Changes in hydrography and suspended particulate matter during a barotropic forced inflow

Frontal zone
Hydrography
Suspended particulate matter
Stratification
Internal waves

Zone frontale
Hydrologie
Particules en suspension
Stratification
Ondes internes

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ABSTRACT

This paper describes the changes in hydrography and the vertical distribution of suspended particulate matter (SPM) that occur during an inflow of highly saline water into a semi-enclosed bay. The study area is situated near the frontal zone in the Kattegat between the highly saline waters (32-34) of the North Sea/Skagerrak and the less saline waters (15-20) of the Baltic Sea. The water column at the frontal zone is stratified throughout much of the year. The study was carried out in a bay in the southwestern part of the Kattegat, and is based on CTD-observations, current direction and speed, and samples of suspended particulate matter obtained during the study period.

The study shows that the hydrography of the bay is strongly influenced by the inflow from the Kattegat of water which originated in the North Sea/Skagerrak. Water with salinities up to 33 reaches the bay as a bottom current. Whether or not the inflow into Aarhus Bay was associated with inflow of the Jutland Current into the Kattegat is discussed. Strong gradients in salinity and thus density are found during the whole study period. Prior to this period, winds from the southwest had established a barotropic field from the Kattegat and towards the Baltic Sea. Wind direction changed to the southeast during the study period and the dense bottom water in Aarhus Bay withdrew. The study indicated that internal waves associated with tidal water were present in the layer of stratification. High SPM concentrations near the sea bed were presumed to be due to lateral advection from shallow water areas, as calculated bottom friction speeds were low. High positive SPM gradients below the layer of stratification were attributed to resuspension by internal waves, as calculated rates of resuspension by surface wave activity were insufficient to have produced them.

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RÉSUMÉ

Variabilité à court terme de l'hydrologie et des particules en suspension dans une baie semi-fermée entre la Mer de Nord et la Mer Baltique

La variabilité de l'hydrologie et de la répartition verticale des particules en suspension a été étudiée pendant l'arrivée d'eau salée dans la baie d'Aarhus (Danemark). Cette baie semi-fermée est située au sud-ouest du Kattegat, près du front qui sépare les eaux salées (32-34) de la Mer du Nord/Skagerrak et les eaux moins salées (15-20) de la Mer Baltique. Dans la zone frontale, la colonne d'eau est stratifiée pendant la plus grande partie de l'année. L'étude a été effectuée à partir de données CTD, direction et vitesse du courant, et d'échantillons de matière particulaire en suspension.

L'hydrologie de la baie est très marquée par l'eau du Kattegat en provenance du Skagerrak et de la Mer de Nord. Le courant de fond apporte dans la baie d'Aarhus une eau dont la salinité atteint 33. Cet apport pourrait être associé à l'arrivée du courant du Jutland dans le Kattegat. De forts gradients de salinité et de densité ont été observés pendant toute la période d'étude. Auparavant, les vents du Sud-Ouest avaient établi un champ barotrope dans le kattegat et en direction de la mer Baltique. Pendant la période d'étude, la direction du vent est passée au Sud-Est, et l'eau de fond dense s'est retirée de la baie d'Aarhus. Les fortes concentrations en particules en suspension à proximité du fond sont dues à l'advection latérale à partir des zones peu profondes, car la vitesse calculée des frottements sur le fond est faible. Les forts gradients positifs en matière particulaire en suspension au-dessous de la couche stratifiée sont créés par des ondes internes, car les calculs indiquent que la remise en suspension serait insuffisante sous la seule action des vagues en surface.

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INTRODUCTION

The study was carried out in the southwestern part of the Kattegat, which is situated in the transitional zone between the highly saline water of the North Sea/Skagerrak and the less saline water of the Baltic Sea. Surface salinities range between 10 and 15, and bottom salinities between 30 and 34 in the Kattegat (Jacobsen, 1980); the former increase northwards, whereas the latter decrease southwards (The Belt Project, 1981). This leads to vertical mixing between the two water masses (Jacobsen, 1980; The Belt Project, 1981). Despite of the mixing, the water column at the frontal zone in the Kattegat is stratified throughout much of the year (The Belt Project, 1981). There is a net outflow of water from the Baltic Sea towards the Kattegat which, in general, is due to freshwater run-off into the Baltic (Kullenberg, 1981).

