Conclusions

Internal tides (internal waves of tidal period, baroclinic tides) are internal waves with tidal frequency, which are distinguished over the background internal waves as waves with fixed frequency, high amplitude, and energy. The measurements in various regions of the World Ocean analyzed in this book were carried out by the global oceanographic community over many years. These data allowed us to reveal many characteristic properties of the oceanic internal tides. Analysis of numerous measurements in different regions of the ocean shows that the properties of tidal internal waves vary from one region to another but their general features remain the same. This fact makes it possible to consider them as a process characteristic of the entire ocean. All the measurements indicate that internal tides are characterized by high energy. They dominate over the other internal waves in the entire range of their existence. The semidiurnal internal tides are usually stronger than the diurnal internal tides.

Large topographic formations such as submarine ridges and continental slopes are the main regions of internal tide generation. Generation of internal tidal oscillations occurs as a result of the interaction between the barotropic tidal currents and irregularities of the bottom topography. When barotropic tidal currents flow over sloping topography the streamlines are no longer horizontal. The currents obtain a vertical component and vertical perturbations of density field appear with the tidal frequency; thus the generation of internal tide occurs.

Since the frequency of the internal tides is always smaller than the buoyancy frequency, the trajectories of water particles are inclined. The relation between the slope angle α, wave frequency ω, Coriolis parameter f, and Brunt-Väisälä frequency N is well known (Phillips 1977):

$$\omega^2 = N^2 \cos^2 \alpha + f^2 \sin^2 \alpha.$$

Angle α is the angle between the wave vector and the horizontal plane. Such sloping (beam) propagation of internal tides unites them with the other internal wave perturbations in the ocean. In the close vicinity of the topographic formations, where the generation of internal tide occurs, the beam type of internal wave propagation dominates. The beam is a region of significant amplitudes of

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oscillations oriented along characteristic lines. In the remaining domain the fluctuations are small. The indications of the beam structure of internal tides were revealed near submarine ridges, seamounts, and continental slopes. The beam starts from the depths close to the top of the slope where the inclination of the slope is the same as the inclination of the characteristic line. It can be traced over 50–100 km from the topographic feature over which the perturbation was generated.

As the beam propagates from the ridge to the ocean it becomes wider and reflects from the surface and bottom. After multiple reflections the mode structure is formed when the vertical components of the wave vector directed from the bottom and from the surface compensate each other. Wave packets propagating upwards and downwards should have approximately the same intensity due to moderate energy losses when they reflect from the surface and bottom. Vertical wavenumbers k_z in the perturbations propagating up and down along sloping surfaces compensate each other, thus a vertically standing wave is formed.

It was found that the mode structure is formed at closer distances from the ridges than from seamounts. Clearly pronounced beam structure exits at a distance of 50 km from a seamount, while the mode structure starts to dominate over the beam structure at this distance from a ridge. This is explained by the fact that a seamount can be considered a point source. A single beam of maximum intensity is radiated from the top of a seamount. A ridge crest is actually a line of seamounts located not strictly along a straight line. Therefore, beams with different phases are radiated from different points of the crest. However, their intensity is approximately the same if the tops are located at the same depth. Unlike only one beam from the top of a seamount, the semidiurnal internal perturbations from different points of the ridge are superimposed and form the mode structure at closer distances than from a solitary seamount. Thus, a submarine ridge can be considered a quasi-linear source of internal tides.

The domination of the first mode at distances exceeding 50–100 km from the ridge is confirmed by observations near the Mid-Atlantic Ridge, Mascarene Ridge, Aleutian Ridge, south of the Mendocino Escarpment, and in many more regions. The study sites were usually located at distances of 100–700 km from submarine ridges. The internal tides generated over the slopes of these ridges were recorded by the temperature meters on moorings. The estimates obtained from these mooring clusters, which are antennas for internal tides, showed that the wavelength of the dominating wave corresponds to the first mode of oscillations. These estimates were always close to the theoretical wavelengths calculated by the numerical integration of the equation for the vertical velocity in internal waves. The stratification was taken from CTD casts near the ridges. The scale of the vertical coherence in these sites located close to the submarine ridges always exceeded 1000 m. Horizontal coherence in these regions over the scales of the sites (~ 100 km) was always significant. The direction of the internal tide corresponded to the generation of waves over the ridge and did not change significantly in time.

