Aus dem Institut für Meereskunde an der Universität Kiel

Observations on scattering layers and thermoclines in the Baltic Sea

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Summary: Records of temperature fluctuations in a thermocline show an energy peak close to the local Brunt-Väisälä frequency. This supports recent observations that short internal waves are common phenomena within the thermocline. The high rate of energy of these waves permits the conclusion that they may break and form patches of turbulence. It is assumed that these short internal waves and turbulence patches contribute to the acoustic backscattering observed from these layers.

Zusammenfassung: Beobachtungen der Temperaturschwankungen in einer Temperatursprungschicht der Ostsee zeigen häufig eine Energiekonzentration dicht bei der lokalen Brunt-Väisälä-Frequenz, die zu einer generellen Erhöhung des Energieniveaus in diesem Frequenzbereich führt. Die relativ großen Amplituden dieser kurzen Wellen legen den Schluß nahe, daß die Wellen zeitweise instabil werden und brechen, wodurch lokal Turbulenz erzeugt wird. Es wird vermutet, daß sowohl die kurzen internen Wellen als auch diese Turbulenzfelder zur Rückwärtsstreuung des Schalles beitragen, die mittels Echolot häufig beobachtet wird.

1. Scattering layers in the Baltic Sea

The mean stratification of the Baltic Sea during summertime west of Bornholm island may be characterized by a three-layer system:

a) a warm surface layer of about 16°—17° C and with salinity of about $8^0/_{00}$, which covers the top 20 m.

b) a cold intermediate layer of about 5°C and with approximately the same salinity as the surface layer, ranging from 20—40 m. This water mass has been formed during winter time.

c) a bottom layer of about 12°C and with $15^0/_{00}$ salinity due to the influx of water from the North Sea.

The three layers are separated by transition regions which are characterized by strong gradients. These transition zones are often subdivided into layers of a few centimeters or meters thickness. It has long been recognized that the main features of the layered structure can be observed easily by standard type echo sounders. The signal transmitted from board the ship is not only reflected from the bottom but also from the transition regions between the layers mentioned above.

A typical example with respect to the transition layer between the cold intermediate water and the bottom water is shown in Fig. 1. If a 30-kcps beam of about 24° is pointed vertically downwards from the ship, then — depending on the sensitivity of the recorder — the transition layer in about 39 m depth is displayed (left part of Fig. 1). The central part of the figure shows the oscilloscope record of the reflected signal for two different emissions. The right part displays the vertical distribution of sound velocity recorded by a sound velocimeter. In this case the layer of strong back scattering is identical with the depth where the density, and due to increasing temperature and salinity, the sound velocity too, strongly increase.

J. Lenz (1965) has shown for the Baltic that contrary to what is widely assumed there is no significant relationship between the intensity of the scattering layer and the accumulation of plancton and detritus. He, therefore, thinks the reason for the development of the scattering layers to be density variations.

T. Hashimoto & Y. Maniwa (1956) confirmed by experiments that differences in temperature of about 5—10°C between two adjacent water bodies are sufficient to obtain backscattering according to Raleigh reflection. Thus, scattering layers can be expected to exist at sufficiently strong temperature and salinity interfaces. However, well defined scattering layers can also be observed in depths characterized by rather small changes in density as well as in sound velocity (with an increase in sound velocity according to an increase in temperature prevailing in general). Cases like that (some hundred) were investigated in the Baltic from 1964—1968. Fig. 2 shows a typical example. Three scattering layers were observed in depths between 29 and 36 m, i. e. depths where the sound velocity unessentially changes. Further observational data can be taken from Fig. 3a-d displaying temperature and salinity distributions for some stations. Shaded regions represent scattering layers. In addition to bottom layers which might be explained by the rapid change in sound velocity, quite a number of scattering layers are observed in mean depths.

In cases as mentioned above no investigations were carried out with respect to the accumulation of plancton and detritus. However, there is no reason to assume passive biological material within these depths because changes in density are relatively small there. It seems likely that the backscattering from these layers must have physical reasons.