The hydrography of the Kattegat has been described by Dietrich (1951), Svansson (1975), Jacobsen (1980), and in The Belt Project (1981). The exchange of water between the North Sea/Skagerrak and the Baltic Sea, which has been studied thoroughly and is described in detail elsewhere (see Jacobsen (1980) for a review), is influenced by both hydrographical and meteorological conditions (The Belt Project, 1981). The relevant factors determining the inflow into the Baltic have been described by Dickson (1973); hydrographical aspects of the inflow of dense bottom water into the Baltic have been described by Pedersen (1977).

The present study provides a time- and process-orientated description of the hydrography of a semi-enclosed bay during an inflow from the Kattegat of water which originated in the North Sea/Skagerrak. The vertical distribution of suspended particulate matter in Aarhus Bay during the inflow is also described.

The larger-scale processes influencing the North Sea and Kattegat region during the inflow described in the present study have been described elsewhere (Skyum and Lund-Hansen, 1992).

STUDY AREA

The study was conducted at a fixed station (56° 09.20 N, 10° 19.20 E) in the northwestern part of Aarhus Bay (Fig. 1). The water depth at the position is 17.0 m, whereas the average water depth of the bay is 14 m. The surface area of the bay is about 250 km^2 and it contains a volume of 5.10^3 km^3 of water. The bay is enclosed by islands and shallow water areas to the south (Fig. 1), and has a tidal range of 40 cm (DHI, 1980).

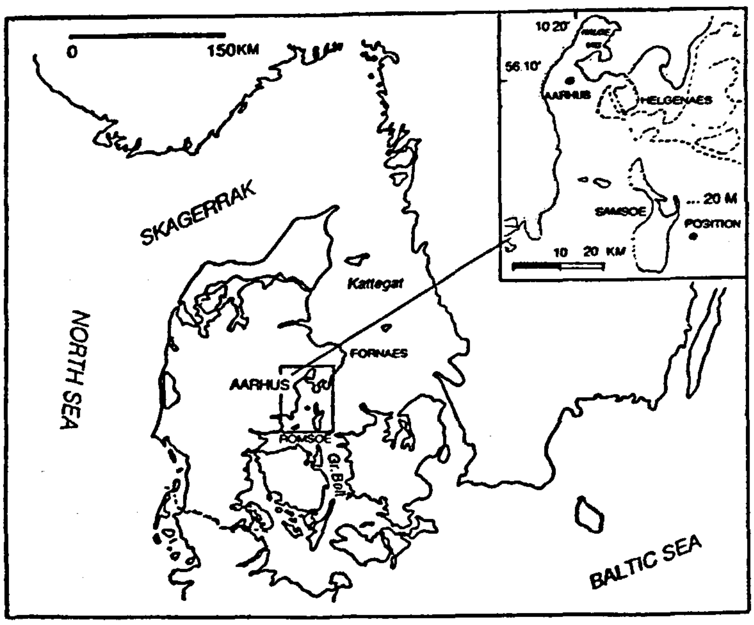

Figure 1

Location of study area.

Situation de la station étudiée.

METHODS

Measurements of salinity and temperature were carried out at depth intervals of 0.25 m using an automated CTD-profiling system (Brown Mark III). CTD measurements were carried out over a period of 53 hours between 10 h 00 on 9 April and 15 h 00 on 11 April 1991, at nearly 1-hour intervals. The day numbers (1), (2) and (3) given in the text correspond to the dates 9, 10 and 11 April 1991.

Water samples were collected with 3 l Niskin bottles mounted on a Rosette, at depths of 2.5, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 12.5, 15.0, and 16.5 m. All samples were filtered using preweighed (0.1 mg) Whatman GF/C microfibre (0.45 mμ) filters. In the laboratory the filters were dried for 24 hours at 110°C and weighed (0.1 mg). The samples were taken at approximately 3-hour intervals, but sampling only began at 8 h 00 (2), due to technical problems.

Measurements of current direction and speed were obtained using a self-recording (every 10 min) Aanderaa RCM 7 moored current meter placed 1.0 m above the sea bed near the anchor position. Data on wind speed and direction, recorded at 3-hour intervals, were obtained from Fornaes lighthouse situated 50 km north east of the anchor position (Fig. 1). Water level measurements were recorded automatically using a conventional tide gauge located at Aarhus Port (Fig. 1).

