4 May 1985	prebloom	low
PEX	bloom -> postbloom	high
15 May 1986	postbloom	medium
19 May 1987	ending	high

Table 4-2 shows that in 1986 the bloom started exceptionally early in this area.

4.1.5 Investigations outside the PEX area

Most ships made investigations on their way to and from the PEX area. The under-way transects of RV ARNOLD VEIMER (Northern Baltic) are shown on Fig. 4-8. Fig. 4-9 shows that on 18-19 April, the spring diatom bloom was around its peak near the entrance to the Gulf of Finland with high chlorophyll a concentration (> 10 $mg \cdot m^{-3}$) and high potential photosynthetic activity. Most of the open Northern Gotland basin was still in the "pre-bloom" condition with the typical "winter" water of very low phytoplankton concentration. Dramatic patches (4-5 n.m. in diameter) were observed west of Gotland and probably represented filaments of slightly warmer water originating from the coastal area. Another explanation might be that the patches were formed in the open sea in waters of different salinities.

In part of the PEX area there was already a vernal phytoplankton bloom before the experiment with chlorophyll a levels up to 5-6 $\mu g \cdot dm^{-3}$. This can be seen as the left-most maxima on Fig. 4-9.

The positive coherence between the temperature and phytoplankton concentration before and during most of the PEX period had become negative by 21 May (see the right-most particle maximum corresponding to the temperature minimum in Fig. 4-10).

In the Bornholm Sea the spring bloom was underway during the last 10 days of April (as observed by PROFESSOR ALBRECHT PENCK). Because of the unfavourable weather conditions during the time before (strong westerly winds, low irradiation, cooling of the surface water during the first half of April) the bloom was not very pronounced. In the Arkona and Belt Seas the bloom had terminated.

A set of data (Figs. 4-11 a-h), collected by the Klaipeda Hydrographic Division during the PEX period coarsely illustrates the general condition of the Baltic with respect to some hydro-chemical parameters and chlorophyll a (data exist outside the map shown).

4.2 GRID STATIONS

4.2.1 Physical measurement results

At the Eddy and Slope grid stations, profiles of temperature and salinity were measured. Investigation of sampling errors (c.f. section 3.2) showed that while the salinity field was properly resolved on the grids temperature was in general very noisy and the temperature maps and sections produced on the basis of grid data may partly contain artificial patterns. Therefore the features of the observed salinity field are presented (section 4.2.1.1) and thereafter the less reliable temperature patterns (section 4.2.1.2). Then some results of high-resolution salinity and temperature measurements by means of undulating towed CTD are given (section 4.2.1.3). Lastly the day-to-day variability of temperature and salinity is shown (section 4.2.1.4).

4.2.1.1 Salinity

Within this study we were particularly interested in the structure of and the processes in the upper euphotic layer. The salinity was, in the upper layer, nearly constant from the surface down to at least 20 dbar but it varied from station to station.

In the observed salinity field the main feature was a front persistent near the western slope of the PEX area during the whole period of the experiment. This can be seen both in the salinity maps at the 10 dbar level contoured for the four Eddy grids (Fig. 4-12) and the first three Slope grids (Fig. 4-13). The front extended from Eddy grid stations AR, AS to FP, FQ (c.f. Fig. 2-2).

On the SE side of the front the salinity amounted to 7.55 while on the NW low-salinity side of the front at stations AP and APS it dropped to 7.35. The maximal horizontal gradient of the salinity in the front amounted to 0.1 per 2 miles. The subsequent salinity maps in Figs. 4-12 and 4-13 show how waters of low salinity on the western side of the front had penetrated further into the PEX polygon from the north near the western slope of the deep channel causing a spreading of the low-salinity water.

To the east of the front a relatively homogeneous water of intermediate salinity in the range of 7.55-7.60 was observed. The medium-salinity, water had a smaller scale patchy structure, evident from both the Eddy and Slope grid data but also from CTD-data with a high horizontal resolution (see Fig. 4-14).

In the SE corner of the Eddy grid the penetration of waters with salinities higher than 7.60 to the polygon area could be followed. On the 25 April (Eddy grid I) the salt water tongue occupied the stations from CX, CY to FX, FY, FZ (c.f. Fig. 4-12). The largest salinity gradients in the front between the high and medium- saline waters were observed between CX, DX and CW, DW comprising 0.08 per 4 miles. On the 29 April (Eddy grid II) an area with salinities higher than 7.64 had grown. On the 3 May (Eddy grid III) the isohaline patterns of the front remained nearly the same but the salinity gradients between the isohalines 7.58 and 7.64 increased. On the 7 May (Eddy grid IV) a salty patch of high salinity water had become detached and penetrated the medium-salinity water at stations DU, EU, CV, CW.

The vertical structure of the water masses and fronts can be seen in Fig. 4-14 where the salinity sections of the upper 50- dbar layer along the Eddy grid station lines C and D are presented for the 25 April Eddy and 26 Aril Slope grid. These sections crossed the three chemical/biological patches which will be described in sections 4.2.2 and 4.2.3. On line C (B for the Slope grid) the fronts between the low- and medium-saline waters (stations CP to CQ) and around the salty waters (stations CW to CX) could be followed. On line D the same fronts were between the stations DP to DQ and DW to DX, respectively. The latter front extended vertically down to 40-50 dbar and was limited by the halocline while the salinity front was limited by the shallow sloping bottom. Within the medium-saline water two patches of slightly lower salinity could be observed - at stations CR, DR, DS for the "western" patch and CV, CW, DU, DV, DW for the "central" patch on the 25 April Eddy grid. On the 26 April Slope grid sections the same patches could be detected in slightly changed positions (stations BUS,BVS,BWS,DTS,DUS and DWS, DXS, DYS, respectively).

Thus, we could distinguish three types of waters in the PEX polygon - low-salinity waters in the west, higher salinity waters in the east and waters of intermediate salinity between them. The low- and medium-salinity waters were separated by the strong quasi- permanent front with a salinity decrease of 0.2 while the high-salinity and medium-salinity waters were separated by the less intensive and less stable front with a salinity decrease less than 0.1 across.

4.2.1.2 Temperature

The temperature profiles were more irregular than the profiles of salinity, especially for the second half of the experiment when the thermal stratification started to develop. Therefore we restrict ourselves here to considering the beginning of the experiment only, when the temperature distribution was less noisy.

On the Fig.4-15a the temperature distribution of the 25 April (Eddy grid I) exhibits some interesting features. On the salty side of the quasi-permanent front a tounge of colder water was observed from AR to FQ, giving evidence of frontal upwelling. On the background of a general temperature increase from P to Z (due to daily heating or advection by general circulation) distinctive local maxima of temperature were observed on transects C-E at three places - on station lines P-R, V-W and Z. These local temperature maxima coincided fairly well with low nutrient/high chlorophyll a patches (cf sections 4.2.2 and 4.2.3). A few days later the temperature distribution became more irregular.

On the 25 April (Eddy grid I) temperature section along line C (Fig. 4-15b) there is a cold tounge at CQ and the three patches of warmer water at stations CR,CS for the western, CV,CW for the central and CZ for the eastern patch. In the western and central patches the warmer waters extended from the surface down to 40 dbar.

The three water masses, distinguished by their salinities (see 4.2.1.1), had no remarkable contrasts in temperature.

4.2.1.3 Salinity and temperature measurements with undulating towed CTD

Every night ARNOLD VEIMER worked towed CTD-transects along section C from halfway between stations CY and CZ to CR covering the upper 80-m layer with horizontal resolution (distance between successive ascents or descents of the towed body) of about 0.77 n.m.

Considering the salinity distribution on the basis of the two transects closest in time to the 25 and 29 April Eddy grids we can conclude the relatively smooth character of changes in salinity (Fig. 4-16). The dominating variations of the isohaline depths had horizontal dimensions of 2-4 n.m. and more, being also properly resolved on obligatory grids. During the first part of PEX a front with the increase of salinity by 0.1 per 3 n.m. between the waters of intermediate salinity and the south-east salty tongue could be followed near CX (Fig. 4-16) as for the grid data (see 4.2.1.1). Patches with salinity differencies of 0.03-0.05 and horizontal scales of 4-10 n.m. were distinguished to the west from the front in the waters of intermediate salinity. The strong salinity front on the western slope was outside of the measurement area with the towed CTD due to too small bottom depths for the operation of this instrument.

A dome-like elevation of isotherms, isohalines and isopycnals could be clearly observed within the halocline. On the 29/30 April transect the of center the elevation was detected between stations CV and CW (Fig. 4-16). Some days later the dome center slowly moved to the west and after 3 May disappeared from transect C.

While the salinity varied smoothly in space within the whole period of PEX the character of temperature variability changed during the experiment. During the first days of PEX, when the water temperature was below or near the temperature of maximum density (2.4 ^{o}C at salinity 7.6), the temperature distribution patterns were rather similar to the salinity patterns (Fig. 4-17), except for the salinity front. But, with the heating of the surface layer and developing of the upper thermocline with corresponding density stratification, the characteristic scales of temperature variations became smaller and smaller (Figs. 4-17, 4-18). In May the dominating small-scale temperature structures could not be resolved on the grids.

Fig. 4-18 (vertical distribution of temperature after the 5 May Slope grid survey and after the 7 May Eddy Grid survey) shows that also the horizontal resolution obtained by the towed CTD seems to be insufficient for resolving the irregular vertical deviations of the upper thermocline. It should be noted that the deviations in the thermocline depth e.q. the deepening to the 30-dbar level 0.6 n.m. to the east of CV on 7 May were not caused by instrumental errors. This was confirmed by repeated successive measurements on the same transect.

For comparison Figs. 4-19a-c show a transect carried out by GAUSS through the PEX box from grid points FZ to AP on 29 and 30 April. This section meets the ARNOLD VEIMER profile from the same day at grid point CT. The temperature pattern already exhibited a high variability in the upper 60 m layer. Typical length scales were in the order of 3 to 15 km, and the vertical scale was of the order of 3-25 m; however, smaller scale disturbances are hardly resolved by these towed CTDs. As in the ARNOLD VEIMER section the salinity varied with small horizontal gradients only. On the other hand the density pattern is governed by the salinity. The stratification was stable throughout the water column with weaker stratification in the upper 60 m and a strong pycnocline below, sloping from FZ to about BR.

4.2.1.4 Spatial patterns of interdiurnal variations of temperature and salinity

The interdiurnal variability reflects the response of the water body to different physical processes superimposed on each other. For example, the mean heating influences the interdiurnal variability. The diurnal cycle of temperature in the data is completely eliminated in this calculation procedure. The interdiurnal variability at the 10 dbar level has been selected as an example because this level is of particular interest from the point of view of biological processes.

During PEX the mean temperature of the upper layer increased due to the positive heat flux. This effect, however, is largely covered by other processes causing considerable day-to-day variability. Concerning the amount of the variability of temperature the above-mentioned two periods are clearly recognizable. In the slope grids 26 - 28 April the day-to-day variations range between -0.2 and +0.5^0 C (Fig. 4-20a), whereas the values during Slope grids 4 - 6 May (Fig. 4-21) range between -1.5 and +2.4 °C. There were no substantial differences between the patterns in the shallow and deep regions of the Slope grid area. During the May period the consecutive change in the tendency of temperature, however, was more frequent and included generally greater variations (e.g. FWS, CXS, CSS, CQS in Fig. 4-21). Positions of the same tendency in the consecutive day-to-day variability occured more frequently in the first Slope grids than in the May period.

The interdiurnal variability of salinity showed a clear distinction between the shallower and the deeper areas of the Slope grid running from AUS to FRS (Figs. 4-20b and 4-22). In the shallower part of the PEX area a strong quasi-permanent salinity front separated lower salinity waters in the west from more saline waters in the east with maximum horizontal gradients of 0.1 per 2 nautical miles (c.f. section 4.2.1.1). During the May period the day-to-day variations ranged between -0.12 and +0.12 in the shallow region and between -0.06 and +0.07 in the deep area. In the front marked patterns of the consecutive interdiurnal variability occured showing the change in tendency, e.g. BSS, DRS, CPS, ARS (Fig. 4-22). This can possibly be regarded as an indication of considerable vertical (e.g. inertial waves), or/and horizontal (e.g. meandering of the haline front) displacements in the front zone. Features of the same tendency in consecutive day-to-day variations can more frequently be observed in the April period. During the May period this phenomenon hardly plays any role (cf. Fig. 4-22).

4.2.2 Chemical measurement results

4.2.2.1 General observations

The winter concentrations of nutrients have on the average been increasing during recent decades in the surface layer of the Baltic Sea (c.f. 4.1.2). In the south-eastern Gotland Sea, the mean winter concentrations ranged from 0.58 to 0.67 $\mu mol*dm^{-3}$ for phosphate, and from 4.3 to 4.7 µmol/l for nitrate in the period 1983-87 (Nehring and Francke, 1988), indicating no strong interannual variations and no significant trends. Measurements carried out in the PEX area on April 19-20 show phosphate and nitrate levels close to those above. However, decreased nutrient values at some stations, together with increased chlorophyll concentrations indicate that the bloom period was just beginning.

The general changes in the nutrient conditions are illustrated in Fig.4-23. The large variability (0.11-0.83 $\mu mol \cdot dm^{-3}$ for phosphate and 0.9-4.8 $\mu mol \cdot dm^{-3}$ for nitrate+nitrite) and the distortion of the distribution pattern from the normal distribution especially towards low values already at the first Eddy grid (25 April), show that the bloom was already underway at the beginning of the measurements in the PEX grids. This conclusion is also supported by the results on the chlorophyll<u>a</u> dynamics (c.f. section 4.2.3). Considering the developement of the distribution of nutrients during PEX one can see that the maximum nutrient concentration variability, and consequently the highest possibility for biologically induced patchiness, occurred between April 25 and 28 to 29. During the following days both the nutrient pool and the concentration range gradually decreased. The Eddy grid IV, with low and uniform nitrate+nitrite concentration, indicates the postbloom period. The average oxygen conditions during the experiment were characterized by positive deviations in the upper layer, and by small negative deviations in the intermediate layer, as compared to the long-term averages.

In the first Eddy grid (April 25), the close correlation of nitrate+nitrite and phosphate at the 10 db level is illustrated in Fig. 4-24. The regression line goes close to origo, thus giving no indication of the limiting nutrient. The regression slope is only 7.0. The nutrients consumed by the phytoplankton were calculated as differences from the mean nitrate+nitrite and phosphate concentrations of the Eddy grids I and II. The resulting differences are roughly 1.6 $\mu mol \cdot dm^{-3}$ for nitrate+nitrite and 0.1 $\mu mol \cdot dm^{-3}$ for phosphate, producing a ratio of 16, the Redfield ratio. This indicates that the phosphate surplus in the Baltic Proper has no significant influence on the nutrient uptake by phytoplankton. The ratio decreases during the study period, because the nitrate pool is consumed earlier than the phosphate pool as shown in Fig. 4-23.

4.2.2.2 Horizontal distribution

Fig. 4-25a (Eddy grid I, 25 April), shows two large minima (patches) for phosphate at the 10 dbar level, the first with its center at the S stations, and the second between the V and W stations. Both patches are quite centrally located (B, C, D and E). A third large patch is located at the right edge of the grid (Y and Z stations). Four days later the grid was run again (Eddy grid II, 29 April, Fig. 4-25b). The patches had now increased in size and had also moved somewhat to the west. The average phosphate concentrations in the patches had also decreased. Five days later (Eddy grid III, 3 May, Fig. 4-25c), the patches had still increased, and merged together. Eddy grid IV (7 May, Fig. 4-25d) was run four days later. The phosphate distribution was now very even, with mostly low values at around 0.1 $\mu mol \cdot dm^{-3}$. At these low concentration levels the differences may be of analytical origin.

The same patches with nutrient minima can also be found in the nitrate+nitrite map for the Eddy grid I, 25 April (Fig. 4-26a). The nitrate, however, disappears faster than the phosphate from the surface layer, and at the end of PEX, almost no nitrate remains in the surface layer. Eddy grid II,29 April (Fig. 4-26b) still shows some similarities with the corresponding phosphate map (Fig. 4-25b), but in Eddy grid IV,7 May (Fig. 4-26d), only traces of nitrate exist.

In order to study closer the development of the patches, maps at 10 dbar for phosphate and nitrate+ nitrite were prepared for the Slope grids. From the Eddy grids, the central areas covering the Slope grid area, were redrawn and added in chronological order, to obtain a more complete conception of the changes in this area (Figs. 4-27a-l and 4-28a-l). The maps of the Slope grid cover the site of the first large patch in Fig. 4-25a. Unfortunately the patch extends outside the area of the Slope grids. Therefore it is difficult to see the further development of the patch.

It seems that the forms of the patches are very complicated and that they change quite fast. It is, however, possible to distinguish a minimum with low phosphate concentrations in the middle of the Slope grid. From Slope grid 1, 26 April (Fig. 4-27b) to Slope grid 3, 28 April (Fig. 4-27d) it moves a little to the left. The minimum is still found in Eddy grid II, 29 April (Fig. 4-27e). The phosphate maximum in the middle of the Eddy grid I, 25 April slowly moves to the right. In Slope grid 3, 28 April (Fig. 4-27d) it is found in the lower edge of the map. In the Eddy grid II, 29 April (Fig. 4-26e), it is difficult to find this maximum because the map does not cgive enough details, but in the Slope grid 4, 30 April (Fig. 4-27f) it is again found in the lower edge of the grid. It also appears in Eddy grid IV, 7 May (Fig. 4-27l). The maximum on the first part of track D in Fig. 4-25a can also be traced in the same manner. In Slope grid 4, 30 April (Fig. 4-27f) the minimum zone seen in Fig.4-27b has moved to the upper left corner. The minimum in the upper right corner of the Slope grid 3 has now grown and extends to station US of section B, and down to section E at station ZS.

Figs. 4-28a-l show the nitrate+nitrite concentrations at the 10 dbar level for the Slope grids. In the figures it is difficult to find similarities, but the large minimum patch in the middle of the Slope grids corresponds to the similar patches in the phosphate figures 4-27a-l. Generally, the concentrations decrease from figure to figure, as in the case of phosphate (see also Fig. 4-23).

Fig. 4-29 shows the oxygen distribution at the 10 dbar level for Eddy grid I. It can be seen that the oxygen maxima generally appear where nutrient minima are found.

4.2.2.3 Vertical distribution

The first large patch in the Eddy grid I, 25 April is also covered by the Slope grids and therefore we have chosen this patch for a study of a vertical cross section along the S stations from F to A (Figs. 4-30a-d and 4-31a-d). The cross section isopleths include data from all the ships. Fig. 4-30a shows the phosphate distribution down to 80 m for the cross section of Eddy grid I. The patch extends to 50 m, and the minimum concentration is found at the station E. The stations F and A are located outside the patch. In the grid IV, 7 May (Fig. 4-29d), we can see that the patch has disappeared, and that the phosphate concentration in the surface water has decreased. In Fig. 4-31d the nitrate has nearly disappeared from the surface layer.

Figs. 4-32 and 4-33 show longitudinal sections along the D-line, that goes centrally through the patches, depicting the concentrations for a number of parameters. Fig. 4-32a shows the oxygen variation along the D section of Eddy grid I. We can see three large oxygen maxima with their centers at DR1, DW1 and DZ1. The isopleths in the longitudinal section of the nutrients and the particle distribution show corresponding patterns (Figs. 4-32b-f). The Figs. 4-33a-f show the same parameters in Eddy grid IV, 7 May. The oxygen values are above 10.0 ml·dm^{-3} all through the section in the surface water, the phosphate has decreased to around 0.2 µmol·dm^{-3} in the morning, at the beginning of the section, and to below 0.1 µmol·dm^{-3} at the stations X, Y and Z in the evening. The nitrate values are close to the detection limit, and also the silicate values are low in the surface water of the whole section. The org-P and the particle content have increased in the whole surface layer.

