THE INFLUENCE OF INTERNAL WAVES UPON THE UPPER ACTIVE LAYER STRUCTURE IN THE BLACK SEA

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In the analysis hydrological and meteorological observations were used, performed by r/v "Vityaz" from February 9 till April 8, 1991 mainly in the central part of the Black sea. The calculation of heat currents through the sea surface and in the upper layer indicated that in February 1991 the conditions for thermal convection were absent both in the center of the Eastern Cyclonic Gyre (ECG) and along its periphery. This rules out the influence of horizontal advection upon the activization of convective processes. Nevertheless the hydrological analysis in the very center of ECG indicated the presence of rather important traits of convective mixing that may be connected with the existence of internal waves (IW) here.

That is why in the center of ECG at the station N 3311, made on February 18-22, 1991, special hysrophysical observations were performed with Neil-Brown probe every three hours to the depth of 150 m during 4.5 days.

The spectral analysis of the obtained data by the method of maximal entropy showed the presence of oscillations with the following periods: 4-6 days (synoptic); 33-34 hours (these oscillations appear to be an effect of the first baroclinic mode of Rossby waves or shelf waves); 16-17.3 hours (inertial waves); 11.7-12.2 hours (semi diurnal tide waves and a longitudinal single-noded seiche); 9.7 and 6 - hour oscillations (seiches peculiar to this region; BLATOV, 1984) and high-frequency oscillations with the periods of 160,20, 8.2, 5.5 min. in the upper part of the pycnocline, obtained according to the results of continuous three-hour registration of T, S and σ at the depth of 28 m. The latter had practically one-mode structure and agreed well with the spectrum GM-75. On the basis of dispersive relations (PHILLIPS, 1980) the wavelengths, local vertical scale and phase velocity were estimated for them which were changing over the range from 5 to 0.25 km, from 11 to 0.3 m and from 0.48 to 0.075 m/s respectively.

The studies of variation of IW spectral composition with depth (in the range from six-hour period to the synoptic) showed :

- in the homogeneous convective layer (HCL) the oscillations with the periods from 30 to 40 hours account for about 70% of IW total energy and the inertial and semi diurnal oscillations account for about 15%;
- in the upper part of the pycnocline (σ is from 15.1 to 15.6 kg/m^3 ; z is 25-35 m) synoptic oscillations (T is 100-150 hours) are notable. They account for 25-30% of total energy, thirty or forty-hour oscillations account for 20-25%, the inertial ones account for 10-15% and semi diurnal for 10%;
- in the rest part of the pycnocline (σ is from 15.7 to 17.6 kg/m^3 ; z is 400-200 m) the share of synoptic oscillations drops essentially (to 10%), but at the depths of 170-200 m it increases to 25-30% again; the share of energy of thirty or forty-hour oscillations increases to 25-30%, the share of energy of the inertial and semi diurnal oscillations makes up 10-15 or 5-10% respectively.

The analysis of currents in ECG demonstrated that about 90% of their variation falls on the inertial and semi diurnal oscillations, practically all the variation of currents falls on the rotating clockwise component that is the indicative of their inertial character. The estimation of spatial energetic spectral densities of current variation showed that these inertial waves were prevailing and, having the length of about 33 km, were moving to the South-East.

The obtained results indicate the important influence of IW on the formation of thermohalinic structure of the upper active layer in the Black sea. Under their influence the vertical gradients of density are considerably diminished both in HAL and in the upper part of the pycnocline that may cause the intensive mixing of waters over the pycnocline. Because of the considerable density gradients at the upper boundary of the pycnocline IW destructions are possible that results in the intensive transport of mass and properties through the upper boundary of the pycnocline.

The obtained data showed (Table) how important is to take into account the existence of IW in hydrophysical mesoscale surveys. It is quite necessary in the evaluations of thickness of HCL and the cold intermediate layer (CIL), in the studies of winter convection and other processes. The order of magnitudes of possible mistakes during measurements of hydrophysical parameters in the presence of IW for winter season in the open part of the Black Sea is given in the Table.