RESULTS

Salinity

The time *versus* depth contours of salinity during the study period are shown in Figure 2 *a*. The mean salinity of the surface water during the study period is about 26.5, whereas the mean salinity of the bottom water is about 32.3. The halocline remains nearly stable at mid-depth between 3 and 4 m between 21 h 00 (1) and 4 h 00 (2). Thereafter, it is gradually displaced, reaching a depth of about 12 m at 15 h 00 (3).

Temperature

Time *versus* depth contours of temperature (°C) are shown in Figure 2 *b*. Strong temperature gradients occur at mid depth between 3 and 4 m between 21 h 00 (1) and 4 h 00 (2). Between 5 h 00 and 19 h 00 (2) water with a higher temperature (6.26°C) than that of both the overlying and the bottom water is present at depths between 9 and 12 m. This water mass is nearly enclosed by the 6.02°C isotherm. The isotherms > 6.18°C and < 6.42°C are gradually displaced downward to a depth of 11 m at 6 h 00 (3) to lie close to the < 5.94°C isotherms, which results in relatively strong temperature gradients in this region.

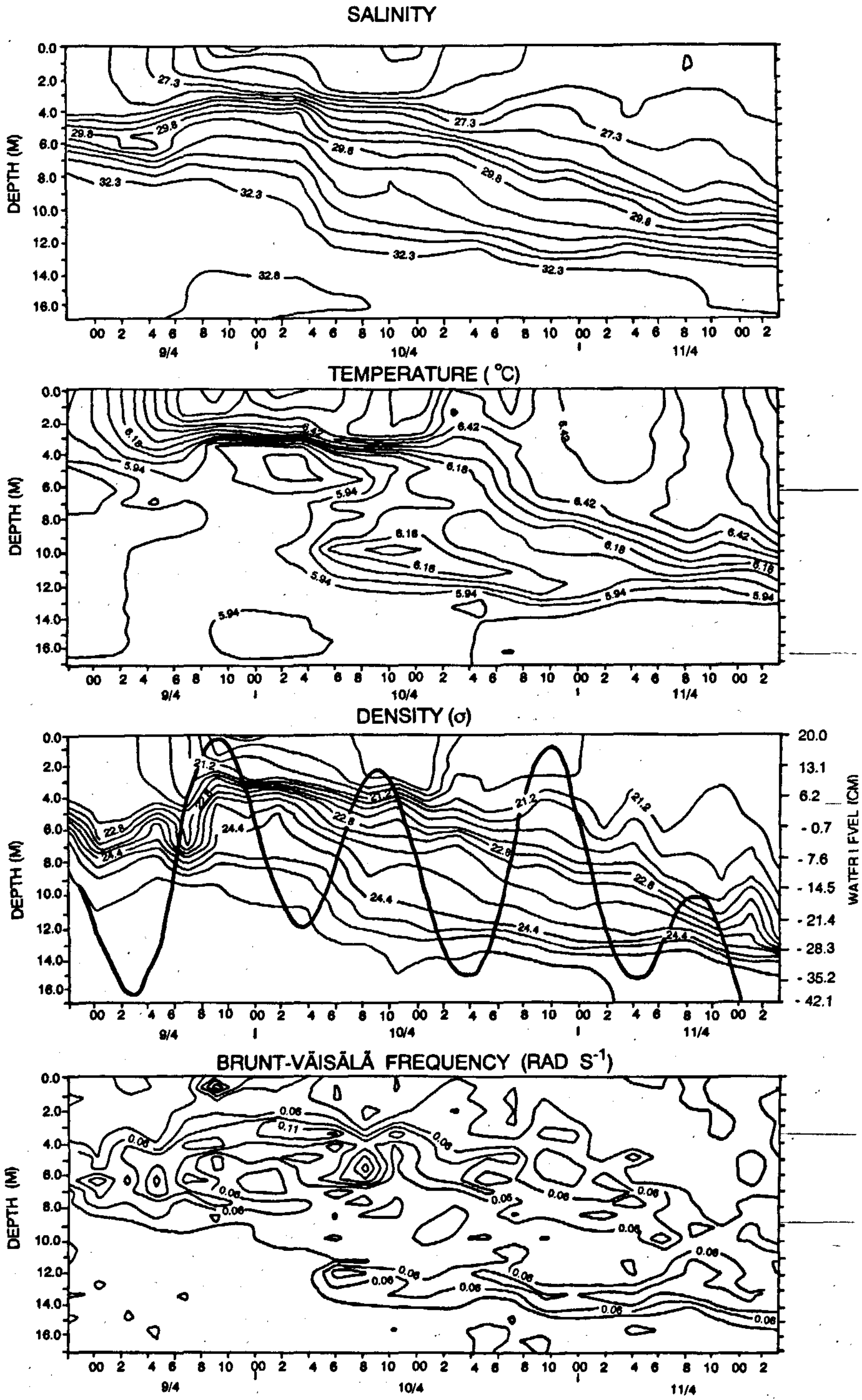

Figure 2

a) salinity; b) temperature (°C); c) density (σ_t) and water level (cm) (——); d) Brunt-Väisälä frequency (rad s^{-1}).

a) salinité ; b) température (°C) ; c) densité (σ_t) et hauteur de mer (cm) (——) ; d) fréquence de Brunt-Väisälä (rad s^{-1}).

Density

Time *versus* depth contours of density (σ_t) are shown together with the variation of the water level (cm) in Aarhus Port during the study period (Fig. 2 *c*). A strong density gradient is found at depths between 3 and 7 m from 10 h 00 (1) to 2 h 00 (2), and at a depth of 12 m from 8 h 00 (3) to 15 h 00 (3). Comparison between the variation in water level and the location of the isopycnals indicates a tendency towards upward movement of the isopycnals < 24.8 (σ_t) at low water levels, for instance at 2 h 00 (2), 16 h 00 (2), 4 h 00 (3), and 1 h 00 (3).

Brunt-Väisälä frequency

The static stability of the water column is expressed by the Brunt-Väisälä frequency (Kullenberg, 1977) given by :