4.2.2.4 Interdiurnal variations

Some examples of the interdiurnal variability of phosphate are shown in Figs. 4-34a-c. The day-to-day variations range from -0.28 to 0.38 µmol·dm^{-3}. The consecutive change in the tendency of phosphate can be observed both in the April period (eg. BSS, BWS, EQS) and in the May period (eg. CXS, EXS). During the May period the interdiurnal variations ranged from -0.06 to 0.24 µmol·dm^{-3} in the shallow region and from -0.25 to 0.34 µmol·dm^{-3} in the deeper region. A positive correlation is recognizable between the day-to-day variations of phosphate and salinity in the April period of the programme. Results of a single grid, however, do not indicate such a correlation at the 10 dbar level. During the May period of PEX, a positive correlation seems to exist between the interdiurnal variations of temperature and phosphate.

4.2.2.5 Conclusive remarks

It is obvious that the observed patchiness was caused mainly by the phytoplankton vernal bloom. Phytoplankton had at the end of the study period almost totally consumed the available nitrate and most of the phosphate and silicate and bound them to organic material. Vigorous phytoplankton production in combination with reduced gas exchange at the sea surface due to very low winds and surface motion also caused the increase in dissolved oxygen in the surface water (permanent oversaturation). There is a very close inverse relationship between the nutrient and chlorophyll _a_ concentrations (c.f. 4.2.3.1).

4.2.3 Biological measurements results

4.2.3.1 Chlorophyll a

The study period covered the end of the increasing phase, the peak, and the declining phase of the phytoplankton spring bloom. Fig. 4-35 shows the general development and variability in phytoplankton biomass during the experiment, expressed as chlorophyll a concentrations.

The development in the vertical distribution of chlorophyll a can be seen in Fig. 4-36. In the beginning high values were confined in the uppermost 20 m causing high vertical variability. The vertical variability decreased toward the end of the study period.

For the description of the horizontal patchiness the 0-10 m layer was selected to represent the euphotic layer, where the signal was strongest. The vertical variation in the chlorophyll a concentrations was small in this layer, thus the mean values give about the same pattern as using single layers. However, this averaging procedure increases the reliability of the contour maps by reducing the effect of methodological background noise.

Three patches with high chlorophyll concentrations (>10 $mg \cdot m^{-3}$) were observed in the Eddy grid window in April 25 (Fig. 4-37). Eddy grid II on 29 April unveils a clearly changed picture: low values in the western side have increased. The distinct positive patch in the western half of the grid had disappeared. The eastern patch was more persistent but the maximum chlorophyll a concentrations had decreased too.

In Eddy grid III, 3 May, the overall heterogeneity was low in the western section (Fig. 4-37) and no high chlorophyll values were recorded in that area of the grid. In the eastern section the previously recorded patch was still clearly identified, but reoriented.

In Eddy grid IV, 7 May, the chlorophyll a concentrations in the westen section had decreased down to the values <3-4 $mg \cdot m^{-3}$. In the eastern side still some relicts of the earlier patch were seen.

The development in the western section of the Eddy grid window can be followed with a better horizontal resolution (2 n.m. between the stations) in the Slope grid window (Figs. 4-38 and 4-39). The western positive patch was clearly seen during the Slope grid 1, 26 April, but disappeared rapidly during the following days. No distinct phytoplankton bloom developed in the shallow western periphery of the window.

4.2.3.2 Primary production capacity

The primary production capacity values revealed the same pattern of spatial and temporal variability as chlorophyll a. The contour maps from the Eddy grids are presented as an example (Fig. 4-40).

4.2.3.3 Phytoplankton

The most abundant phytoplankton species in the PEX area were Chaetoceros spp., Thalassiosira levanderi, Achnanthes taeniata and Skeletonema costatum. Chaetoceros spp. were identified as C. holsaticus and C. wighamii although evidently more Chaetoceros-species were present in the samples but counted as C. holsaticus and C. wighamii (Jan E. Rines, pers.comm.). The cell concentrations of Thalassiosira baltica and Gonyaulax catenata were low and usually less than 200 cells were counted. Therefore the results of these two species are not incuded here. In addition to the selected species other species with varying, sometimes high abundances were found (e.g. an unarmored, unidentified dinoflaggelate, nannoflaggelates and an atotrophic ciliate, Mesodinium rubrum).

During the PEX-period some changes in species composition indicating succession could be detected. There was a clear decrease in the abundance of T. levanderi whereas A. taeniata and S. costatum seemed to increase on the average in the grids (Fig. 4-41). The increase in the abundance of a species was connected with an increase in spatial variation and vice versa. It was noticed that the cells of Chaetoceros spp. were in poor condition in the April grids but during the May grids the cells were healthy and actively growing and a lot of sporulated cells were also present.

Eddy grid I, 25 April, showed distributional patterns that were quite different for different phytoplankton species (Fig. 4-42). Skeletonema costatum was not found in high abundances in any other area except the south-eastern corner (YZ-EF-transects). Also Achnanthes taeniata was abundant in this corner but had an other maximum within the RS-transects of the Eddy grid. Chaetoceros spp. and Thalassiosira levanderi had similar distribution patterns with two maxima within the W and S-transects but were less abundant in the south-eastern corner. When compared to the complete grid data of chlorophyll aand primary production it is probable that the actual maxima were more towards the north.

Before 7 May the cell number of S.costatum at 0 m had increased by an order of magnitude in the eastern part of the Eddy grid area and the patch had penetrated the inner part of the Eddy grid area (Fig. 4-43). On the contrary the maximum of A.taeniata in the south-eastern corner had disappeared and the pronounced four patches of Thalassiosira levanderi declined. The Chaetoceros spp, however, did not show considerable changes in abundance and distribution patterns.

The same patchy distribution as found for chlorophyll a values in the Slope grid area during 26 to 28 April was seen in the cell concentrations of T. levanderi, Chaetoceros spp., A. taeniata and, due to the lower cell concentration, less clearly in the distribution of S. costatum (Fig. 4-44). On 27 April the western shallow area was characterized by low cell numbers of all species but on 28 April A.taeniata had penetrated into that area, too.

The species distribution in the Slope grid area during 3 to 5 May differed from the April period (Figs. 4-47 to 4-49). A.taeniata was more abundant in the northern part of the area through all transects. T.levanderi, which had sedimented between the April and May period (cf section 4.7) did not show any clear patchy distribution. The cell numbers at 30 m on 3 May were remarkably higher than at 5 m. There were two patches of S.costatum found on 4 May , one within the SP-transect and another in the BZ-corner. Both of these moved southwards and the latter also westwards within three days. On 5 May a patch of Chaetoceros spp. appeared in the SE-corner of the slope grid area. Next day it had disappeared from the 5 m level. Patches were found in deeper layers of thr central and western part of the Slope grid arear.

4.2.3.4 Zooplankton

Horizontal distribution pattern of Pseudocalanus minutus elongatus in the upper layer was characterized by highest abundances in the south-eastern part of the Slope grid area (Fig. 4-50). At the shallower stations, the abundance is generally lower except Slope grid 3 (28 April), where a maximum is situated at the north-westernmost corner of the Slope grid area window.

Fritillaria borealis was present in very low number in the western section of the study area (Fig. 4-51). Starting in the east, the species abundance was increasing from day to day reaching maximal values in May in the whole area.

For Acartia spp., an opposite tendency could be seen: higher abundances in the western part reaching maxima at the NW corner of the investigated area in May (Fig. 4-52).

The distribution pattern of Harmothoe sarsi larvae wasmore even than those described above (Fig.4-53). In April higher numbers were recorded in the west and north with a small zone of lower concentrations in the middle part of the Slope grid section. In May low concentrations were found in the north-western part.

As Temora longicornis and Centropages hamatus occured in very small numbers - except for some sampling stations - there were no significant differences in concentration.

Some distribution patterns were similar for some species and may characterise distinct water masses. One such zooplankton patch of high abundance was situated in the north-western corner of the Slope grid 3, 28 April . Another one was observed at the south-east border of Slope grid 1, 26 April (Fig. 4-50 to 4-53). In Slope grid 8, 6 May , a maximum was located at station BRS except for _F. borealis_ and _P. minutus elongatus_ (Fig.4-50 and 4-51).

The subhalocline layer was in main characterized by low abundances for all species except _P. minutus elongatus_. Some remarkable patterns are, however, clearly visible. All species showed local maxim with very high concentrations as compared with the surroundings at different occasions.

4.2.3.5 Particle measurements

Figures 4-58, a-d show the results of particle counting on board ARGOS (transect D) in the four Eddy grids in time order. The size-range counted (cf. 3.1.2.5) should be sufficient to include all the most common phytoplankton species. Various parts of the zooplankton populations may also be included in the counting results.

Distinct particle maxima were shown in the grids on 25 - 29 April and 3 May, coinciding, as a whole, with oxygen and phytoplankton maxima and nutrient minima.

On 7 May the particle concentration was more evenly distributed, but still high, in accordance with the results of the phytoplankton counts.

Fig.4-59 shows the particle size distribution at 5 m in Eddy grids of 25 April and 3 and 7 May. A certain displacement towards larger particles can be seen, possibly due to a larger percentage of zooplankton.

4.2.4 High-resolution particle measurements

From the quasi-continuous on-track data of particle concentrations, chlorophyll _a in vivo_ fluorescence and temperature collected by ARNOLD VEIMER before, during and after the PEX it is possible to resolve the variability on scales smaller than the synoptic scale of the Eddy and Slope grids. The data set comprises horizontal transects from the northern Baltic to the PEX area and back (c.f. 4.1.5), as well as repeated transects along the Eddy grid C-line of the PEX area.

The overnight transects on the 40-mile Eddy grid C-line were used to construct isoline plots of the temporal evolution of the patchiness structure in the middle of the Eddy grid from 25 April to 8 May 1986. An example of the transects is given in Fig. 4-60 . The distance vs. time plots are given in Fig. 4-61. The isolines have been extrapolated towards both shallow ends where measurements were not made.

The temperature pattern looks quite straightforward: low variability in the beginning (a marginally colder patch in the center), a uniform warming around 1 May by about 1 °C, and increased smaller-scale patchiness afterwards. The both margins of the anticyclonic eddy (seen as the colder patch) were associated with the sharp phytoplankton minima.

While there was a general decrease in the chlorophyll a fluorescence, the patchiness structure did not show dramatic changes during the 13-day period. The smaller particles (1-20 µm) showed a general minimum around 30 April - 1 May and a significant increase in the eastern part around 3 May. The particles in the size range 28-42 and 42-73 µm showed a general decrease along the western side and some evidence of reaching a maximum and then decreasing in the eastern side. It is clear that the strong synoptic scale patchiness may over-shadow the temporal trends.

4.3. Anchor stations

4.3.1 General remarks

Though the two anchor stations were only less than 5 km apart, parameter ranges as well as frequencies and amplitudes of variabilities deviated considerably (see Table 4-3). The vertical oscillation of the halocline at AN1 is clearly expressed by the strong variability of parameters in the deep water samples. General features are a persistent salinity difference between the two anchor stations and more clearly expressed diurnal cycles in most of the parameters at AN1, less influenced by water exchange from the surrounding as compared to AN2.

Table 4-3: Parameter variation ranges

AN1				AN2			
min	mean	max	param.	min	mean	max	im.
			surface:				
7.49	7.61	7.67	salinity	7.45	7.55	7.59	S
1.62	2.68	5.31	temperat.	1.79	2.71	5.20	°C
9.15	9.98	10.80	oxygen	9.47	10.12	10.60	cm^3/dm^3
-	-	-	pH	8.13	8.47	8.68	units
0.10	0.62	4.00	nitrate	0.10	0.58	2.24	$\mu mol/dm^3$
0.12	0.29	0.55	phosphate	0.07	0.25	0.48	-"-
3.40	6.30	9.20	silicate	3.61	5.05	6.40	-"-
	65 - 70 m		bottom:		88 - 93 m		
7.70	7.81	9.20	salinity	9.51	9.62	9.79	
1.74	1.82	2.72	temperat.	3.84	3.93	4.21	
4.23	8.36	9.02	oxygen	1.81	2.01	2.24	
-	-	-	pH	7.16	7.21	7.28	
4.38	4.82	6.47	nitrate	7.38	7.94	9.11	
0.59	0.82	1.21	phosphate	1.92	2.10	2.19	
16.2	22.5	28.8	silicate	38.10	45.60	53.10	

4.3.2 Temperature and salinity measurements results

General information about the temperature and salinity variability, i.e. mean values profiles, minimum value and maximum values profile for each period of measurements separately and for the entire period is presented in Fig. 4-62 and 4-63.

This information is supplemented by histograms shown in Figs. 4-64 and 4-65. They reveal great diversity of temperature in thr upper layer, decreasing with depth. The salinity is nearly uniform down to 65 m. Below this depth distinct differences occured.

The mean halocline surface was found at about 65 m depth on both anchor stations (Figs.4-73,4-82 and 4-83). Following the development of the 7.80 S isoline, the halocline at AN2 rose from 72 m on 25 April to 68 m on 30 April. This continued to a maximum level of 65 m just after the break on 1 May. In the following days of May a lowering of the 7.8 isoline was observed, and 70 m depth was finally reached. The elevation and depression of the halocline were accompanied by changes in the salinity gradients (thickness of halocline). The distance between the 7.8 and 9.4 isolines varied from 11 to 14 m.

AN1-data showed an identical halocline development, with the exception of the first 3 days of investigation (April 25 to 27) when the halocline started above the mean level and had a decreasing tendency (Fig. 4-77a).

A period of mixing (cloudy and windy weather) preceeded the PEX-period which was in turn characterized by modest winds and high solar irradiation (cf 4.1.1). Thus the development of the surface temperatures during PEX showed a constant increase from 1.5 to 5 °C (Fig.4-63a-b, 4-67a and 4-70b). Superimposed a diurnal cycle with amplitudes (difference between temperature maximum at 1500 GMT and minimum at 0200 GMT) varied from max. 0.3 K during the April period to max. 0.9 K during the May period of PEX. The mean increase of temperature was similar for 3 selected levels (1, 5 and 15 m) during 25 to 30 April. From 2 to 7 May the temperature at the 15 m level was nearly constant while the 1 and 5 m levels were heated rapidly. This effect, caused by the formation of the thermocline (Figs. 4-80 and 4-81) was disturbed at AN2 by events of different water masses which are discussed later (c.f. 4.3.4.4).

Table 4-4: Temperature and Salinity correleations AN1/AN2 (K_{TS} - mutual correlation coefficient)

Correlated parameters	Correlation between profiles in period:	Correlation at the depth z[m]	K_{TS} momentary value	K_{TS} mean daily val.
Temperature (T)	25 April - 30 April	5	0.65	0.85
		50	-0.14	-0.45
	2 May - 8 May	5	0.77	0.93
		50	-0.15	-0.18
	25 April - 8 May	5	0.92	0.97
		50	-0.07	-0.08
Salinity (S)	25 April - 30 April	5	0.08	0.33
		50	-0.03	0.45
	2 May - 8 May	5	-0.07	-0.32
		50	-0.16	-0.43
	25 April - 8 May	5	-0.05	-0.24
		50	-0.07	-0.04

Distributions of instantaneous temperatures reveal generally poor stability during the April period; this stability improved distincly during the May period in the upper sea layer, where a seasonal thermocline was formed at the depth of 12-14 m. The vertcal T-profiles at AN1 (Fig. 4-80) reveal a large number of local thermal inversions at both stations during the entire investigated period.

Salinity distributions indicate weak haline stratification down to 65 m during the entire period. The small-scale structure is distincly steplike and shows local inversions in numerous places (Fig. 4-82).

The mean surface salinity at AN1 was 0.05 higher than at AN2 and showed four disturbances by water of lower salinity (nearly 0.1 lower). The main disturbance from 4 - 7 May (Fig. 4-70a) coincided with the occurrence of low saline water (7 May) at AN2 (Fig. 4-66b). These events were not followed by corresponding changes in temperature, oxygen or nutrients (Figs. 4-67 to 4-72).

An advection of higher saline water was observed at AN2 from 26 to 28 April. This event was accompanied by changes of all other parameters including the biological ones.

Examination of instantaneous and daily mean variabilities of temperature and salinity for both anchor stations (Table 4-4) lead to the following conclusions:

- in case of instantaneous values only the temperature variations at 5 m showed an evident correlation,

- in case of daily means, the temperature at 5 m showed a relatively strong correlation, while the salinity correlation was much weaker; at 50 m practically no correlation was found.

4.3.3 Chemical measurement results

Oxygen surface layer concentrations showed increasing trends on both anchor stations from the experiment start to about the 5 May and a slight decrease during the last days of measurements (Figs. 4-72a 4-67b. The results of AN1 showed a weak but significant diurnal cycle with an oxygen maximum occurring 3-4 hrs after the temperature maximum (t_{max}=1500 GMT, O_{max}=1800 GMT , c.f. 6.3). At AN2 this oxygen cycle was concealed by all the variabilities caused by inflows.

Phosphate and nitrate concentrations followed the trend expected at the beginning of a plankton bloom (Figs 4-68 and 4-71). As both parameter concentrations were strongly modified by inflow processes, it is extremely difficult to establish an initial value. Mean values from the first 3 days of PEX (April 25 to 27) suggest 0.35 $\mu mol \cdot dm^{-3}$ for phosphate and 1.2 $\mu mol \cdot dm^{-3}$ for nitrate (sum of NO2+NO3). The nitrate concentration was reduced to almost zero during April, the phosphate concentration stabilized at about 0.15 $\mu mol \cdot dm^{-3}$. The silicate concentration was considerably lower, especially in the upper water layers during the May period (Figs. 4-69b and 4-72b). pH showed a slight increase at AN2 (Fig. 4-69a).

The structure of the mixed layer at both AN1 and AN2 was very complex. Upward turbulent influence of the halocline and downward one of the surface layer resulted in only short periods of relatively homogeneous zones (Figs. 4-73, 4-74 and 4-77). The mixed layer features during PEX require very detailed evaluation

As the patchiness experiment was aimed at interdisciplinary studies of variabilities (physical, chemical and biological) the photic zone - i.e. the top 20 to 30 m - is the most relevant part of the water column. Thus the following interpretations of anchor station data mainly treat the corresponding part of data.

4.3.4 Biological measurement results

4.3.4.1 Chlorophyll a, primary production capacity at anchor stations AN1 and AN2

The results of primary production capacity time series measured at AN1 and AN2 are shown in Fig.4-84 and 4-85. In both cases they agree with the chlorophyll concentration diagrams (ref.to 4.6.1 and Fig. 4-86a), but due to night-time breaks in measuring, short time variation could have ben lost. For example on April 25 at AN1 only an increasing phase of the patch was recorded at 1500 GMT. Similarly a chlorophyll a peak observed at night-time (May 4 to 5) was not illustrated by the primary production capacity pattern. Correlation coefficients for chlorophyll a concentration determined by standard methods and primary production capacity (Fig. 4-87) are high for both stations (0.84 at AN1 and 0.93 at AN2) which suggests a constant value of assimilation number (Fig. 4-88 , 4-89). The profiles of mean values and histograms of assimilation number demonstrate that this value is nearly constant, about 2 mg $C \cdot mg^{-1}$ $chl \cdot h^{-1}$. Some decrease of the mean value of assimilation number was recorded only at the 30 m level (Fig. 4-90a). This result can be interpreted as an increased share of sinking of probably less active phytoplankton to the pool of chlorophyll-containing cells present in the layer below the euphotic zone. The variability of all the phytoplankton parameters decreased during the May period (Figs. 4-86, and 4-90 to 4-93).