Internal tides are characterized by high energy; thus, they can propagate over large distances from the regions of their generation. Beams forming the wave reflect many times from the surface and bottom. High energy and ability for multiple reflections make internal tides significantly different from waves of smaller scale, which lose part of their energy without even a single reflection.

Internal tides get additional energy supply from the interaction between the barotropic tide and the irregularities of smaller scale rather than large topographic formations. It is likely that this mechanism facilitates the excitation of higher modes at distances far from the slopes of the ridges and continental slopes.

Moored measurements in some of the study sites located at distances exceeding 1000 km from submarine ridges, for example, Polygon-70, and Mesopolygon-85 reveal several oscillation modes. In the case that two or more modes exist, the vertical coherence scale decreases to one hundred meters. Horizontal coherence decreases compared to the values recorded in the study sites close to the submarine ridges. However, the direction of the waves is quasi-stationary even in such regions. Observations indicate that the waves do not change direction within a few months. This may happen in such regions where the wave systems generated locally over the irregularities of the bottom topography on the deep bottom in the region of the study site can play a significant role.

At even larger distances from the generation sources, the internal tide loses its property of a deterministic process as it propagates through the oceanic fields with variable buoyancy frequency and vertical and horizontal shears of velocity. Owing to the fact that the ocean bottom is far from being flat, reflections and refractions occur over the bottom irregularities and the generation of new waves occurs.

Loss of the property of a deterministic process was found in the Array and POLYMODE experiments in the Sargasso Sea at far distances from the continental slopes and the Mid-Atlantic Ridge. This effect was found to an even greater degree in the southern part of the Indian Ocean north of Kerguelen Island and in the Madagascar Basin. The semidiurnal peaks on the temperature spectra in these regions are variable in time. Their confidence level is not high. Horizontal coherence on the scales of the study site is always below the confidence level.

In this study, the author attempted to reveal the regularities of internal tide dissipation in the course of its propagation. There are not many moored measurements over long lines of moorings extended in the direction of internal tide propagation that would allow us to estimate the energy losses. Moored measurements east of the Mascarene Ridge and in some other regions indicate that wave energy decreases by approximately 10–15% over one wavelength (120–150 km).

The measurements in the study sites located at distances greater than 1000 km from the sources indicate that the energy level of internal tides at such long distances from the sources is close to the background level. This estimate (1000 km) is not very reliable because only a few measurements were conducted when the tidal peak of temperature spectra is completely lacking. Local generation of internal tides over small irregularities of the bottom topography occurs everywhere in the deep basins. Exact estimates of the energy contribution from this mechanism to the total energy balance are only approximate.

The major part of the energy of internal tides is transferred from the energy of the barotropic tide in the regions of large underwater topographic formations: slopes of submarine ridges and continental slopes. Numerous islands and solitary seamounts also make a contribution to the energy balance of the internal tide. It becomes clear from the previous results that submarine ridges are the main sources of energy for internal tide generation in the open ocean. We applied the Baines model (1982) to estimate the energy fluxes of internal tides generated over submarine ridges. The energy fluxes depend on the geometry of the slope, stratification, and water transport by the currents of the barotropic tide. The direction of tidal currents relative to the ridge is an important factor of internal tide generation. If the inclination of the slope is close to the characteristic curve of internal tides, which depends on stratification, the energy fluxes reach the maximum level.

Our estimates indicate that the energy fluxes of internal tides generated over the slopes of submarine ridges are higher than the energy fluxes from the continental slopes. This is explained by the fact that the currents of the barotropic tide are generally parallel to the continental slopes and shores (Accad and Pekeris 1978; Gordeev et al. 1974; Schwiderski 1979; Ray 1999). Therefore, the transport of water by the tidal currents in the direction across the continental slopes is not high. Only a small portion of the barotropic tide energy is transported to the shelf. Very frequently underwater ridges are normal to the propagation of the barotropic tide currents. Therefore, the entire tidal flow in the water column overflows the ridge and induces stronger generation of internal tide than over the continental slope.

The maximum energy fluxes and hence, the maximum amplitudes of internal tide are formed in the regions in which the currents of the barotropic tide are normal to the crests of the ridges. One of the typical regions is the southern part of the Mid-Atlantic Ridge in the Southern Hemisphere. In addition, the amplitudes of the barotropic tide and tidal currents are high in this region. The energy fluxes are maximal when the crest of the ridge is close to the maximum stratification and the surrounding depths of the ocean are deep. Typical examples are the Mascarene Ridge, the Aleutian Islands, and the ridges in the Luzon Strait. High amplitudes of the internal tides were found in these regions.