2. Backscattering from rough surfaces and oceanic microstructure

The fact that backscattering takes place from layers with minor changes in temperature and salinity may be due to the roughness of these layers. Specular and nonspecular reflection by rough surfaces have been studied intensively during the last decade (H. W. Marsh, 1961, 1963; H. W. Marsh, M. Schulkin & S. G. Kneale, 1961; E. Y. T. Kuo, 1964); these studies mainly concentrate on the sea surface and the ocean floor. Sound level fluctuations due to thermal microstructure are known since World War II. The basic theory is summarized in L. M. Brekhovskikh (1960) and V. I. Tatarski (1961). Backscattering from a rough surface is mainly due to patches with a diameter $d = (\lambda/2)$ where λ is the wave length of the sound wave (λ is about 5 cm for 30 kcps and $c = 1450$ m sec^{-1}). The scattering intensity is proportional to the energy of sound velocity fluctuations.

In order to interpret backscattering from weak interfaces as shown by Fig. 3, we must admit that strong fluctuations occur in these layers with wave lengths of a few centimeters.

The first reports on fine structure of temperature measured vertically have been published after World War II. The commercial production of salinity-temperature-depth profilers made it possible to observe this phenomenon in many areas. A summary of all these observations has been given by J. P. Bethell (1972). These observations have revealed quasi-homogeneous layers ranging from a few centimeters to tens or hundreds of meters separated by sharp gradients. The formation of the layers may either be due to horizontal advection of water of slightly different origin along isopycnic surfaces, double diffusion or shear instability.

Horizontal advection is the major reason for the existence of the haline bottom layer in the Baltic and the strong pycnocline separating this water from the colder one above.

Double-Diffusion processes may occur in the Baltic Sea especially at the interface between fresh cold intermediate water and the warm bottom water of higher salinity. J. S. Turner & H. Stommel (1964) have shown that due to this fact well-mixed turbulent

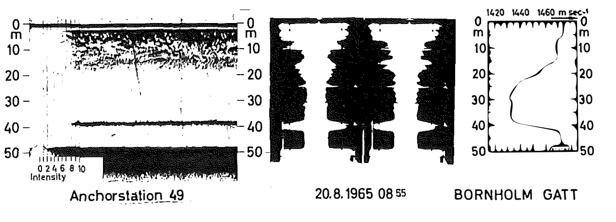

Fig.1

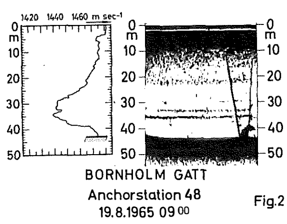

Fig.2

Fig. 1: Left: Scattering layer; central: oscilloscope record of the backscattering; right: sound velocity profile

