C.M. 1980/C:11, Hydrographic Committee. Ref. Marine Environmentel Quality letter

On the mixing conditions in the Baltic Transition Area

by

E. Buch and G. Kullenberg

Institute of Physical Oceanography, University of Copenhagen
Haraldsgade 6, 2200 Copenhagen N.

Abstract

Results of a number of mixing eksperiments in the Transition Area carried out during different seasons over several years are summarized, relations between mixing and environmental conditions are presented and some applications are discussed.

Introduction

The Transition Area, consisting of the Sound, the Great and the Little Belt, and the Kattegat, forms the connection between the Baltic Sea and the open ocean (North Sea). An understanding of the flow and mixing conditions in the Transition Area is crucial to the understanding of the conditions in the deep and bottom waters of the Baltic Sea and hence to our ability to model and predict the development in the Baltic Sea which is also subject to man's various uses. The Transition Area is characterized by large variability, with situations of two-layer flow, out from the Baltic in the top layer, and a very stable stratification, as well as situations with flow out of or into the Baltic over the whole water column. Normally the separations between the Baltic water and the Kattagat water, and between the latter and the Skagerrak water, are marked by strong salinity fronts, which oscillate between the Darss Sill in the south and the Skaw latitude in the north.

In this paper results are summarized from field experiments in various parts of the area aimed at determining the mixing in different layers of the water column. The experiments were carried out during different seasons, over several years, so as to cover a large range of environmental conditions. Horizontal and vertical mixing parameters were determined from tracing of rhodamine dye injected at subsurface levels, with the density adjusted to the appropriate sea water density. The dye was traced over periods of half a day to several days, towing an in situ fluorometer after the ship, cruising in an organized fashion over the area (Kullenberg 1969, 1974). During the tracing, salinity and temperature profiles were taken at intervals as well as wind observations. Salinity, temperature and current profile observations were carried out at anchor, over periods of half a day to days, before the dye tracing and in many cases also after the tracing. In some cases current data from moored instruments have also been obtained. These environmental observations have been used to determine appropriate mean values of current shears, and vertical density gradients, taking averages over periods of time comparable to the averaging time used for determining the mixing parameters.

Results

The mixing has been quantified by applying different mixing models to the observed dye concentration distributions. After injections in thermocline or halocline layers the dye was usually found to be distributed in thin layers with a thickness in the range 20 to 200 cm, often pulse-formed with sharp boundaries, and slowly decreasing concentration. Such layers could exist for days in the highly stratified waters. An effective vertical mixing coefficient K_z has been calculated from observations on such layers using the equation (Kullenberg 1969, 1971):

$$K_z = \frac{h^2}{\pi^2(t_2 - t_1)} \ln \frac{C_1}{C_2} \quad (1)$$

maximum concentrations at the times t_1 and t_2.

Several surface layer experiments have also been done, and K_z calculated from the observed penetration of the dye down into the nearly homogeneous surface layer.

The horizontal mixing has been studies by means of the equation given by Joseph and Sendner (1958)

$$C(r,t) = \frac{M}{2\pi (Pt)^2 \cdot h} e^{-r/Pt} \quad (2)$$

where P is the horizontal diffusion velocity M the injected amount of dye, r the radius of a circle with an area equivalent to the observed area covered by the isoline C(t). Alternatively the longtidunal and lateral variances σ_x^2 and σ_y^2 of the observed concentration $C(x, y, t)$ have been calculated, and the consistency with the Joseph and Sendner model prediction has been checked.

The values of the mixing parameters are given in Tables 1 and 2. It is noted that the vertical mixing has varied over a considerable range, clearly depending upon the environmental conditions. Mean values are also given in Table 1 of the vertical current shear, the wind and the Brunt-Väisälå frequency squared, $N^2 = \frac{g}{\rho} \frac{d\rho}{dz}$, where ρ is the density, g the acceleration of gravity and z the vertical coordinate.