$$N = \left(-\frac{g}{\rho_i}\frac{\partial \rho}{\partial z}\right)^{1/2} \qquad (1)$$

where g is acceleration due to gravity and $\partial \rho$ is the difference in density (σ_t) between layer (i) and layer (i-1), where ρ_i is the density of layer (i) with z (depth) positive upwards. N was calculated for each two layers with ∂z = 0.25 m, which was the CTD depth recording interval. Time versus depth contours of the Brunt-Väisälä frequency show (Fig. 2 *d*) the presence of two layers of stratification. One strong layer is recognized at mid-depth between 5 and 7 m from 10 h 00 (1) to about 10 h 00 (2), and the second layer at a mean depth of 13 m from 4 h 00 (2) to the end of the measurements. A concurrent downward movement and gradual disintegration of the first layer begin at 10 h 00 (2), whereas the downward movement of the second and stable layer is about 1 m. A maximum of the Brunt-Väisälä frequency (N = 0.21 rad s^{-1}) in the first layer is found at 8 h 00 (2) at a depth of about 5 m; another maximum (N = 0.18 rad s^{-1}) in the second layer is found at a depth of about 12 m at 6 h 00 (2).

The vertical displacements of the isolines in Figures 2 *a-c* have not been corrected for changes in sea level, as these are relatively small compared to the changes in the isoline positions.

Current direction and speed

The mean current speed 1.0 m above the seabed is 8.8 cm s^{-1} between 10 h 00 (1) and 2 h 00 (2) (Fig. 3 *a*). Due to the precision of the current meter it is anticipated that the 1.0 cm s^{-1} readings recorded between 2 h 00 and 10 h 00 (2), signify the absence of or very low current speeds. Between 10 h 00 (2) and 16 h 00 (3), the mean current speed is 10.4 cm s^{-1} and with higher variations compared to the first part of the study period. The mean current direction is 314° between 10 h 00 (1) and 2 h 00 (2), and 144° from 10 h 00 (2) to the end of the measurements (Fig. 3 *b*). 314° is into Aarhus Bay, whereas 144° is out of the bay relative to the deep-water entrance near Helgenaes (Fig. 1).