At AN2 in the 0 - 10 m layer on April 25 - 26 a phytoplankton maximum, with high chlorophyll a concentration (Figs. 4-86a and 4-94a) and similarly high phytoplankton cell number (Figs.4-86d and 4-94b-e) was recorded. The results of chlorophyll a and primary production measurements at both anchor stations show a diurnal rhythm in phytoplankton physiological activity (Figs. 4-84 to 4-86a and b).

4.3.4.2 Phytoplankton

At AN2 the population developments of the counted phytoplankton species differ. Thallassiosira levanderi at AN2 follows the decrease of chlorophyll a (Figs. 4-86a and d). This decrease can not be seen in other species, Skeletonema costatum for instance increased in the May period (Fig. 4-97 and 4-94d) and Chaetoceros spp. and Achnantes taeniata did not show any clear trends in cell numbers (Figs. 4-94b and e and 4-96). Figure 4-86c presents the summed phyto-plankton carbon of the four species. Comparison of Figs.4-94c, 4-95 and 4-86a clearly indicate that T. levanderi is the species with the prevailing influence on chlorophyll a and primary production at both anchor stations.

At AN1 the most distinct pattern of a species bloom is that of Thalassiosira levanderi (Fig. 4-95). This species was present at 5 and 10 m with increasing cell numbers during the first phase of the April period with a maximum abundance on April 27 followed by a decline in the upper layer with simultaneous increase at 30 m. From 5 May , T.levanderi cells nearly disappeared from the upper layer while some are still recorded at 30 m depth. This obviously indicates increased reduction in population density and elimination of cells by sinking at the end of the bloom of this species. Thus it contributes to a patchy distribution at greater depths.

An increase in abundance as in the case of Thalassiosira levanderi,followed by a maximum period and then a sharp decrease in abundance in the euphotic zone accompanied by distinct increase of sinking rate, seems to be the classical pattern of a bloom. Rapid sedimentation of T. levanderi at AN1 coincided with increased transparency of water determined by means of Secchi disk and lower attenuation coefficient recorded at AN1 (cf section 4.6). An opposite pattern was that of Skeletonema costatum and Chaetoceros wighamii, whose cell numbers increased in May (Figs. 4-94c and d) while Achnantes taeniata showed an intermediary development.

It is evident from these results that in the phytoplankton bloom at anchor station AN1 some structural changes occurred which are related to different rates and phases in population development of individual species. At AN2 chlorophyll a and the nutrient concentration declined over the whole investiga-tion period. High chloropyll a concentrations were correlated with low nutrient concentration caused by phytoplankton uptake (e.g. Fig. 4-99).

The patchiness was affected and, to some degree, generated by ecological succession phenomena, including probably some populational interactions and changes in cell buoyancy causing sinking and sedimentation.

Factors such as grazing, light and nutrient availability, horizontal and vertical transport etc. also contribute to the patchiness pattern.

4.3.4.3 Zooplankton

The mesozooplankton investigations at station AN1 were carried out from 25 to 30 April and from 2 to 9 May, thus covering the entire PEX period. Therefore that station was chosen to show the temporal variatons in zooplankton community.

The variability of the mesozooplankton abundance during PEX (Fig. 4-100) shows considerable temporal differences in number of individuals. The coefficient of variation for the most numerous components of zooplankton fluctuated from 98% in case of Fritillaria borealis to 51% in the case of Acartia longiremis. For total zooplankton it reached 56% (Table 4-5 below).

Table 4-5: Mean values (April + May) of zooplankton abundance at AN1. SD=standard deviation; CV = coefficient of variation; 1 = CI - CIII; 2 = CIV - CV; 3 = female; 4 = male.

Species	Mean ind. m^{-3}	SD	CV %
P.min.elong., 1 - 4	173	118	67.82
A.logiremis, 2 - 4	86	44	51.35
A.Bifilosa , 2 - 4	6	7	115.66
Acartia spp., 1	53	35	66.24
T.longicornis, 1-4	34	18	54.45
C.hamatus, 1 - 4	24	14	58.22
F.borealis	468	458	97.96
Polycheta-larvae	64	36	55.86
others	5	6	107.33
total	913	515	56.41

The minimum number of all zooplankton organisms has been noted on 27 April (187 ind.$\cdot m^{-3}$) and the maximum on 9 May (2972 ind.$\cdot m^{-3}$). The mean value of the zooplankton abundance is 914 ind.$\cdot m^{-3}$ (Tab.4-5).

The following species were the abundant: Fritillaria borealis (average 468 ind.$\cdot m^{-3}$), Pseudocalanus elongatus (average 173 ind.$\cdot m^{-3}$) and Acartia spp. (average 145 ind.$\cdot m^{-3}$).

Larvae of Polychaeta, Temora longicornis and Centropages hamatus were less numerous. Other species were extremely rare (Tab. 4-5).

In the first period of PEX (April) P. minutus elongatus was the dominating species (34,7%), codominants were F. borealis (24.2%) and Acartia spp. (23.6%). During the May period, F. borealis predominated (59.5%). P. minutus elongatus (14.2%) and Acartia spp. (13.6%) were codominating species.

After 1 May mesozooplankton was considerably more numerous (average 1167 ind.$\cdot$m^{-3}) than during the April period (average 533 ind.$\cdot$m^{-3} , Fig. 4-101). The main reason for this was the increase in F. borealis abundance (from 129 ind.$\cdot$m^{-3} in April to 694 ind.$\cdot$m^{-3} in May) and some increase in the number of Acartia copepodids (from 32 to 65 ind.$\cdot$m^{-3}) and larvae of Polychaeta (from 43 to 78 ind.$\cdot$m^{-3}, Fig. 4-101 to 4-103). T. longicornis and C. hamatus were also slightly more numerous in May than in April (Fig. 4-101).

The abundance of the older copepodids and adults of Acartia spp. was similar in April and May (90 and 85 ind.$\cdot$m^{-3}, respectively; Fig. 4-102) . An insignificant decrease in the abundance of olfer copepodid stages and adults of P. minutus elongatus was noted (177 ind.$\cdot$m^{-3} in April , 140 ind.$\cdot$m^{-3} in May), while the younger copepodids were more numerous in May (26 ind.$\cdot$m^{-3}) than in April (7 ind.$\cdot$m^{-3}, Fig.4-103). The increase in the number of F. borealis, younger copepodid stages of Acartia spp. and P. minutus elongatus was connected with the spring spawning of these species.

The results from AN2 are generally in good agreement with those from AN1 although with some remarkable exceptions (Fig.4-104). For example there was a higher amount of P. minutus elongatus in the upper layer (halocline to surface) of AN2 in comparison with AN1. This can be explained by the fact, that this species prefers deeper and colder waters and AN1 was situated in a shallower area so the plankton hauls missed the layers just above the halocline which were too close to the bottom. In the subhalocline layer at AN2, P. minutus elongatus was the most abundant species with three times higher numbers than in the surface layer in April and even ten times higher in May (Fig. 4-105). Another important difference was the fact that the younger copepodid stages of Acartia spp. did not increase in May but stayed stable in both periods (Fig. 4-106). It seems, that the development of younger copepodid stages which caused the maximum abundance in the north-western corner of the Slope grid 6 - 8 (4-6 May , Fig. 4-52 , section 4.2.3.4) was influencing only station AN1. AN1 and AN2 were situated at the border of two water bodies.

The general pattern of development of the zooplankton species at the anchor stations is valid also for the grid stations (c.f. 4.2.3.4).

Using AN2 station data, the attempt was made to find out whether there was a daily ryhthm in the distribution of the zooplankton species (Fig. 4-107). For P. minutus elongatus a vertical migration from the surface water to below the halocline could be established for females and older copepodid stages in the last week of April. This migration was, however, less visible during the first week of May due to much higher variation in the samples (Fig. 4-105). The males and the younger copepodid stages did not show vertical migration.

4.3.5 Temporal variability

Figs. 4-73 to 4-79 represent variability, time versus depth, of physical and chemical parameters measured on both anchor stations.

The AN2 surface data suggest three different types of waters which were clearly characterized by their salinities but not always by characteristic differences of the other parameters. Variations in salinity were not always homogeneous troughout the entire surface layer (1 to 15 m). The dominating salinities were 7.53 - 7.54 at 1 and 5 m and 7.57 at 15m (Fig. 4-66a).

Several short time events (≈ 10 hrs) of low salinity water (< 7.51 at 1-5m, 7.53 at 15 m) appear on 25 - 27 April followed by a 24 hrs period of higher and nearly homogeneous salinity (7.56 to 7.58 at 1 to 15 m). This salinity increase was accompanied by marked changes of all the other parameters.

Table 4-6: Parameter shifts in the surface layer at AN2 corresponding to the salinity increase from 27 to 28 April (Fig.4-68a and b and 4-69a and b).

salinity	from 7.52	to	7.58 S
oxygen	10.2		9.5 $cm^3 \cdot dm^{-3}$
pH	8.4		8.45 units
nitrate	0.4		2.2 $\mu mol \cdot dm^{-3}$
phosphate	0.2		0.43 -"-
temperature	was modified in a way that the diurnal cycle is completely suppressed (Fig. 4-67a). The entire 0 to 15 m layer had a temperature of 1.8 °C.		

The fine structure of the salinity curve was matched in all biological and chemical parameters suggesting that the variability was caused by either an inflow of water from outside or by elevation of water from deeper layers.

The coarse maps of general parameter distributions in the Baltic (c.f. section 4.1.4, Figs. 4-11a - h), indicate the possible origin of a corresponding water type from the Polish or Soviet Union coast. However, the same water type is found at 20 to 25 m in the PEX area and could have been lifted by physical processes and than shifted towards the AN2 position.

The very high concentrations of nitrate and phosphate suggest a stimulation of plankton growth which in fact can be seen on the corresponding plankton graphs (see Figs. 4-84 to 4-94, section 4.3.4).

Another inflowing patch occurred from 6 to 7 May in the surface layer of AN2. The mean salinity of about 7.57 was considerably reduced by inflowing water of very low salinty (<7.45). The inflow only affected the 1 and 5 m levels, the latter only to a minor extent. The 15 m level was not modified (Fig. 4-66b).

All the other parameter concentrations/levels were nearly identical both in the original surface water and the occasionally occurring fresher water. There was some vague indication of very small increases in nitrate, phosphate and oxygen contents.

4.4 Current measurements

4.4.1 General description

In this section some general results of current measurements that are useful for analyzing mass transport in the PEX area are considered. For positions of current meter stations, see Fig. 2-3.

The easterly wind speed was up to 8 $m \cdot s^{-1}$ on 25 through 27 April. There was persistent wind direction only during the second half of the experiment with wind speed about 3-5 $m \cdot s^{-1}$ (c.f. Figs 4-2 and 4-3). These weak winds did not generate strong drift current variability.

There was no permanent large-scale current for the whole polygon. Nevertheless, there existed a well developed current pattern. At current meter station 5 westward currents dominated both in the surface layer and near the bottom (Fig 4-108). At station 3 currents are mainly directed northwards were very weak near the bottom. At station 4 southward and at station 11 southwestward currents dominated but at station 4 the current direction variability was greater. Currents at station 9 in the eastern part of the Eddy grid reached 30 $cm \cdot s^{-1}$ in the surface layer and 20 $cm \cdot s^{-1}$ near the bottom layer with strong variability in direction. At other stations current speeds seldom exceeded 12 $cm \cdot s^{-1}$. During the first half of the experiment currents of this magnitude were observed only at station 8. In May strongest westward and southwestward currents of up to 15 $cm \cdot s^{-1}$ occurred at station 11.

The vertical distribution of currents was rather homogeneous. Coherence of current speed and direction between near-surface and at near 40 m level was high everywhere. This fact is important for the general picture of currents of a certain level generally allowing (in case of absence of data) the use of data of the nearest measured level. On Figures 4-109 and 4-110 hourly current vectors at stations 3 and 5 are shown and in Figure 4-111 the progressive vector diagram of hourly mean currents at station 11 . They illustrate the vertical coherence between currents at three upper levels and somewhat different currents near the bottom.

Oscillations close to the local inertial period of 14 hours 26 minutes at 56°N and sub-inertial oscillations were present in most of the current meter records. The strongest sub-inertial processes occurred, as already mentioned, at station 9 where oscillations with the period of about 9-10 days were observed (Fig. 4-112). No inertial oscillations were observed there. Although sub-inertial processes were observed also at station 5 and somewhere else, they were not as pronounced as than at the station 9. This low-frequency variability may be the result of topographic waves or passing eddies. Regarding the Slope grid the possible mechanisms are discussed in the next section.

Variability at the local inertial frequency was distributed unevenly. At stations 9 and 3 there was no remarkable variability with inertial period. At other stations the strongest inertial oscillations were observed during the first week of measurements, then the oscillations subsided. In the bottom slope region inertial oscillations (here we do not specify inertial oscillations or inertial waves) may cause vertical transport of water with inertial frequency. Water particles under inertial oscillations move circularly clockwise with the diameter:

$$D = 2 \frac{V}{f}$$

where V is the current speed and f is the inertial ferquency ($f = 1.2 \cdot 10^{-4}\ s^{-1}$).

In case of a current speed of 10 $cm \cdot s^{-1}$ the diameter of the circle is 1.6 km. Thus, for example, the bottom slope of 0.002 will generate vertical undulations of water particles of 3.2 m (in case of the speed of 5 $cm \cdot s^{-1}$ the lifting will be 1.6 m). Therefore, the influence of inertial oscillations would be expected. In Fig.4-113 the hourly mean currents are shown at five levels. The strongest oscillations occurred at 96 m having amplitudes up to 12 $cm \cdot s^{-1}$ and were weakest at 86 m. These data allow the existence of inertial waves (not pure oscillations) and will be discussed in section 5.1.4.

The current pattern near anchor stations AN1 and AN2 to allow a comparison with other measurements carried out there. From 25 to 30 April water masses at AN1 moved westward (Fig. 4-114), then veered clockwise towards the northeast. Presumably this direction was similar through the whole layer from surface to approximately 40 m whereas the velocity of current decreased from surface to bottom. After 1 May the direction of the current changed distinctly. For the following three days it was oscillating near 90°. After 5 May the current direction changed to south and the speed increased rapidly to 8 - 12 $cm \cdot s^{-1}$ through the whole water column.

Hourly mean currents at AN1 and AN2 at the level 10 m are presented in Fig. 4-115 and show that from 25 to 27 April the current at AN2 was deviated about 50° to the left compared with the current which was observed at AN1. At this time its speed was greater than 10 $cm \cdot s^{-1}$. Starting from 2 May, the direction of current at AN2 deviated to the left by about 60° in comparison to AN1.

At AN2 mean currents of 5-8 $cm \cdot s^{-1}$ directed north-westward and northward were estimated during the first days of experiment. In May also northward currents (NW to NE) seemed to prevail at. Note that such a current will transport water about 4-7 km per day. To get a further, but rough, idea about the order of magnitude of the advection in the PEX area, progressive vectors were drawn, based on 24 hours mean values of the observed currents. Some of these vectors are shown in Fig. 4-116. It has to be stressed though, that these progressive vectors do not show the actual advection but a fictive Lagrangian representation of the current. However, it seems likely that the mean local horizontal displacement has been of the order of 4 nm per day. The water movements on scales comparable to those of the Eddy grid seem to be dominated by circular patterns. The advection of these gyres themselves can not be deduced from the progressive vector diagrams. More informative will be stream-function patterns discussed in next section.

At the positions 3, 5 and 6 current meters were moored from 12 April until 4 June 1986. Comparing the currents measured during PEX with those measured before and after the experiment makes clear that during the days from 25 April to 8 May currents in the PEX area were rather slow. To find out a prevailing current direction the 360 degree circle was divided into 16 sectors. The vector means of all current records , falling within the two 45 degree sectors adjacent to the middle of the sector with the maximum number of observed directions were calculated. The result, given in Table 4-7 shows that the vector mean velocity of the prevailing current during PEX at all three positions and sampling depths is slower than in the time before and after PEX. The percentage frequency distribution of velocities faster than 8 $cm \cdot s^{-1}$ indicates even more obviously how calm current conditions were during PEX compared with before and after experiment when current speeds of over 8 $cm \cdot s^{-1}$ ocurred at least twice as often.

Table 4-7: Statistics of speeds and directions of prevailing currents

		POS. 3		POS.5		POS.6	
		DEG	$cm \cdot s^{-1}$	DEG	$cm \cdot s^{-1}$	DEG	$cm \cdot s^{-1}$
near surf.	during PEX	335	7.2	266	5.3	109	6.6
	bef./after	118	10.7	37	7.6	130	10.9
near 40 m	during PEX	8	5.5	257	3.8	129	5.5
	bef./after	219	6.8	23	5.7	225	7.4
near bott.	during PEX	52	0.8	249	2.3	210	3.6
	bef./after	53	3.3	249	4.3	229	5.3

Percentage frequency of observed speeds greater than 8 $cm \cdot s^{-1}$

		POS.3	POS.5	POS.6
		%	%	%
near surf.	during PEX	26.2	20.9	28.6
	bef./after	59.5	43.9	75.6
near 40 m	during PEX	14.4	3.7	10.7
	bef./after	32.9	32.5	47.1
near bott.	during PEX	1.3	0.1	6.4
	bef./after	13.4	13.3	12.4

4.2.2 Daily mean current patterns

To estimate the current patterns the initial daily mean values of near-surface currents from the mooring stations, and if available, from the drifters were interpolated on a regular grid via the streamfunction calculated by the method of optimal interpolation of the vector fields (Bretherton et al., 1976). By "near-surface" we mean the 10-m current meter level for moorings No. 1,2,3,4,10 and 13, 6-m for No. 5, 8-m for No. 6, 20-m for No. 11 and 36-m for No. 12. The current patterns estimated in the western part of the Eddy grid for the period from 25 April to 8 May are presented in Fig.4-119.

Estimated currents are directed along streamfunction contour lines, with higher speeds corresponding to smaller distances between the neighbouring contour lines.

Due to the small number of current meter moorings the calculated stream function patterns are quite sensitive to the variation of measured current values and the applied mathematical method of approximation. To make this clear a second set of streamfunction patterns has been calculated based on another mathematical procedure (Figs. 4-117 and 4-118), which assumes that the stream function is presented by a cubic polynomal. A least square fit is then evaluated.

An anticyclonic synoptic-scale eddy was dominant in the near-surface current patterns from 25 to 27 April in the eastern part of the Slope grid. (Fig. 4-119). The current speed in the eddy amounted to 11 $cm \cdot s^{-1}$, the diameter of the eddy being about 20 km. On the basis of the drifting buoy data from 10-m depth the a Eddy now with the diameter of about 15 km was found from 28 April to 1 May centered at CUS, CVS (Fig. 4-120). The eddy disappeared after 1 May from the mapping region. From 28 to 30 April a small scale cyclonic current pattern was found north of the Slope grid.

