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In-Situ Recordings of the Changes in the Regimes of Heat–Mass Exchange Between Sea and Atmosphere at the Shore

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Abstract—Using instrumental investigations at the Black Sea shore, new data on the change in the heat-mass exchange under upwelling are obtained for the first time; the interrelation between the regimes of heat-mass exchange with a difference in air and water temperatures near the interface is established. The increased values of total heat flow at the shore as compared with the same flows in the open sea are recorded.

Key words: ocean-atmosphere interaction, surface layer, heat-mass exchange, cool skin, warm skin.

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The rise of cold depth water during upwelling influences the ocean–atmosphere interaction by changing the direction of components of the sensible and latent heat flows. As we know, heat and moisture flows between the ocean and the atmosphere have not been recorded instrumentally during upwelling.

Shore upwelling means the rise of extremely cold depth water to upper layers of the ocean or the sea and the displacement of warm bodies of water. It is a frequent event on the Black Sea. We performed measurements on the sea stationary platform of the Experimental Division under the Marine Hydrophysical Institute in Katsiveli settlement, near the city of Simeize (in the Crimea). The platform was mounted on a traverse beam at a distance of 800 m from the shore. The conditions around the platform are similar to the open sea conditions, and the platform itself is equipped with a weather station recording basic meteorological parameters, such as water and air temperatures, moisture, as well as velocity and direction of wind, etc. As well, the water-temperature sensors are placed on different levels from the surface to the depth of 25 m at a space of 5 m, which allowed us to obtain information on the beginning, end, intensity of upwelling, and layer temperatures. To measure a vertical temperature profile, quick-response thermorecording device and five platinum resistance thermometers with sunshield screens, to determine water and air temperatures on different levels to ±0.1°C, were installed on a triple float buoy that drifted 30–50 m away from the platform. The quick-response device [1] made it possible to record a vertical temperature profile in thin adjacent layers of air and water with a resolution of approximately 50 mcm (in water) to ±0.1K, which enabled us to calculate the intensity of heat flows between the sea and the atmosphere under different meteorological conditions using a gradiometric method [2]. A copper-constant thermocouple served as a device sensor. It was made of wire 30 mcm in diameter and was fixed in a Y-shaped holder. Under control command, a special drive moved it vertically at a rate of 17 cm/s, so that the temperature sensor continuously recorded the temperature on its way, i.e. in a layer 30–40 cm above and 20–30 cm under the water, and a signal transmitted from the sensor went to the recording device through the amplifier. In 1996 we used an oscillograph with a camera adapter as a recording device. A vertical deviation of the beam by one point in the coordinate grid on the oscillograph screen corresponded to a temperature difference of 0.5 K recorded by the thermocouple; a horizontal deviation by one point, to 0.85 mm.

To increase the accuracy of measured gradients after 1997, we used a personal computer connected via AD converter as a recording device. A reference potential difference between the thermocouple and the junction point with a frequency of 2 000 times per second within 3 s was recorded to the computer hard disk. For the calculation of total heat flows, we used a program developed to scale the obtained data, to plot a temperature profile graph, and to determine gradients of water and air temperatures. If gradients of water temperature are positive and the surface temperature is higher than the underlying water temperature, then the total heat flow is directed to the sea from the atmosphere, a regime consisting of a warm skin exists. If temperature gradients are negative and the surface temperature is below the