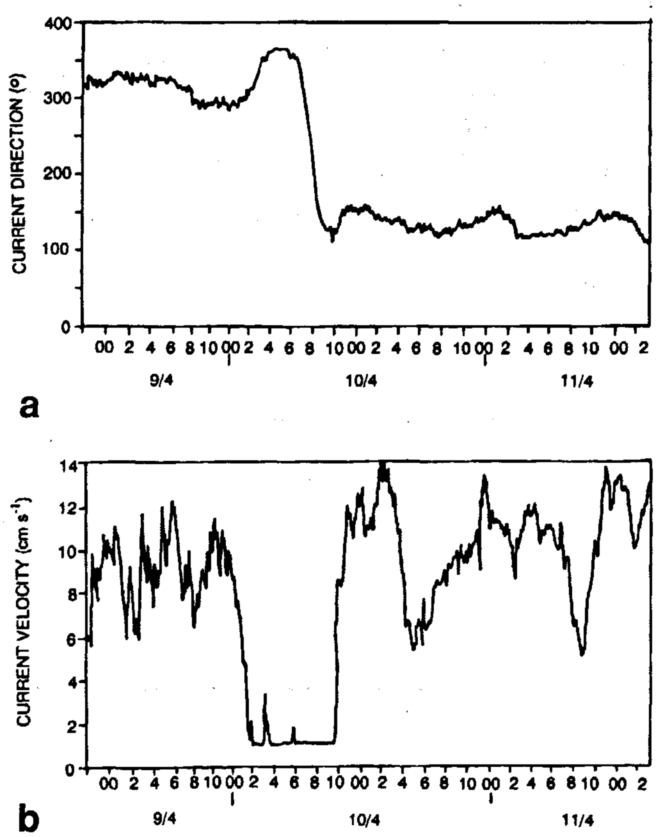

Figure 3

a) current direction (°); b) current velocity (cm s^{-1}).

a) direction de courant (°) ; b) vitesse de courant (cm s^{-1}).

Suspended particulate matter

Ninety samples from nine sampling profiles were collected from ten different depths. The time of sampling, profile number, and vertical distribution of suspended particulate matter (SPM) (mg l^{-1}) are shown in Figure 5. SPM concentrations are nearly uniform between 2.5 m and 12.5 m in profiles 7-9, whereas the uniformity in profiles 1-6 extends to a depth of 9-10 m. The mean concentration above the high SPM gradients at the depths of 10 and 12.5 m in the profiles considered is 4.7 mg l^{-1}, whereas the mean concentration below the gradients is 11.9 mg l^{-1}.

DISCUSSION

Hydrography

On 7 and 8 April, *i. e.* prior to the study period (9-11/4), wind speeds between 12.0 and 14.0 m s^{-1} from the southwest and west prevailed over the North Sea and Kattegat area (Skyum and Lund-Hansen, 1992). These directions and speeds force water from the North Sea/Skagerrak into the Kattegat, and water in the Baltic towards the Northeast, with establishment of a barotropic field between the Kattegat and the Baltic Sea (Jacobsen, 1980; The Belt Project, 1981; Stigebrandt, 1983). However, the barotropic field which moves the frontal zone southward in the Kattegat (Jacobsen, 1980; The Belt Project, 1981; Svansson, 1975) was established prior to the study period (Skyum and Lund-Hansen, 1992).

The mean salinity of the bottom water during the study period was about 32.3, with a maximum of 32.9. These salinities clearly show that the bottom water recognized in the Aarhus Bay originated in the North Sea/Skagerrak, where salinities range between 32 and 34 (The Belt Project, 1981).

Horizontal distributions of nutrients (Richardson *et al.*, 1987) and radioactive tracers (Aarkrog *et al.*, 1985) have recently indicated a transport of these substances from the North Sea and into the Kattegat by the Jutland Current. The current, with salinities between 30 and 33, flows northward along the Danish West coast (Fig. 1) and enters Skagerrak/Kattegat during periods of relatively strong winds from the southwest (Pedersen *et al.*, 1988). The requirements for inflow of the Jutland current into the Kattegat were achieved prior to the study period, and the salinities of the inflow bottom water in Aarhus Bay correspond to those of the Jutland current. However, daily hydrographical observations obtained in April 1964 from a now-withdrawn light-vessel situated in the southwestern part of the Kattegat (56° 06'N, 11° 09'E) show salinities ranging between 34.0 and 29.4 (Danish Meteorological Institute, 1964). These salinities are considered typical for the season and position (*op. cit.*), which is situated about 60 km east-southeast of Aarhus Bay. Given unchanged hydrographical conditions, they indicate that the inflow water could have been transported towards Aarhus Bay from these deeper (40 m) parts of the Kattegat.

However, due to the southward movement of the frontal zone in the Kattegat prior to the study period, a definite conclusion as to where in the Kattegat the water originated cannot be reached, although the high salinities indicate that the inflow water originated in the North Sea/Skagerrak.