Mixing in relation to environmental conditions

Using some of the present experiments and experiments from other areas Kullenberg (1971; 1974), later corroborated by Buch (1979), showed that for persistant winds above 4 - 5 $m \cdot s^{-1}$ the vertical mixing in the wind-mixed layer could be expressed through the relation

$$K_z = Rf \cdot c_d \cdot \frac{\rho_a}{\rho} \cdot \frac{\overline{W_a^2}}{N^2} \cdot \left|\frac{dq}{dz}\right| \quad (3)$$

Here Rf is the flux Richardson number, c_d the surface drag coefficient, ρ_a/ρ the ratio of densities of air and water, W_a the wind velocity and dq/dz the gradient of the horizontal currentvector. This result is shown in Fig. 1 for the present data.

It is clear that the wind has a strong influence on the mixing. In many cases it may be relevant to consider the vertical mixing as essentially an entrainment from the deep layer into the surface layer.

The entrainment velocity u_e can be determined from the mixing coefficient, under the assumption that only entrainment occurs (Kullenberg 1977)

$$u_e = \frac{K \cdot N^2}{g \frac{\Delta \rho}{\rho}} \tag{4}$$

where $\Delta\rho$ is the density change across the pycnocline. The ratio of entrainment velocity u_e to friction velocity u_* is found to be related to the overall Richardson number Ri_*, in basic agreement with results from other laboratory and field investigations,

$$\frac{u_e}{u_*} = c \cdot Ri_*^{-1} \quad , \quad Ri_* = \frac{gh \frac{\Delta \rho}{\rho}}{u_*^2} \tag{5}$$

where c is of the order of 5.

The energy transferred from the wind

$$E_w = k \; \tau_o W_a = k \; \rho_a c_d W_a^3 \tag{6}$$

(k being the wind factor)
is partly consumed for vertical mixing. It is important to note that this is only a small fraction of the energy available, on the basis of the present experiments on an average 10% (Kullenberg 1976). This is in good agreement with other results.

The momentum transfer coefficient K_m can be related to the wind (Kullenberg 1976)

$$K_m = \frac{1}{f} \left(\frac{\rho_a}{\rho} \cdot \frac{c_d}{k}\right)^2 W_a^2 \tag{7}$$

The ratio of vertical transfer of matter and momentum is often expressed as

$$\frac{K_z}{K_m} = \frac{Rf}{Ri} \tag{8}$$

where $Ri = N^2 \cdot \left(\frac{dq}{dz}\right)^{-2}$ is the Richardson number. Combining (3) and (8) yields

$$K_m = \frac{Ri}{Rf} \cdot K_z = \frac{\rho_a \, c_d}{\rho} \cdot \frac{W_a^2}{\left|\frac{dq}{dz}\right|} \tag{9}$$

$$K_m \cdot \rho \left|\frac{dq}{dz}\right| = \left|\tau_o\right| = \rho_a \; c_d \; W_a^2 \tag{9a}$$

which shows that the relations are consistent, τ_o being the wind stress. Using (3) and (7) we find

$$\frac{K_z}{K_m} = \frac{Rf \cdot c_d \cdot \rho_a \cdot \bar{\bar{W}}_a^2}{\rho \cdot \bar{N}^2} \cdot \frac{f \cdot (\rho \cdot k)^2}{(\rho_a c_d)^2 \cdot W_a^2} \left|\frac{dq}{dz}\right| \qquad (10)$$

Inserting (V_o being the surface current velocity)

$$k = \frac{V_o}{W_a} \quad , \qquad \rho_a c_d = \frac{\bar{\tau}_o}{W_a^2} \quad ,$$

$$\frac{K_z}{K_m} = \frac{Rf}{Ri} \cdot \frac{\rho \cdot V_o^2 \cdot W_a^2 \cdot f}{W_a^2 \cdot \tau_o \left|\frac{dq}{dz}\right|} \qquad (11)$$

The surface current velocity V_o is by the Ekman theory (Ekman 1905)

$$V_o = \frac{\tau_o}{\rho (K_m f)^{1/2}} \quad , \qquad \text{implying}$$

$$\frac{K_z}{K_m} = \frac{Rf}{Ri} \cdot \frac{\rho_w \cdot \tau_o^2 \cdot f}{\rho^2 \cdot K_m \cdot f \cdot \tau_o \cdot \left|\frac{dq}{dz}\right|} = \frac{Rf}{Ri} \qquad (12)$$

showing that these expressions are also consistent.