Fig. 2: Sound velocity profile and multiple scattering layers

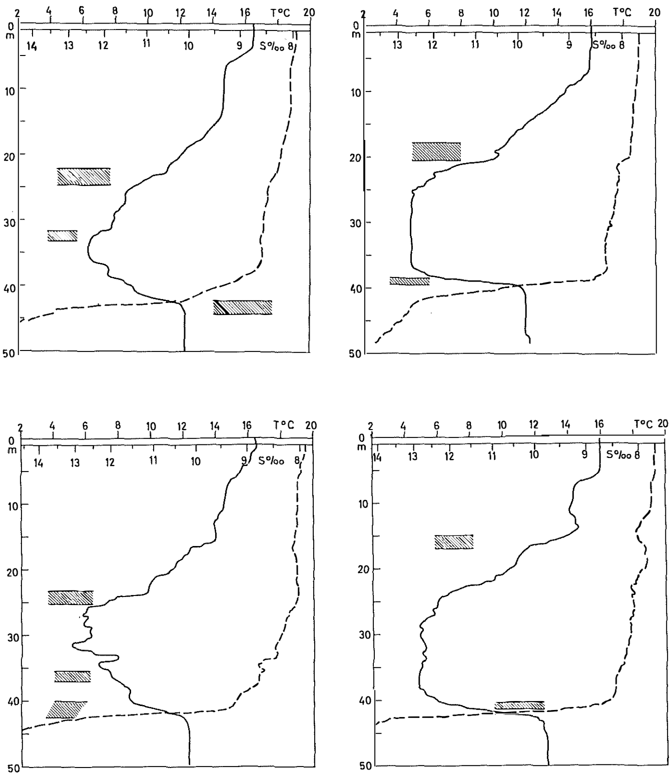

Fig. 3

Fig 3 a—d: Examples of temperature (full line) and salinity profiles (broken line) and depth of scattering layer (shaded)

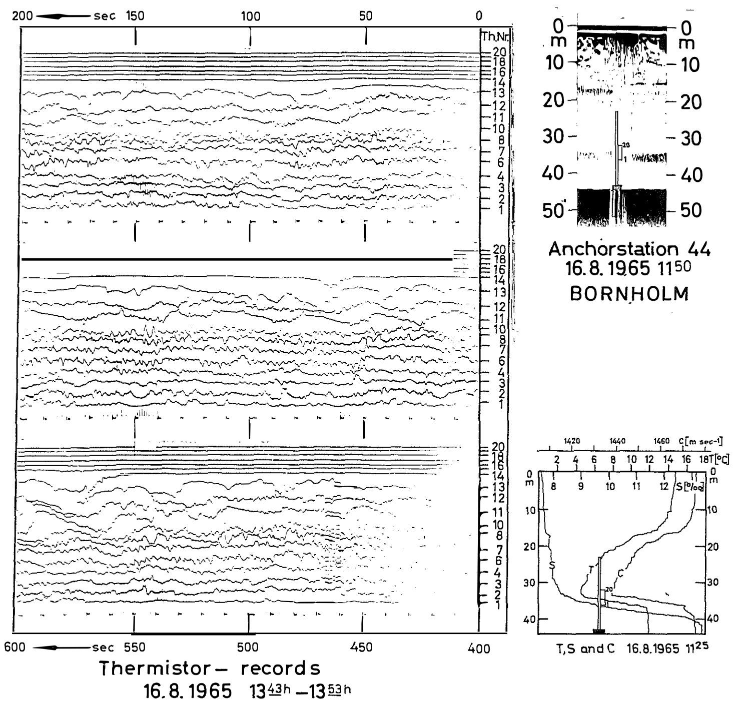

Fig. 4

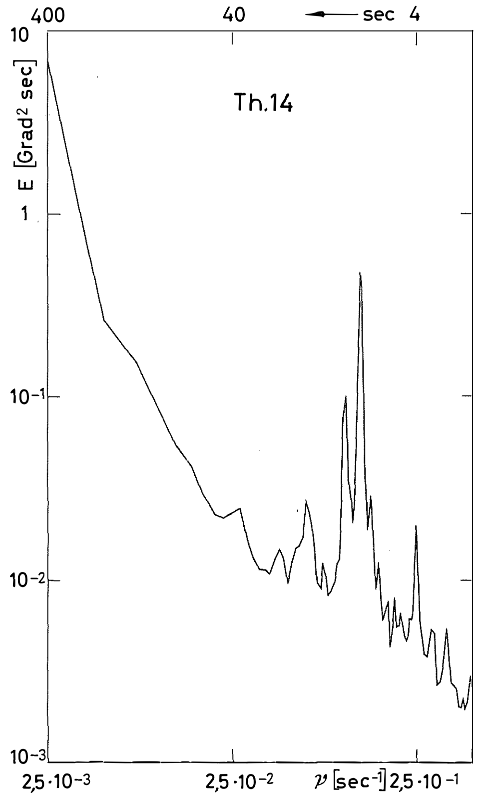

Fig. 5

Fig. 4: Top right: scattering layer and observation mast with 20 thermistors.
bottom right: Distribution of temperature (T), salinity (S) and sound velocity c. The 20 thermistors record in and above the lower thermocline.
left: continuous temperature record (from right to left, top to bottom) of 20 thermistors separated by a vertical distance of 20 cm

Fig. 5: Temperature spectrum of the fluctuations in the thermocline. The energy peak is close to the local Brunt-Väisälä frequency.

