Strongly Stratified Turbulence Wakes and Mixing Produced by Fractal Wakes

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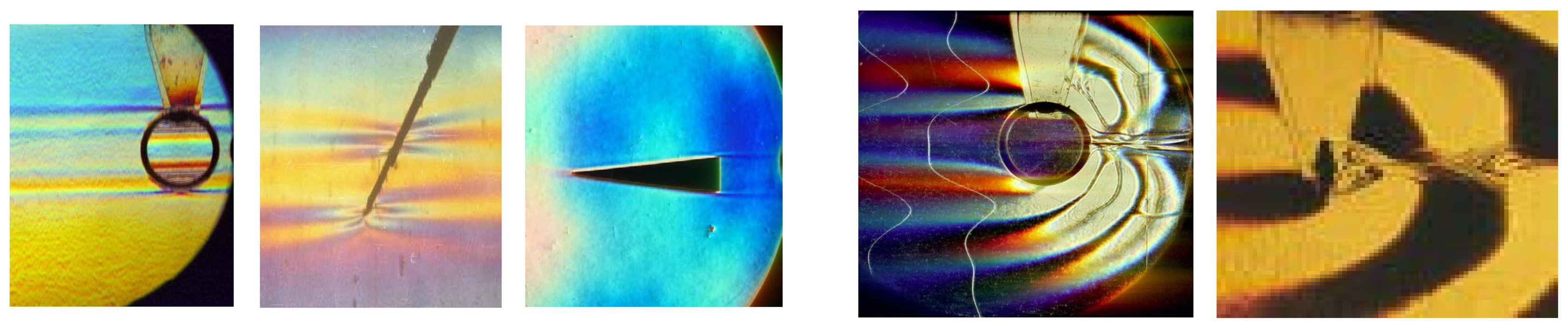
Experimental observations of flows in stratified fluid (Institute for Problems in Mechanics of the RAS)



Motionless objects   Moving objects

Mathematical model

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}\nabla)\mathbf{v} = -\frac{1}{\rho_{00}}\nabla P + \nu\Delta\mathbf{v} - s\mathbf{g} \qquad \mathrm{div}\,\mathbf{v} = 0$$

$$\frac{\partial s}{\partial t} + \mathbf{v}\cdot\nabla s = k_s\Delta s + \frac{v_y}{\Lambda} \qquad \rho = \rho_{00}(\exp(-y/\Lambda) + s)$$

$$\left[\frac{\partial S}{\partial n}\right]\bigg|_{\Sigma} = -\frac{1}{\Lambda}\frac{\partial y}{\partial n} + \left[\frac{\partial s}{\partial n}\right]\bigg|_{\Sigma} = 0 \quad s\Big|_{x,y\to\infty} = 0 \quad \mathbf{v}\Big|_{x,y\to\infty} = 0 \quad v_x\Big|_{\Sigma} = U \quad v_y\Big|_{\Sigma} = 0$$

$\mathbf{v}$ is velocity vector, P is the pressure, ρ is density, $\rho_{00} = 1020$ kg/m^3 is density at zero (neutral buoyancy horizon), s is the salinity perturbation, $\nu = 10^{-6}$ m^2/s and $\kappa_S = 1{,}41 \cdot 10^{-9}$ m^2/s are the constant kinematic viscosity and salt diffusion coefficients

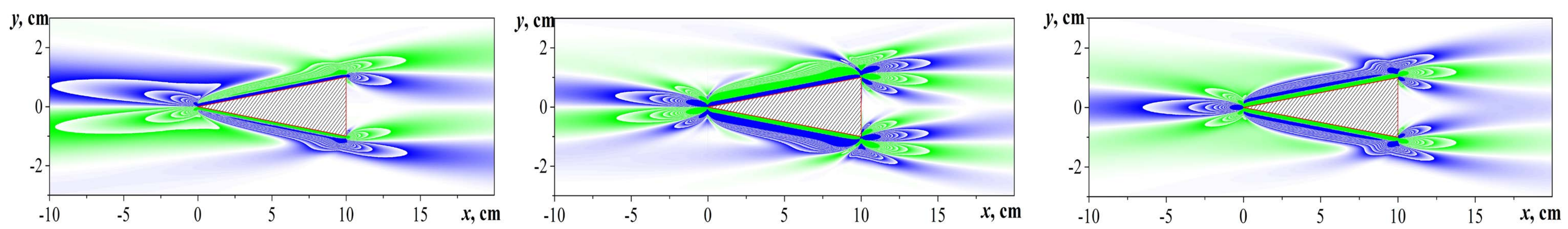
Numerical simulation

- **Geometry and meshing:** OpenFOAM SALOME
- **Numerical model:** OpenFOAM

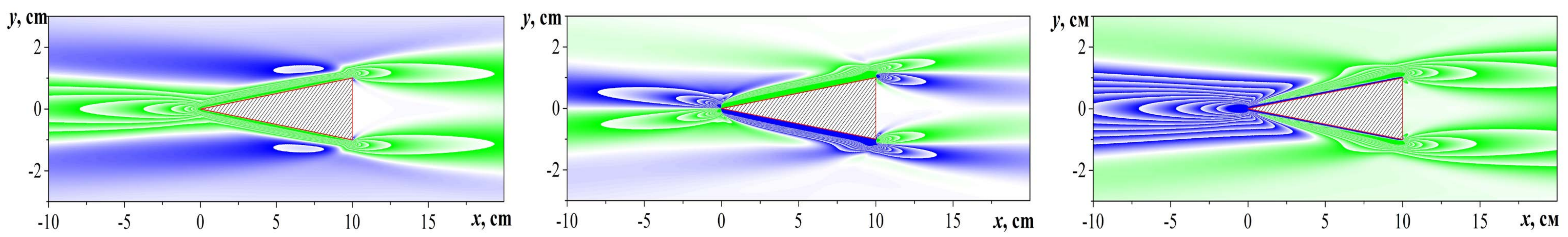
  original solver stratifiedFoam
- **Cluster Computing:** UniHUB.ru PARALLEL.RU
- **Visualization:** ParaView ORIGIN

