LONG THERMOCLINE WAVES IN THE NORTH SEA

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In September 1968, near 56°20'N, 1°E (northern North Sea) four moorings of temperature and current recorders were set out in a triangle 4.5 km on a side, with one in the middle. The water depth at the array position was 82 m, the density was two-layered with the thermocline in 35 m depth.

The vertical amplitude of the semidiurnal internal tidal wave was about 2 m, only the first mode was of significance. To determine the direction of propagation and wave-length of the internal tidal wave the co- and quadrature spectral functions were computed from the temperature fluctuations in the thermoclines.

The directional energy spectrum can be written in the form

$$E(\varkappa,\eta,\omega)=\iint_{-\infty}^{\infty}[C(\zeta,\mu,\omega)-iQ(\zeta,\mu,\omega)]e^{-i(\varkappa\zeta+\eta\mu)}d\zeta d\mu$$

with $\varkappa,\eta$ horizontal wave-numbers, ω frequency, ζ,μ horizontal spacings. For p discrete points of measurement (p = 4 in our case) the real part of the integral-treating all unknown values of the co-and quadr.spectral functions C and Q as zero - is :

$$\tilde{E}(\varkappa,\eta,\omega)=\frac{1}{2N+1}[C_o+2\sum_{i=1}^{N}C_i\cos(\varkappa\zeta_i+\eta\mu_i)-2\sum_{i=1}^{N}Q_i\sin(\varkappa\zeta_i+\eta\mu_i)].$$

With $N=\frac{1}{2}p(p-1)$. An approximation is determined for the set of the measured C_i, Q_i by a sine-wave of amplitude a_o and wave-numbers $\varkappa_o,\eta_o$ with infinite long crests. The directional spectrum

$\tilde{E}_o$ for this sine-wave has the coefficients :

$$C_{oo}=a_o^2;\; C_{io}=a_o^2\cos(\varkappa_o\zeta_i+\eta_o\mu_i);\; Q_{io}=a_o^2\,\sin(\varkappa_o\zeta_i+\eta_o\mu_i)\,.$$

A best fit - in the least squares sense - of these coefficients to the C_i, Q_i is determined by a minimum of $(\tilde{E} - \tilde{E}_o)^2$. For the internal tidal wave the best fit was a wave-length of 38 km and a propagational direction of 3°. So the internal tidal wave travels almost against the surface tide at the observation site (propagation of the surface tide towards 210°). The wave-length fitted well in between the values of 36 km at the beginning and of 45 km at the end of the registration time which were determined from the changing density distribution. The same procedure was applied to the 4th harmonic of the internal tidal wave for a part of the registration time with almost constant density distribution. The result was a similar propagational direction (10°) and a wave-length of 5.2 km close to the value of 5.9 km as calculated by help of the eigen value. The area of generation of the internal tidal waves observed in this area should be the slopes of the Doggerbank region.

The inertial period currents derived from the experiment show antiphase between upper an lower layer, the coherence between both layers is high. The temperature oscillations are in phase throughout the thermocline.

The interpretation is that by wind action at the sea surface internal waves are generated with frequencies above the inertial frequency, and that these frequencies approach the inertial frequency in the course of time.

During this frequency variation the vertical elevation declines quickly compared with the horizontal currents. So the current oscillations contain more energy for the very small wave-numbers than the temperature fluctuations. This is demonstrated by horizontal phase differences.

From the current records the free oscillations are eliminated, and the time series of the remaining forced oscillations are shown to depend upon variations of local winds.

The horizontal wave-lengths and propagation of the forced oscillations for different weather situations are determined by help of directional spectra. The wave-lengths were abcut 50 km, the direction of propagation could not satisfactorily be related to the motions of the wind fields.