A southward current with a speed of 14 $cm \cdot s^{-1}$ and a cyclonic curvature was observed at the eastern part of the Slope grid from 1 to 8 May. A northward jetlike current pattern was observed from 30 April to 2 May in the central part of the Slope grid. This stream was located close to the western slope of the grid where the halocline touched the bottom. A southward jet detected from 5 to 7 May in 5 miles from the western edge of the grid was obviously related to the persistent salinity front (see 4.2.1 and 5.1.2) whose meanders crossed the mooring stations No. 1 and 5. The current speeds in that southward jet were up to 8 $cm \cdot s^{-1}$. In the shallow western edge of the grid the currents were very weak.

4.5 Remote sensing results

4.5.1 General remarks

The satellite and SLAR data reveal surface structures on at least three different scales:

- Large scale (100km) patterns of temperature, such as warm surface water masses along the Latvian, Lituanian and Estonian coasts east of the PEX area and a warm water patch located over the shallow Hoburg Banks to the west of the PEX area.

- Medium scale (10-20 km) patterns, like finger-like outflows from the warm water patch over Hoburg Banks. A rather persistent eddy observed inside the PEX eddy grid between 3 May and 8 May also belongs to this scale.

- Small scale (< 1 km) features, like narrow bands of cold water observed on the LANDSAT TM as well as a slick pattern and internal wave phenomena revealed by the SLAR.

The station grids used during PEX - with 4 and 2 n.m. spacing respectivly - were sufficient for the large and some of the medium scale structures that occurred, but definitively too coarse to resolve the small scale phenomena that were detected by the remote sensing sensors.

4.5.2 Large scale sea surface pattern

Water temperature patterns indicate, on sequences of NOAA-infrared satellite images, the advection of surface water in the south eastern and central Baltic (Fig. 4-121). During the months of March, April and the first half of May the water of the Baltic is colder than the water of the rivers. The warm, low saline river water spreads at the sea surface because of its lower density. The rivers Vistula and Nemunas with increased water masses in spring emit distinct near-surface water discharges which could be traced through high amounts of suspended matter on satellite images of the Coastal Zone Color Scanner. Also in previous years river-water induced processes have been observed on satellite images to increase the surface water temperature of water masses in the South Eastern Baltic.

Large areas of eutrophic waters in the southeastern Baltic show considerable increase in temperature in areas where high chorophyll a values are indicated from the satellite images (Horstmann, 1988). During PEX the southeastern Baltic surface water was determined by river water induced phytoplankton blooms which apparently have an influence on surface temperature pattern.

The general direction of the movement of warmer surface water in the South-eastern Baltic in April 1986 was towards the north. This can be determined even from partly clouded images on April: 4, 9, 13, 16, 24, 26, 28, 29 and on 1 May . The cloud free scenes from 3 to 7 May (Figs. 4-122a - c) demonstrate the advection of river water of Vistula and Nemunas in a northern direction. The AVHRR scene of May 7 indicates that part of the Wistula waters moved directly towards the north while another part was advected along the coast towards northeast and mixes north of Coorlande Lagoon with the Nemunas river water. Detailed information on the expansion of river influenced water in the southeastern Baltic can be obtained from the sequence of images in the quick motion picture, mentioned in 3.1.5.

The LANDSAT TM scene of sea surface temperature from 7 May also gives an informative overview over the water mass distribution (Fig. 4-123). Starting from the south, there was a mushroom like front of warm water in the left lower part of the image, which presumably can be attributed to the warm water masses extending from the Wistula river mouth towards the north. There was another area of warmer water streching from the right corner of the image towards the northwest and a third warm water body which extends from the upper right border of the image towards the east. This water mass obviously reached the eastern part of the PEX Eddy grid.

There is evidence from channel 2 of the Thematic Mapper that the warm water was correlated with higher radiometric intensity of reflected radiance in the visible spectrum. For the PEX grid the signal was rather weak and did not permit sufficient contrast to be reproduced here. However, it shows clear evidence of more particles - including phytoplankton - in the warmer water patches. The ground truth data of chlorophyll from 7 May showed higher values in the eastern part of the Eddy grid where also higher temperatures were measured in the surface waters.

Quantitative evidence of the association of high Chorophyll a values with high temperatures can be obtained from an investigation of Klaiped Hydrographical Division (c.f. 4.1.5, Figs. 4-11b and h). The temperature increase of 4 °C outside the Vistula estuary could be obtained from ground truth evidence from the long transect of HYDROMET on her way back to Gdansk.

The comparison of isolines on the sequence of satellite images indicate the approach of warm water fronts from the southeast and east towards the PEX area. They show, furthermore, a general southwest advection of surface waters in the PEX area and indicate a more or less north-south front with its general pattern parallel to the eddy grid baseline in the western part of the PEX area. These general advection patterns are superimposed by smaller mushroom- or fingerlike fronts as well as eddies of different scales.

4.5.3 Medium scale patterns

The large scale distribution of sea surface temperature in the PEX area, i. e. warmer water to the east and to the west of the Eddy grid, is complemented with some perturbations on smaller scales. Two prominent features are revealed by the satellite data.

Figure 4-124 shows how the warm water patch (which also is low-saline) flow out into the colder surrounding waters in finger-like filaments, with a distance of 20-25 km between each of them. These fingers affect the western part of the PEX grid, as can be seen on the isotherm map of 5 May (Fig. 4-125), although there is an elongated cloud masking parts of the polygon. The quick motion video revealed a stripe of colder water along the meandering front, which was also measured by ARNOLD VEIMER.

Fig. 4-124 shows a cyclonic eddy situated in the lower, central parts of the Eddy grid. The eddy, consisting of a 15-20 km spiralformed temperature pattern with a warm core, was observed inside the Eddy grid between 3 May to 8 May. Moreover, the eddy also appeared in the dynamic height distribution (see 5.1.3). On May 8 it is possible to localize the eddy by identifying the temperature front southeast of the eddy (Fig. 4-126), although the isotherm spacing of 0.25°C is too crude to permit a good representation of the circulation pattern.

4.5.4 Small scale patterns

The LANDSAT TM scene from 7 May (Fig. 4-123a), suggests patterns in the sea surface temperature on length scales less than 1 km. Sinuous bands of colder water with widths of 500 to 1000 m occur frequently over the PEX area. The isotherms analyzed from that scene (Fig. 4-123b) show that the ship measurements at least once was performed within such a narrow band of colder water.

The SLAR data offered another way to detect surface patterns of small scales. The weak winds persisting during PEX lead to a limited range detectability, as the surface roughness was not large enough to backscatter electromagnetic energy above noise level for distances exceeding 8 to 10 km perpendicular to the flight track. However, the formation of slicks (narrow bands where short gravity waves are absent) was frequently observed. Sometimes the slick pattern formed circular patterns, and one of these was correlated to with the warm-core eddy described earlier. Figure 4-127 also shows that when the radar passed over the narrow band of colder water (less than 3.3 K in the figure), the range detectability decreased almost to zero. The slick patterns could often be observed visually directly from the aircraft.

A more front like signal was observed by SLAR on 27 April in the position of the quasi-permanent front between the warmer and less saline water over the Hoburg Banks and the colder waters inside the PEX polygon. Probably some frontal currents interact with the short gravity waves that reflect the radar signal.

A weak but rather clear indication of internal wave activity on 27 April is presented in Figure 4-156 According to the discussion in section 4.4.1, inertial oscillations were present in the PEX area at this date. The wavelengths deduced from the SLAR data - 1,5 to 3,0 km - fits well with the hypothesis that the wave-pairs seen on the SLAR photo were dispersive inertial waves propagating towards the north.

4.6. Radiant energy and optical properties of the water

The optical phenomena and properties of waters discussed in this chapter deal mainly with the variability of the environment at station AN1 during PEX.

If we assume that the processes occurring in the PEX-86 region were approximately ergodic and statistically uniform in the horizontal, the statistical characteristics of the investigated optical parameters as well as the daily totals of solar radiation at different depths will be similar at other PEX stations. The demonstrated temporal relationships of these parameters, manifested a.o. as patchiness at station AN1, illustrate how the environment varies with time at a given position, which in the top layer of water should be the same as elsewhere in the PEX region.

4.6.1 Solar radiation and its transmittance into the sea

From earlier statistical investigations (Dera 1983) it is known that the long-term mean daily totals of solar radiation at the sea surface in the area of AN1 is 1764 $J \cdot cm^{-2} \cdot d^{-1}$ for the last third of April and 1820 $J \cdot cm^{-2} \cdot d^{-1}$ for the first third of May.

Thus apart from the first three days of the experiment, the solar radiation level during PEX-86 was much above the average. This can be seen from Table A-2 (see appendix) where the first line of figures gives the measured daily totals of solar radiation at the sea surface (0^{-} means "in the air"). From 2 to 8 May this radiation exceeded the long-term mean by ca.35%, while the value recorded on 5 May was as much as 42% higher. The rest of Table A-2 gives daily totals of solar radiation at selected depths in the sea for the whole spectral range (Total) and for the visible light range from 400 to 700 nm (Vis). To a good approximation, this visible light range (Vis) in the Baltic can be identified with the Photosynthetically Active Radiation PAR. The PEX-86 solar radiation data collected at station AN1 also include the hourly solar irradiation at different depths for 6 wavelength intervals and the diffuse attenuation coefficient of downward irradiance with respect to depth for 8 wavelengths.

As Table A-2 shows, the day-to-day changes in the solar irradiation at the same depths were very considerable as they were due to the changes in the daily sea-surface irradiation being superimposed on the changes in the transmittance of downward irradiance through the water column. Detailed data show that these changes were equally marked within a few hours. The depth at which 1% of the surface irradiance in the wavelength interval maximally transmitted in a given water (here ca. 525-535 nm) roughly coincided with the depth range of the euphotic zone according to the optical criterion. Thus, the depth range of the euphotic zone at station AN1 varied during PEX-86 from 11.5 m (on 29 April at 1500 GMT) to 21 m (on 26 April at 0900 GMT). These changes, averaged each day before midday local time (0400-1000 GMT) and after noon (1000-1700 GMT), are illustrated in Fig. 4-128. This shows clearly the abrupt optical changes taking place in the water which caused such considerable changes in the thickness of the euphotic layer from one day to the next, particularly in the April period of PEX. The depth ranges of the Secchi disc visibility, presented for the station AN1 in Fig. 4-129, express these optical changes with time in the surface layer of water. These changes resulted chiefly from the temporal changes in water transparency, discussed in the next section, which were principally due to the patchiness of the waters.

4.6.2 Light attenuation

The attenuation of light in the sea, which determines the transparency of the water, is, in the violet band of light waves, a sensitive optical indicator of the content of suspended particles and organic substances in sea water. Quantitatively, this attenuation is exbressed by the attenuation coefficient c, a clearly defined inherent property of sea water, measured <u>in situ</u> using a beam transmittance meter (Jerlov 1976). So far, the statistical distributions of this coefficient in the Baltic have not been studied because of the difficulty in getting together a sufficiently representative number of measurements. Many earlier measurements of the light attenuation coefficient c [m^{-1}] for a wavelength of 425 nm have shown that in the open Baltic it varies from 0.4 m^{-1} to 1.2 m^{-1}, whereas it is barely 0.04-0.05 m^{-1} in the clean Sargasso Sea but around 10 m^{-1} in polluted estuarine waters, such as of the Vistula (Jerlov 1976, Dera 1983). Vertical measurements at station AN1 made in each 0.5 m every 1.5 h during 13 days showed that this coefficient varied widely between 0.3 m^{-1} and 4.4 m^{-1}. Such a range of changes recorded during only two weeks turned out to be much larger than that previously reported for the open Baltic (Hojerslev 1974, Kopelevich et al. 1974, Jerlov 1976, Dera 1983). Fig. 4-130 and Table 4-8 illustrate this variability in detail.

Table 4-8: Light attenuation coefficient c (425 nm) in different water layers at the station AN1 Mean values in [m^{-1}]

Depth range (m)	Time period					
	25 April-8 May		25-30 April		2-8 May	
	max	min	max	min	max	min
0-10	1.64	0.64	1.79	0.54	1.51	0.33
10-30	1.16	0.32	1.30	0.38	1.05	0.20
30-50	0.81	0.27	0.84	0.25	0.79	0.18

Such a wide variability in the light attenuation coefficient is indicative of the appearance at station AN1 of both the cleanest water in the Baltic c(425) $< 0.4\ m^{-1}$ below 30 m depth and very turbid waters (e.g. coastal water or water optically polluted to the same extent as coastal waters c(425) $> 2\ m^{-1}$). In the subsurface layer down to 30 m these changes at selected depth as PEX-86 progressed are illustrated in Fig. 4-131. The sudden changes in the light attenuation coefficient in a matter of hours indicate the inflow of a variety of patches of water into the study area; no other mechanism explaining such large and abrupt changes in the transparency of open Baltic waters is known.

The vertical distribution of the light attenuation coefficient is especially variable in the subsurface layer of water to 30 m depth (see Table 4-8). These changes could be due to surface waters flowing in from shallow coastal areas, containing plankton-rich suspended matter from river estuaries and/or detritus from productive parts of the sea.

Fig. 4-132 shows the spectral distribution of the light attenuation coefficient in water of average turbidity at station AN1. (Date: 2 May, 1986; depth 14 m). Confirmation of this is the spectral distribution of c(425) measured at the same place in water of average turbidity (c(425) $\approx 1.5\ m^{-1}$) at 14 m depth. On comparing this distribution with the data for different sea waters (Dera 1983), it is readily shown that it is typical for coastal waters (e.g. the Gulf of Gdansk).

The graphs (Fig. 4-131) showing the isolines of the light attenuation coefficient c(425) in the vertical at station AN1 as a function of time illustrate in a way the evident optical patchiness of the water. At some times, single patches of very turbid water are clearly visible, at others, the mosaic of different waters becomes extremely complicated. From a whole series of such graphs, we have chosen by way of illustration the example in Fig. 4-133. The continuous isolines represent values of c equal to whole numbers (1 m^{-1}, 2 m^{-1}, 3 m^{-1} etc.) i.e. very high in comparison with the optical differentiation of water one usually comes across in open seas. The dotted lines indicate the intermediate values 0.5 m^{-1}, 1.5 m^{-1} or 2.5 m^{-1} as the case may be. Where one places the limits of a patch of water is of course a matter of discussion. Nevertheless, one can state with certainty that areas where c(425) exceeds 2 m^{-1} characterise water optically polluted to a great extent, but very untypical compared with the predominant mass of water in the open Baltic. On the other hand, areas where c(425) is less than 1 m^{-1} are typical of Baltic water in the light of earlier research, with the exception of bays and coastal (littoral) zones. On the transect from Gdansk to the PEX area (18-19 April 86) only in the Gulf of Gdansk and on the station P63 of open Baltic (55°21'N, 19°03'E) values of c(425) > 2 m^{-1} were recorded in the upper layer of water.

Patches of strongly turbid water, in which c(425) > 2 m^{-1}, reaching from the surface down to 20 m depth were recorded at station AN1 on a number of occasions in the period 25 -30 April. Similarly turbid patches but of shorter duration were recorded on 2, 5, 6 and 7 May. Assuming a boundary criterion for turbid water different from c(425) > 2 m^{-1} would of course change both the number and dimensions of the recorded patches. If one assumes that the above patches flowed past station AN1 with the average flow velocity recorded by the adjacent current meters that horizontal extent can be estimated. So, for example, the patch with c(425) > 2 m^{-1} recorded on 27 April from 0200 GMT to 0100 GMT on 28 April from the surface down to 15 m depth, with the average flow velocity of the water at 10 m depth u = 4.7 $cm \cdot s^{-1}$ (in direction 310-360) had a horizontal extent of 3.9 km. The next patch on Fig. 4-133 was only 120 m in extent. The other patches, measured in the same way, were from a few hundred meters to a few kilometers in length.

Notice, however, that these optical patches are extremely inhomogenous,so their boundaries indicated by isolines of c(425)=2 m^{-1} are merely conventional ones. One could define the limits of patches in another way, e.g. from the deviations of a measured parameter from its mean value, σ , which depend on the averaging interval.

4.6.3 Conclusions regarding the optical properties of the water

The optical patchiness of the water at 425 nm wavelength at station AN1 was pronounced. The flow past of patches having different optical attenuation and the intensive primary production of plankton appears to be the most significant direct cause of the sudden changes in the optical parameters measured, changes which were of a magnitude never yet reported in the literature on the open Baltic. For example, the light attenuation coefficient c(425 nm) measured at the same site in the surface layer changed from c. 0.7 m^{-1} to over 4 m^{-1} within a few hours. This variability with increasing depth, as Figs. 4-130 and 4-131 show. Such a great variability in the water transparency in this spectral range is uncharacteristic of the open Baltic sea, however, typical for areas of shallow water, or areas affected by inflows of turbid coastal or bottom water.

4.6.4 In situ fluorescence

The fluorescence of sea water measured in situ using the fluorimeter described by Hundahl and Holck (1980) is mainly the fluorescence of chlorophyll a in phytoplankton cells and in a way reflects the chlorophylla concentration in the water. So, the fluorescence can indirectly indicate inhomogeneities in the chlorophyll a distribution and thus the patchiness of this distribution in the sea. The nature of chlorophyll fluorescence in a mixture of marine phytoplankton cells of different species in various stages of development and photo-adaptation in various temperature and light conditions precludes the establishment of a definite relationship between the fluorescence and the mass concentration of chlorophyll a in water (Papageorgiu 1975) . The relationship is further distorted by the fluorescence and light absorption of other organic substances in the sea water (Karabashev 1987). We shall therefore refer to the intensity of fluorescence (in situ), or simply fluorescence, and present its connection with the concentration of chlorophyll a in water by means of a statistical correlation with chlorophyll measurements in samples of water taken simultaneously from suitable depths.

The vertical in situ fluorescence distributions, measured by OCEANIA at station AN1 at 1.5 h intervals was no less differentiated than the light attenuation described in 4.6.2. Figs.4-134 and 4-135 and Table 4-9 illustrate this. Fig. 4-134 shows the maximum, minimum and mean values of fluorescence recorded in the vertical profile and their statistical distributions as histograms for the different depths. Fig.4-135 exemplifies the situation on 25 April when an sudden change in the vertical fluorescence profile was recorded in the afternoon hours when a patch with a higher concentration of chlorophyll a passed.

Table 4-9: Fluorescence in different water layers at AN1

Mean values and standard deviations in relative units

Depth range (m)	25 April-8 May		25-30 April		2-8 May	
	Mean	SD	Mean	SD	Mean	SD
0-10	25.26	12.00	32.80	12.26	18.57	6.59
10-30	22.98	8.67	27.83	10.07	18.67	3.52
30-50	14.99	5.60	16.50	7.06	13.66	3.35

The relative units of fluorescence used here are linked to the mass concentration of chlorophyll a by a regression equation resulting from the correlation shown in Fig. 4-136. The minimized function of this regression was the weighted sum of distances between the line and the given set of points. One of the variable metric methods (the Davidan-Fletcher-Powell algorithm) was used to evaluate the most appropriate parameters of the regression equation (Polak 1971). For the reasons given above, the correlation coefficient is only 0.79, and the linear regression equation is

$$Chl = (Fl \cdot 0.1761 - 0.3221)\ [mg \cdot m^{-3}] \qquad (1)$$

The results of profiling at a fixed point every 1.5 h for each 0.5 m depth distance allow the isolines of fluorescence intensity in the vertical as a function of time to be mapped fairly accurately. They are an excellent illustration of how the vertical distributions of this fluorescence and its patchiness (and indirectly the approximate concentration of chlorophyll a) evolve. Examples of such isolines, selected from the data for the whole period, are shown in Figs.4-137a and b. The isolines corresponding to fluorescence intensities of 20, 30, 40, 50 rel. units (continuous lines) and 25, 35, 45 rel. units (dotted lines) have been drawn. In accordance with the regression equation (1), they correspond to chlorophyll a concentrations of 3.20, 4.96, 6.72, 8.48 $\mu g \cdot dm^{-3}$ (continuous lines) and 4.08, 5.84, 7.60,... $\mu g \cdot dm^{-3}$ (dotted lines) respectively.