For the characteristic values of sigma-t σ (kg/m^3) the following symbols are used : $\Delta\sigma/\Delta z$ (kg/m^4) is a vertical gradient of density; z (m) is a mean depth; σ_z (m) is a mean-square deviation of z; $\Delta T/\Delta z$ (°C/m), $\Delta S/\Delta z$ (‰/m) - are mean for the given values of σ vertical gradients of temperature and salinity; ΔS(‰), T(°C) are deviations of salinity and temperature with the adequate σz ; R_Z, R_T, R_S (m) are maximal measured amplitudes of depth, temperature and salinity values respectively.

σ	$\Delta\sigma/\Delta z*10^{-2}$	Z	σ_Z	R_Z	$\Delta T/\Delta Z*10^{-2}$	ΔT	R_T	$\Delta S/\Delta Z*10^{-2}$	ΔS	R_S
14,95	0,56	15,3	8,55	27,8	0,3	0,25	0,28	0,05	0,004	0,26
15,00	1,40	21,9	5,53	18,8	0,3	0,165	0,32	0,5	0,0028	0,26
15,10	2,10	28,8	2,69	11,5	10,0	0,27	1,75	5,6	0,15	0,92
15,25	2,80	30,8	2,70	10,9	24,0	0,67	2,27	9,1	0,24	1,67
15,70	6,08	37,0	2,84	12,8	10,0	0,28	1,45	4,4	0,12	0,82
16,00	2,02	48,7	2,94	12,6	2,0	0,06	0,17	2,3	0,068	0,35
16,50	1,80	75,9	2,79	9,0	1,0	0,028	0,12	1,7	0,047	0,25
17,00	0,83	117,6	2,61	11,2	0,4	0,010	0,05	0,7	0,018	0,14
17,50	0,71	173,7	2,25	10,0	0,16	0,004	0,06	0,4	0,009	0,08

Table Statistical characteristics of the internal waves (IW)

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GENERATION OF INTENSE MESO-SCALE FLOWS OVER THE CONTINENTAL SHELF BY SHELF WAVE SCATTERING IN THE PRESENCE OF A MEAN ALONGSLOPE CURRENT

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In both the Black and Mediterranean seas, persistent narrow currents flow along the upper continental slope, roughly parallel to the local isobaths, in the direction of Kelvin wave propagation. These slope currents are accompanied by highly variable, mesoscale flow features with time scales of one to two weeks and spatial scales of O (10-100 km) which may persist in certain locations or propagate along the current, varying in both intensity and location. Particularly good examples may be found along the northwest Black sea shelf edge, where the Rim Current flows along the slope through a region of highly variable topography and coastline, and the Gulf of Lions in the northwestern Mediterranean. These mesoscale features are most often attributed to instabilities (barotropic and/or baroclinic) of the mean current as it encounters variable bottom topography or coastline. While instability processes undoubtedly play an important role in many cases, they may not be the only mechanisms which contribute to the development of these meso-scale features associated with slope currents. Sometimes meso-scale features are present along currents which appear too weak to be unstable. Furthermore, it is not always clear that the observed temporal and spatial patterns are consistent with the proposed instabilities. As an alternative mechanism, we have developed a linear, barotropic model which shows that the scattering of shelf waves in the presence of a narrow slope current may generate intense mesoscale currents in regions of strong alongshore topographic irregularities when the slope current is entirely stable. In the absence of a mean current, barotropic shelf waves may exhibit forward (long waves) or backward (short waves) energy flux propagation relative to the direction of phase propagation. The addition of the mean current enhances the shelf wave phase speeds due to the Doppler shift. This effect is small for long, low modes which travel much faster then typical mean current speeds. However, the Doppler effect is enormous for the shorter and/or higher mode waves which propagate slowly. In addition, only waves which travel faster than the maximum velocity of the mean current can exist as propagating modes. As a result, the backward propagating modes may be entirely eliminated, and the number of forward propa-gating modes can be severely limited. Figure 1 shows the effect that increasing the Rossby number has on wave frequency and the number of propagating modes. The Rossby number is defined as $\mathcal{R}o=\mathcal{U}_{max}/fL$ where $\mathcal{U}_{max}$ is the maximum velocity of the mean current, f is the Coriolis parameter and L is the width of the channel. The wave frequency of the lowest three modes is not altered appreciably over this range of Rossby numbers. However, the higher modes are consecutively eliminated as $\mathcal{R}o$ increases, until only the lowest three modes can propagate when $\mathcal{R}o > 0.05$. Changes in the mean current shear also alter the shelf wave dispersion properties and structure. This effect becomes especially notable for waves whose phase speed is close to $\mathcal{R}o$. In this case, the wave structure tends to concentrate in the vicinity of the mean current and contains small-scale features near the current axis.

