FISHERY BOARD OF SWEDEN
Series Hydrography, Report No. 2

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ELANDERS BOKTRYCKERI AKTIEBOLAG

Since 1923, observations of temperature and salinity at 10 Swedish lightships have been carried out. Two ships in the Kattegatt, the »Fladen» and the »Svinbådan», have collected material daily during the whole period except for an inevitable break of 6 years during the war. After 30 years hydrographic work the observations can now be examined in order to trace some long-period fluctuations of the vertical distribution of properties in the stratified Kattegatt water.

A great number of investigations into the hydrography of the Kattegatt have established its complex character. There is a brisk exchange of water in the Kattegatt, low-salinity water being supplied from the Baltic and high-salinity water from the North Sea. Under the influence of strong winds the mixing of these two water masses is intense. A third type of water, recognized as Kattegatt water, is generally sharply bounded in the surface layer by the Baltic water and the North Sea water. The positions of these fronts are to a high degree governed by wind conditions (WATTENBERG, 1941).

Recently, the transport mechanism in the Kattegatt and its relation to weather conditions has been studied by DIETRICH (1951) and KÄNDLER (1951). It appears that west winds favour the inflow from the North Sea, whereas the outflow of Baltic water is increased by easterly winds. At high air pressure the outgoing surface current of Baltic water is compensated by North Sea water which penetrates as a deep current, and the vertical stratification is well developed.

This investigation will chiefly be confined to the present experimental material from the »Fladen», which is anchored at 57°13'N and 11°51'E. The north-going Baltic current follows the Swedish coast owing to the Coriolis deviation and this is usually the prevailing current at the »Fladen». Furthermore the »Fladen» observations extended down to a depth of 40 m and represent fairly well the circulation in the Kattegatt deep channel.

The vertical temperature distribution is of interest chiefly in summer when the thermocline is well developed. In the following,

TABLE I. *Mean summer temperatures (June—August) at the »Fladen».*

Year	Depth						
	0 m	5 m	10 m	15 m	20 m	30 m	40 m
1923	14°.0	13°.8	13°.3		11°.7	(10°.7)	(8°.5)
24	15°.2	14°.7	13°.4		10°.9	8°.9	6°.9
25	16°.8	16°.6	15°.4		12°.5	10°.1	8°.5
26	16°.9	16°.7	14°.5		11°.5	8°.8	7°.5
27	15°.6	15°.1	14°.1		11°.0	9°.6	8°.4
28	13°.8	13°.7	13°.1		11°.4	9°.7	7°.9
29	14°.6	14°.5	13°.5		11°.1	9°.1	7°.3
30	17°.0	16°.7	15°.2		12°.2	10°.2	7°.9
31	15°.2	15°.0	13°.5		10°.9	8°.7	6°.9
32	(17°.1)	(17°.1)	(15°.1)		(11°.6)	(9°.0)	(7°.7)
33	17°.7	17°.5	15°.1		12°.1	10°.5	8°.7
34	17°.0	16°.2	14°.9		11°.5	8°.8	7°.4
35	16°.4	16°.1	15°.0		12°.9	9°.9	7°.7
36	17°.3	17°.1	15°.2		11°.4	9°.8	8°.3
37	17°.3	17°.0	15°.2		11°.7	8°.6	6°.8
38	16°.3	16°.1	14°.0		12°.6	11°.3	9°.9
39	17°.0	16°.9	15°.5		12°.8	10°.6	8°.3
47	18°.0	17°.6	16°.3	(14°.7)	(12°.0)	(10°.0)	(8°.0)
48	16°.9	16°.6	15°.2	12°.9	12°.7	11°.7	9°.5
49	16°.7	16°.6	15°.1	13°.8	11°.7	9°.6	8°.3
50	16°.6	16°.2	15°.0	13°.8	12°.3	9°.7	8°.3
51	15°.9	15°.6	13°.2	11°.3	10°.7	8°.6	6°.7
52	15°.6	15°.3	14°.7	14°.1	13°.3	11°.9	10°.7
1923—39	16°.2	15°.9	14°.5		11°.8	9°.6	7°.9
1923—52	16°.3	16°.0	14°.6		11°.9	9°.8	8°.1

only average values during the summer months are considered. No great attention is paid to extreme conditions of short duration which lead to strong inflows from the North Sea or outflows from the Baltic.