Tidal dissipation based on the astronomical data of the length of the day was estimated by Cartwright (1977) at 4.3×10^{12} J/s (10^{12} J/s are terawatts: TW). Recent estimates are smaller. Munk and Wunsch (1998) report that tidal dissipation is 3.7 TW. The dissipation of M_2 tide only is 2.5 TW. Le Provost and Lyard (1997) estimate the tidal dissipation at 2.35 TW. However, they consider only the bottom friction. Close values of tidal dissipation were reported by Le Provost et al. (1998), Kantha and Tierney (1997), and by Schrama and Ray (1994).

Previously, tidal dissipation was thought to occur in the bottom layers of shallow seas due to turbulent mixing. However, the balance of tidal dissipation remained not closed. Our estimates based on the sum of the energy fluxes of internal tides from the major underwater ridges account for approximately 25% of the tidal dissipation. This estimate has been supported by many authors (Sjöberg and Stigebrandt 1992; Morozov 1995; Egbert and Ray 2000).

Thus, the energy balance of the barotropic tide dissipation becomes clearer because the energy of the barotropic tide dissipation that was transferred to internal waves had not previously been estimated (Olbers 1983). Bell (1975) estimated the energy transfer from the barotropic tide to internal waves due to the interaction of the tidal currents with rough topography at the abyssal depths at 10%. The estimate of Baines (1982) of the energy transfer over continental slopes is smaller than 1%. However, all estimates are approximate.

Numerous spectra calculations performed in this work and other studies indicate that the spectral peak corresponding to the semidiurnal internal tides is very narrow. The peak is clearly distinguished over the background spectra of internal waves in the frequency range of internal wave existence. The width of the semidiurnal spectral peak changes only slightly from one region of measurements to another.

The bandwidth corresponding to the semidiurnal internal tides is very narrow. The width of the spectral peak corresponding to the M_2 internal tide (at half-height of the peak) is usually 3–4 times greater than the resolution of the spectrum. For example, if the time series is 400 days long and the spectral resolution is $\Delta\omega = 0.0005$ cph, the width of the spectral peak at its half height is $\Delta\omega = 0.0015$ cph. Unfortunately, the current data from moorings do not provide a better resolution. Longer time series are needed.

The strong elevation of such a narrowband semidiurnal peak over the background spectra and many other properties of internal tides indicate that they cannot be described by the Garrett-Munk models (1972, 1975). However it should be noted that the authors never stated that the model describes internal tides. Such distinguishing properties of internal tides are related to the existence of a source corresponding to the range of existence of internal waves between the inertial and buoyancy frequencies. The existence of such a source has not been assumed in the model.

Long time series with a duration of one-two years allowed us to calculate spectra with high resolution. This made it possible to study detailed structure of spectra in the semidiurnal frequency band. It is known that diurnal and semidiurnal tides are divided into a number of individual constituents (Doodson 1921). Thus, the existence of individual internal tidal constituents is expected. Spectra with high frequency resolution allowed us to reveal the fine structure of spectra in the vicinity of the semidiurnal and diurnal frequencies.

The M_2 internal tide dominates in the semidiurnal frequency range. The oscillations of this frequency dominate both in the spectra of velocity components and temperature. The latter provide evidence that among the internal waves the M_2 wave (period 12.42 h) has the maximum energy. The S_2 wave (period 12.00 h) is less intense but it is still sufficiently strong. Almost no manifestations of the N_2 and K_2 waves were observed.

The maximum energy in the diurnal range is associated with the K_1 internal wave (period 23.9 h). The energy of the O_1 wave (period 25.8 h) is smaller. These estimates were obtained from the measurements in the Sargasso Sea. The inertial frequency at these latitudes is close to the diurnal and the peaks sometimes merge. In several regions, the amplitudes of the diurnal and semidiurnal peaks are almost the same, for example in: the Bab el Mandeb Strait, and Bay of Biscay.

Vertical variations in the amplitudes of internal tides are found everywhere in the ocean. Near the generation sources, the amplitudes of maximum vertical displacements are in the main pycnocline at depths of 700–1200 m. These are exactly the depths of the maximum of the eigen function for the vertical velocities in internal tides of the first mode. This fact provides evidence that the first mode dominates in the major part of the regions where the measurements were conducted.