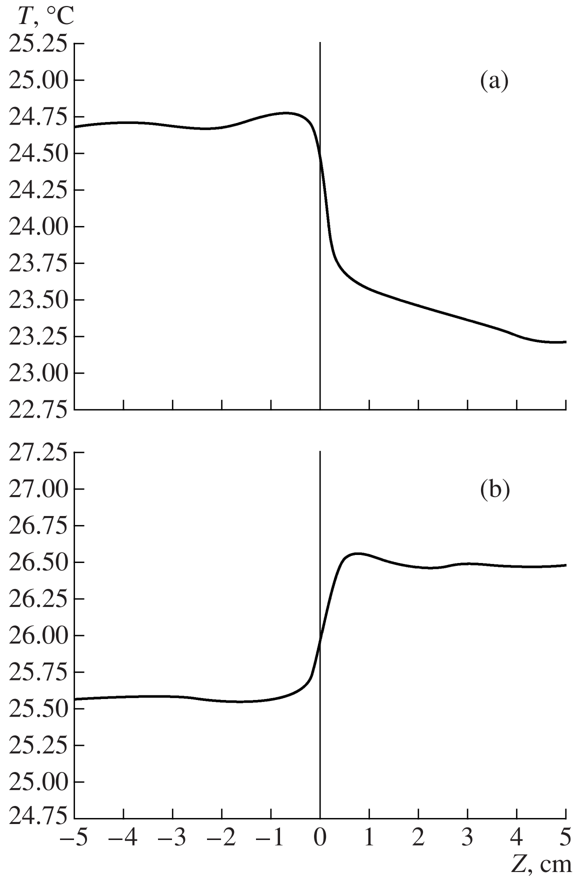

Fig. 1. (a) Temperature profile recorded at 6 a.m on August 24, 2003. (b) Temperature profile recorded at 7:05 p.m on August 23, 2003

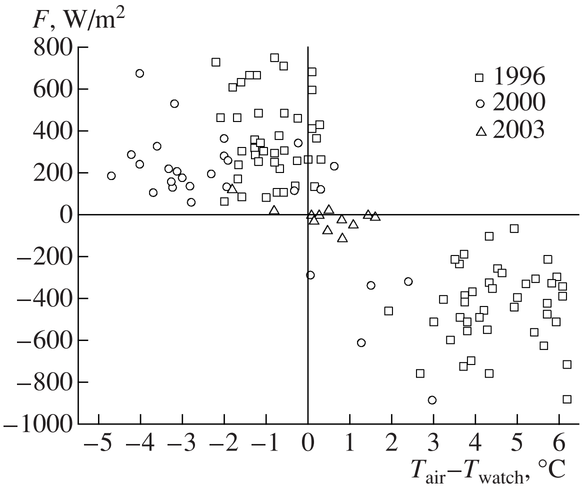

Fig. 2. Dependence of total heat flow on difference of air and water temperature near the surface

underlying water temperature, then a regime consisting of a cool skin occurs.

During the expeditions to the Black Sea in 1996, 2000, and 2003, during sea-shore upwellings 153 temperature profiles were recorded in a thin layer near the sea-atmosphere interface, including 59 profiles with a warm skin. In 1996 a warm skin occurred in 49% of all cases; in 2000, in 12%; and in 2003, in 78% of all cases, unlike in the open sea, where the number of such cases did not exceed 20%. Figure 1a and b presents the recorded profiles with films of cold and warm air, respectively. The analyzed data show that the formation of regimes of films of cold or warm air in the sea shore mostly depends on the difference of air and water temperature in the layers adjacent to the interface that are 30 cm high and 30 cm deep. This dependence is shown in Fig. 2. As is plotted on the graph in Fig. 2, if the air and water temperature difference is less than 1°C, both regimes may exist, whereas if it is more than 1°C, a film of cold or warm air steadily occurs, which depends on the difference sign. However, we did not reveal an obvious dependence of total flow in the sea shore separately by the air and water temperature difference, relative humidity, wind velocity, cloudiness, and surface temperature. We could not determine the total flow value by direct comparison, due to features of the nearshore area and many factors influencing heat-mass exchange between the sea and the atmosphere, such as strong surface currents, the carryover of bottom slurries during nearshore heaving (probably the effect of urban sewage), intense operation of small-size vessels around the platform, etc. Also we should mention that in the area in question, the values of total heat flows exceed that ones in the open sea areas by a factor of 1.5–2 on average, which may be caused by better heating of shore water, which is more turbid and less deep than in the open sea.

The measurements recorded for several years indicate that both regimes consisting of films of cold and warm air are typical for the shore area. The data on the change in heat–mass exchange between the sea and the atmosphere were obtained for the first time. However, the problem of determining the influence of different meteorological factors on heat–mass exchange between the sea and the atmosphere requires more detailed and accurate measuring, including simulation under laboratory conditions.

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