ISSN 0027-1349, Moscow University Physics Bulletin, 2007, Vol. 62, No. 5, pp. 332–333. © Allerton Press, Inc., 2007.
Original Russian Text © D.A. Solov'ev, N.S. Blokhina, A.E. Ordanovich, 2007, published in Vestnik Moskovskogo Universiteta. Fizika, 2007, No. 5, pp. @–@.

A Laboratory Model of a Spring Thermal Bar

D. A. Solov'ev, N. S. Blokhina, and A. E. Ordanovich

Department of Physics of Sea and Land Water, Faculty of Physics, Moscow State University, Leninskie gory Moscow, 119992 Russia

e-mail: blokhina@phys.msu.ru

Received November 22, 2006

Abstract—A laboratory setup for thermal bar simulation is developed and mechanisms behind the bar formation and evolution are experimentally studied. The results of the model experiments are compared with the data from natural observations, and the principal feasibility of laboratory simulation of thermal bars observed in natural water basins is demonstrated.

DOI: 10.3103/S0027134907050153

A thermal bar is a frontal layer of water with a temperature of 4°C that extends from the surface to the bottom of a freshwater or slightly saline ($S \leq 24‰$) basin. Thermal bars usually appear during periods of spring heating and autumn cooling [1] as a result of the anomalous water temperature density, in the vicinity of 4°C. Having originated near the shore, thermal bars travel toward the center of a water basin, usually in a direction parallel to the shore line. During the entire lifetime of a thermal bar, its existence in a water basin is accompanied by specific thermohydrodynamic processes, which are a topic of much interest today. The state of the art in this field is characterized by a considerable database of the results of natural measurements, a scarcity of adequate mathematical models and laboratory simulations [2–4], and incomplete elaboration of application aspects.

In this study, a thermal bar is simulated under laboratory conditions. The experimental setup provides for model studies of bar formation and evolution with allowance for the effects of wind on the water surface.

A schematic of the laboratory setup is shown in Fig. 1. It consists of a rectangular glass basin of length $l = 1.5$ m and width $n = 0.4$ m. The bottom of the basin is inclined in the longitudinal direction at an angle α, which can be varied in the range 0–15°. The basin was filled with tap water, forming a wedge. To prevent heat loss, the bottom and walls of the basin were sealed with foam plastic. Electric IKZ-250 bulbs supplied a heat flow Q in the range $(1–5) \times 10^{-3}$ cal/(cm^2 s) to the water surface. The heat flow was measured by an AZ-8561 digital light-intensity meter providing ±2% accuracy. The water temperature was measured by a system of four vertical probes with K1019EM1 semiconductor integrated circuits (heat sensors) mounted on them, and detected by the LA70M4 board of an analog-to-digital converter. The calibrated heat sensors were coupled to a PC, which accumulated the time series of temperature values at different points of the water bulk. A single sensor was placed above the water surface to detect the air temperature. The temperature measurements were accurate to 0.15°C. In parallel with the temperature measurements, circular motions in the water were recorded with a video camera. The recorded tracks of the water elements were used to determine the velocity of the circulation motion of vortices. Potassium permanganate crystals were used as the tracer agents.

This setup also offered the opportunity to study the wind dynamics of the thermal bar. For this purpose, a

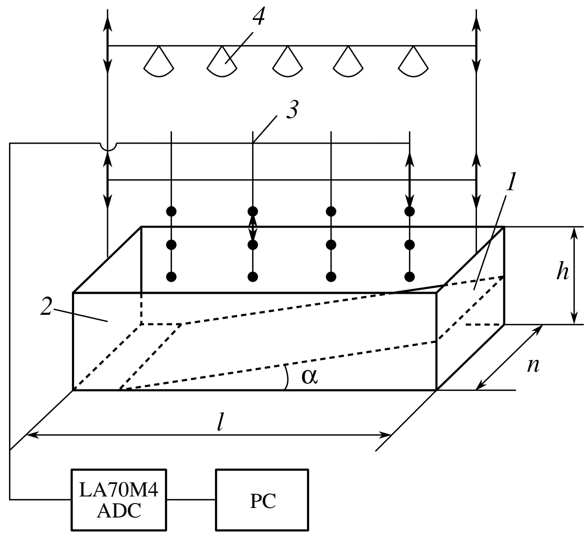

Fig. 1. Schematic of the laboratory setup: *l* basin length, α bottom tilt, *n* basin width, *h* basin depth, *1* inclined bottom (wedge), *2* transparent observation window, *3* vertical probes with thermal sensors, and *4* electric bulbs.

wind generator producing an air flow over the water surface was used.

At the beginning of each test, the basin was filled with a mixture of tap water and ice; as the latter melted, the water temperature decreased to $T_0 < T_m$ ($T_m = 4$°C). To equalize the temperature, the water was agitated and settled for several minutes prior to heating. The measurements were carried out at a longitudinal section passing through the middle of the basin. The spacing between neighboring sample points could be varied from 0.5 to 20 cm. A series of simulation experiments was conducted.