Results :

I. Motionless wedge



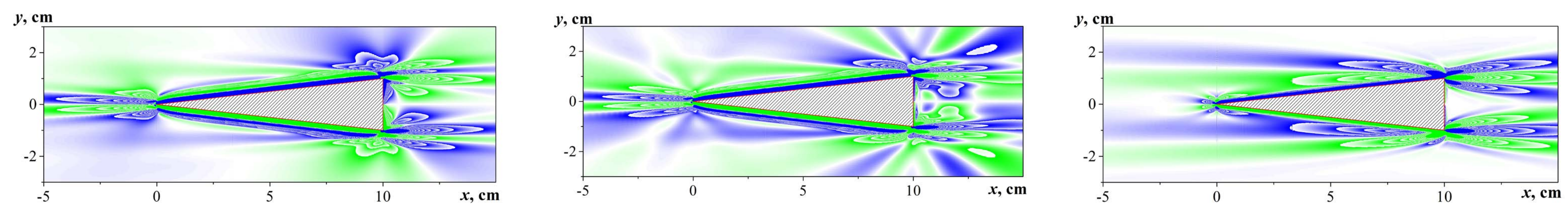
Salinity perturbations s $\partial s/\partial x$ $\partial s/\partial y$



Horizontal component of velocity v_x Vertical component of velocity v_y Preasure P

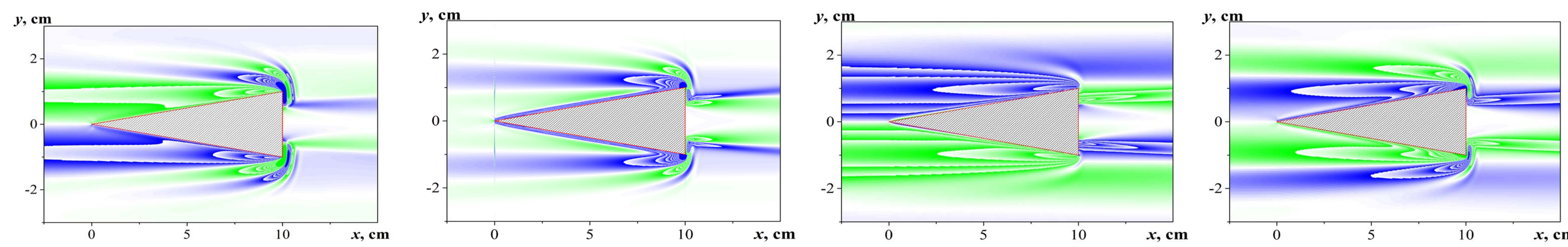
the areas of surplus (green) and deficit (blue)   *L = 10 cm, h = 2 cm, T_b = 6.28 s, U = 0*

II. Moving wedge



$t = 0.5\ T_b$ $t = 2\ T_b$ $t = 10\ T_b$

Evolution of the flow pattern



v_y $\partial P/\partial x$ $\partial P/\partial y$ vorticity

the areas of surplus (green) and deficit (blue)   *L = 10 cm, h = 2 cm, T_b = 6.28 s, U = 10^{-2} cm/s*

The Non-stationary dynamics and structure of stratified fluid flows around a wedge were studied. Due to breaking of naturally existing background diffusion flux of stratifying agent by an impermeable surface of the wedge a complex multi-level vortex system of compensatory fluid motions is formed around the body. The flow is characterized by a wide range of values of internal scales that are absent in a homogeneous liquid. The problem is solved using the finite volume method in an open source package OpenFOAM. The computations were performed in parallel.

The complex structure of the fields of physical quantities and their gradients has been shown. Structural elements of flow differ in size and laws of variation in space and time. High-gradient layers near the sharp edges of the obstacles have been identified. Formation of an intensive zone of pressure depression in front of the leading vertex of the wedge is responsible for generation of propulsive mechanism that results in a self-motion of the obstacle along its neutral buoyancy horizon in a stably stratified environment.

The initial structure of the medium formed by diffusion-induced flows around the motionless wedge is changed dramatically with start of a forced body motion with the lowest velocity comparable with the typical velocities of diffusion-induced flow. Advanced perturbations, rosettes of transient and extended fields of attached internal waves and downstream wake past extreme points of the body are formed in a continuously stratified fluid. Number of the observed attached waves, which do not penetrate into the wake behind the body, increases with time. Observed in experiment are multiple flow components, including upstream disturbances, internal waves and the downstream wake well reproduced.

References

- Dimitrieva N.F. The numerical solution of the problem of stratified fluid flow around a wedge using OpenFOAM. *Proc. ISP RAS*, vol. 29, issue 1, 2017, pp. 7-20 (in Russian)
- Dimitrieva N.F., Zagumennyi Ia.V. Diffusion-driven flows on a wedge-shaped obstacle *Physica Scripta*, 2016, vol. 91, No 8, p. 084002(1-8).
- Dimitrieva N.F., Chashechkin Yu.D. The structure of induced diffusion flows on a wedge with curved edges *Physical Oceanography*, 2016, N3, p.77–86.