Tafel 3 (zu W. Krauß, P. Koske u. J. Kielmann)

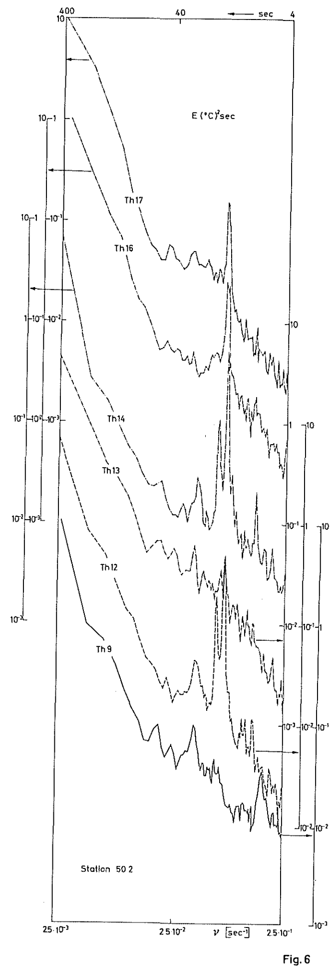

Fig. 6

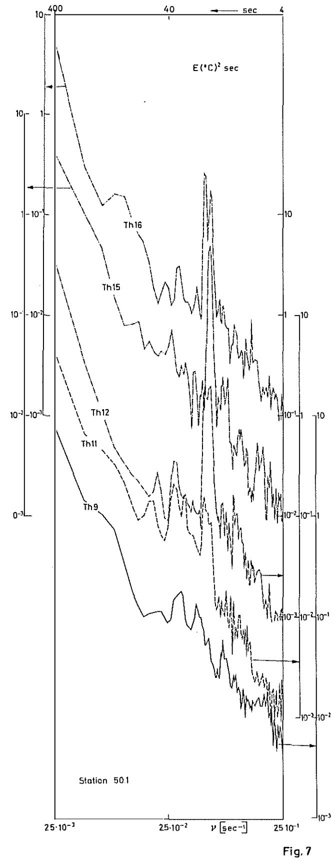

Fig. 7

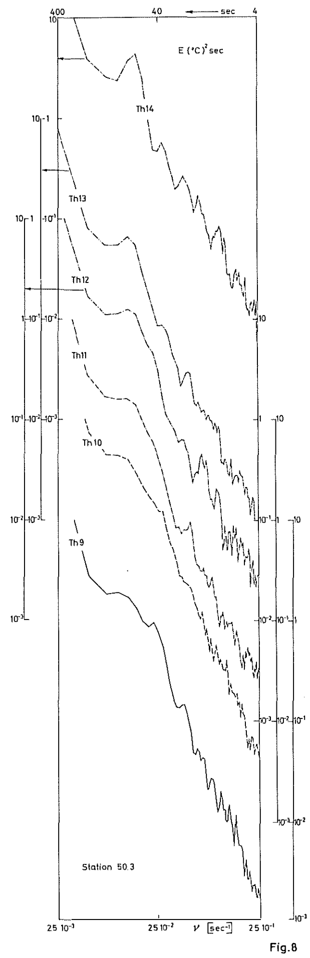

Fig. 8

Fig. 6—8: Temperature spectra of the fluctuations in the thermocline at three different times.