Besides the energy input from the wind the tidal energy may be important in parts of the Kattegat and the frictional influence of the boundaries generating mixing in the narrow parts of the Belts. The tidal current amplitude is typically 20 cm $\cdot s^{-1}$, and using estimates given by Pingree et al.(1978), we find that a mean wind speed of 5 $m \cdot s^{-1}$ will produce an equivalent rate of energy dissipation per unit mass.

As regards the horizontal mixing, the vertical shear effect has been shown to be an important mixing mechanism in the transition Area (Kullenberg 1972, 1974).

Applications

An important factor in environmental considerations is the rates of dilution which can be expected for different conditions. The volume V(t) of a dispersing patch can be estimated as follows, assuming that the rotationally symmetrical approximation may be used,

$$V(t) = \pi \cdot r^2 \cdot H = 9\pi\, \sigma_{rc}^2 \cdot H \tag{13}$$

with $r = 3\sigma_{rc}$. The variance σ_{rc} can be obtained from the Joseph and Sendner theory as $\sigma_{rc}^2 = 6\,P^2 t^2$ or as $\sigma_{rc}^2 = \sigma_x \cdot \sigma_y$, where σ_x^2 and σ_y^2 are the longitudinal and lateral variances, respectively, for an elliptical distribution. The latter expression can be predicted by means of a shear diffusion model (Kullenberg 1974) as

$$\sigma_x \cdot \sigma_y = K \cdot \frac{dU}{dz} \cdot \frac{dv}{dz} \cdot \frac{t^2}{\omega} \tag{14}$$

where U is the mean current in the longitudinal direction, v is the time-dependent transversal current component with oscillation frequency ω.

The thickness of the patch H(t) can be obtained from the vertical mixing as

$$H = \sqrt{2\,Kt}$$

yielding two expressions for the volume

$$V_1 = 9\pi K \cdot \frac{dU}{dz} \cdot \frac{dv}{dz} \cdot t^2 \sqrt{2\,Kt} \tag{15a, b}$$

$$V_2 = 54\pi\, P^2 t^2 \sqrt{2\,Kt}$$

This quite clearly shows the importance of environmental variability in this context.

The results of the mixing studies can be used to estimate the flux of different substances through the pycnocline layer, by using the diffusion approximation

$$Q_m = KA \frac{dm}{dz} \tag{16}$$

where Q_m is the rate of transfer of the property m, given in mass per volume.

Taking the Sound as bounded by the Drogden Sill and the line Elsinor-Helsingborg, with the pycnocline at 10 m depth, the area $A = 360\ km^2$. A mean value of the vertical mixing is $K = 0.5\ cm^2 \cdot s^{-1}$. Knowing the volume transport T_s through the Sound, which is on an average $6 \cdot 10^9\ cm^3 \cdot s^{-1}$ (Jacobsen 1979), we can estimate the increase of salinity in the top layer during the passage through the Sound, as

$$\Delta s ‰ = \frac{KA \frac{ds}{dz}}{T_s}$$

A few examples are as followes (data from Herman and Olsen 1976):

$\frac{ds}{dz} = 1.8 \cdot 10^{-2}\ ‰ \cdot cm^{-1}$, $\Delta s = 5.4\ ‰$

observed $\Delta s = 4.5\ ‰$

$$\frac{ds}{dz} = 2.3 \cdot 10^{-2}\ ‰ \cdot cm^{-1} \quad , \qquad \Delta s = 6.9\ ‰$$

observed $\Delta s = 5.5\ ‰$.