Mean summer temperatures (June—August) have been computed for different years and levels at the »Fladen», and are shown in Table I. Observations at 15 m depth were obtained after the war only. In some cases, when the data are not complete, interpolation has been made, or other available observations have been used. These values, which are subject to some uncertainty, are within brackets.

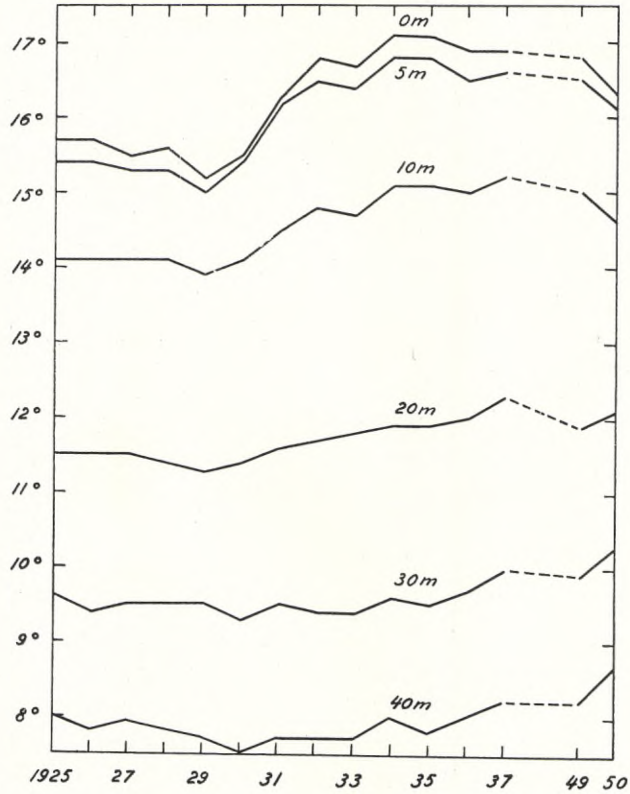

Fig. 1. Progressive averages (5 year means) of the summer mean temperature (June-August) at the »Fladen».

Some features in Table I may be explained simply. Summers characterized by high-pressure conditions and weak winds show high surface temperature but the temperature is not above normal in the deep water (1932, 1937, and 1947). Low-pressure activity with strong winds causes an increase in the depth to the thermocline owing to intense mixing in the upper layers (1923, 1928). The lowest surface temperature occurred in 1928, the highest in 1947 both in good agreement with observations of air temperature.

More information about the vertical temperature structure is gained if some smoothing model is employed. There is reason to believe that fluctuations within a period as short as 5 years are not significant. Therefore, it would be satisfactory to consider progressive averages with 5 year means. Values derived in this way are shown in Fig. 1.

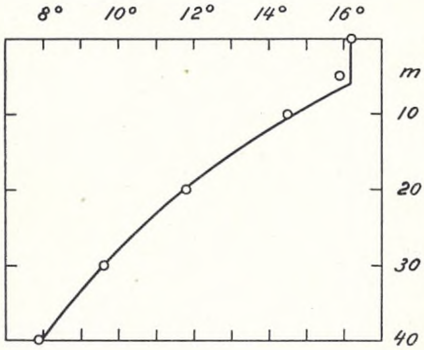

Fig. 2

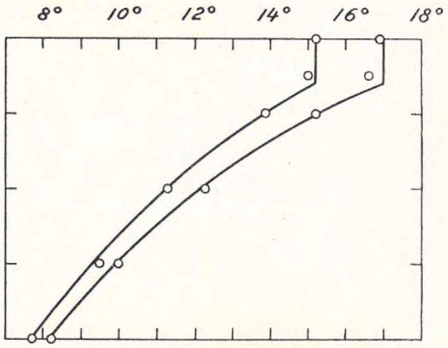

Fig. 3

Fig. 2. Mean values of the summer temperature at the »Fladen» for the period 1923—39 compared with the computed temperature distribution curve.

Fig. 3. Mean values of the summer temperature at the »Fladen» for the cool period 1927—31 and for the warm period 1935—39 compared with the computed temperature distribution curves.