If several low modes exist, vertical variability is determined by the sum of their contributions. Vertical variation of each mode is determined by the eigen function of this mode. If the beam structure dominates in a close vicinity to the generation region the amplitudes are maximum on the beam line and low outside the beam.

Usually, the vertical displacements associated with internal tides are 15–25 m. The maximum amplitudes are found near large topographic features. For example, near the North Mid-Atlantic Ridge south of the Great Meteor Banks, the amplitude of vertical displacements was 36 m. East of the Meteor Banks the amplitudes reached 50 m. Near the Mascarene Ridge in the Indian Ocean, the maximum amplitudes were as high as 160 m. In the South China Sea and near the Aleutian Islands the amplitudes were even greater. Amplitudes up to 200 m were reported in the South China Sea. However, the record belongs to the Strait of Gibraltar, where vertical displacements up to 300 m were found.

The regions of the Polygon-70 and Megapolygon-87 experiments located at distances of many hundred kilometers from submarine ridges are characterized by moderate internal tide amplitudes within 15–20 m.

In the regions of the Sargasso Sea and the Indian sector of the Southern Ocean located very far from large topographic formations, the amplitudes of internal tides are even smaller. Such a distribution of the amplitudes of semidiurnal oscillations over the ocean basin confirms the concept that internal tides are generated over the slopes of topography and then propagate to the other regions of the ocean as free internal waves. In the course of their propagation they lose energy and also obtain new portions of energy from the generation over bottom irregularities at abyssal depths.

Our temperature meters set on the moorings recorded temperature time series. The amplitudes of temperature fluctuations caused by the propagation of internal tide and vertical displacements of water particles are determined by the product of vertical displacement and vertical temperature gradient. The variations of temperature fluctuations by vertical are very complex. It is impossible to judge about wave amplitudes from temperature fluctuations only. The maximum temperature fluctuations are usually found in the seasonal thermocline mainly due to the high vertical temperature gradient. Sometimes temperature fluctuations may be as much as a few degrees especially in the seasonal thermocline. At the same time, the amplitudes of vertical displacements caused by internal tide in the seasonal thermocline may not be very high because this layer is close to the surface. It is known that owing to the structure of the eigen function for the vertical displacements in internal waves, the maximum of amplitudes is approximately at mid-depth, while close to the surface and bottom the vertical displacements in the internal tide are not large. Analysis of internal tides based on the temperature fluctuations in the seasonal thermocline, and in particular, comparison of wave intensity at different points can lead to wrong conclusions if the variations in the temperature fluctuations are interpreted as variability associated with internal waves. In such a formulation of the problem it is important to know the vertical temperature gradient, which eventually determines the variations in the intensity of fluctuations.

Internal tide amplitudes are not high in the seasonal thermocline in the upper layer and their measured signal may be even lower than noise. This fact could explain why internal tides in the upper layer are sometimes not recorded.

Horizontal variations in the spectral functions can be determined by the bottom topography influencing the conditions of internal tide generation. If the bottom topography is rough and the generation of internal tides occurs in the bottom layer, significant horizontal variations in the semidiurnal fluctuations are observed. This variability is related to the fact that the beam character of fluctuations did not transfer to the mode structure, and large amplitudes of fluctuations are observed only along the characteristic lines. A typical example of such variations was observed in the Madagascar Basin. To some extent this effect was also observed during the Polygon-70, Mesopolygon-85 experiments, and in some experiments in the Sargasso Sea.

Analysis of the variations in the semidiurnal spectral peaks in different study sites demonstrated that the greater the variations in the mean state of the ocean over the scales of the study region, the greater differences found in the spectral functions. In the regions with moderate variations in temperature, salinity, and velocity fields located far from clearly pronounced frontal zones, the spectral functions do not significantly differ over the scales of the order of 100 miles. In the layer of the main pycnocline, where horizontal differences in the mean conditions are small, we observed low variations in the spectral characteristics of the semidiurnal internal tides. Typical examples of such low variations are Polygon-70 and Mesopolygon-85 experiments located far from the jet currents, in which the eddy activity does not gain high levels.

In the Sargasso Sea, the mean state of the ocean changes significantly over the horizontal scales of the order of 100 miles because of the intense mesoscale eddies existing in this region. Despite the fact that the wavelength within the POLYMODE study site changed by no more than 10%, this variation was sufficient to influence the internal tide waves and cause notable variations in the spectral functions over horizontal scales of 100 miles. Strong currents with powerful mesoscale eddies displace the spectral peaks from their theoretical frequency owing to the strongly pronounced Doppler effect. The frequency shift of the peaks can be as high as $\Delta f = 0.015$ cph. In other regions of the ocean, in which currents are not so strong, the shift of the semidiurnal peak does not exceed $\Delta f = 0.005$ cph.