The same can be done for phosphate and nitrate.

$$\frac{dP}{dz} = 6.25 \cdot 10^{-4}\ \mu g\,at \cdot l^{-1} , \qquad \Delta P = 0.2\ \mu g\,at \cdot l^{-1}$$

observed $\Delta P = 0.2\ \mu g\,at \cdot l^{-1}$

$$\frac{dN}{dz} = 8 \cdot 10^{-3}\ \mu g\,at \cdot l^{-1} \cdot cm^{-1} , \qquad \Delta N = 2.4\ \mu g\,at \cdot l^{-1}$$

observed $\Delta N = 1.0\ \mu g\,at \cdot l^{-1}$

These results are fairly consistent and indicate the applicability of the approach over limited areas.

Acknowledgements

Support from the Danish Belt Project, the Nordic University Group for Physical Oceanography and the Danish Natural Science Council is gratefully acknowledged.

References

Buch, E.B. (1979). Mixing experiments in fiords. Marine Science communications, 5 (4 and 5), p.297-314.

Ekman, V.W. (1905). On the influence of the earth's rotation on ocean currents. Ark. f. Mat. Antr. Fys., Kungliga Svenska Vetenskaps Akademien, Stockholm, 52 pp.

Herman, F. and V. Olsen (1976): Bæltprojektets kemiske undersøgelser. In: Kemiske og Biologiske undersøgelser, Belt Project, Danish Environmental Protection Agency. p. 19-25.

Jacobsen, T.S. (1979), Sea water exchange of the Baltic. ICES Hydr. Comm. 1979.

Joseph, J. and H. Sendner (1958). Über die horizontale diffusion im Meere. Deutsche Hydrogr. Zeitsch. 11 (2), p. 49-77.

Kullenberg, G. (1069). Measurements of horizontal and vertical diffusion in coastal waters. Kungliga Vetenskaps- och Vitterhets-samhället, Göteborg, ser. Geophysica 2, 52 pp.

Kullenberg, G. (1971). Vertical diffusion in shallow waters. Tellus 23 (2), p. 129-135.

Kullenberg, G. (1972). Apparent horizontal diffusion in stratified vertical shear flow. Tellus, 24 (1), p. 17-28.

Kullenberg, G. (1974). An experimental and theoretical investigation of the turbulent diffusion in the upper layer of the sea. Rep. Inst. Phys. Oceanogr. University of Copenhagen, 25, 250 pp.

Kullenberg, G. (1976). On vertical mixing and the energy transfer from the wind to the water. Tellus 28 (2), 159-165.

Kullenberg, G. (1977). Entrainment velocity in natural stratified shear flow. Estuarine and Coastal Mar.Sc. 5, p. 329-338.

Pingree, R.D., P.M. Holligan and G.T. Mardell (1978). The effects of vertical stability on phytoplankton distribution in the summer on the Northwest European shelf. Deep-Sea Res. 25, p. 1011-1028.

Table 1. Observation depth, mean stability parameter $\bar{N}^2$, vertical shear $\left|\frac{dq}{dz}\right|$, overall Richardson number Ri, wind W_a, mean vertical exchange coefficient $\bar{K}$ and the factor $\frac{W_a}{\bar{N}^2}\left|\frac{dq}{dz}\right|$

