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Peculiar Discontinuities in Small-Scale Currents at the Shelf in the Area of Natural Convection Impact

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Abstract—The variability of current velocity fields at the shelf was analyzed in the course of studies on anthropogenic impacts upon the ecosystems of coastal aquatic areas. The results revealed the appearance of drastic outbreaks of the flows of a specific structure in the impact area of the deepened runoff of low-saline waters. It was found that drastic short-term outbreaks exceeding the standard error three- to fourfold appeared occasionally at the shelf of Oahu Island, Hawaii, and enveloped almost the entire water mass. Their probability was considerably higher that the values characteristic for a Gaussian process. The studies of these outbreaks, including the data on the variability of sound-scattering layers and of temperature, allowed us to conclude that the effects observed were caused by the passage of fine eddies associated with the convection caused by the rise of low-saline waters from the ocean near-bottom layers.

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INTRODUCTION

The variability of current velocity fields at the shelf was analyzed in the course of studies on the anthropogenic impact upon the ecosystems of coastal aquatic areas. The results showed the appearance of drastic outbreaks of the flows of a peculiar structure in the impact area of the deepened runoff of low-saline waters. It was found that drastic short-term outbreaks exceeding the standard error three- to fourfold appeared occasionally at the shelf of Oahu Island, Hawaii, and enveloped almost the entire water mass. Their probability was considerably higher than the values characteristic for a Gaussian process. The studies of these outbreaks, including the data on the variability of sound-scattering layers and of temperature, allowed us to conclude that the effects observed were caused by the passage of fine eddies associated with the convection caused by the rise of low-saline waters from the ocean near-bottom layers.

FEATURES OF THE EXPERIMENTAL STUDIES

In the aquatic area of Oahu Island (Hawaiian Islands), integrated studies were performed for several years to research the anthropogenic impact caused by deepening runoff upon the ecosystems of coastal aquatic areas [1–5]. In the course of these studies, the variations of current velocities and temperature were measured at the shelf edge for many days by means of moored thermal chains and ADP bottom acoustic profilographs [4, 5]. The location of stations where the vertical profiles of temperature (stations At, Bt, Ct, and Dt) and the three components of current velocity vectors (stations Av, Bv, and Cv) were measured is shown in Fig. 1. The flows were measured at the depths from 4 to 76 m, in the intervals of 2 m by depth and 1 min by time. The water temperatures were measured in different layers (from 3–18 to 45–76 m) in the intervals of 2–5 min in 2002–2003 and of 30 s in 2004.

At the Hawaiian shelf in Mamala Bay, as for other shelves, short-period internal waves occur. The most

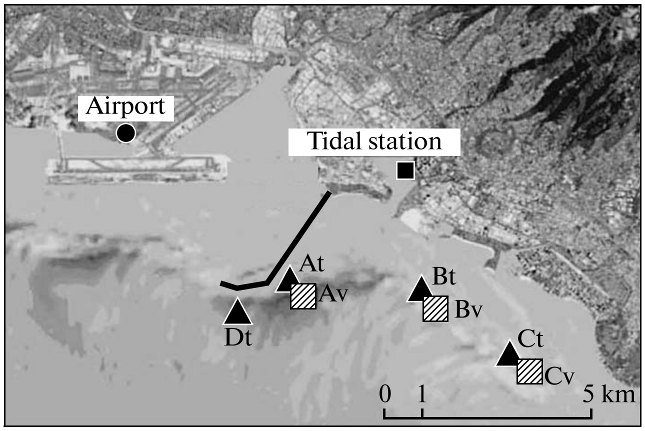

Fig. 1. Scheme of the location of stations for measuring temperature and current velocities in Mamala Bay.

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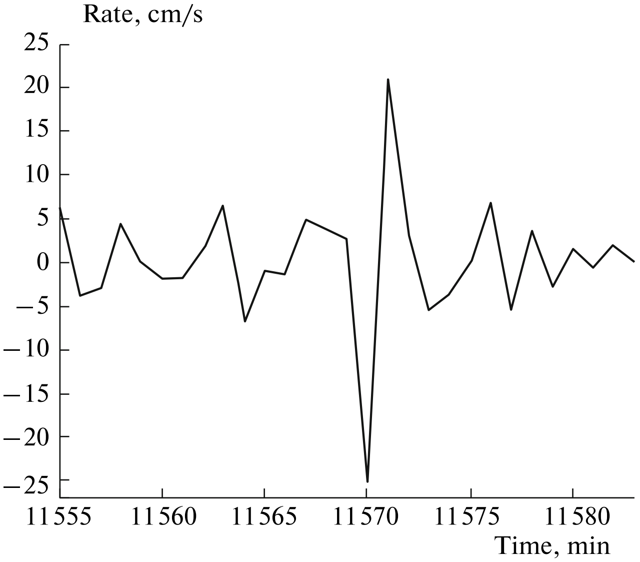