High salinities (29-31) in Aarhus Bay are observed every year in spring (Aarhus County, 1990), and are due to the inflow of water originating in the North Sea/Skagerrak, although the salinities show that some mixing has taken place. These inflows are due to upwards entrainment by the outflowing Baltic water (Jacobsen, 1980). The duration of these inflows ranges from fourteen days to one month (Aarhus County, 1990), whereas the duration of the inflow described is about 3-4 days.

The isohalines below 4 m are between 4 h 00 and 7 h 00 (2) displaced downwards, the displacement increasing with depth (Fig. 2 *a*). This shows that the pressure gradient increases with depth, suggesting a baroclinic forcing mechanism (Officer, 1976). During 9 April the wind was blowing from the northwest, but ceased during the afternoon (Fig. 4). The following night the wind blew from a southerly direction, and this direction moves less saline surface water from the Baltic towards the Kattegat (The Belt Project, 1981). There are no measurements of salinity and temperature just outside Aarhus Bay during the study period, but CTD-measurements at Romsoe, situated approximately 50 km south of Aarhus Bay (Fig. 1), showed that the stratified layer between 8 and 11 April had moved from a depth of 11 m to a depth of 13 m (Skyum and Lund-Hansen, 1992). The downward movement of the stratified layer is thus supposed to be due to both a ceased baroclinic force working from the Kattegat towards the Baltic, and the renewed outflow of Baltic water.

The presence of relatively warm water (6.18°C) from about 5 h 00 to 19 h 00 (2) at depths between 9 and 12 m (Fig. 2 *b*) immediately follows the vertical downward movement of the isolines between 4 h 00 and 7 h 00 (2)(Fig. 2 *a-c*). Due to the water movements in the baroclinic field, the presence of the anomalous warm water is attributed to an intrusion of bottom water from outside Aarhus Bay, which enters the bay to replace the highly saline outflowing bottom water (Fig. 3 *b*). The salinity of the intrusion water varies between 29.6 and 31.2 (Fig. 2 *a*).

The isopycnals < 24.8 (σ_t) showed a tendency towards upward movement in periods of low tidal water (Fig. 2 *c*), whereas no clear relation is recognized in periods of high tidal water. However, there are indications that internal waves with periods of about 12 hours occurred in the stratified layer, although such waves are not fully recognized, probably due to the rapidly changing conditions.

Kaloe Vig

Between 20 h 00 (1) and 15 h 00 (2), the respective contour lines (Fig. 2 *a-c*), from the surface to a depth of about 3-4 m, enclose distinct water masses with comparatively low salinities (< 26.0) and high temperatures (> 6.60° C). The enclosed surface water supposedly originated in the Kaloe Vig, situated north of Aarhus Bay (Fig. 1). Kaloe Vig has a mean depth of 7.3 m and large shallow-water areas (DHI, 1980), in which the water is warmed up somewhat more rapidly. The presence of the Kaloe Vig water clearly enhances the stratification by producing a thermocline between 19 h 00 (1) and 2 h 00 (3) at a depth of 3-4 m (Fig. 2 *b*). The presence of this water indicates that water from Kaloe Vig is flowing towards the southwest at the surface, to balance the amount of water entering Aarhus Bay at the bottom, between 10 h 00 (1) and 3 h 00 (2)(Fig. 3 *b*).

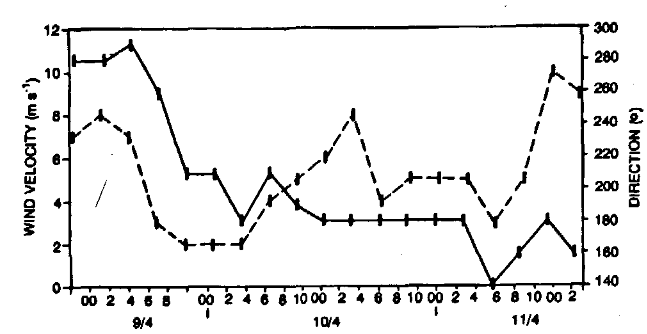

Figure 4

Wind velocity (m s-1) (—) and wind direction (°).

Vitesse (m s-1) (——) et direction (°) de vent.