Area and date	Depth interval m	$\bar{N}^2$ sec^{-2}	$\left\|\frac{dq}{dz}\right\| 10^2$ sec^{-1}	Ri	W_a m sec^{-1}	$\bar{K}$ $cm^2\ sec^{-1}$	$\frac{W_a^2}{\bar{N}^2}\left\|\frac{dq}{dz}\right\|$ $cm^2\ sec^{-1}$
The Sound 650226	16 - 18	$1.9\cdot10^{-2}$	5.9	5.4	3	0.04	-
SE Kattegat 650621	12 - 14	$5.6\cdot10^{-2}$	5.4	19.3	10	0.10	$9.6\cdot10^{5}$
The Sound 651117	12 - 14	$7.7\cdot10^{-2}$	9.6	8.4	10	0.08	$1.2\cdot10^{6}$
Kattegat 661024	10 - 15	$4.8\cdot10^{-3}$	0.5	1.8	4-5	0.2	-
Kattegat 661027	20 - 25	$7.0\cdot10^{-3}$	0.4	3.6	2	0.07	-
Kattegat 670816	18 - 24	$9.5\cdot10^{-3}$	5.9	2.7	8.5	0.35	$4.5\cdot10^{6}$
The Sound 671207	0 - 10	$7.9\cdot10^{-5}$	4.0-6.3	0.03	8	35	$3.7\cdot10^{8}$
The Sound 671208	0 - 10	$2.2\cdot10^{-5}$	4.1	0.01	6	60	$6.7\cdot10^{8}$
Kattegat 671220	17 - 25	$1.4\cdot10^{-3}$	4.8	0.6	5	0.7	$8.5\cdot10^{6}$
Kattegat 671221	17 - 19	$2.5\cdot10^{-3}$	7.7	0.4	8	1.5	$2.0\cdot10^{7}$
The Sound 680320	7 - 11	$4.9\cdot10^{-3}$	5.1	1.9	9	0.9	$8.4\cdot10^{6}$
The Sound 680322	8 - 10	$3.9\cdot10^{-3}$	7.3	0.8	10	1.2	$2.3\cdot10^{7}$

Table 1 continued.

Table 1 continued.

Area and date	Depth interval m	$\bar{N}^2$ sec^{-1}	$\left\|\frac{dq}{dz}\right\| 10^2$ sec^{-1}	Ri	W_a m sec^{-1}	$\bar{K}$ $cm^2 sec^{-1}$	$\frac{W_a}{\bar{N}^2}\left\|\frac{dq}{dz}\right\|$ $cm^2 sec^{-1}$
The Sound 680325	0 – 8	$2.6 \cdot 10^{-4}$	6.0	0.07	5	5	$5.8 \cdot 10^{7}$
The Sound 680329	5 – 8	$3.9 \cdot 10^{-4}$	–	–	1	0.2	–
Kattegat 681127	12 – 15	$1.1 \cdot 10^{-2}$	7.9	1.8	1	0.05	–
Baltic 691209	22 – 27	$1.1 \cdot 10^{-3}$	5.5	0.4	0–6	0.13	–
Baltic 691210	30 – 35	$1.0 \cdot 10^{-3}$	6.9	0.2	4–10	–	–
Baltic 700829	26 – 32	$4.8 \cdot 10^{-4}$	–	–	0–6	0.10	–
Baltic 700830	49 – 53	$2.0 \cdot 10^{-3}$	3.2	2.0	0–7	0.03	–
Baltic 700901	50 – 54	$2.7 \cdot 10^{-3}$	–	–	6–8	0.04	–
Baltic 700902	26 – 29	$5.3 \cdot 10^{-4}$	2.5	0.9	0–6	0.02	–
N Great Belt 741127	9 – 11	$6.1 \cdot 10^{-3}$	7.5	1.1	9	0.65	$9.9 \cdot 10^{6}$
N Great Belt 741128	0 –10	$8.5 \cdot 10^{-4}$	5.1	0.33	14	9.0	$1.2 \cdot 10^{8}$
Great Belt 750409	15 – 17	$4.1 \cdot 10^{-2}$	6.2	10.9	10–6	0.06	$9.7 \cdot 10^{5}$
Baltic 750508	40 – 45	$9.0 \cdot 10^{-5}$	–	–	8	0.05	–

Table 1 continued.

