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On the seasonal fluctuations in the T-S properties of quasi-permanent water types in the Fehmarn Belt

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The T-S relation which is applied in full to oceanic water bodies has been applied to shallow water areas which are subject to considerable fluctuations. Despite the requirement of selecting the period of observation in a restricted sea area in such a way that roughly constant meteorological conditions can be assumed, considerable differences were found in the properties of the water types in the Baltic and the areas connecting it to the North Sea, so that HELA and KRAUSS (1959) introduced the concept of the "quasi-permanent water type".

The stratification to the west of the "Darsser Schwelle" is determined mainly by three water types with two discontinuity layers (see WOLF, 1972, 1973). The number of water types and their properties at a fixed station is subject to an annual change on the one hand and, on the other, temperature and salinity fluctuations of the same magnitude are produced at short intervals (hours or days) by the alternation between inflow and outflow situations. If these fluctuations are observed from day to day using a T-S diagram, it is possible to decide, for any period of 10 days and, subsequently, for every month, which changes are due to short-term fluctuations and which can be ascribed to the annual cycle.

As a first step, 363 vertical series taken from the lightship "Fehmarnbelt" for the year 1953 were investigated with regard to the annual distribution of haloclines and the depths and intensities of these layers were checked (the vertical density distribution is determined by the salinity).
The largest absolute changes (in the sense of the definition of discontinuity layers stated by CASTENS (1927) in measurements taken at intervals of 5 m were used to estimate the depth and intensity.

The numbers of haloclines found per interval were one in 52.3 % of the cases, two in 42.7 % of the cases and none in 5.0 % of the cases. The lowest intensity was 1.0 $^{o}/oo$ (according to definition) related to the distance between measurements and the greatest intensity of 16 $^{o}/oo$ was obtained in summer when only one halocline was observed in one layer with a thickness of 5 m.

The upper halocline (a) which is identified as the Belt Sea-discontinuity layer occurs most frequently at a depth of 7.5 m. It separates the surface water (A) flowing out of the Baltic from an intermediate water type (B) which generally enters the "Arkona Becken" over the "Darsser Schwelle" with the undercurrent. The intermediate water (C) by a further halocline (b), the bottom water usually being found at a depth of 21.0 m and which is identified as the Skagerrak-discontinuity layer. If there is only one halocline (c), it is usually found at a depth of 17.5 m. The great intensity (up to 16 $^{o}/oo$ in an interval of 5 m) indicates that it is formed by the union of the two haloclines (a) and (b).

The monthly distribution of the haloclines,and thus of the water types (table 1) is important with regard to the validity of figure 1, which must still be discussed. On the other hand, it shows that the considerable differences between the monthly means for different years is probalby less due to differences in the quality of the water types themselves than to the considerable fluctuations which occur from year to year in the frequency distribution of the types of water at the station.

Table 1: Monthly distribution of the haloclines at the lightship "Fehmarnbelt", 1953

In the station area	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
both haloclines (a) and (b) present	15	9	–	13	26	8	9	15	15	20	10	7
only upper halocline(a) present	10	5	20	–	–	–	–	–	–	–	–	–
only lower halocline(b) present	5	7	–	5	5	3	–	11	15	11	20	24
unification haloclines(c) of (a) and(b)	–	–	–	–	–	19	22	5	–	–	–	–
no halocline found	1	7	11	3	–	–	–	–	–	–	–	–

It can be seen that, from May to October, both haloclines usually occur or that they may also appear in the form of a uniform discontinuity layer in the area of the station. The haline bottom water may be absent during the other months, this being obvious only during the first months for 1953. Strong west winds (and, more rarely, strong east winds) can cause the presence of only one water type.

The annual cycle of the three water types which describes the annual fluctuations of the T-S properties of each water type separately was derived from the previously mentioned 10-day fluctuations in the T-S diagram on the one hand and, for the surface water and bottom water, was calculated on the basis of the extreme values over five years (1950 to 1954) on the other. It was assumed that the monthly absolute salinity minima (and the corresponding temperature) at the surface can be assigned to the surface water (A), whereas the absolute salinity maxima (and the

corresponding temperatures) at the bottom characterise the bottom water (C). Good agreement has been found. Figure 1 shows the relation lines for the surface water

$$S_o = -0.036\ T_o + 9.86 \qquad 0.5^\circ < T_o < 20^\circ$$

and for the bottom water

$$S_B = 0.319\ T_B + 23{,}34 \qquad 1{,}5^\circ < T_B < 13^\circ$$

The domain of definition can be seen from figure 1. The temperature and salinity of the surface water (A) vary between 1 °C and 19 °C and between 9 ‰ and 10 ‰ respectively in the course of the year.
The Roman figures I to XII designate the temperature and salinity values in the corresponding months. The extremes are reached in February and August, the salinity decreasing with rising temperatures during the first half of the year and the reverse procedure taking place during the other half of the year. The temperature and salinity of the bottom water (C) fluctuate between 2 °C and 12 °C and between 24 ‰ and 27.5 ‰ respectively, the extreme values being reached in March and September.
The temperature and salinity fluctuations correspond with regard to the direction of change.

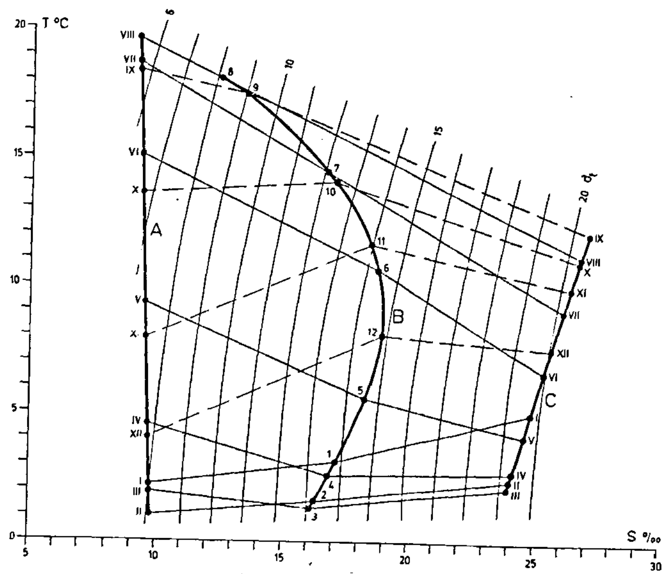

Figure 1: Annual cycle of the T-S properties of quasi-permanent water types in the Fehmarn Belt

The behaviour of the intermediate water (B) is different. The temperature fluctuates between 1 °C in March and 18 °C in August, but the salinity increases from 16 °/oo to 19 °/oo as the temperature rises from March to May/June and then drops from 19 °/oo to about 12.5 °/oo while the temperature continues to rise. At the beginning, the direction of the changes is the same as for the bottom water, but it corresponds subsequently to that of the surface water.
In the second half of the year, the direction of the changes is reversed (double annual variation in salinity).
The short-term fluctuations generally follow the full and dashed lines showing the T-S values for the different months in figure 1.
When the water masses become superposed, they produce the relation lines V - 5 - V, the typical vertical T-S course for May.
In the ideal case, all measured points for the vertical series would lie on this line and the effects of the prevailing weather, for example, generally alter only the distances between the corner and angle points. There is considerable room for variability because the differences between the densities of the water types involved are very large. The annual cycle is influenced primarily by the temperature, whereas the short-term fluctuations have a greater effect on the salinity.

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