Suspended particulate matter

Mean SPM concentrations were higher near the sea bed compared to the upper layer, and positive SPM concentration gradients were found below the layer of stratification in profiles 7-9. The vertical distribution of SPM in profile 1 (Fig. 5) is nearly uniform and with no increased SPM concentrations near the sea bed. This profile was sampled after a preceding period of six hours of no or very low bottom current speeds (Fig. 3 *a*). Profile 2, which shows a high gradient in SPM concentration at a depth of 9 m, was sampled in a period with relatively high bottom current speeds (12 cm s^{-1}). Profiles 4, 5, 6 , 8, and 9 were sampled in periods with bottom current speeds of 10-11 cm s^{-1}, whereas profiles 3 and 5 were sampled in periods with current speeds of 6 cm s^{-1}.

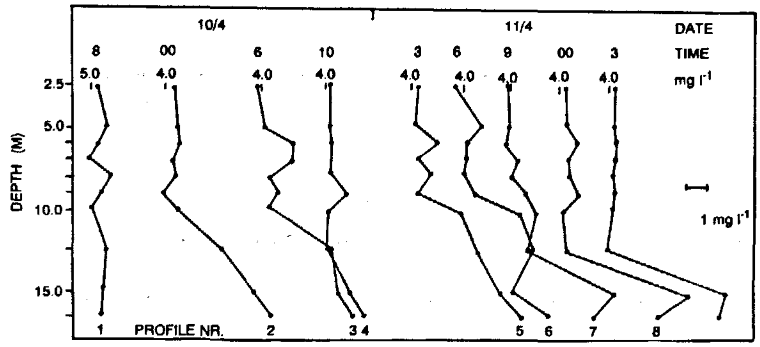

Figure 5

Vertical distribution of suspended particulate matter (SPM) concentrations (mg l^{-1}), profile number, date and time of sampling.

Distribution verticale de concentrations de matières particulaires en suspension (SPM) (mg l^{-1}), numéro de profil, date et heure de l'échantillonnage.

The friction speed (u_*) due to bottom shear stress has been calculated according to:

$$\frac{u}{u_*} = \frac{1}{\kappa} \ln \frac{z}{z_0} \qquad (2)$$

where u is the current speed, κ von Karman's constant (0.4), z (1.0 m) height above the sea bed in which current speed has been measured. z_0 is taken to be 0.01 (cm) for mud (Heathershaw, 1981), as sediment collected at the anchor position consisted of fine silt and clay with 10.5 % of organic material, and had a dry bulk density of 1.1 g cm^{-3}, these being typical characteristics of cohesive sediments (Dyer, 1986). The current speed in the period of sampling profiles 2-9 varied between 5 and 13 cm s^{-1}, which corresponds to bottom friction speeds between 0.2 and 0.6 cm s^{-1}, respectively. The relationship between settling velocity and friction speed of suspended particles by McCave (1984) shows that particles with settling velocities in the range between $1.0*10^{-6}$ and $1.0*10^{-4}$ m s^{-1} can be transported in suspension by friction speeds ranging between 0.2 and 0.6 cm s^{-1}. A mean settling velocity of suspended particles of $1.4*10^{-3}$ m s^{-1} has been determined by *in situ* measurements in Aarhus Bay in spring 1990 (Lund-Hansen *et al.*, 1992). Particles with settling velocities about $1.4*10^{-3}$ m s^{-1} require friction speeds above 1.0 cm s^{-1} to be kept in suspension (McCave, 1984). Provided that a settling velocity of $1.4*10^{-3}$ m s^{-1} of suspended particles was also valid in this study period, it may be strongly inferred that the high SPM concentrations near the bottom in profiles 2-9 are not due to erosion by bottom current. The current direction at the position when profiles 2-9 were sampled was towards Helgenaes (Fig. 3 *b*), which indicates that the bottom water probably originated northwest of the anchor position. The wind direction during sampling of profiles 2-9 was between the south and southeast, giving a long fetch in the bay (Fig. 1). Wind velocities between 5-11 m s^{-1} were recorded (Fig. 4) and surface waves developed. The high SPM concentrations recognized at the anchor position were thus presumably due to resuspension of bottom material in the shallow water areas (Gabrielson and Lukatelich, 1985; Demers *et al.*, 1987), and its transport towards the position by the current. However, the calculated friction speeds were relatively close to the limit for keeping particles in suspension, and some sedimentation must have taken place. This corroborates the higher sediment accumulation rates measured by sediment traps during the same period, as outlined by Lund-Hansen *et al.* (1992).