Table 1 continued

Area and date	Depth interval m	$\bar{N}^2$ sec^{-1}	$\left\|\frac{dq}{dz}\right\| 10^2$ sec^{-1}	Ri	W_a m sec^{-1}	$\bar{K}$ cm^2 sec^{-1}	$\frac{W_a^2}{\bar{N}^2}\left\|\frac{dq}{dz}\right\|$ cm^2 sec^{-1}
Baltic 750509	30–40	$3.0\cdot10^{-5}$	–	–	3	0.07	–
Baltic 750510	45–50	$3.1\cdot10^{-4}$	–	–	3	0.02	–
Baltic 750510	50–55	$2.8\cdot10^{-3}$	–	–	3	0.01	–
S Great Belt 760113	0 – 6	–	–	–	11	–	–
S Great Belt 760810	18–22	$4.0\cdot10^{-3}$	6.1	1.1	0–1	0.01	–
S Great Belt 760811	9–13	$6.5\cdot10^{-3}$	14.8	0.34	1–2	0.17	–
Little Belt 760928	15–20	$1.9\cdot10^{-2}$	6.2	2.9	3–4	0.05	–
Little Belt 760929	15–20	$6.8\cdot10^{-3}$	9.5	0.8	11–12	0.02	$1.8\cdot10^{7}$
Kalundborg 800307	8–10	$5.5\cdot10^{-2}$	9.2	6.7	5	0.02	$4.2\cdot10^{5}$
Kattegat 750710	8–10	$4.3\cdot10^{-3}$	1.8	13.3	2	0.03	–
Kattegat 750711	14–16	$4.2\cdot10^{-3}$	3.6	3.2	3	0.1	–
Kattegat 750714	14–16	$8.8\cdot10^{-3}$	5.0	3.5	7–8	0.21	$3.2\cdot10^{6}$
Kattegat 750717	15–17	$1.6\cdot10^{-2}$	8.0	2.5	5	0.18	$1.3\cdot10^{6}$

Table 2. Diffusion time, symmetrical variance σ_{rc}^2, diffusion velocity P ($P^2(1) = \frac{\sigma_{rc}^2}{Gt^2}$, $P^2(2)$ see eq. 2.), apparent horizontal diffusivity K_h, horizontal length scale l_h, longitychinal variance σ_x^2 , transversal variance σ_y^2 ,and the product $\sigma_x \sigma_y$.

Area and date	t sec	σ_{rc}^2 cm^2	P(1) $cm\ sec^{-1}$	P(2) $cm\ sec^{-1}$	K_h $cm^2\ sec^{-1}$	l_h cm	σ_x^2 cm^2	σ_y^2 cm^2	$\sigma_x \sigma_y$ cm^2
The Sound 650226	$2.2 \cdot 10^4$	$2.8 \cdot 10^7$	0.10	0.09	$3.2 \cdot 10^2$	$1.6 \cdot 10^4$	–	–	–
SE Kattegat 650621	$2.2 \cdot 10^4$	$1.1 \cdot 10^7$	0.06	0.08	$1.3 \cdot 10^2$	$1.0 \cdot 10^4$	–	–	–
	$3.8 \cdot 10^4$	$5.4 \cdot 10^7$	0.08	0.07	$3.5 \cdot 10^2$	$2.2 \cdot 10^4$	–	–	–
	$4.8 \cdot 10^4$	$1.0 \cdot 10^8$	0.09	0.10	$5.2 \cdot 10^2$	$3.0 \cdot 10^4$	–	–	–
The Sound 651117	$7.2 \cdot 10^3$	$3.0 \cdot 10^6$	0.10	0.09	$1.1 \cdot 10^2$	$5.2 \cdot 10^3$	$1.8 \cdot 10^7$	$1.8 \cdot 10^6$	$7.0 \cdot 10^6$
	$1.3 \cdot 10^4$	$1.7 \cdot 10^7$	0.13	0.10	$3.3 \cdot 10^2$	$1.2 \cdot 10^4$	$2.3 \cdot 10^7$	$1.0 \cdot 10^7$	$1.5 \cdot 10^7$
Kattegat 661024	$1.5 \cdot 10^4$	$5.1 \cdot 10^7$	0.19	0.16	$8.5 \cdot 10^2$	$2.1 \cdot 10^4$	$4.1 \cdot 10^8$	$2.0 \cdot 10^7$	$9.0 \cdot 10^7$
Kattegat 670816	$1.1 \cdot 10^4$	$4.7 \cdot 10^7$	0.25	0.29	$1.1 \cdot 10^3$	$2.0 \cdot 10^4$	$1.7 \cdot 10^8$	$1.7 \cdot 10^7$	$5.4 \cdot 10^7$
Kattegat 671220	$2.9 \cdot 10^4$	$1.2 \cdot 10^8$	0.15	0.23	$1.9 \cdot 10^3$	$3.3 \cdot 10^4$	$2.5 \cdot 10^8$	$5.0 \cdot 10^7$	$1.1 \cdot 10^8$
	$4.9 \cdot 10^4$	$9.5 \cdot 10^8$	0.26	0.23	$4.8 \cdot 10^3$	$9.3 \cdot 10^4$	$8.9 \cdot 10^8$	$2.8 \cdot 10^8$	$5.0 \cdot 10^8$
Kattegat 671221	$1.2 \cdot 10^4$	$1.2 \cdot 10^8$	0.37	0.32	$2.5 \cdot 10^3$	$3.3 \cdot 10^4$	$2.8 \cdot 10^8$	$1.0 \cdot 10^7$	$5.3 \cdot 10^7$