The figure brings out the conspicuous rise of surface temperature in the thirties (Cf BRATTSTRÖM, 1941). The air temperature shows a similar trend, discrepancies being accounted for by the high heat capacity of water. The rise becomes less marked towards deeper layers but the minimum is still present in 1927-31 or in 1928—32. The last period 1948—52 displays an anomalously high temperature at 40 m which will be discussed below.

The temperature at a certain level in the sea is chiefly altered by the process of heat diffusion. From June to August the thermocline curve for 5 year means of the summer temperature happens to have the same curvature from 10 m to the bottom. The temperature at 5 m shows a constant deviation of 0°.3 from the surface temperature. A theoretical distribution is suggested which consists of a straight line down to 6 m, corresponding to a homogeneous top layer, and a part of a circle according to the formula (with reference to Figs. 2 and 3).

$$(T_c - T)^2 + 1/25\,(103 - z)^2 = (T_c - 3.9)^2,$$

where T is the temperature at the depth z m, and T_c the centre of the circle which is always at the depth 103 m. By introducing the surface temperature T_o for $z = 6$ m, T_c is obtained.

TABLE II. *Mean summer salinities (June—August) at the »Fladen«.*

Year	Depth						
	0 m	5 m	10 m	15 m	20 m	30 m	40 m
1924	18.6 ‰	19.2 ‰	22.9 ‰		31.8 ‰	32.8 ‰	33.2 ‰
25	19.7	21.7	26.3		32.5	33.2	33.6
26	18.1	19.4	27.2		32.4	33.3	33.6
27	17.7	18.2	21.4		30.9	33.1	33.4
28	23.6	24.7	27.0		31.3	32.6	33.3
29	20.1	(21.0)	24.1		31.8	32.9	33.4
30	21.3	22.9	27.0		32.8	33.6	33.8
31	19.1	20.3	27.3		32.1	33.0	33.4
32	18.5	19.7	26.1		32.9	33.6	33.9
33	20.4	21.8	26.2		32.5	33.4	33.9
34	21.2	22.4	26.4		32.2	33.3	33.9
35	20.1	21.5	24.9		31.0	32.8	33.5
36	19.6	19.9	23.1		32.7	33.5	33.8
37	20.0	21.9	26.8		32.1	33.0	33.4
38	19.6	20.6	23.9		31.5	32.3	33.3
39	20.9	21.4	24.1		31.6	33.2	33.2
48	(20.7)	(21.0)	(22.8)	(28.4) ‰	(32.1)	(32.9)	(33.4)
49	19.9	20.4	23.8	28.7	31.4	32.9	33.4
50	(20.7)	(23.5)	(27.5)	30.2	31.7	33.0	33.5
51	20.7	21.2	27.0	30.9	32.5	33.6	34.0
52	21.6	23.6	26.5	29.5	31.6	33.0	33.5
1924—39	19.9 ‰	21.0 ‰	25.3 ‰		32.0 ‰	33.1 ‰	33.6 ‰
1924—52	20.1	21.3	25.3		32.0	33.1	33.6

Fig. 2 shows that the summer temperatures for the whole period 1923—39 are expressed satisfactorily by this equation. All progressive averages representing the summers 1923—51 fit into this scheme with maximum deviations of 0°.2. The consistency obtained is illustrated for the coldest period 1927—31 and for the warmest 1935—39 (Fig. 3).

The last period 1948—52 in the sequence constitutes a striking exception. In this case the temperature at 40 m is 0°.7 higher than the theoretical value. For the individual years we notice great fluctuations in the temperature at 40 m; 1948 is high, 1951 low, and 1952 extremely high, *i. e.* 2°.6 above the average. Although the summer of 1952 was cool the 40 m water column at the »Fladen»