Profiles 7-9 show positive SPM gradients at a depth of 15 m. Due to the southerly wind direction and increased wind speeds (Fig. 4), surface waves developed, and wave heights between 1.0 and 1.5 m were observed as profiles 7-9 were sampled. The effect of resuspension of bottom material by surface waves at the anchor position has been calculated. Wave parameters were calculated according to Beach Erosion Board (1975), and maximum wave orbital velocity (u_{max}) at the bottom was calculated according to Komar and Miller (1973). The friction speed (u_*) at the bottom produced by the orbital movements of the waves was calculated according to Rakoczi (1986). This gives a mean friction speed (u_*) of $1.5*10^{-3}$ cm s^{-1} for u_{max} of 0.4 cm s^{-1} in the period between 9 h 00 and 16 h 00 (3), such a speed being too low to resuspend or maintain particles in suspension (McCave, 1984). This shows that the positive SPM gradients in profiles 7-9 are not due to resuspension by surface waves.

The combined shear stress due to both waves and currents is non-linear (Grant and Madsen, 1979). An estimate of the ratio of the shear stress due to both waves and current (τ_{wc}), and current (τ_c) τ_{wc}/τ_c is given by Heathershaw (1981). For data obtained in the period during which profiles 7-9 were sampled, the ratio is unity ($\tau_{wc}/\tau_c = 1.003$), which shows that either or both of the shear stresses combined could have caused resuspension and thus the high SPM gradients. It is not likely that SPM could have been transported across a layer of stratification, as turbulent vertical transport of SPM and dissolved substances is strongly reduced by the layer of stratification (Kullenberg, 1977; Baker *et al.*, 1983). The movements of the pycnoclines (Fig. 2 *c*) indicated the presence of internal waves in the layer of stratification, especially between 9 h 00 and 15 h 00 (3) when profiles 7-9 were collected.

Internal waves have been suggested as a possible mechanism for the resuspension of sediment in shelf areas (Cacchione and Southard, 1974; Cacchione and Drake, 1986). However, the presence of internal waves in the layer of stratification in this study was only indicated, and no clear conclusions can be drawn concerning the cause of the positive SPM gradients at the bottom in profiles 7-9.

Hydrography and suspended particulate material

In general, there is no distinct correlation between the physical properties of the water with respect to salinity and temperature and the vertical and time distribution of SPM. Nevertheless, a comparison of the Brunt-Väisälä frequencies and the time and vertical distribution of SPM (Fig. 5) shows that the highest SPM gradients in profiles 7-9 are located below the layer of stratification. In profiles 1-6, however, the placement of the high SPM gradients at a depth of 9-10 m does not show any correlation with the layer of stratification at the depth of 13 m. High SPM concentrations above a layer of stratification have been observed by Baker *et al.* (1983), whereas the present study has shown that high concentrations of SPM can also be found below the layer of stratification.

CONCLUSION

The occurrence of highly saline water (33) in Aarhus Bay was due to a barotropic forced inflow from the Kattegat of bottom water which originated in the North Sea/Skagerrak. However, a conclusion as to a specific place of origin in the Kattegat cannot be reached. The inflow was due to specific meteorological conditions prior to the study period. The high salinities indicate that little or no mixing of bottom and surface water has taken place between the place of origin in the Kattegat and Aarhus Bay. The salinities of the inflowing water correspond to those of the Jutland Current, but data do not permit a clear conclusion as to whether the inflow was associated with inflow of the Jutland Current into the Kattegat. As the barotropic field between the Kattegat and the Baltic ceased, a baroclinic field was established between water masses inside and outside Aarhus Bay. The baroclinic field was enhanced by renewed outflow from the Baltic. The study shows that dense bottom water enters and leaves Aarhus Bay through the deep water (40 m) entrance. During the study period the water column was dominated by two layers of stratification. Vertical distribution of water density and water level in Aarhus Port indicated the presence of internal waves associated with the variations in tidal water level. High SPM concentrations were found near the bottom in periods with current speeds in the range between 5.0 and 13.0 cm s^{-1}. However, the calculated friction speeds (u_*) were relatively low (0.2-0.6 cm s^{-1}), and the high SPM concentrations were presumed to be due to lateral advection from more shallow water areas, where deposited material possibly has been brought in suspension by resuspension. High positive SPM gradients occurred below a layer of stratification, and calculations showed that the high gradients were not due to resuspension by surface waves, but possibly due to resuspension by the internal waves.

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