The patchiness of fluorescence is evident here, even if we determine the patch boundary in a conventional manner, as we did for the light attenuation in 4.6.2. Its complexity is due to the superposition of the dynamic movement of plankton with that of the water flow, to the diurnal increment of chlorophyll resulting from primary production and the local losses of phytoplankton, and perhaps to a vertical migration of plankton cells.

Depending on how these four complex factors interact or on the evident prevalence of one of them, the patchiness picture of fluorescence is either very complicated (as on Fig. 4-137a), or relatively simple with patches of increased fluorescence distinct as in Fig. 4-137b. Taking into acount the average velocity of the water recorded at station AN1 by the HYDROMET current meter station and the time for which the fluorescence patch shown on Fig. 4-137b was recorded, one can estimate the horizontal extent of this patch, in the same way as for patches of turbid water (see 4.6.2). Here the average speed measured on 10 m depth was $u = 5.1\ cm \cdot s^{-1}$ on 7 May and $u = 8.2\ cm \cdot s^{-1}$ on 8 May (the flow direction changed from 196 to 230 degrees). The detection time of the fluorescence patch > 20 units illustrated on Fig. 4-137b was 17 h on 7 May and 14 h on 8 May. Hence the horizontal extent of this patch (Fig. 4-137b) was approximately 7.3 km.

The dominant phenomenon causing rapid changes in fluorescence intensity at station AN1 appears to be movement of the water carrying clouds of phytoplankton. However, a distinct decrease in the fluorescence intensity of the surface water layer was recorded every day around noon. Using the regression equation (1) and the data from fluorescence recording, it is possible to make a rough estimate of the changes in the total chlorophyll a content in a water column beneath a 1 m^2 area of the sea surface at station AN1. These changes are illustrated in Fig. 4-138. As the figure shows, these changes are considerable. They depend primarily on horizontal advection, primary production and local losses.

Measurements of the spatial distribution of chlorophyll a concentrations in the surface layer of the sea along a transect were carried out by a remote laser spectrometer (ARNOLD VEIMER). Remote laser spectrometry high spatial resolution in the studies of the surface fluorescence on sections not disturbed by the ship's movement. From the back-signal spectrum registered per laser pulse the so-called fluorescence factor (the ratio of integrals of fluorescence and water Raman scattering bands) proportional to the concentration of fluorescent matter was calculated. The measured distributions (see Fig. 4-139) reveal a distinct regularity existing for several hours (the right part of the Fig. 4-139 corresponds to the reverse way along the section during ca 3 hours).

4.7 Sediment trapping

From 25 to 29 April the two drifters carrying the sediment traps remained in the anticyclonic eddy on the west side of the Eddy grid (c.f. 4.2). Both followed the main currents of this eddy (Fig. 3-2). From 30 April to 4 May the drifting arrays were deployed more to the south, in the center of the slope grid.

High chlorophyll a values (10-15 $\mu g \cdot dm^{-3}$; 0.5g chlorophyll a $\cdot m^{-2}$, integrated from 0m to 60m) were measured before the 27 April. Chlorophyll a then decreased to 3 $\mu g \cdot dm^{-3}$ (0.2 g chl.a m^{-2} integrated over 60m) on 3 and 4 May (Fig. 4-140). The decrease in chlorophyll a content from 27 April to 4 May was concurrent with the decline of the cell numbers of the dominant diatoms. Numbers of Thalassiosira levanderi dropped from more than $70 \cdot 10^9$ to $20 \cdot 10^9$ cells m^{-2} in the 60m water column. The respective numbers for the upper 30m layer decreased from $50 \cdot 10^9$ to less then $10 \cdot 10^9$ cells m^{-2}. Roughly 20% of the T.levanderi population was present in the form of paired cells, indicative for ongoing cell division. Cell numbers for Chaetoceros spp. in the upper 60m decreased during this time interval as well, from $140 \cdot 10^9$ to $35 \cdot 10^9$ cells m^{-2}. About 1/2 to 2/3 of the Chaetoceros cells were found in the upper 30m. Mesodinium rubrum and Gonyaulax catenata were found only in the upper 30m with 10^3 to 10^4 cells$\cdot dm^{-3}$, with an increasing tendency with time.

The sedimentation rate of chlorophyll a increased greatly after 25/26 April, from less than 1 to 12-23 mg chlorophyll a $m^{-2} \cdot d^{-1}$ (see Fig. 4-141a - d). Sedimentation of T.levanderi at 60m varied between $10 \cdot 10^9$ and $16 \cdot 10^9$ cells$\cdot m^{-2} \cdot d^{-1}$. Vertical flux of Chaetoceros spp. cells was less then $11 \cdot 10^9$ cells$\cdot m^{-2}$ d^{-1}.

Figures 4-172,a and b compare the sedimentation of T.levanderi and Chaetoceros spp. cells (trap material) with their respective suspended standing stocks for the period 30 April to 4 May. The sedimentation rates of T.levanderi cells increased, whereas the standing stock in the water column decreased. The standing stock of Chaetoceros spp. decreased more pronouncedly during this period but the increase in sedimentation was small compared to that of T.levanderi.

A comparison of the sedimentation rates in the traps on 30m and 60m depth revealed increasing vertical chlorophyll-a-fluxes over depth. The reasons are as yet not clear and may be related to differences in the settling behaviour of different phytoplankton organisms at the species level. Increased vertical fluxes over depth in this case cannot be caused by resuspension from the bottom, since the permanent halocline formed an effective boundary at 70m depth. Furthermore, both trap collections were identical with respect to the qualitative composition and contained little detritus and mineral particles.

Sedimented material, however, differed significantly from that suspended in the water column: No Mesodinium rubrum and Gonyaulax catenata were collected by the traps. T.levanderi occurred only as single cells in trap collections, whereas in the water samples chains (5 cells on the average) were most common. No paired cells of the latter were found in trap material, although in water samples they were quite abundant. For Chaetoceros spp. no difference between trap and water column samples was observed.

For the purpose of vertical budgets including losses via sedimentation, it is essential to assure that drifting traps stay within defined water bodies and that current shear in the water column above the traps are negligible. For the deployed drifter arrays during PEX, the main drogue was the sediment trap itself. From a comparison of drifter trajectories and main currents it can indeed be concluded that the traps did follow the main currents and that shear stress above the halocline was low (cf chapter 4.4.). Small-scale patchiness of chlorophyll a at a scale of hundreds of meters, however, was intense especially during April. Thus, changes in the chlorophyll a content of the water column and trap collections may well be influenced by patchiness, instead of reflecting a true time-series only. Due to the higher horizontal uniformity of the chlorophyll a distribution in May, however, sedimentation data from this period are more directly related to processes in the water column above the traps, so budgets will be made for this period only.

Despite the problems associated with patchiness, the time-series of chlorophyll a measurements along the drifting trajectories correspond well with the general picture of the horizontal chlorophyll a distribution (see section 4.2.3). Sediment trap data confirm that the decrease of the phytoplankton population was caused by the sedimentation. On 25/ and 6 April already, the trap was located directly under the western chlorophyll a patch (12 µg $chl.a \cdot dm^{-3}$). Sedimentation rates at this date were extremely low, whereas they increased significantly the following day, staying at a level of 12-23 mg $chl.a \cdot m^{-2} \cdot d^{-1}$ thereafter. Thus they reached higher values as during the maximum spring bloom sedimentation in 1975 (6 mg $chl.a \cdot m^{-2} \cdot d^{-1}$ measured by Smetacek et al. 1978).

A comparison between the amount of chlorophyll a that disappeared from the water column with the amount collected by the traps gives the following results:

Between 30 April and 4 May phytoplankton standing stocks decreased by 64 mg $chl.a \cdot m^{-2}$ (30m water column) or 141 mg $chl.a \cdot m^{-2}$ (60m water column). The trap in 30m depth collected 35 mg $chl.a \cdot m^{-2}$ and two separate traps in 60m depth collected 66 and 62 mg $chl.a \cdot m^{-2}$. Thus about 50% of the material lost from the water column was recovered in the sediment traps. If primary production in addition to the changes in the standing stocks is considered, the following picture arises: About 180-200 mg $chl.a \cdot m^{-2}$ were calculated to have been produced by photosynthesis during these 4 days (taking AN1 primary production data and assuming a carbon/chlorophyll a-ratio of 1:40). As the primary product neither accumulated in the water column (stocks in contrast declined), nor was collected by the traps, the question arises where to look for the "missing" biomass. For the PEX investigation little information is at hand about the processes controlling the relationship between primary production and phytoplankton biomass increment (e.g. importance of grazing, autotrophic DOM production, cell lyses). Further, the assumed carbon/chlorophyll a-ratio may be too low under cell nutrient deficiency, that locally prevailed at this time (section 4.2.2). A comparative estimation of all these loss processes shows, nevertheless, that sedimentation of biomass was the most important one.

When making such a budget on the basis of chlorophyll a, it has also to be kept in mind, that the chlorophyll a content per cell might be less for sinking cells than for suspended ones, thus it is worthwhile to calculate loss rates for individual species (see Fig. 4-142). In fact the discrepancy between cells lost from the water column and cells collected in traps does not arise if calculated on the species level: Plankton composition of the trap collections differed from that in the water column, which is indicative for species-specific sedimentation. *Mesodinium rubrum* and *Gonyaulax catenata* for example did not sediment at all. For *Chaetoceros spp.* the amount of disappeared cells from the water column is in the range of the sedimentation of these cells. For *T.levanderi*, however, more cells were collected by the traps, than were missing in the water column (see Tab. 4-10). This suggests that the population of *T.levanderi* was activly dividing during this time and produced approx. $20 \cdot 10^9$ $cells \cdot m^{-2}$ in 3 days. The high percentage of dividing cells (paired cells) in the water column supports this reasoning. If growth and sedimentation occurred simultaneously in this population, this indicates that sedimentation was not only species-specific but differences in sinking behaviour were also found within one single species. Species-specific sedimentation is probably caused by the different demands different species have concerning their immediate growth environment (e.g. nutrient supply). Intra- specific differences in settling behaviour could be related to different histories that parts of one population may have experienced in the past.

Table 4-10: Comparison of suspended and sedimented cell numbers of *T.levanderi* and *Chaetoceros spp.* for the period 30 April to 3 May

	T.levanderi	*Chaetoceros spp.*
water column (0-60m) cells lost ($10^9 cells \cdot m^{-2}$)	15	39
sediment trap (60m) cells collected ($10^9 cells \cdot m^{-2}$)	34	38

5 Processes

5.1 Physical processes

5.1.1 Heating

During PEX there was a pronounced increase in surface water temperature. The increase was observed not only in the near surface layer but also at depths down to the halocline at 60 - 70 m (Fig. 5-1), indicating deep convection. Simultaneously, there was a rapid increase in the temperature standard deviation as well (Fig. 5-2) indicating an increased patchiness due to variable heat input and distribution. This is evidence of a physically induced patchiness.

Changes in heat content above the halocline occurs due to heat flux through the sea surface and heat flux due to advective/diffusive transport across the vertical boundaries, assuming that the exchange through the halocline is negligible. The heat flux through the sea surface is made up of four terms: net solar radiation, long-wave back radiation, heat conduction and evaporation heat flux. These terms were calculated based on measurements by OCEANIA, and are shown in Table 5-1. Net solar radiation dominated the heat flux and the average during PEX (228 $W \cdot m^{-2}$) exceeded the seasonal mean (165 $W \cdot m^{-2}$).

The heat flux through the sea surface was integrated separately for the periods between each Eddy grid and compared to the change in heat content within the PEX area during the same periods and within different depth intervals (Fig 4-175). The change in heat content exceeds the heat flux by 10 - 20 %.

According to the current measurements and horizontal temperature gradients the horizontal heat transport were small, indicating that the heat flux through the sea surface may be somewhat underestimated. However, it cannot be excluded that advection contributed to the heat budget.

Table 5-1: Heat flux terms during PEX [$MJ \cdot m^{-2} \cdot d^{-1}$]

	25 - 29 Apr	29 Apr - 3 May	3 - 7 May
Incoming solar radiation (QS)	16.1	19.2	22.3
Long-wave back radiation (QB)	2.9	5.3	5.4
Evaporation heat flux (QE)	-0.4	0.1	-0.4
Conduction (QC)	-1.3	-0.6	-1.7
Sum (del Q)	14.9	14.6	19.0

5.1.2 Water masses, fronts and thermohaline patches

In the upper layer of the Baltic it is possible to distinguish between the larger relatively homogeneous water masses of different salinity separated by fronts with gradients. Waters with different salinity often tend also to have different temperature and/or different concentrations of chemical and biological parameters. Fronts which serve as some kind of barriers isolating larger water bodies are characterized by specific horizontal and vertical currents, mixing etc.

In section 4.2.1 we could distinguish three types of waters in the PEX area - low-saline waters in the west, saline waters in the east and waters of intermediate salinity between them. The low- and medium-saline waters were separated by a strong quasi- permanent front with a salinity drop of 0.2 while the saline and medium-saline waters were separated by the less intensive and less stable front with a salinity drop of less than 0.1 across the front.

According to data provided by Klaipeda Hydrometeorological section (c.f. 4.1.5, Fig. 4-11a) the low saline water extended from the PEX area to the area between Gotland and Swedish coast. Near the eastern coast of the Baltic both high and low saline waters were observed. Satellite data show that the waters near the eastern coast were warmer than in the open sea (c.f. section 4.5). Increase of temperature towards the east was observed also in the PEX grid (Fig. 4-15). Thus is may be concluded that the low saline waters were carried to the PEX area by the general circulation of the Baltic from the north, mainly via western Gotland Basin between Gotland and the Swedish coast. From the south more saline and warmer waters were brought. To the latter low saline and warmer water of the large east coast rivers were added. As the satellite images show the waters of the east coast could reach the PEX area by bursts of currents.

The persistent salinity front on the western slope of the PEX area was observed in the SLAR data and satellite images. The persistency of the front is obviously related to the steep increase of depth on the slope (Fig. 2.2). Historical CTD-data from the PEX-BOSEX area, available from 1978, reveal the existence of an almost permanent salinity front near the western slope of the PEX polygon, with the increase of surface salinity by 0.2 from shallow to deep area at a distance of a few miles (Elken et al., 1987). Both the shallow western and deep eastern water masses tend to be of about the same amplitude both seasonally and interannually. This is in general agreement with long-term salinity observations at international stations BY38 and BY9 (Matthäus, 1984) which show the decrease of the mean salinity in the upper layer from SSE to NNW by 0.4. The "western" front observed during PEX and described in 4.2.1 is obviously of the same nature.

The front of the western slope meandered around the mean position. The oscillation of the front axis relative to the slope increased by the end of the experiment. This is evident both according to the grid and anchor station data. At AN1 the "visiting" of lower salinity waters on 5 to 6 and 8 May could be followed (Fig. 4-70) and at AN2 on 7 May (Figs. 4-65 and 4-66). AN1 was located 5.4 miles from the western edge of the Eddy grid in the part of the front area characterized by higher salinity and lower temperature (c.f. Figs. 4-14, 4-15). AN2 was located in the water of intermediate salinity, with the mean salinity lower than at AN1. The front was meandering with a period of 1-2 days. Day-to-day changes of salinity demonstrated a wave-like pattern (Figs. 4-21, 4-22).

The penetration of higher salinity water to the south-east corner of the PEX area and the structure of the related "eastern" front has been described in detail in section 4.2.1 (Figs. 4-12, 4-13).

The water of intermediate salinity between the two fronts was of more complicated, patchy structure consisting of thermohaline patches. By a thermohaline patch we mean a water body characterized by its temperature and/or salinity.

During the early spring when temperature variations in the upper layer have minor influence on the water density, the latter is determined mainly by salinity, taking into account that in hydrostatically stable conditions lighter waters are floating on top of heavier water, water bodies of lower salinity than that of the surrounding water take the form of lens-like patches floating in the surface layers, while water bodies of higher salinity extend down to the pycnocline. The newly-formed patches of lower salinity have often sharp edges and they are relatively isolated from the surrounding water because the sharp density change at the edges supresses turbulent mixing.

We can characterize the three PEX patches of lower salinity and higher temperature described in section 4.2.1 in a following way: the western patch extended down to 30-40 m. On the 25 April Eddy grid the patch was more pronounced on transect D than C (Fig. 4-14). The central patch, extending down to 40 m, had a very homogeneous nucleus (Fig. 4-16). The patch was located in the core of the cyclonic eddy above the uplifted halocline (see 5.1.3). On the east the patch was bounded by the salinity front. The eastern patch, half of which appeared on the 25 April Eddy grid, extended down to 10-20 m only (Fig.4-14).

5.1.3 Current jets and eddies

Direct current measurements (Figs. 4-117 to 4-120) displayed the anticyclonic eddy and jetlike currents in the western part of the Eddy grid area. Spacing of current measurements was not uniform over the Eddy grid. While the Slope grid was relatively well covered the eastern part of the Eddy grid was almost not at all covered. For a better understanding of the current systems density data from the grid stations and some remote sensing observations will also be considered. The low-frequency currents are expected to be in geostrophic balance with density gradients. This means that the mutual adaptation of independently measured current and density values allows for a better accuracy and resolution reproducing both the current and density fields. Dynamic topography provides the geostrophic streamfunction of relative currents. If the deep currents are slow compared to the upper layer currents, the dynamic height of an upper layer isobar relative to a deep layer isobar presents satisfactorily the absolute currents. During PEX this was valid for the Slope grid area except for the easternmost part.

Maps of the dynamic height of 10 dbar relative to 90 dbar calculated for the four Eddy grids are presented in Fig. 5-4. Comparison with direct current measurements and satellite data is also provided. The evolution of several structures of relative currents could be traced.

a) A southward current jet meandering around the central axis of the deep channel (Eddy grid lines U and V).

The easternmost and westernmost extremes of the meandering jet showed southward phase propagation with the speed of 1 mile per day at the meander wavelength of about 20-30 miles (40-60 km). The dynamic height patterns are in agreement with the current measurements at mooring stations No. 11 and 4 which showed southward components of velocity during the whole experiment. Jetlike penetration of water to the Eddy grid from the northeast was also shown by the satellite data (e.g. Figs.4-123 and 4-124). The current jet had the width of about 10 km, the southward currents were about 10-15 $cm \cdot s^{-1}$ in the upper layer.

b) A northward current jet near the western slope of the polygon.

This current jet with speeds less than 8 $cm \cdot s^{-1}$ was located just to the east of the salinity front between the Eddy grid lines R and S, passing also through mooring stations No. 2, 3 and 13. The current jet was better observed during the second half of the experiment (Figs.4-117 to 4-120).

c) A southward current jet in the shallow low saline water front.

The described currents are due to crossfrontal density gradient, being less than 5 $cm \cdot s^{-1}$. The current jets b) and c) create remarkable current shear leading probably to barotropic-baroclinic instability of the front and frontal meandering.

d) An anticyclonic eddy between the stronger southward and weaker northward current jet.

On the maps of dynamic height this eddy corresponded to "dynamic high" around CS and CT on 25 and 29 April. This anticyclonic eddy was very clearly detected by direct current measurements (Figs. 4-117 to 4-120). The diameter of the eddy was about 20 km, the anticyclonic speeds amounted to 11 $cm \cdot s^{-1}$ in the upper layer.

e) A cyclonic south-migrating eddy to the east of the southward current jet.