Fig. 2. The intense pulse outbreak at the high-frequency component (over 10 h^{-1}) of *V* flow at station Av in 2003 at 40 m depth.

powerful of these waves are associated with internal solitons accompanied by drastic changes in flow fields and thermocline depths [6, 7]. The time scales of these changes usually amount to tens of minutes, although pronounced changes in the medium parameters in particularly intense solitons proceed in minutes. At the same time, at the Mamala Bay shelf, even more drastic changes take place, which is reflected in ADP recording as pronounced pulse outbreaks of current velocities changing to the opposite directions in a minute.

STUDY RESULTS AND ANALYSIS

The analysis of ADP measurement data in Mamala Bay showed the occurrence of pronounced outbreaks in current velocities. The probability of their appearance is considerably higher than the values characteristic for a Gaussian process. The extreme outbreaks of current velocities were registered at all stations throughout the time of surveys. An example of the pronounced outbreak observed in the high-frequency component of the flow at station Av in 2005 is given in Fig. 2. From the graph presented, it is seen that the outbreak amplitude of the horizontal flow component (V) was as high as ±25 cm/s at standard error (SE) of measurements of ~4 cm/s, and the outbreak duration was 2 min or shorter.

Some of the flow outbreaks observed might be caused by the passage of internal wave solitons accompanied with the depth shift of isotherms and sound-scattering layers (SSL).

The figures below show examples of both types of drastic changes in the aquatic environment in Mamala Bay. The minute profiles of flows were measured by means of bottom ADP sets installed close to the shelf edge. The temperature variations were measured with thermistor chains moored near the ADP sets (Fig. 1).

In the soliton registered at site Bv in 2004 (Fig. 3), about the 13 560th minute of the survey (started at 10:59 a.m. on August 20, 2004), the thermocline soared 18 m upwards as rapidly as in three minutes. This was also reflected on the field of sound-scattering layers, and the current velocity was doubled (to 15 cm/s), with a sharp turn to the northeastly direction. The extremes of vertical rates, being as high as +4 and −5 cm/s, were observed on each side of the horizontal rate maximum, as it must be in solitons [9].

A typical pulse outbreak of the current velocity registered at the site Av in 2003 in the 8531st–8532nd minutes of measurements is drawn in Fig. 4. Here, like in other cases of similar outbreaks observed by all the ADP sets, the weak chaotic high-frequency flows were abruptly substituted by some drastically intensified and directed equally over the entire water mass. Here, this direction was stepwise changed to the opposite even in the next minute.

Just in the experiments performed in 2004, 25 pulse outbreaks as such were registered. However, the more drastic change in flows compared to solitons is not the only characteristic feature of the zigzag pulse outbreaks. Unlike solitons, the extreme moments of vertical rate coincide here to those of horizontal rates. The isotherms show no vertical movements at all at these moments, although the temperatures were measured at a distance of more than 100 m from the site of the flow profile surveys.

The observed outbreaks of current velocities might be treated as measurement errors, but some features raise doubts about such a simple explanation. First, it seems to be improbable that the errors as such appeared simultaneously in many layers, as seen in Fig. 4. Intense outbreaks were observed for the initial values of *U, V,* and *W* flows and for their high-frequency components.

The frequency of occurrence of pulse outbreaks of current velocities in the aquatic area treated may be characterized by the results of the analysis of the flows measured over 19 days at station Bv in 2004 (27 370 readings in 1-min intervals). To reduce the errors, we used the data smoothed by depth with a low-frequency third-order Butterword filter of 100 km^{-1} cutoff frequency (smoothing in 10-m intervals). In total at this station, at the depths of 12–70 m, we registered 920 pulses satisfying the condition of their amplitude excess over the standard error by a factor of at least 3.5. In percentage terms, the amount of the outbreaks as such per layer