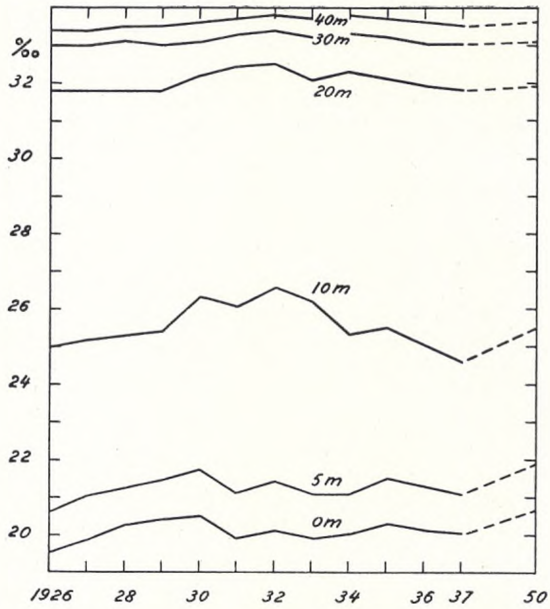

Fig. 4. Progressive averages (5 year means) of the summer mean salinity (June—August) at the »Fladen».

then held a maximum storage of heat. The anomalous situation in 1952 marks the whole period 1948—52 and increases the 5 year means considerably.

The question arises whether the temperature in deep layers in 1952 is high at other localities in the Kattegatt. At the Danish lightships »Anholt Nord» and »Laesø Nord» the temperature was not exceptionally high (THOMSEN, personal communication) nor at the Swedish lightship »Vinga» in the northern Kattegatt. On the other hand, at the »Svinbådan», anchored where the Sound opens out into the Kattegatt, similar conditions as at the »Fladen» were found in the summer of 1952, the bottom temperature being 2° higher than the normal value. The anomaly, thus, is chiefly limited to the region of the Baltic current and may be ascribed to intense vertical mixing and damming up of the current due to action of strong westerly winds.

The vertical structure of salinity during the summers is also relevant to the problem. Values for the different years are given in Table II. The years 1928 and 1952 previously selected as being characterized by strong west winds show high surface salinity. A slow fluctuation in salinity appears from the progressive averages (fig. 4). The comparatively high salinity in the deep layers during the middle thirties, which has been discussed by JENSEN (1937). NEUMANN (1940) and BRATTSTRÖM (1941), comes out clearly. The salinity at 10 m culminates 1930—34 after which it declines till 1939. As the halocline is practically linear between 5 and 15 m, the 10 m curve illustrates fluctuations in the vertical position of the halocline. The opportunity for a strong inflow of salt water to the Baltic is most favourable when the high-salinity water is on an average near the surface. It may be recalled that in the spring of 1933 an intense inflow occurred, which led to a supply of new water in the deep basins of the Baltic.

Surface salinity gradually increases from a low value in the first 5 year period to a maximum in 1928—32 which is surpassed only be the last period 1948—52. The temperature anomaly in the deep layers is thus associated with a salinity anomaly involving the highest surface salinity ever found during the 30 years. The clue is chiefly afforded by the strong inflow in 1952 induced by the westerly winds. This point of view is borne out by the salinity distribution at the »Svinbådan» which displays high salinity at the surface, and low at the bottom, which indicates an intense mixing.

References

BRATTSTRÖM, H., 1943. Studien über Echinodermen des Gebietes zwischen Skagerrak und Ostsee, besonders des Öresundes, mit einer Ubersicht über die physikalische Geographie. Unters. a. d. Öresund 27.

DIETRICH, G., 1951. Oberflächenströmungen im Kattegatt, im Sund und in der Beltsee. Deutsche Hydr. Zeitschr. Bd 4, p. 129.

JENSEN, A. J. C., 1937. Fluctuations in the Hydrography of the Transition area during 50 years. Conseil Perm. Int. p. l'Explor. de la Mer, Rapp. et Proc.-Verb. v. 102.

KÄNDLER, R., 1951. Der Einfluss det Wetterlage auf die Salzgehaltsschichtung im Ubergangsgebiet zwischen Nord- und Ostsee. Deutsche Hydr. Zeitschr. Bd 4, p. 150.

NEUMANN, G., 1940. Mittelwerte längerer und kürzerer Beobachtungsreihen des Salzgehaltes bei den Feuerschiffen im Kattegatt und in der Beltsee. Ann. d. Hydrogr. u. marit. Meteorol. v. 68, p. 373.

WATTENBERG, H., 1941. Über die Grenzen zwischen Nord- und Ostseewasser. Ann. d. Hydrogr. u. marit. Meteorol. v. 69, p. 265.

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