The subsequent positions of this "dynamic low" eddy center (Fig. 5-4) corresponding to the dome-like uplift of isopycnals within the halocline (Fig. 5-5) were BW on 25 April, CW on 29 April, CV on 3 May and EV on 7 May. On the last day the eddy was clearly seen from the LANDSAT 5 image (Fig. 4-123). The diameter of the eddy was also about 20 km, the cyclonic speeds in the upper layer were estimated at 10 $cm \cdot s^{-1}$.

A simplified scheme of the surface currents, water masses and fronts is depicted in Fig. 5-6. Actual currents may considerably differ from that scheme.

5.1.4 Inertial waves and oscillations

The currents in the Baltic Proper usually show strong inertial signals, however, due to the weak winds during PEX inertial motions were only slightly excited. In this section some indications of inertial signals are briefly discussed.

Basically inertial motions occur as inertial oscillations and inertial waves (Poincaré-waves). The inertial oscillations are slab-like motions, which affect only the horizontal current components. The inertial waves are dispersive with locally varying wave numbers and frequencies. They are associated with both horizontal and vertical motions. They are generated at the boundaries, propagating offshore with their maximum group velocity and leave behind a geostrophically adjusted state.

We assume that the steep slope northeast of the PEX area acts similarly as a wall and consider the rest of the PEX area as flat-bottomed. To any change of the wind the upper mixed layer responds like a slab with classical inertial oscillations. From the boundaries barotropic and baroclinic modes of inertial waves start to propagate off shore with their associated maximum group speeds. The barotropic front moves rather fast and changes the initial excited motion into a slab-like motion whereby the signals in the lower layer are about one third or less of that within the upper layer. Later the baroclinic modes arrive successively and modify the slab-like oscillations to motions with upward vertical phase propagation and frequencies somewhat higher than the inertial. The baroclinic inertial waves propagate with their maximum group speeds

$$1 / \lambda_n = \bar{N}H / n\pi \quad , n=1, 2, 3.....$$

were $\bar{N}$ is the mean Brunt-Väisälä frequency and H is the mean depth. Thus the baroclinic fronts would need many hours or even a day to arrive at a certain grid point. In particular it would take several days for baroclinic inertial waves to cross the channel. Thus the dominating part of the horizontal inertial motion is the slab-like oscillation which directly responsed to the wind. The vertical inertial motion is due to inertial waves excited by wind events a few days ago.

There is strong evidence that wind stress enters the sea like a body force more or less evenly distributed in the upper layer of the thickness H_{mix}. As there was no thermocline during the first part and only a weakly developed one during the second part of PEX, the mixing depth is defined by the penetration depth of surface-wave-induced turbulence. According to FENNEL et al. (1986) the mixing depth is related to the wind speed V as

$$H_{mix} = c \cdot V^{3/2}$$

were $c = 1.3\ s\ (s \cdot m^{-1})^{1/2}$ is an empirical constant. The amplitude of the inertial oscillation is proportional to U_*^2/fH_{mix}, where U_* is the friction velocity defined by

$$U_*^2 = \tau / \rho_o$$

(ρ_o = standard density of the water, τ = wind stress).

The wind stress is related to V by

$$\underline{\tau} = \underline{V} \cdot V \cdot \rho_a \cdot c_{10}$$

where $\rho_a = 1.225\ 10^{-3}\ g \cdot cm^{-1}$ is the density of air and c_{10} is the drag coefficient.

$$c^{10} \begin{cases} 1.6 \cdot 10^{-3} & \text{for } V < 7\ m \cdot s^{-1} \\ 2.5 \cdot 10^{-3} & \text{for } V > 7\ m \cdot s^{-1} \end{cases}$$

Thus we get $U_*^2 / fH_{mix} = V^{1/2} \cdot \rho_a/\rho_o \cdot c_{10}/fc$

Table 5-2 : Amplitudes of inertial oscillations and the corresponding mixing depths for some wind speeds.

V in $m \cdot s^{-1}$	U_*^2/fH_{mix} in $cm \cdot s^{-1}$	H_{mix} in m
2	1.8	3.7
4	2.5	10
6	3.1	19
8	5.6	30
10	6.2	41
12	6.7	54

Obviously, if there is no thermocline, the amplitude of the inertial oscillation increases rather slowly - with the square root - of the wind speed. As shown in Figs.4-2 and 4-3 the wind speed during PEX was only a few $m \cdot s^{-1}$ except for the very beginning where the wind reached about 10 $m \cdot s^{-1}$. Thus from table 5-2, based on the previous calculations we can expect weak inertial oscillations with magnitudes close to the instrumental thresholds.

This was found qualitatively at mooring position 6 (see the histograms in Fig. 5-9) . From 24 to 28 April some inertial oscillations at both 8 and 38 m depth can be seen. They are in phase and overlaid by a low-frequency current towards N-NE. These oscillations may be attributed to a wind event before PEX. From 28 April to 3 May the current shows practically no inertial motion although the wind magnitude is almost the same from 25 April 1200 GMT to 26 April 0600 GMT as on 27 April. It seems that the gap in the wind speed of approximately one inertial period on 26 April caused an excitation of new inertial oscillations with the opposite phase which cancels the former one. After 3 May new inertial oscillations started in the 8-m level but not at 38 m depth. This is in accordance with Table 5-2, where mixing depths less than 20 m correspond to wind speeds of about 5 to 6 $m \cdot s^{-1}$. The magnitudes of the oscillations fit also roughly the values given in Table 5-2. Examination of the time series of the other mooring stations reveals that there are well developed inertial signals at stations 5, 6, 7, 10, 11, 12 and 13 but no inertial signals were found at stations 3, 4, 8 and 9 (Fig. 5-7). No sufficiently long time series was available from stations 1 and 2.

One possible explanation of the patchy occurrence of the inertial motions could be an interaction with sub-inertial processes. Since the scales of the wind fields generally by far exceed those of the PEX area it seems to be unlikely that this could be attributed to the wind.

During PEX no attempts were made to measure vertical velocities directly. However, the up- and downward motions of certain isolines can be used to estimate them. A relatively well-defined oscillaton at the inertial frequency is appearant in the phosphat time series, Fig. 5-8. The vertical motions of the phosphate isolines suggest a vertical velocity amplitude of about $20 \text{ m}/0.5\, T_f \approx 0.08 \text{ cm} \cdot s^{-1}$, $T_f = 14.5$ h is the local inertial period. This value indicates that the vertical motion is due to the wind events preceding PEX. Then the inertial waves had enough time to propagate through the location of the anchor stations and, probably, through the Slope grid and maybe through the whole PEX area. It is also supported by the persistence of the oscillations. Otherwise such amplitudes could hardly be explained in terms of the wind events during PEX-86.

According to Kundu et al. (1983) the local wavelength of the inertial waves can roughly be estimated by

$$L \approx 2\pi \,/\, \delta/\delta_y \; \Phi$$

where Φ is the phase $\Phi = f\sqrt{t^2 - y^2\lambda^2}$.

$$\text{Thus} \quad L = \frac{2\pi R^2 \Phi}{y}$$

Here R is the internal Rosby radius. For example, at the anchor station AN1 we obtain with y= 30 km and R = 4 km

$t \cdot days^{-1}$	$L \cdot km^{-1}$
1	25
2	64
3	100

Thus the horizontal scales of the vertical inertial motion range from a few to about 50 km.

An important aspect of these findings with regard to the generation of patchiness follows from the fact that the up- and down-ward motion of nutrients affects the biological dynamics so far as it implies a change in the nutrient content of the euphotic zone.

5.1.5 Fine structure and small scale mixing

Formation of quasi-uniform regions in stratified fields of temperature, salinity and density of sea water can result from two causes:

- intrusion (advection) of strongly mixed water masses characterized by features distinctly different from those of the surrounding environment,

- local turbulent mixing of water masses in the stratified environment due to internal sources of turbulent energy.

Both the mentioned sources generate mechanisms changing in time and space the local characteristics of hydrophysical fields of temperature, salinity and density of the sea water. Identification of these sources can be accomplished on the basis of the variability of vertical distributions of temperature (T) and salinity (S) of the sea water using the Hesselberg equation of water mass stability for the non-adiabatic state:

$$\frac{1\overline{\Delta\rho}}{\rho_0 \Delta z} = -\alpha \frac{\overline{\Delta T}}{\Delta z} + \beta \frac{\overline{\Delta S}}{\Delta z} \qquad (1)$$

where :

$\alpha = - (1/\varrho_0)(\delta\varrho/\delta T)|_{p,S}$, $\beta = (1/\varrho_0)(\delta\varrho/\delta S)|_{p,T}$

and $\overline{\Delta}/\Delta z$ is the difference between the mean values of temperature and salinity at the borders of the layer of thickness Δz. ϱ_0 is the mean density of water in the Δz layer. Vertical distribution of density ϱ can stabilize water masses in a Δz layer ($\overline{\Delta\varrho}/\Delta z > 0$) or destabilize them ($\overline{\Delta\varrho}/\Delta z < 0$) causing vertical convective mixing. Using the stability parameter $R_\varrho = (\alpha/\beta)\cdot(\overline{\Delta T}/\overline{\Delta S})$, the following possible cases can be distinguished:

1. Stable vertical density distribution is formed under the conditions of inversive temperature distribution ($\overline{\Delta T}/\Delta z > 0$) stabilized by salinity distribution ($\overline{\Delta S}/\Delta z > 0$). Sources of local convective instability due to the processes of "double diffusion" in the places of occurrence of stronger local inversive temperature gradient can be formed in such a case and $0 < R_\varrho < 1$.

2. Stable vertical density distribution is formed under the conditions of salinity inversion ($\overline{\Delta S}/\Delta z < 0$) stabilized by temperature distribution ($\overline{\Delta T}/\Delta z < 0$). Sources of local convective instability due to the processes of "double diffusion" related to the phenomenon of "salt fingers" (Fedorov, 1972, Pingree, 1972, Schmitt, 1981) can be formed in such a case in the places of occurrence of strong local salinity inversions and $1 < R_\varrho < 2$.

3. Stable vertical density distribution is formed under the conditions of stable salinity distribution ($\overline{\Delta S}/\Delta z > 0$) and stable temperature distribution ($\overline{\Delta T}/\Delta z < 0$). Absolutely stable density field is dealt with in such a case and $-1 < R_\varrho < 0$. This criterion defines the conditions of absolute stability of hydrophysical fields of temperature, salinity and density in the layer. Local patchy structures can occur in such a case only when mechanisms generating Kelvin-Helmholz hydrodynamic gradient instability come into being. Such conditions are most often fulfilled in laminar layers of strong density gradients, in the presence of internal waves (Fedorov, 1972, Linden, 1975, Pingree, 1972).

Strongly mixed quasi-uniform layers separated with layers of significant gradients of a given hydrophysical feature can be formed in such cases in the vertical stratified structure of a hydrophysical field. The results of a series of investigations demonstrated that in such layers the Richardson number $Ri < 0.25$, and the Pingree criterion (Pingree,1972) basing on a half-empirical Prandtl hypothesis on turbulent mixing should be fulfilled in the layer. This criterion can be written in the following way for the Δz layer:

$$\frac{\sigma_T}{\sigma_S} = \left| \frac{\overline{\Delta T}}{\overline{\Delta S}} \right|_{\Delta z} \qquad (2)$$

where σ is standard deviation.

Since fluctuations of T' and S' also can be due to kinematic effect of internal waves in laminar sublayers, also fulfilling this criterion, differentiation of the processes of turbulent mixing and kinematic effect of internal waves must be carried out on the basis of additional criteria (Linden, 1975, Zurbas et al., 1984).

4. Vertical density distribution is a neutral distribution ($\Delta\rho/\Delta z$) = 0. Uniform advection can occur in such a case and R_ρ = 1. Pingree criterion for such a case has the following form:

$$\frac{\sigma_T}{\sigma_S} = \left.\frac{\beta}{\alpha}\right|_{\Delta z} \qquad (3)$$

5. Intrusions of water results in stratification of the Δz layer through convective mixing caused by double diffusion at the borders of inversion sublayers. Fluctuations of all the physical parameters of water are characterized in such a case by a so-called "relative intrusion amplitude" and a criterion formulated by Zurbas and Lips (1987).

The abovementioned five cases describing the sources of processes capable of formation of patchy structures of temperature, salinity and density of sea water cover in principle all the possibilities of nature in this field. On this basis the sources and mechanisms conditioning formation and size of patchy structures within the region of the PEX anchor stations will be considered.

The correlation coefficient between momentary dimensionless fluctuations of temperature ($\alpha T'$) and salinity ($\beta S'$) recorded with CTDs reveal very weak relationships between the recorded magnitudes, which means that within the examined layer the processes of turbulent mixing are not of inertial character, i.e. they are not generated by Kelvin-Helmholtz gradient instability. The correctness of this evaluation is testified by the Richardson number (Ri) in the layer from 10 to 40 m, calculated on the basis of instantaneous values of the Brunt-Väisälä parameter and mean daily gradients of the module of current velocities measured at the AN1 station. Absolute instantaneous Ri values, greater by two orders of magnitude than the critical value Ri = 0.25, distinctly indicate lack of small-scale turbulence from the inertial interval. Hence, it can be stated that in the vast majority of cases they are the local thermal and salinity inversions fulfilling the conditions 1, 2 or 3 earlier described, which are the sources of local hydrodynamic instabilities of water masses within the regions of AN1 and AN2, capable of formation of patchy structures in temperature, salinity and density fields.

Let us verify this diagnosis using the Pingree criterion. Figure 5-7 shows diagrams illustrating variability in time of the R_ρ, and $|\Delta T/\Delta S|$, σ_T/σ_S and α/β parameters. These characteristics distinctly indicate that during the PEX April period, when $R_\rho > 0$ and $\beta/\alpha \ll \sigma_T/\sigma_S$, the Pingree criterion is not fulfilled within the regions of both the measurement stations. Hence, temperature inversions observed in the momentary distributions are not generated by thermohaline intrusion processes in the density field, but are most probably due to anisotropic circulation of water masses of similar salinity and different temperature. Hodographs of sea currents within the region of AN1 indicate the possibility of the existence of such a mechanism. A similar situation takes place within the region of AN2 Characteristics recorded at AN1 reveal strong similarity of the values of the $|\Delta T/\Delta S|$ and β/α parameters on 5 May, indicating the possibility of fulfilling of the Pingree criterion during this period. It follows from vertical temperature and salinity distributions recorded on 5 May that this diagnosis holds true.

This diagnosis can be summarized in the following manner:
- during April the vertical stratification of the density field is not absolutely hydrodynamically stable and weak anisotropic advective processes of waters of similar salinity often resulted in the formation of local thermal inversions at various depths, generating convective instability. This instability was a source of mixing and conditioning the dimensions of the quasi-uniform patchy structures in temperature, salinity and density. This characterizes both AN1 and AN2 during the entire May investigation period. The above-described processes continued to condition the mechanisms of local mixing, yet they occur under the conditions of much more stable stratification, close to absolute stable stratification. A short-term thermohaline inversion within the region of AN1 on 5 May constitutes the only exception to this.

Figures 5-11 and 5-12 illustrate examples of isolines of similar values of temperature, salinity and density in the (z,t) coordinates obtained during the May measurement period at AN1 and AN2. These isolines, drawn every 0.2°C in the case of temperature and every 0.05 units in the case of salinity and conventional density, reveal the existence of distinct structures in all three hydrophysical fields. The amount of these structures in the temperature field was however much greater than in the salinity field.

An evaluation of the dimension of a patchy structure has been made for the region of AN1. This study presents an example of an analysis of the evolution of the temperature field during the period from 25 April to 8 May. The result of this analysis, shown in Table 5-3, indicate that the thickness of 80% of all the patchy structures fall within the range $2m \leq b \leq 4m$, 50 % of which is characterized by the horizontal dimensions contained in the interval $0.1\ km \leq a \leq$

1 km. The analysis also revealed the existence of patches of dimensions largely exceeding those of the most common ones. This includes two patches of the horizontal dimension a ≈ 7 km and thicknesses equal to b1 ≈ 4m and b2 ≈ 8m, three patches of the horizontal dimension a ≈ 9 km and thicknesses equal to b1 ≈ 10m, b2 ≈ 7m and b3 ≈ 4m, one patch of the dimensions a ≈ 11 km and b ≈ 4m, one patch of the dimension a ≈ 13 km and b ≈ 10m, as well as one patch of the dimensions a ≈ 16 km and b ≈ 4m. The evaluation of the horizontal dimension "a" is obviously erroneous to some extent, particularly in the case of layers situated below 20 m, which results from the errors accompanying empirical data on the current velocity, used in the formula: $a = \Delta t |u|$, and from the error of graphical evaluation of the Δt time interval. All the patchy structures in the temperature, salinity and density fields at AN1 and AN2 were estimated with respect to the "b" parameter. These data are listed in Table 5-4. It is characteristic that all the thicknesses of patchy structures fall within the range 2m ≤ b ≤ 10m, i.e. in the range characteristic of quasi-uniform layers revealed in field investigations of fine structure of hydrophysical fields in seas. This fact confirms indirectly the correctness of the diagnosis made in this study. It also follows from data listed in Table 5-4 that patches in the density field are determined mainly by the salinity field.

Table 5-3 Characteristics of thermal patchy structures of thickness up to 10 m at AN1 25 April to 8 May

a(m) ----- b(m)	>100 <500	>500 <1000	>1000 <1500	>1500 <2000	>2000 <2500	>2500 <3000	>3000 <3500	>3500 <4000	>4000 <4500	>5000 <5500	Total
2-2.9	12	8	5	3	2	1	-	1	1	-	33
3-3.9	-	5	-	2	2	1	1	-	-	1	12
4-4.9	-	2	2	-	-	1	1	-	1	-	7
5-5.9	-	-	-	-	-	-	-	-	-	-	-
6-6.9	-	-	1	1	-	-	-	1	-	1	4
7-7.9	-	-	-	-	-	-	-	-	-	-	-
8-8.9	-	-	-	-	-	-	-	-	-	-	-
9-9.9	-	-	-	1	-	-	-	1	-	-	2
Total	12	15	8	7	4	3	2	3	1	2	58

Table 5-4: Number of patchy structures of the thickness (b) in temperature (T), salinity (S) and density (σ_t) fields, 25 April to 8 May

b (m)	AN1 Temp.	AN1 Salin.	AN1 Dens.	AN2 Temp.	AN2 Salin.	AN2 Dens.
2-2.9	33	27	29	29	19	17
3-3.9	12	6	3	16	6	10
4-4.9	7	3	2	9	4	2
5-5.9	-	1	2	3	2	1
6-6.9	4	1	1	2	1	1
7-7.9	-	-	-	-	-	-
8-8.9	-	1	1	-	-	-
9-9.9	2	-	-	2	1	1
Total	58	39	38	61	33	32

5.1.6 Convection

In this chapter different physical processes, which are associated with vertical motions are discussed.

Wind - induced small scale turbulence within the upper mixed layer mixes down water particles within one hour from the sea surface to the mixing depth H_{mix}, which depends in a first order only on the local wind velocity if H_{mix} (c.f. 4.1.4) is smaller than the depth of the local pycnocline. According to the wind velocities given in section 4.1.1 H_{mix} was calculated about 40 m at the very beginning of PEX but decreased to 20 m and less during PEX. H_{mix} varies with the local wind field, i.e. the spatial scale of H_{mix} is the basin scale.