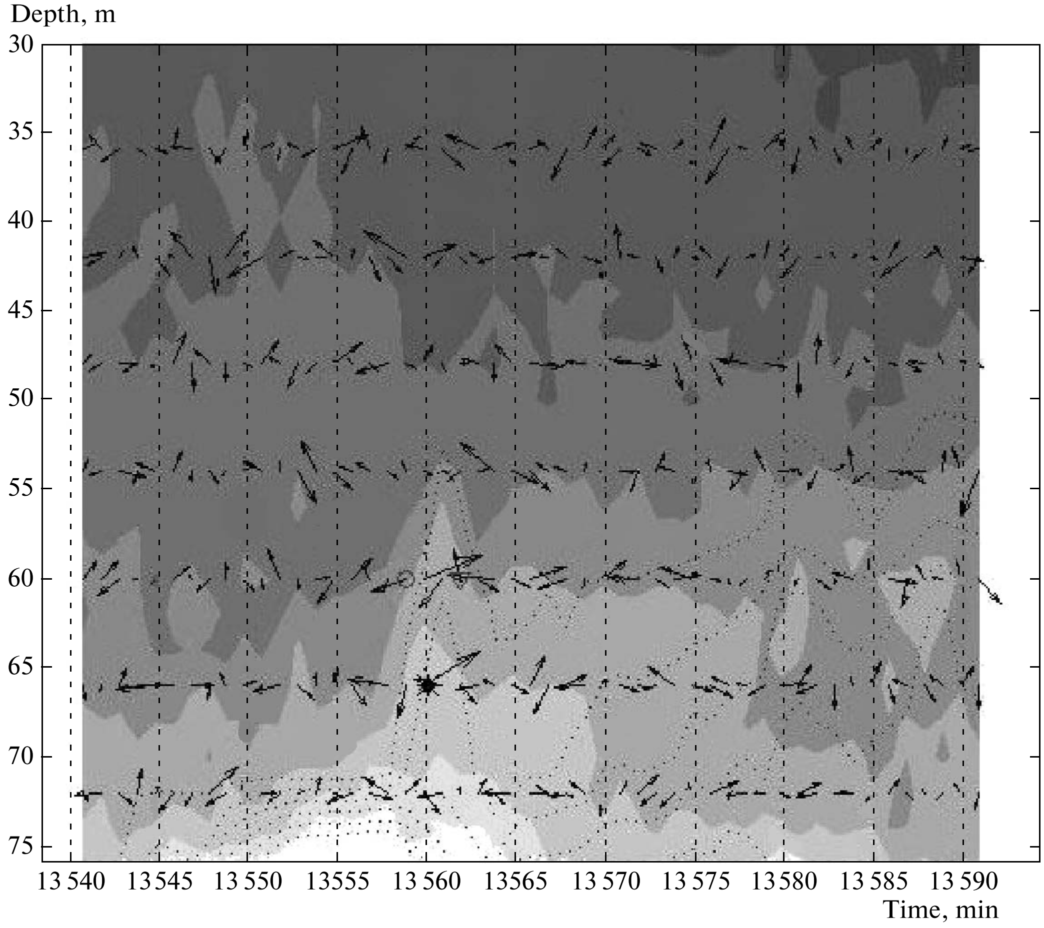

Fig. 3. The event of a typical soliton in Mamala Bay in the field of flows, temperatures, and SSL. The vectors of flows are drawn (arrows; north on top). The position of the rate maximum (15 cm/s) is marked with the asterisk; the circle and triangle, respectively, show the extremes of vertical rate equal to +4 and –5 cm/s. The intensity of the scattered acoustic signal is shown by the shaded picture. The isotherms (dotted) were plotted by the data of the thermal chain moored near the ADP set.

accounted for 0.11%, which exceeded pronouncedly the parameter for a Gaussian process (0.046%).

The measurement errors were estimated by the white noise level in the spectra of flows calculated using the data smoothed by depth with a low-frequency third-order Butterword filter of 100 km^{-1} cutoff frequency (smoothing in 10-m intervals). With the smoothing as such, the SE values amounted to about 4 and 1 cm/s for horizontal and vertical rates, respectively. As another important sign of zigzag pulses, high values of the difference between the neighboring vectors (over 4 SE) were considered.

Synchronously with the analysis of current velocity outbreaks, the intensity of ADP-registered scattered acoustic signals was studied. Attention was drawn to the absence of sources in the ADP-sonicated field, which might cause outbreaks of the rates calculated by the ADP data. (The agglomerations of active scatterers are usually well pronounced in the intensity of the scattering of ADP signals.)

In the case of flow measurements with moored impeller chains, the minutely zigzag outbreaks of flows might be ascribed, most reasonably, to the transfer of low-scaled eddies crossing a chain completely in 1 min. At the typical rate of transfer by background currents of about 0.1–0.2 m/s, this conforms to an eddy diameter of about 10 m.

The case of ADP sets is much more complicated because they measure the rates correctly only if the scale of flow discontinuities is considerably higher than the distance between the ADP rays [10]. The minute rate jumps in the readings of this device cannot be related to sufficiently high spatial scales and hence, point only to the discontinuity of the field of flows between the ADP rays.