Tafel 4 (zu W. Krauß, P. Koske u. J. Kielmann)

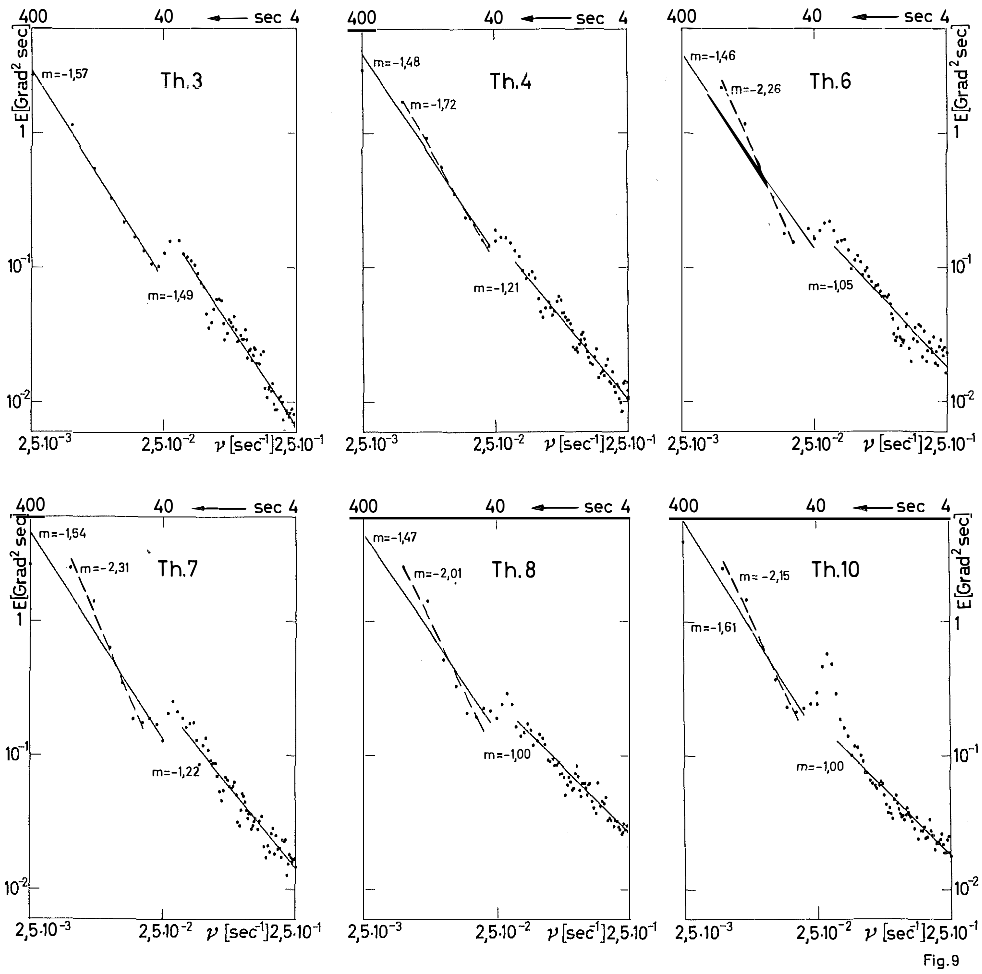

Fig. 9: Regression lines approximating the shape of the energy spectra in the thermocline.

layers separated by sharp interfaces can be produced. The process is based on the fact that the transfer of heat by molecular diffusion is a hundred times quicker than that of salt yielding unstable conditions under certain circumstances. However, it has been doubted if this is relevant in the real ocean (M. G. Briscoe, 1971).

Shear instability seems to be the primary reason for mixing processes in the interior of the sea.

As mainly reported by J. D. Woods (1968a, 1968b) and J. D. Woods & R. L. Wiley (1972) the flow throughout the whole thermocline is primarily laminar. Short internal waves are a common feature of the thermocline. Occasionally, shear instability at the wave crests is locally produced by the shears resulting from the superposition of geostrophic motions and internal waves. This occurs if the Richardson number falls below 1/4 according to theory (W. Krauss, 1966, p. 122 ff). The breakers degenerate into patches of turbulence which entrain water from the layers above and below the patches until turbulence finally decays due to dissipation.

3. Observed spectra of temperature fluctuations in the thermocline

In order to study temperature fluctuations in sound scattering thermoclines an array of fixed thermistors was installed during the summer of 1965 and 1968 in the area west of Bornholm at positions with significant backscatter signals.