Large vertical velocities are induced by convection which occurs in cells having a spatial scale equal to the first baroclinic Rossby radius (Killworth, 1983) which, during PEX, was about 4 km. Convection is driven by negative buoyancy flux through the sea surface increasing the density of the uppermost layer until it is higher than the density of the layers immediately below it. Then the surface water particle will sink under the action of gravity with velocities up to 1 $cm \cdot s^{-1}$ (Killworth, 1983) down to a depth D_c, where the density of the surrounding water is larger than that of the sinking water.

During PEX the surface salinity varied between 7.36 and 7.68 (c.f. section 4.2.1). Hence, the temperature of the maximum density of the sea water was between 2.35 °C to 2.34 °C. The mean surface temperature was below this interval before 29 April and above it after this date. That means that positive heat flux forced convection before the end of April and supressed it during the first week of May. In the case of negative heat flow the inverse follows.

However, the heat flow contributes only a very small amount to the buoyancy flux if the water temperature is near that of the density maximum T_M, since according to the equation of state (e.g.Fofonoff, 1985) the density is near T_M.

$$\rho = \rho_o + 8\ 10^{-1}\ kg/m^3\ (S-S_o) + 1.7\ 10^{-2}\ kg/m^3\ (\ °C\ )^{-2}\ (T-T_M)^2$$

The temperature $T = T_M + (T_G - T_M) + (T - T_G)$ may vary only by a small amount around the mean grid temperature T_G. Then we can neglect the term $(T - T_G)^2$. Since T_G is about 0.5 °C below T_M during the first Eddy grid at the 25 April, the density varies in this particular grid

$$\rho = \rho_o + 8\ 10^{-1}\ kg/m^3\ (S-S_o) + 1.7\ 10^{-2} kg/m^3\ \ °C^{-1} (T-T_G)$$

From Figs. 4-12 and 4-15 it follows that the salinity and temperature variations were 0.1 and some 0.1 °C respectively. Thus density changes in the PEX grid at 25 April due to temperature variations were by one order of magnitude smaller than those due to the salinity variations. During the May period of PEX the temperature and salinity variations contributed equally to the density in the PEX area. That means that thermally forced convection in the first phase of PEX could be prevented by very weak salinity stratification, which is governed by inertial and subinertial dynamical proesses.

A measure of the convection depths (Fig. 5-13) for the April period has been derived from the CTD profiles on the Eddy grid stations by estimating the depth where the salinity was 0.02 and 0.04 larger than at the 5 dbar level. For the May period the corresponding depths have been estimated by using an increase in $\rho_{(T,S,p=0)}$ of 0.02 $kg \cdot m^{-3}$ and 0.04 $kg \cdot m^{-3}$. Both convection depths are depicted in Fig. 5-13 at almost all Eddy grid stations. The convection depth exhibits a "w"-shape on most of the Eddy grids in April. Low convection depths at the western edge of the grid due to the shallow water depth were observed as well as at the center and the eastern edge of the grid. Deep convection depths were located between the areas of shallow convection depths. The "w"-shape was aligned normal to the contours of the bottom topography. The typical length scale in this direction was 40 km. In May phase the "w"-shape disappeared and became gradually shallower due to the heating of the near surface layer. The grid mean value of the convection depth at 7 May is shallower than 20 m in agreement with the depth of wind mixing mentioned above.

The similarity of the shape of the convection depths with the vertical salinity distributions (c.f. 4.2.1.1) suggest that convention was determined by dynamical processes governing the local salinity stratification below the wind mixing depth.

Let us assume that by a strong wind event the salinity is well mixed between the surface and the halocline. Then the salinity stratification could be re-established by ageostrophic currents advecting salinity in the direction of the horizontal gradients. We note the existence of a basin wide salinity gradient. Simultaneously the vertical salinity gradient together with vertical velocities affect the stratification in an important manner. Significant vertical velocities in the water column are associated with inertial waves (c.f. 5.1.4.).

Further vertical velocities associated with subinertial eddies can have similar effects on the salinity stratification as in inertial waves.

The corresponding vertical velocity can be estimated by

$$w = \frac{\delta \eta}{\delta t}$$

where w is the vertical velocity, t the time and η the vertical displacement of an isoline of temperature and salinity, it may be deduced from Fig.4-16 that the occurrences of vertical velocities in stratified areas above the halocline are associated with subinertial dynamic patterns, e.g. eddies and topographic waves. The time and space scales of these patterns are at least 4 days and 4 n.m. respectively. In particular we observe that at the bottom of the euphotic layer, upwelling between the stations CR-CS, CU-CV and downwelling between CX-CY occurs.

The western edge of the PEX grid is a special area with respect to vertical motions. There the stratification may be affected by Ekman-upwelling and -downwelling. In the last week of April a sequence of upwelling and downwelling occurred due to the changing wind direction. In May, however, neither upwelling nor downwelling was present according to the prevailing wind direction.

5.2 Chemical processes

The PEX programme did not include the study of strictly chemical processes. Chemical variations observed during the investigations are mainly caused by physical and biological processes. The development of the concentrations and the variability of the nutrient concentrations in the surface

(10 dbar) layer was very similar in both cases. The, on average, decreasing nutrient concentrations reflect the development of the phytoplankton. The variability in these trends reflects the patchy distribution of the phytoplankton which is mainly the consequence of physical processes.

5.3 Biological processes

In PEX, because of the season, only phytoplankton and related biological processes influence the biological and chemical distribution patterns.

The biological processes are:

- -growth
- -succession and
- -sedimentation

The growth of phytoplankton is a biological process which counteracts the dispersion of the algal cells by water movements. Therefore the growth rate has to be sufficiently high to create a heterogenous distribution. A bloom starts at certain places ("lenses", "filaments", etc.) and extends by physical transport and local growth promoted by nutrients and physical factors. This is sufficient to create a heterogenious distribution, while other factors also help promoting patchiness (Fig. 5-14). In the phytoplankton growth process important processes e.g. nutrient uptake, photosynthesis, carbondioxid and oxygen production/consumption are included, which might have an influence on the distribution patterns of served parameters. The succession of phytoplankton species is mainly caused by various eco-physiological demands of the species such as nutrient uptake kinetics and light requirements. Ecological competition between species presumably plays an important role. Besides the cell dispersion by physical processes sedimentation of phytoplankton is most important during this season (c.f. 4.7). The sedimentation rate ran parallel to the increase in suspended phytoplankton and different species dominated according to the succession order. Thus, e.g., <u>Thalassiosira levanderi</u> more or less disappeared from the surface layer at the end of the spring bloom, given place to e.g.<u>Sceletonema costatum</u>.

Due to the relatively low abundance of zooplankton compared with the phytoplankton bulk and the seemingly low grazing rates at the observed temperatures, it was not possible to establish any direct impact of the zooplankton on the phytoplankton abundance and distribution.

6. Interdisciplinary links: some examples

6.1 General remarks

The initial development, groth and final sedimentation of phytoplankton are influenced by extreme physical structures, e.g. stratification, fronts and eddies. Convection, advection and turbulent mixing also influences the distribution pattern.

Besides the physical structures and processes the biological processes mentioned in 5.3 determine the patchiness of both biological and chemical parameters (Fig. 5-14). The physical structures are most importanr for the generation of biological/chemical patchiness in the initial and terminal phases.

6.2 Some relations between physical and biological structures and processes.

The results of investigations of heterogeneity depend on observation characteristics and signal-noise ratio of the parameters. According to the sampling theorem patterns of more than double the measuring distance can be resolved. That means distances of 4-8 n.m. in horizontal direction, 5-20 m vertically, and patterns of at least two days persistence in this study. From the biological point of view the most important features to be observed are patterns of phytoplankton.

Seasonal and basin-wide scales were not resolved in PEX. Transects before PEX show that the spring bloom had already finished in the western Baltic, commenced in the Arkona Sea, started in the Bornholm Sea and in the northern Baltic Proper, and existed in the form of filaments and lenses in the central Baltic. The filaments, with slightly higher temperature, might be initiated by salinity stratification or originate from the coastal areas.

With the sampling scheme used during this investigation the resolution of patches observed was in the range of 2-15 n.m. and the time resolution was one day. Higher resolution in time was achieved by the ships anchored and the free drifting ship, higher resolution in space was achieved by one ship measuring on track.

The development of the plankton bloom was influenced by the comparatively weak vertical mixing resulting from the very calm weather conditions. The seasonal thermocline, important for limiting the vertical transport of nutrients, was established around 1 May.

The physical processes in that are, in particular, stratification, patterns of currents and mass fields, and convection were of crucial importance for the generation of thr phytoplankton patches. The nutrient concentrations were at this time sufficiently high not to have any influence on phytoplankton patchiness. Several physical structures could be traced in the biological patterns

1) the cyclonic and anticyclonic eddies,

2) the permanent salinity front in the shallow western area,

3) the higher salinity water in the SE-corner.

Within the two eddies and the higher salinity patch the bloom was probably initiated by the salinity-related stratification of the water column. The different water masses however were characterized by different species compositions. High abundances of Skeletonema costatum together with Achnanthes taeniata were found exclusively in the higher-salinity water while Thalassiosira levanderi and Chaetoceros spp. were especially abundant in both eddy areas. Those three species were not abundant to the west of the salinity front while A. taeniata was abundant on both sides.

The spring bloom phytoplankton species succession in the Baltic Proper generally proceeds from the community characterized by Achnanthes taeniata and Thalassiosira spp. towards the community of Skeletonema costatum and Gonyaulax catenata (Edler 1979, Schulz 1985). This succession might be caused by the physiological demands and morphology of the species.

The successional stages observed in the PEX area were complex. There were signs of a transition between the two stages mentioned above indicated by the opposite development of the abundances of Thalassiosira levanderi and Skeletonema costatum in the surface layer and the intense sedimentation of T.levanderi from the end of April. However, no signs of a decline of A. taeniata could be seen.

The mesozooplankton showed a typical spring community with Pseudocalanus minutus elongatus, Fritillaria borealis and Acartia spp. being the most abundant components. These species were in different stages of their spring spawning period: Pseudocalanus females started their seasonal migration downwards, and the first generation of young copepodite stages appeared at the end of the PEX period (7 - 9 May). Young stages of Acartia were quite numerous; females numbers were still increasing, while Fritillaria borealis had started mass development.

In the high salinity water in the southeastern corner on 25 May A. taeniata and S.costatum dominated but probably not representing a late successional stage. This can be concluded on the basis of higher nutrient concentrations and assimilation numbers. It seems that within this water mass the first Thalassiosira-stage had been skipped.

The chlorophyll a concentration west of the salinity front stayed persistently high but did not reach the maximum typical to the eddy areas, indicating different bloom dynamics.

In the beginning of the experiment the two eddies were associated with very high chlorophyll a concentrations. The cyclonic eddy was persistent during the whole study period but moved slowly southwards. The chlorophyll a content in the eddies decreased after sedimentation of the phytoplankton. The very distinct minima of phytoplankton concentrations on the periphery of the eddies were probably due to a complicated vertical circulation pattern (convergence-divergence cells), while the extremely sharp gradients were maintained by the velocity shear between the eddy boundary and the surrounding water.

The vertical stratification and the distribution of chlorophyll a were different in the two eddies. In the cyclonic eddy the water was vertically mixed to 40-50 m, but in the anticyclonic eddy the salinity stratification prevented vertical mixing below 30 m. The phytoplankton communities in both eddies were similar and characterized by A. taeniata, T. levanderi and Chaetoceros spp. but very few Skeletonema cells. Sedimentation explained the decrease in phytoplankton concentrations in the eddies. Sedimentation rates were, however, species specific. Sedimentation of the spring bloom is a well known process, but to what extent sedimentation was triggered by external factors like nutrient limitation and what role internal cell rhythms played can not be concluded at this stage. Low assimilation numbers gave an indication of a bad physiological condition.

The patchy development of the phytoplankton bloom was the main reason for the patchiness of nutrients. pAfter the formation of the thermocline in the first days of May the nutrients were rapidly exhausted in the upper 15 m.

Significant patchiness was observed on the fine scale (0.1 to 4 km) but the sampling schemes on the grids were generally not sufficient to resolve that. However, the chlorophyll a gradient at the periphery of the cyclonic eddy was characterized by a jump from less than 2 mg m^{-3} to 13 mg m^{-3} within a horizontal scale of 200-300 m.

The salinity front in the western region of the Slope grid can be seen in the distribution pattern of the zooplankton species. In the low-salinity-waters west of the front, P.m. elongatus occurred in lower numbers than east of it, while Acartia spp. were more numerous in this area. It is not clear, whether this was due the salinity or to the fact, that for example Pseudocalanus prefers the deeper area. A second pattern ssemed to be a very strict border between the three northern and the southern transects. This was also found in the chlorophyll a distribution of 26 April and in the contour maps of some phytoplankton species. It is possible that certain phyto- and zooplankton species were either attracted to zones of high turbulence or strong gradients in the periphery of the eddy situated in the northeast corner of the slope grid area or avoided them. While this pattern disappear in phytoplankton contour maps after the 27 April due to the sedimentation of the phytoplankton bloom, it was relatively stable for the zooplankton to the end of the investigation period.

6.3 Diurnal cycles at anchor stations

Diurnal cycles have been calculated as relative deviations from the corresponding 24-hour-means. They are shown for temperature, oxygen, primary production (<u>in situ</u>) and secchi depth in Fig.6-1. With respect to diurnal cyles of primary production which is dependent on day light intensity and duration, true local time has to be considered. The mean length of day during the investigation period was about 15 hours (sunrise: 0422, sunset: 1932 true local time on 1 May, 0306 / 1816 GMT rsp.; preceded/followed by about 110 min of dawn).

The oxygen and temperature cycles are similar with a phase delay of of oxygen of three hours relative to temperature. The temperature minimum is shown just before or at sunrise, increasing rapidly until a maximum at between 1300 and 1400 GMT (3 hrs after local noon) and slowly decreasing during the following 12 hours.

Primary production and secchi depth show negative correlations. Secchi depth is lowest when primary production reaches a maximum and vice versa. Additional measurements showed that primary production values after 2100 GMT are close to zero (approx. 2 hrs after sunset).

Maximum primary production is reached in the early morning (about 0500 GMT, 2 hrs after sunrise). So the phytoplankton is productive already at dawn. After this maximum the production decreases rapidly until 1200 GMT. A second but weaker maximum of primary production is found at 1500 GMT.

The 6 to 9 hrs delay of the oxygen maximum relative to the primary production maximum (6-9 hrs) surprises. However, considering that oxygen is an integrative parameter, i.e. is increasing as long as primary production (even low level) is going on. The oxygen maximum is reached just before "negative production", i.e. respiration is starting or exeeding the production rate which occurs during and after dawn. (Note that Fig. 6-1 shows <u>relative</u> deviations from the 24 hrs mean, i.e. negative values of relative primary prod. do not mean negative productivity !).

The diurnal cycles in chlorophyll <u>a</u> concentrations and abundance of the main phytoplankton (Fig. 4-86a, c, d) corresponded with those of primary prductivity.

Well defined diurnal cycles were also found in the abundance of zooplankton species (Fig. 4-105a-d). Quantitative description, however, requires more detailed data evaluation because of significant differences in the phases and amplitude of the diurnal cycle at 5, 10 and 30 m depth as well as during the two investigation periods in April and May. The results indicate considerable vertical migration difference between April and May.

The station times were fixed with respect to GMT and did not adequately cover the local light period. Due to analytical procedures the sampling frequency was restricted to 5 samples per day only. It is very difficult to calculate diurnal cycles (time of maximum and minimum especially for primary production) based on coarsely spaced data. However, it was found that the (negative) correlation between primary production and secchi disk readings would allow reliable interpolation of production measurements for the entire day-light-period. Thus primary production measurements shoud be supplemented by collection of secchi disk readings at 1 hour - or even less - intervals during day light. In addition the first/last primary production samples should be taken just before/after sunrise/sunset.

7 Conclusions and Executive Summary

7.1 Introduction

Since the 1960s the interest in spatial and temporal inhomogeneity in the distribution of marine parameters has increased considerably.

Inhomogeneities are manifested in the patchy distributions of various parameters. Patchiness is, in fact, 4-dimensional since it has both spatial and temporal dimensions. Studies of satellite images and direct investigations have revealed very complicated patterns. An understanding of this is important for, e.g., the planning of monitoring programmes and for the understanding of the nutrient/fish distribution.

The Baltic Sea shows a marked patchiness (Fig.4-121 and 4-123). At the turn of the 1970s scientists became more actively engaged in research in this field, and within ICES the suggestion to carry out a joint international expedition to study the phenomenon took shape The objective was to make detailed 'maps' of the distribution of the most important parameters and to try and explain some of the dynamics by following the changes from day to day.

The joint Baltic Patchiness expedition, called PEX-86 was the largest international cooperative marine science investigation in the Baltic and took place in the last week of April and the first week of May 1986 in the Central Baltic (Figs. 2-1 and 2-2). Seven ships collected data in two grids, one 40 x 20 nautical miles, the other 20 x 10 nautical miles and situated inside the larger one. Four ships were anchored at two fixed stations inside the grids. In addition, two ships made special observations moving around in the area. More than 100 stations were repeatedly investigated. Depending on the parameter studied samples were taken from up to 10 different standard depths. The investigation also comprised studies of satellite images and aircraft remote sensing. About 150 scientific personnel and 190 crew members were involved, as well as additional scientists for the working up of data. A list of the ships is in Table A-1.

The data from all the ships were after the field investigation sent to the ICES Data Center in Copenhagen. After having been compiled and corrected they were sent out to groups of scientists working up different parts of the entire data complex and preparing the General Report of PEX-86. Besides this Report a number of individual papers, published in different connections and also issued in collected reprint volumes, will give more detailed information. Furthermore a Data Atlas will be published.

7.2 Methodology

The obligatory parameters investigated were:

Physical:	Temperature, salinity, currents and Sechhi depth
Chemical:	Oxygen, phosphate, and nitrate + nitrite
Biological:	Chlorophyll <u>a</u>, primary production capacity, phytoplankton and zooplankton

Besides, a number of non-obligatory parameters were measured by different ships. Satellite images and other remote sensing methods were also used (c.f. Table A-1).

Conventional and generally accepted methods were employed, in some cases with slight modifications.

Intercalibrations of methods and equipment for a number of parameters were carried out both before and during the investigation. The results of the intercalibrations were partly difficult to interpret. They were therefore not used for obtaining correction factors necessary for adequate comparison of measurement results from the different ships. Instead it was decided to use the values obtained at the 50 dbar level, where conditions appeared spatially uniform for the establishment of correction factors. For a few parameters, e.g. plankton, no correction factors were used.

Because it was possible to establish correction factors those inaccuracies do not play a major role for the interpretation and description of the main results, but they point to the fact that certain caution should be observed in relation to some details. They also give a warning for the future handling of intercalibrations and that continued vigilance in acquiring data sets that are consistent with one another is necessary.

7.3 Results

Spatial inhomogeneity (patchiness) was established for all measured parameters and temporal variabilitiy occurred on scales from hours to days. Continuous measurements with specialized equipment demonstarted the occurrence of variability on very small scales.

As planned, the investigation was carried out during the vernal plankton bloom. Both nutrient concentrations and larger quantities of phytoplankton could thus be studied simultaneously. The decline of the bloom could also be observed.

The investigation period was characterized by a calm weather situation. This was advantageous because it allowed observation of a development without too many disturbances. On the other hand it was not possible to see what changes occur during rough weather.