It is important to note that such frequency shifts are observed only if the duration of the time series is close to the interval of constant currents associated with a mesoscale eddy, during which the currents have approximately the same direction. In the region of the POLYMODE experiment in the Sargasso Sea, in which detailed observations of eddies were available, this time period is approximately 15–20 days. The westward drift of the eddies during this time is not significant. If longer time series are used to calculate spectra the shifts of different sign compensate each other because the spectral functions are averaged over the duration of the time series.

Numerous calculations of spectral functions show that the frequency shifts of the semidiurnal spectral peaks from the M_2 frequency decrease when the duration of the time series for spectrum calculation increases. Frequency shifts with variable signs caused by the Doppler effect lead to widening of the spectral peak if the spectrum is calculated from the data of a long time series.

Since internal tides are generated by the barotropic tide they should inherit the property of the spring-neap (half-month) variability. Analysis of long time series confirmed this theory. Long time series from the Sargasso Sea, the Bay of Biscay, and the Polygon-70 experiment allowed us to distinguish half-month (spring-neap) variations in the amplitudes of semidiurnal internal tides.

Since the direction of internal tides is quasi-stationary, the revealed half-month variability of amplitudes becomes very important. A basis for forecasting semidiurnal internal waves appears on the basis of these two properties. The sources of internal tides are stationary in space (bottom topography) and quasi-stationary in time with a half-month variability, which is determined by the spring-neap variability of the barotropic tide. Therefore, in principle if the internal tide regime is known in a given region, it is possible to forecast the amplitude of internal tide knowing the prediction results of the barotropic tide. The forecast is complicated by the fact that internal waves pass a distance from the region of generation through variable oceanographic medium. The state of this medium is variable, which influences the propagation and properties of internal tide.

The velocity of wave propagation on the pathway from the generation region to the place in which they are measured depends on the complex character of the distribution of temperature, salinity, and currents, which form the conditions of the mean state of the ocean. Irregular types of variation in the velocity field over the ocean basin and variable topography and stratification that lead to variable wavelength should cause variations in the direction of internal tide propagation relative to the mean direction. Variable directions and amplitudes make the forecast of internal tides difficult. The forecast of internal tides requires knowledge of the mean state of the ocean (temperature, salinity, and velocity fields) not only at the location of recording but also on the pathway of the internal tide propagation from the generation region.

It follows from the equation for internal waves that the wavelength of the internal tide and its phase velocity for each mode is determined by the ocean stratification, depth, and latitude of the location. The wavelength is quite stable within the usual study sites despite variations in the stratification and other local conditions of the ocean mean state. This conclusion was drawn on the basis of the numerical integration of the equation for internal waves with variations of different parameters. Seasonal variations in stratification or changes in the temperature, salinity, and velocity fields associated with the propagation of powerful mesoscale eddies and also depth variations within the study sites over the deep ocean lead to variations in the semidiurnal internal tide wavelength not exceeding 10%.

The form of the eigen functions of the equation for the vertical velocity of internal tides shows that the maximum vertical displacements approximately correspond to the middle part of the water column. The maximum displacements related to the first mode are in the main thermocline (700–1200 m). Despite the fact that temperature fluctuations associated with internal waves can be high, the vertical displacements in the upper 50–200 m are not large. This is exactly the layer, in which the seasonal thermocline is usually located. Such a form of the eigen function agrees well with the previous conclusions about the maximum vertical displacements in the main thermocline.

The maxima of horizontal velocities of internal tides are in the upper layer at the surface and at the bottom. This follows from the form of the eigen functions for horizontal velocities in the internal tide. This may lead to additional distortions of the temperature spectra in the upper layer caused by advection of horizontal temperature inhomogeneities by the tidal currents and by the Doppler effect. Horizontal displacements of water particles by the internal tide may be as high as a few kilometers; therefore, advection of temperature inhomogeneities, which are in abundance in the upper layer, may cause the appearance of additional non-realistic peaks sometimes found on the spectra. The opinion that no internal waves exist in the surface layer is incorrect. Vertical velocities are actually small. Horizontal velocities caused by internal waves in the upper and bottom layers may be high. Horizontal velocities at the surface lead to the surface manifestations of internal waves that cause alternating convergence and divergence zones at the surface. They can be observed by remote methods as regions of different intensity of ripples. In the upper and bottom layers of the ocean internal tides manifest themselves as strong periodical horizontal currents.