Fig. 4 (top right) displays the scattering layer and the array used. The distribution of temperature and salinity as well as the sound velocity at this position can be taken from Fig. 4 (bottom right). The scattering layer shown is identical with a layer of high vertical temperature and salinity gradients. To record the temperature fluctuations at fixed depths within this scattering layer, a rigid observational mast was equipped with 20 thermistors fixed in distances of 20 cm each within the scattering layer. The temperature fluctuations (see Fig. 4 displaying a 600 sec profile) were recorded by means of cable connection to a visicorder on board the moored vessel. In our case the thermistors Nos. 14—20 (Th 14 — Th 20) had been fixed above the scattering layer. The fluctuations in the scattering layer are of magnitude $^1/_{10}$°C; the shortest periods are about 2 sec. The records were taken during a period of about 3,5 h and scanned with $\triangle t = 1$ sec. Temperature, salinity and sound velocity profiles, as function of depth, were taken additionally, in $^1/_2$ h intervals.

The Brunt-Väisälä-period $\tau = 2\pi/\sqrt{g\Gamma}$ was computed from these T, S-distributions. The local Brunt-Väisälä-period in the bottom layer of T and S varied typically between about 30 and 60 sec. Sometimes, it was even shorter. The Brunt-Väisälä period is the theoretical limiting case for internal waves, where the wave length approaches zero. All real waves have larger periods and, thus, larger wave lengths. However, based on the temperature and salinity profiles, it seems reasonable to assume that internal waves at such extremely strong interfaces have wave lengths of a few cm and periods ranging from about 10 sec — 3 min.

Simultaneous measurements of current shear have not been carried out. From current records, however, it is known that the interface between bottom water and the intermediate layer is a shear zone. Breaking of short internal waves and forming of turbulent patches may, therefore, be very common in this pycnocline.

A typical spectrum of the temperature fluctuations is shown in Fig. 5. The spectral shape is governed by a general decrease of energy with increasing frequency. A significant peak occurs closely to the local Brunt-Väisälä frequency at about $\nu = 10^{-1}$ sec $^{-1}$. The energy level at this frequency is typically increased by a factor 10—50.

The same spectrum has been plotted together with the spectra of the neighbouring levels in Fig. 6. They all have the same shape, the resonance exaggeration at the local

Brunt-Väisälä frequency is well pronounced in general and the energy level is raised at both sides of the Brunt-Väisälä frequency. The same can be observed from Fig. 7 which displays results from another station. For comparison, Fig. 8 shows spectra where internal waves have not been exaggerated at the local Brunt-Väisälä frequency. The spectra compared to figs. 6 and 7, fall off more rapidly in the frequency range from $2.5\ 10^{-2}$ — $2.5\ 10^{-1}$ sec^{-1}. Thus, short internal waves closely to the local Brunt-Väisälä frequency seem to be responsible for the general increase in the energy level within the range $2.5\ 10^{-2}$ — $2.5\ 10^{-1}$ sec^{-1} in figs. 6 and 7.

Further examples for the influence of the local Brunt-Väisälä frequency on the general shape of the spectra are given by Fig. 9 displaying spectra from a different station. The energy density distribution has been approximated by two regression lines left and right of the local Brunt-Väisälä frequency. Left of the local stability frequency the spectra fall off according to power laws of — 1.52 to — 2.00 (depending on whether the lowest frequency-band analysed is taken into consideration. These values are close to a — 5/3 power law. To the right of the local stability frequency, however, the spectra fall off with a mean value of only — 1.15.

4. Conclusion

A band of energy concentration for short internal waves often exists closely to the local Brunt-Väisälä frequency. If these waves break due to shear instability, patches of turbulence may be formed. Thus, in addition to strong gradients of density or sound velocity, both the internal waves and these patches of turbulence too may contribute to backscattering which can be recorded by commercially available echosounders. Further studies on this subject are needed. They should include direct measurements of the current shear in order to allow quantitative statements.

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