Below, the most important findings during PEX-86 are listed. They generally relate to the upper water layers where patchiness was most pronounced. Below 40-50 m depth conditions were much more uniform, even if irregularities could be found also here (c.f. chapter 4).

1. The investigated area was a channel, slightly more than 100 m deep, the western slope reaching up to about 25 m depth and the eastern slope up to about 80 m depth (Fig. 2-2). The channel-like structure proved important for, e.g., the patterns of currents and inertial oscillations.

2. Well defined fronts, eddies, lenses, tongues, and other formations were observed, both by <u>in situ</u> measurements and by satellite images (e.g. Figs. 4-12 to 4-19 and 4-121 to 4-127). They were created by salinity/temperature/density differences in combination with the wind force, etc., and variability, life-times and scales of these formations could be established.

3. Two eddies, cyclonic and anticyclonic, and three meandering current jets following the length of the channel were

found by a joint analysis of the current and CTD data. Two of the current jets were located at the different sides of the near-slope salinity front having opposite direction, and the third, southward current jet meandered around the central axis of the deep channel (Figs. 5-4 to 5-6).

4. Physical pcharacteristics, e.g. of salinity and heat content showed that some of the water masses were advected from outside the PEX area (Fig. 4-123). The size of smaller "visiting water bodies" could be estimated at the anchor stations.

5. Inertial signals, although generally weak, were observed on several occasions (Fig. 5-7). They had a patchy occurrence, for reasons which are not fully understood.

6. Solar radiation was above average, especially during the latter part of the investigation. This in combination with the calm weather conditions accelerated the formation of the thermocline. Horizontal heat transport became much smaller than vertical heat transport in the upper water layers. Convection currents were active in the formation of patches.

7. Results of measurements at the anchor stations permitted conclusions on short-term variations, fine patchiness structures and small-scale mixing processes which could not be resolved by the grid measurements, (cf. e.g. Figs. 4-66, 4-70 and 5-11).

8. Considerable day to day variations in solar radiation influenced the transmittance of light energy to the water mass (Figs. 4-130 and 4-131).

9. There was a pronounced optical variability in the PEX area (Figs. 4-128 and 4-129), which in some cases did not coincide with the patchiness structures. This variability was in general of a scale not before observed in the open Baltic Sea.

10. At the beginning of the period the concentrations of phosphate and nitrate + nitrite values showed a variability down to a depth of about 50 m. The most pronounced features were three minima associated with three eddies (Fig. 4-32).

11. Nutrient concentrations in the upper water layers decreased successively during the period, due to consumption by autotrophic organisms. At the end of the investigation period nitrate + nitrite was almost totally consumed, while there was still some phosphate available (c.f. Figs. 4-27 and 4-28).

12. The initial nutrient minima corresponded to maxima in the distribution of chlorophyll, particles and phytoplankton. The maxima levelled out as nutrients became scarcer and more evenly distributed. The general concentrations of phytoplankton decreased but remained high until the end of the investigation.

13. The distribution of oxygen corresponded largely with that of phytoplankton. The surface layer became oversaturated with oxygen (Fig. 4-29).

14. Primary production capacity values revealed the same patterns as chlorophyll a values.

15. The patchiness of phytoplankton was more related to the patchiness of physical factors than to the patchiness of chemical (nutrient) parameters. Different phytoplankton species showed different variability as compared with the physical patchiness (e.g. Fig. 4-48a).

16. Some changes in the phytoplankton species composition pointed to the development of a succession.

17. Mesozooplankton showed a typical spring community. Patchiness was often different from that shown by phytoplankton but was at least to some extent controlled by dynamical processes. Some species showed different patterns (e.g. Figs. 4-53 and 4-54).

18. It was not possible to establish whether phytoplankton was influenced by mesozooplankton grazing, nor could any certain relationship be established between light and planktonic migration.

19. At the anchor stations long- and short-term variability of both phytoplankton and mesozooplankton species was very high, both in numbers and species composition (c.f. Figs. 4-96 and 4-100).

20. Special studies with sediment traps confirmed the general conclusions as to the patchiness of chlorophyll and the distribution and species composition of plankton.

To sum up: The physical, chemical and biological factors showed a pronounced patchiness with spatial scales from hundreds of meters to hundreds of kilometers and a timescale from hours to weeks. During the investigation considerable changes occurred. The physical factors determined to a great extent the distribution of the biological factors. During the bloom the consumption by autotrophic organisms was, however, most important for the distribution of the chemical factors. Processes and interrelationships between different factors under the "patchiness umbrella" are described.

7.4 Some remarks on patches

The term "patch" is used for a more or less isolated water body with certain physical, chemical and/or biological properties as compared to the surrounding water. The different properties are variable in space and time.

According to the properties of the isolated water mass the the patches can be devided into:

physical patches	salinity patch temperature patch density patch	thermohaline patches
	velocity patch (rotating patch, eddies etc.)	
chemical patch	isolated water body with concentration of some substances different from the concentration in the surrounding water.	
biological patch	according to the kind of its biological characteristics.	

The patch can be multikind at the same time - being of physical, chemical and biological origin. Such patches could be named according to their origin - physical-chemical, chemical-biological etc. patches.

Most interesting are the links or interactions between different kinds of processes in the buildup, growing, existence and decrease of multikind patches. The patches are moving water bodies with variable properties and so they can highly affect e.g. the state of sea pollution.

8 References

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					LOGISTICS								
Disp(tons)	2140	1000	250	250	1600	1000	150	900		210	700	550	35
Length (m)	ca 80	ca 60	28	31	69	61	31	53		33	61	52	15
Call Sign	UWEP	UDFH	DLMG	DDIG	DBBX	SEPI	FMJU	OHLV		SPIC	SNSP	SQOC	
ICES code	47	49*	29	14	11	14	15	01	40	06	14	21	
No. scient.	24	13/14	6	7	12	12	4	15		12	12	12	2
Dur.(days)	50	30	14	14	20	30	14	14		14	30	30	
Day & night	x	day	x	x	x	x	day	day	x	x	x	x	
					EQUIPMENT/PHYSICS (OBLIGATORY)								
Meteorology	x	x	x	x	x	x	x	x	x	x	x	x	
CTD	x		x	x	x	x	x	x	x			x	
Rosette	x			x	x	x		x	x			x	
Auto-analyser	x			x		x		x					
Cur. meters	20(6)		(V. Hensen)-		9(3)	12(2)			4(1)	4(1)	4(1)		
Quanta meter	x				x			x				x	
Secchi Disk	x	x	x	x	x	x	x	x	x		x	x	
					CHEMICAL (OBLIGATORY)								
Oxygen	x	x	x	x	x	x	x	x	x	x	x		
PO4-P	x	x	x	x	x	x	x	x	x	x	x		
NO3+NO2	x	x	x	x	x	x	x	x	x	x	x		
pH(C14 only)	x	x	x	x	x	x	x	x	x		x		
Alkal.(C14)				x	x	x		x	x		x		
					BIOLOGICAL (OBLIGATORY)								
Chlorophyll	x	x	x	x	x	x		x	x		x	x	
P. Production	x	x	x	x	x	x,		x	x		x	x	
Plankton samp	x	x	x	x	x	x		x	x		x	x	
					CHEMICAL (VOLUNTARY)								
NO3	x	x		x				x		x			
NO2	x	x		x				x		x			
Si	x	x		x		x	x	x		x			
Tot-P	x									x			
Tot-N	x							x		x			
					BIOLOGICAL (VOLUNTARY)								
Plankton samp	x	x	x	x	x	x		x	x		x	x	
Microstruc.												x	
Sediment trap			x					x					
Part. Counts.	x		x			x							

Table A-1: Ships taking part in PEX-86, and measured parameters.

Table A-2 Daily totals of solar radiation energy in full(Total) and visible 400-700 nm (Vis) spectrum range at the station AN1 (PEX 86",r/v "Oceania") given in [J/cm^2*d]

April 1986

Depth\Day:	25		26		27		28		29		30	
H(m)	Total	Vis	Total	Vis	Total	Vis	Total	Vis	Total	Vis	Total	Vis
I-0	1813	---	1571	---	1542	---	2203	---	2054	---	1835	---
+0	1.62E+03	7.53E+02	1.36E+03	6.45E+02	1.34E+03	6.36E+02	2.00E+03	9.01E+02	1.84E+03	8.43E+02	1.62E+03	7.54E+02
1	5.66E+02	4.97E+02	5.03E+02	4.58E+02	4.21E+02	3.83E+02	6.11E+02	5.56E+02	5.75E+02	5.27E+02	5.37E+02	4.97E+02
2	3.73E+02	3.41E+02	3.50E+02	3.34E+02	2.47E+02	2.36E+02	3.69E+02	3.56E+02	3.51E+02	3.40E+02	3.44E+02	3.36E+02
3	2.57E+02	2.39E+02	2.57E+02	2.50E+02	1.53E+02	1.49E+02	2.39E+02	2.35E+02	2.29E+02	2.26E+02	2.35E+02	2.33E+02
4	1.81E+02	1.70E+02	1.93E+02	1.90E+02	9.78E+01	9.62E+01	1.61E+02	1.60E+02	1.54E+02	1.53E+02	1.65E+02	1.64E+02
5	1.29E+02	1.22E+02	1.48E+02	1.46E+02	6.37E+01	6.30E+01	1.12E+02	1.11E+02	1.06E+02	1.06E+02	1.18E+02	1.18E+02
6	9.30E+01	8.89E+01	3.72E+02	1.14E+02	4.21E+01	4.18E+01	7.81E+01	7.79E+01	7.49E+01	7.48E+01	8.58E+01	8.57E+01
7	6.75E+01	6.50E+01	8.93E+01	8.88E+01	2.81E+01	2.80E+01	5.55E+01	5.54E+01	5.30E+01	5.30E+01	6.27E+01	6.27E+01
8	4.94E+01	4.78E+01	6.94E+01	6.91E+01	1.90E+01	1.89E+01	3.95E+01	3.95E+01	3.78E+01	3.78E+01	4.61E+01	4.61E+01
9	3.64E+01	3.54E+01	5.39E+01	5.37E+01	1.29E+01	1.29E+01	2.83E+01	2.83E+01	2.71E+01	2.71E+01	3.40E+01	3.40E+01
10	2.71E+01	2.64E+01	4.19E+01	4.18E+01	8.83E+00	8.83E+00	2.03E+01	2.03E+01	1.95E+01	1.95E+01	2.52E+01	2.52E+01
11	2.02E+01	1.98E+01	3.26E+01	3.25E+01	6.10E+00	6.10E+00	1.46E+01	1.46E+01	1.41E+01	1.41E+01	1.87E+01	1.87E+01
12	1.51E+01	1.48E+01	2.54E+01	2.54E+01	4.23E+00	4.23E+00	1.06E+01	1.06E+01	1.02E+01	1.02E+01	1.39E+01	1.39E+01
13	1.12E+01	1.10E+01	1.99E+01	1.99E+01	2.94E+00	2.94E+00	7.66E+00	7.66E+00	7.40E+00	7.40E+00	1.03E+01	1.03E+01
14	8.38E+00	8.26E+00	1.57E+01	1.57E+01	2.05E+00	2.05E+00	5.59E+00	5.59E+00	5.38E+00	5.38E+00	7.70E+00	7.70E+00
15	6.22E+00	6.14E+00	1.23E+01	1.23E+01	1.43E+00	1.43E+00	4.08E+00	4.08E+00	3.92E+00	3.92E+00	5.73E+00	5.73E+00
20	1.40E+00	1.39E+00	3.91E+00	3.91E+00	2.51E-01	2.51E-01	8.77E-01	8.77E-01	8.40E-01	8.40E-01	1.33E+00	1.33E+00
25	2.58E-01	2.57E-01	1.31E+00	1.31E+00	4.76E-02	4.76E-02	1.62E-01	1.62E-01	1.58E-01	1.58E-01	2.78E-01	2.78E-01
30	4.11E-02	4.09E-02	4.17E-01	4.17E-01	9.87E-03	9.87E-03	2.94E-02	2.94E-02	3.05E-02	3.05E-02	5.74E-02	5.74E-02
35	5.57E-03	5.57E-03	1.27E-01	1.27E-01	2.22E-03	2.22E-03	5.13E-03	5.13E-03	5.94E-03	5.94E-03	1.14E-02	1.14E-02
40	7.70E-04	7.70E-04	3.98E-02	3.98E-02	5.12E-04	5.12E-04	9.09E-04	9.09E-04	1.29E-03	1.29E-03	2.34E-03	2.34E-03

Table A-2 (cont)   May 1986   [J/cm^2*d]

Depth\Day:	2		3		4		5		6		7		8	
(m)	Total	Vis	Total	Vis	Total	Vis	Total	Vis	Total	Vis	Total	Vis	Total	Vis
I-0	2440	---	2450	---	2203	---	2575	---	2522	---	2492	---	2478	---
+0	2.22E+03	1.00E+03	2.24E+03	1.00E+03	1.97E+03	8.96E+02	2.36E+03	1.05E+03	2.31E+03	1.03E+03	2.29E+03	1.02E+03	2.27E+03	1.02E+03
1	6.81E+02	6.25E+02	7.45E+02	6.78E+02	6.72E+02	6.16E+02	7.47E+02	6.84E+02	7.62E+02	6.95E+02	7.75E+02	7.04E+02	7.84E+02	7.13E+02
2	4.16E+02	4.05E+02	4.88E+02	4.70E+02	4.51E+02	4.36E+02	4.73E+02	4.59E+02	4.99E+02	4.80E+02	5.21E+02	5.00E+02	5.30E+02	5.09E+02
3	2.75E+02	2.72E+02	3.38E+02	3.32E+02	3.20E+02	3.15E+02	3.20E+02	3.16E+02	3.45E+02	3.38E+02	3.72E+02	3.64E+02	3.78E+02	3.70E+02
4	1.88E+02	1.87E+02	2.41E+02	2.39E+02	2.35E+02	2.33E+02	2.22E+02	2.21E+02	2.46E+02	2.43E+02	2.74E+02	2.71E+02	2.77E+02	2.74E+02
5	1.31E+02	1.31E+02	1.75E+02	1.74E+02	1.75E+02	1.74E+02	1.58E+02	1.58E+02	1.78E+02	1.77E+02	2.06E+02	2.05E+02	2.07E+02	2.06E+02
6	9.38E+01	9.37E+01	1.29E+02	1.29E+02	1.32E+02	1.32E+02	1.14E+02	1.14E+02	1.32E+02	1.31E+02	1.58E+02	1.57E+02	1.58E+02	1.57E+02
7	6.76E+01	6.76E+01	9.64E+02	9.62E+01	1.01E+02	1.01E+02	8.33E+01	8.33E+01	9.85E+01	9.81E+01	1.21E+02	1.21E+02	1.20E+02	1.20E+02
8	4.89E+01	4.89E+01	7.27E 01	7.26E+01	7.77E+01	7.77E+01	6.10E+01	6.10E+01	7.48E+01	7.46E+01	9.37E+02	9.36E+01	9.31E+01	9.30E+01
9	3.55E+01	3.55E+01	5.50E+01	5.50E+01	6.02E+01	6.02E+01	4.48E+01	4.48E+01	5.72E+01	5.71E+01	7.30E+01	7.30E+01	7.25E+01	7.25E+01
10	2.57E+01	2.57E+01	4.20E+01	4.20E+01	4.67E+01	4.67E+01	3.31E+01	3.31E+01	4.43E+01	4.42E+01	5.70E+01	5.70E+01	5.66E+01	5.66E+01
11	1.86E+01	1.86E+01	3.22E+01	3.22E+01	3.65E+01	3.65E+01	2.45E+01	2.45E+01	3.45E+01	3.45E+01	4.46E+01	4.46E+01	4.44E+01	4.44E+01
12	1.35E+01	1.35E+01	2.48E+01	2.48E+01	2.84E+01	2.84E+01	1.82E+01	1.82E+01	2.71E+01	2.71E+01	3.48E+01	3.48E+01	3.48E+01	3.48E+01
13	9.90E+00	9.90E+00	1.91E+01	1.91E+01	2.22E+01	2.22E+01	1.36E+01	1.36E+01	2.13E+01	2.13E+01	2.71E+01	2.71E+01	2.71E+01	2.71E+01
14	7.26E+00	7.26E+00	1.47E+01	1.47E+01	1.73E+01	1.73E+01	1.02E+01	1.02E+01	1.69E+01	1.69E+01	2.11E+01	2.11E+01	2.11E+01	2.11E+01
15	5.34E+00	5.34E+00	1.13E+01	1.13E+01	1.35E+01	1.35E+01	7.75E+00	7.75E+00	1.34E+01	1.34E+01	1.69E+01	1.63E+01	1.63E+01	1.63E+01
20	1.21E+00	1.21E+00	3.21E+00	3.21E+00	3.94E+00	3.94E+00	2.02E+00	2.02E+00	4.39E+00	4.39E+00	4.65E+00	4.65E+00	4.55E+00	4.55E+00
25	2.96E-01	2.96E-01	9.18E-01	9.18E-01	1.14E+00	1.14E+00	5.47E-01	5.47E-01	1.47E+00	1.47E+00	1.35E+00	1.35E+00	1.20E+00	1.20E+00
30	6.62E-02	6.62E-02	2.36E-01	2.36E-01	3.11E-01	3.11E-01	1.26E-01	1.26E-01	4.71E-01	4.71E-01	3.92E-01	3.92E-01	3.24E-01	3.24E-01
35	1.34E-02	1.34E-02	5.37E-02	5.37E-02	7.92E-02	7.92E-02	2.45E-02	2.45E-02	1.42E-01	1.42E-01	1.13E-01	1.13E-01	8.67E-02	8.67E-02
40	2.80E-03	2.88E-03	1.24E-02	1.24E-02	2.15E-02	2.15E-02	4.85E-03	4.85E-03	4.16E-02	4.16E-02	3.28E-02	3.28E-02	2.46E-02	2.46E-02

Table A-3: Heat content [10^{-8} $J \cdot m^{-2}$]

Interval (m)	25/4	29/4	3/5	7/5
0 - 15	1.140	1.544	2.037	2.674
0 - 30	2.213	2.787	3.422	4.170
0 - 50	3.545	3.986	4.962	5.727
0 - 70	4.875	5.342	6.352	7.177

Table A-4: Integrated Changes in heat flux [10^{-8} $J \cdot m^{-2}$] and observ. heat cont. [10^{-8} $J \cdot m^{-2}$]

Date	heat flux	obs. heat cont.
29 April	0.692	0.467
3 May	1.691	1.477
7 May	2.716	2.302

Table A-5: Daily heat flux during PEX, calculated from measurements by OCEANIA [$kJ \cdot m^{-2} \cdot d^{-1}$]
del Q = QS - (QB + QE + QC)

	APRIL 25	26	27	28	29	30
QS	16240	13630	13390	19960	18420	16160
QB	516.42	879.41	2284.4	6140.0	4078.3	5408.8
QE	-169.48	31.152	-1198.5	-440.34	94.969	203.95
QC	-970.03	-205.58	-2694.7	-1059.7	-1246.2	-65.571
del Q	16863	12925	14999	15320	15493	10613

	MAY 02	03	04	05	06	07	08
QS	22220	22400	19660	23650	23130	22870	22720
QB	6929.1	6008.9	3651.3	5871.8	6307.7	6420.9	4316.0
QE	-19.065	-248.42	-582.76	-497.29	-195.73	-565.16	-1289.6
QC	-529.18	-639.64	-1934.1	-2113.8	-1574.6	-1939.4	-3666.9
del Q	15839	17279	18526	20389	18593	18954	23361

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