A method has been suggested, by which one can separate the velocity fluctuations caused by the barotropic and internal tide of the same periods. The method was tested on the data from the Sargasso Sea and a region near the Mid-Atlantic Ridge. The calculations showed that in the Sargasso Sea the energies of the internal and barotropic tides were approximately the same. Near the Mid-Atlantic Ridge, the energy of the internal tide was 1.5–2.0 times greater than the energy of the barotropic tide. This may be explained by the energy losses of the internal tide in the course of its propagation from the region of generation. In the Sargasso Sea, the study site was located at a greater distance from the generation region than in the experiment near the ridges.

At present, it is generally accepted that internal tides are stable fluctuations of water particles and correspondingly temperature, salinity, and velocity. The spectral peak that corresponds to the internal tides is high above the background spectra of internal waves as a peak close to the delta-function, whereas the background spectrum is described by the Garrett-Munk model.

Unlike the other internal waves of the entire frequency range the direction of internal tides is quasi-stationary; they conserve their properties and energy over spatial scales exceeding the scales of one wavelength. Their generation generally occurs over the slopes of submarine ridges. This presents an important principal opportunity to forecast internal tides.

The highest energies in the frequency spectra of internal waves correspond to the inertial and tidal internal waves. These two processes occupy special places in the spectra of internal waves. Internal tides are distinguished by their clearly pronounced anisotropy, stability, and high amplitudes. These properties of internal waves are related to the existence of the source of internal tides. Variations in the internal tide are related to the variations in the barotropic tide that generates them.

The construction of the general model of internal waves describing the energy transfer to the internal wave frequency range, dissipations of this energy, energy cascade over the spectrum, and joint behavior of internal waves of the entire spectrum is possible only after the models of particular behavior of internal waves of different scale have been developed.

Our lack of detailed knowledge of internal waves is caused by the limited data of observations. Special experiments are needed to study various frequency ranges and interaction between internal waves of different scales. Unfortunately, our level of knowledge of the processes related to internal waves is not sufficient to contrive a model that could satisfy the practical needs of an internal tide forecast.

Concise Conclusions

1. We determined the properties of oceanic internal tides on the basis of numerous moored measurements in various regions of the ocean.
2. Moored measurements of internal waves showed that submarine ridges are the regions of intense generation of internal tides. The waves propagate from the ridges, and their direction does not change significantly over time. The energy fluxes from the barotropic tide to the internal tide over submarine ridges were calculated. These fluxes exceed the fluxes to the internal tides from the continental slopes. This occurs because the currents of the barotropic tide are generally parallel to the continental slopes; hence they do not transport much water across the slope. In the case of submarine ridges, the situation is different because tidal currents can flow normal to the ridge and overflow it. The sum of energy fluxes transferred to internal tides over all submarine ridges in the World Ocean is approximately 25% of the barotropic tide energy dissipation.
3. Moored measurements near large topographic formations such as submarine ridges showed that wave propagation in the close vicinity of submarine slopes has a beam character. Mode structure is formed at a distance from the slopes of the order of one wavelength of the internal tide (~ 100 km). Usually, the first mode dominates in this structure.
4. As the internal tide propagates over the ocean basins it loses its energy and at the same time more waves are generated over irregularities of the bottom topography. At large distances from the sources (of the order of 1000–1500 km) the internal tide loses its property of a deterministic process.

5. A chart of the distribution of internal tide amplitudes was constructed on the basis of calculations and measurements. Usually internal tide amplitudes are within 10–30 m, but the maximum amplitudes exceed 100 m.
6. The amplitudes of the semidiurnal internal tides are subjected to the variations with a spring-neap cycle equal to 14 days related to the variations in the semidiurnal barotropic tide.
7. Internal tides in the vicinities of the diurnal and semidiurnal frequencies are characterized by fine structure. The maximum energy is usually associated with the M_2 frequency; the energy of the waves of the S_2 frequency is smaller. The sources of internal tides are stationary in space and their time variation is close to the half-month periodicity; hence a possibility of predicting internal wave amplitudes and direction in some regions of strong internal tides appears.

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