Table 2 continued.

Table 2 continued.

Area and date	t sec	σ_{rc}^2 cm^2	$P(1)$ $cm\ sec^{-1}$	$P(2)$ $cm\ sec^{-1}$	K_h $cm^2\ sec^{-1}$	l_h cm	σ_x^2 cm^2	σ_y^2 cm^2	$\sigma_x\sigma_y$ cm^2
Kattegat 681127	$1.4 \cdot 10^4$	$3.0 \cdot 10^7$	0.16	0.17	$5.4 \cdot 10^2$	$1.7 \cdot 10^4$	$1.6 \cdot 10^8$	$1.8 \cdot 10^7$	$5.4 \cdot 10^7$
Baltic 691209	$3.8 \cdot 10^4$	$4.3 \cdot 10^8$	0.20	0.20	$2.9 \cdot 10^3$	$6.3 \cdot 10^4$	$3.7 \cdot 10^9$	$3.0 \cdot 10^7$	$3.3 \cdot 10^8$
Baltic 700830	$2.7 \cdot 10^4$ $6.0 \cdot 10^4$	$1.6 \cdot 10^8$ $2.4 \cdot 10^8$	0.19 0.11	0.19 0.11	$1.5 \cdot 10^3$ $1.0 \cdot 10^3$	$3.8 \cdot 10^4$ $4.7 \cdot 10^4$	$2.3 \cdot 10^8$ $1.4 \cdot 10^9$	$4.1 \cdot 10^7$ $3.4 \cdot 10^7$	$9.7 \cdot 10^7$ $2.2 \cdot 10^8$
Baltic 700902	$2.4 \cdot 10^4$	$1.2 \cdot 10^8$	0.16	0.16	$1.3 \cdot 10^3$	$3.3 \cdot 10^4$	$1.5 \cdot 10^8$	$5.6 \cdot 10^7$	$9.2 \cdot 10^7$
Great Belt 750409	$1.1 \cdot 10^4$ $1.8 \cdot 10^4$ $4.9 \cdot 10^4$	– $5.2 \cdot 10^8$ $4.0 \cdot 10^9$	– 0.51 0.52	0.25 0.42 0.28	– $7.2 \cdot 10^3$ $2.1 \cdot 10^4$	– $6.8 \cdot 10^4$ $1.9 \cdot 10^5$	– – –	– – –	– – –
Baltic 750509	$4.8 \cdot 10^4$ $6.7 \cdot 10^4$	$1.6 \cdot 10^8$ $2.9 \cdot 10^8$	0.11 0.11	0.09 0.11	$8.1 \cdot 10^2$ $1.1 \cdot 10^3$	$3.8 \cdot 10^4$ $5.1 \cdot 10^4$	$5.3 \cdot 10^8$ –	$3.1 \cdot 10^7$ –	$1.3 \cdot 10^8$ –
Baltic 750510	$1.0 \cdot 10^5$ $1.4 \cdot 10^5$	$6.1 \cdot 10^8$ $1.2 \cdot 10^9$	0.10 0.10	0.09 0.12	$1.5 \cdot 10^3$ $2.0 \cdot 10^3$	$7.4 \cdot 10^4$ $1.0 \cdot 10^5$	$9.4 \cdot 10^8$ –	$1.6 \cdot 10^8$ –	$3.9 \cdot 10^8$ –

Table 2 continued.