After the heating began and the water temperature in the shallow part of the basin T reached higher values than the temperature of the bottom water ($T_0 < T \leq T_m$), the track of the tracers clearly indicated the formation of two circulation cells separated by a frontal interface, which was associated with a thermal bar. The horizontal axes of the closed circulation cells were oriented along the bar. Analysis of the measured velocities of the tracers has shown that there was no horizontal transfer of water across the front, as follows from the almost vertical (undistorted by flows) tracks of the tracers near the interface. The interface zone between the circulation cells was 4–8 cm thick. With an increase in the area of the warm shallow zone, the frontal interface shifted toward the deeper part of the basin, tilted, and distorted. After approximately 60 min, the thermal bar passed through the entire basin. As a result of the experiments, two phases of the bar drift were distinguished, each characterized by a different velocity of bar propagation in the inclined zone of the basin: a first fast phase (10–30 min after the beginning of observation) and a second slow phase (from 30–60 min). Since the heat flow across the free water surface is assumed to be constant in one experiment, the nonlinear character of the bar velocity points to a significant horizontal advection of heat in the course of the bar displacement, with a related change in the volumes of the warm- and cold-water fractions at its opposite sides. With the advent of the second phase, the frontal interface between the circulation cells acquires a vertical distortion, the tongue of the warm surface water crawls over the lower cool layer, and the velocity profiles take a profound S-like shape near the bar. This fact was not reported in previous natural observations.

The results of the laboratory experiments simulating the dynamics of the thermal structure of water and flows were compared with the data from natural observations [5, 6]. Qualitative agreement between the results was obtained (Fig. 2). In particular, satellite IR observations of a natural thermal bar [6] confirm the spatial–temporal nonlinearity of the bar's average velocity of propagation in the model experiment. The results of the laboratory experiment are intended to contribute to verification of the mathematical model developed in [7, 8].

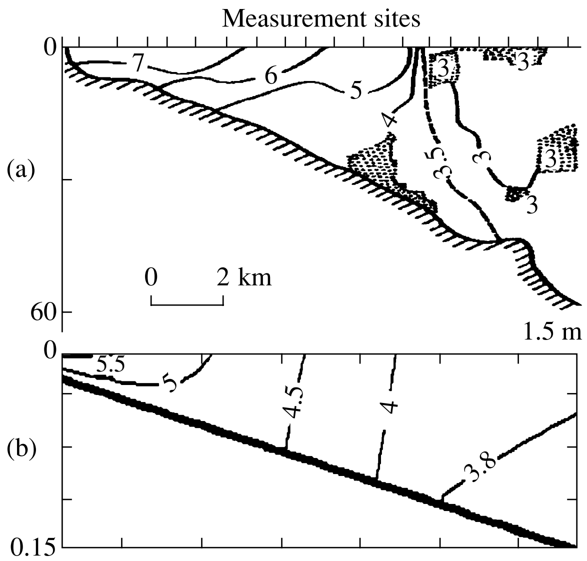

Fig. 2. Cross-sectional distribution of water temperature (a) in the southern part of Ontario Lake during the period of existence of a thermal bar (according to [5]) and (b) in the laboratory basin.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research, project nos. 06-05-64911-a and 05-05-64870-a.

REFERENCES

1. A. I. Tikhomirov, Izv. Vsesoyuzn. Geogr. O-va **91**, 424 (1959).
2. S. S. Zilitinkevich and K. D. Kreiman, Okeanologiya **30**, 750 (1990).
3. G. H. Elliott and J. A. Elliott, in *Proceedings of the 13th Annual Conference on the Great Lakes Research, Buffalo, N. Y., June 2–6, 1970*, p. 413.
4. V. A. Gritsenko, N. Yu. Demchenko, A. I. Rudenko, and I. P. Chubarenko, in *Proceedings of the Scientific Conference on the Physical Problem of Ecology (Ecological Physics), Moscow, 22–24 June, 2004*, No. 12, p. 12.
5. O. K. Rodgers, in *Proceedings of the 11th Annual Conference on the Great Lakes Research, Milwaukee, Wisconsin, April 18–20, 1968*, pp. 480–486.
6. I. A. Bychkova, S. V. Viktorov, and M. D. Demina, Okeanologiya **29**, 551 (1989).
7. N. S. Blokhina, A. V. Ovchinnikova, and A. E. Ordanovich, Vestn. Mosk. Univ., Ser. 3: Fiz., Astron., No. 2, 60 (2002).
8. N. S. Blokhina and D. A. Solov'ev, Vestn. Mosk. Univ., Ser. 3: Fiz., Astron., No. 3, 59 (2006).

SPELL: OK