With no data available on the flows at different rays, one may advance the following hypothesis of the appearance of the pulse outbreaks observed in ADP recordings. As the reason for the zigzag pulse outbreaks of the flows registered, we consider the passage of narrow eddies through one of the ADP rays, when

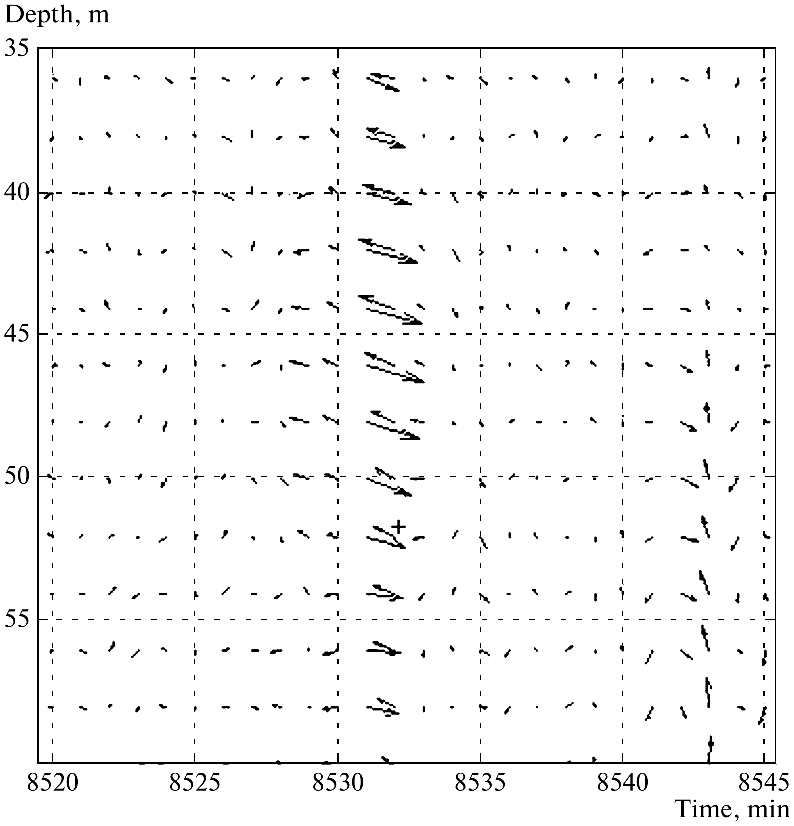

Fig. 4. The pulse outbreak of high-frequency flows (over 10 h^{-1}) registered at the 8531st minute of the measurements at Av site in 2003. The position of the rate maximum (52 cm/s) is marked with the asterisk; the dagger and circle, respectively, show the extremes of the vertical rate equal to +3 and –6 cm/s.

an eddy is touched to the ray by its leading edge at the first moment of an outbreak, and by the trailing edge at the following moment. This hypothesis is confirmed by the coincidence of extreme moments of vertical and horizontal rates, which is not common for internal waves. Note that the proper fact of ADP registration of cophasal variations of horizontal and vertical rates at no vertical motions of the thermocline (see Fig. 4) testifies as well to the eddy hypothesis.

We cannot exclude other possible interpretations of the data obtained. However, one must note that low-scale discontinuities of flows of amplitudes as high as those in the pulse outbreaks described are unlikely to occur in the ocean. Even a phenomenon as drastic as solitons is of a much larger spatial scale and from other relationships between the horizontal and vertical flows.

CONCLUSION

The appearance of narrow eddies at the shelf under the occurrence of runoff of desalinated waters is quite probable, if not unavoidable, because, in this case, intense convection appears in the water. Within the field of this convection, the small eddies may arise, like the dust ones in the surface air observed in hot weather over heated land areas ("dust devils").

A kind of analogy of the eddy formation as such may also be seen in the results of laboratory experiments on convection in the rotating water volume, when a drop of a heavier liquid sinking in water forms an eddy concentrating inside it all the admixtures [10]. The admixture concentration as such may explain the scattering intensification inside the eddies we observed often during the experiments in the Mamala Bay aquatic area. One must note that similar outbreaks of the scattered signal intensity will be studied later on as well.

If the hypothesis on the eddies in the convection layer advanced should be confirmed in the course of further studies planned by the authors, this should necessitate correction of the notion of a purely diffusive propagation of admixtures in the impact zone of deep water runoffs, including the capture and transfer of an admixture by more or less long-living eddies. Note also that similar effects may arise in the areas of near-bottom discharge of methane and desalinated waters, as occurs, for example, near the coasts of Crimea and the Caucasus [11].

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