Table 2 continued.

Area and date	t sec	σ_{rc}^2 cm^2	P(1) $cm\ sec^{-1}$	P(2) $cm\ sec^{-1}$	K_h $cm^2\ sec^{-1}$	l_h cm	σ_x^2 cm^2	σ_y^2 cm^2	$\sigma_x\sigma_y$ cm^2
S Great Belt 760113	$1.0 \cdot 10^4$ $2.3 \cdot 10^4$	$5.5 \cdot 10^8$ $4.2 \cdot 10^9$	0.93 1.35	0.61 0.53	$1.4 \cdot 10^4$ $4.6 \cdot 10^4$	$7.0 \cdot 10^4$ $1.9 \cdot 10^5$	$6.0 \cdot 10^8$ –	$1.8 \cdot 10^8$ –	$3.3 \cdot 10^8$ –
N Little Belt 760928	$5.2 \cdot 10^4$	$1.2 \cdot 10^9$	0.27	0.32	$5.7 \cdot 10^3$	$1.0 \cdot 10^5$	$4.1 \cdot 10^9$	$2.2 \cdot 10^9$	$3.1 \cdot 10^9$
N Little Belt 760929	$3.5 \cdot 10^4$	$2.0 \cdot 10^9$	0.52	0.55	$1.4 \cdot 10^4$	$1.3 \cdot 10^5$	$3.9 \cdot 10^9$	$9.7 \cdot 10^8$	$1.9 \cdot 10^9$
Kalundborg 780307	$1.8 \cdot 10^4$ $2.5 \cdot 10^4$	$1.3 \cdot 10^8$ $5.0 \cdot 10^8$	0.26 0.37	0.16 0.42	$1.8 \cdot 10^3$ $5.0 \cdot 10^3$	$3.4 \cdot 10^4$ $6.7 \cdot 10^4$	$1.8 \cdot 10^8$ $6.4 \cdot 10^8$	$6.2 \cdot 10^6$ $9.1 \cdot 10^7$	$3.3 \cdot 10^7$ $2.4 \cdot 10^8$
Kattegat 750710	$2.4 \cdot 10^4$ $3.2 \cdot 10^4$	$2.8 \cdot 10^8$ $6.2 \cdot 10^8$	0.29 0.32	0.10 0.21	$2.9 \cdot 10^3$ $2.4 \cdot 10^3$	$5.0 \cdot 10^4$ $7.5 \cdot 10^4$	– $1.2 \cdot 10^9$	– $1.0 \cdot 10^8$	– $3.5 \cdot 10^8$
Kattegat 750711	$1.2 \cdot 10^4$	$6.9 \cdot 10^7$	0.28	0.38	$1.4 \cdot 10^3$	$2.5 \cdot 10^4$	$1.7 \cdot 10^8$	$2.4 \cdot 10^7$	$6.4 \cdot 10^7$
Kattegat 750714	$8.0 \cdot 10^4$	$1.0 \cdot 10^9$	0.16	0.17	$3.1 \cdot 10^3$	$9.5 \cdot 10^4$	$1.7 \cdot 10^9$	$3.1 \cdot 10^8$	$7.2 \cdot 10^8$
Kattegat 750717	$2.3 \cdot 10^4$	$8.1 \cdot 10^8$	0.50	0.35	$8.8 \cdot 10^3$	$8.5 \cdot 10^4$	$1.4 \cdot 10^9$	$1.7 \cdot 10^8$	$5.0 \cdot 10^8$