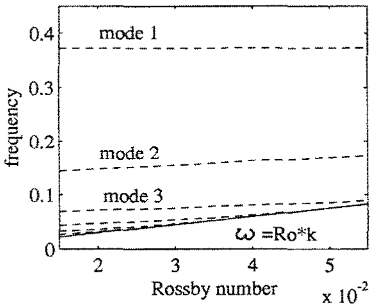

Figure 1 : Frequency ω versus the Rossby number $\mathcal{R}o$ for propagating modes at a fixed wavenumber k=1.5 (normalized by the channel width).

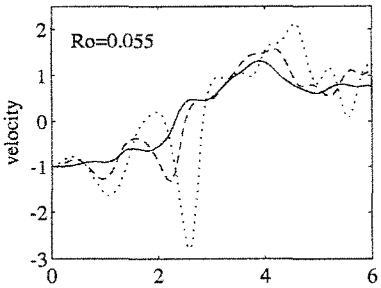

Figure 2: Along-shelf velocity component at the coast for cases of a shelf narrowing by a factor of (solid line) 1.25, (dashed line) 1.5, and (dotted line) 1.75. The velocity is normalized by the amplitude of the incident wave. The alongshelf extent of the scattering region is 1.3 to 2.5 for the two weaker scattering cases, and 1.6 to 2.8 for the strongest scattering case. Evanescent modes with wavelengths 1.3-1.5 are evident upstream and within the scattering region.

As the shelf wave encounters a region of varying topography/ coastline, the wave structure adjusts to satisfy the condition of no flow through the solid boundaries. This adjustment excites additional modes available at the incident wave frequency. If the mean current is absent, then a limited number of propagating modes exist at the incident wave frequency, with both forward and backward propagating waves possible. With the mean current present, only a few propagating modes may exist downstream of the scattering region, and reflection of the incident wave energy may not be possible. The regime can easily be reached in which the propagating modes which exist downstream of the scattering region are insufficient to provide the incident mode adjustment. In this case adjustment occurs through the generation of evanescent modes (e.g. NARAYANAN and WEBSTER, 1987) which do not propagate energy alongshore, but instead decay exponentially outside the scattering region, thereby introducing new spatial scales of the order of the topographic irregularities or even smaller. When the scattering is strong, the evanescent modes may be quite large, dominating the velocity field over the shelf and appearing as intense, isolated mesoscale flows. Figure 2 shows the increase in amplitude of these modes as the scattering becomes stronger. Evanescent modes can also produce a signal upstream of the scattering region, even when backward propagating modes do not exist, in agreement with the results of WILKIN and CHAPMAN (1990). In the present study the amplitudes of the evanescent modes are much larger relative to the incident and transmitted wave fields. We suspect that this mechanism may contribute to the generation of observed mesoscale flows over the shelf and slope in the presence of a mean alongslope current.

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