Interaction of a surface vortex with a topographic feature in a three-layer geophysical flow

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Problem formulation

Topographic vortices

- *A topographic vortex* is a coherent structure occurring over bottom feature in the ocean or atmosphere
- *Topographic vortices* play an important role in particle advection and mixing processes
- Topographic vortices, besides mass advection producing, can also trap other vortical structures, for instance, surface monopoles

Problem formulation

Analytical model of monopole-topographic vortex interaction

- The aim of the work is to study *particle advection* being induced by a surface monopole interacting with a topographic vortex
- We employ the *background flow concept* to formulate a *dynamically-consistent* model of the vortical interaction
- We obtain a *three-layer* model of geophysical flow with a point-vortex topographic vortex in the bottom layer and a point-vortex surface monopole in the upper layer

Problem formulation

Stream-function

- Dynamically-consistent stream-functions in layers $i = 1, 2, 3$

$$\psi_i = Uy + \frac{\mu_1}{H_1}\left(a_0 \log\left(\varepsilon_0 r_1\right) + \sum_{j=1}^{2} a_j K_0\left(\varepsilon_j r_1\right)\right)$$

$$+\frac{\mu_0}{H_3}\left(b_0 \log\left(\varepsilon_0 r\right) + \sum_{j=1}^{2} b_j K_0\left(\varepsilon_j r\right)\right)$$

- μ_1, μ_0 are intensities of the monopole and topographic vortices, (x_1, y_1) is monopole position, $r_1 = \sqrt{(x - x_1)^2 + (y - y_1)^2}$
- ε_0 is the barotropic Rossby deformation radius, ε_j are baroclinic Rossby deformation radii at the layer interfaces and U is the background flow velocity

Problem formulation

Dimensionless parameters

- Topographic vortex linear scale

$$\chi = \frac{\mu_0 \varepsilon_1}{H_3 U}$$

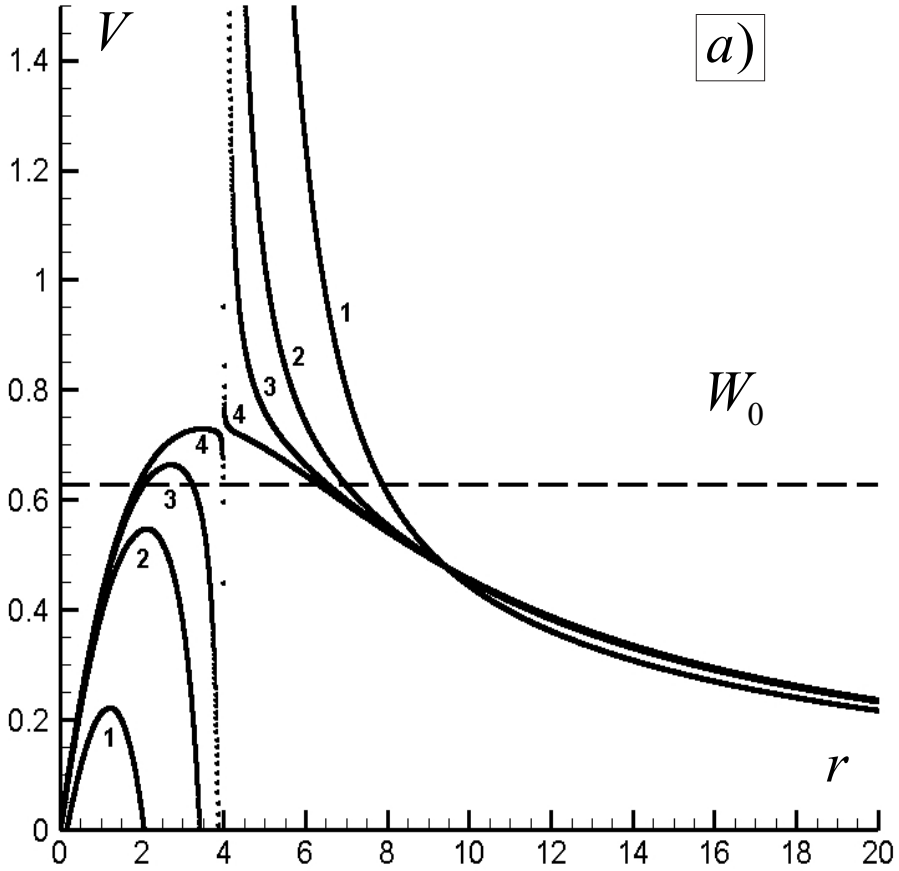
- Monopole vortex linear scale

$$\kappa = \frac{\mu_1 \varepsilon_1}{H_1 U}$$

- Further we demonstrate the influence of the parameters on the system dynamics

Stationary dynamics

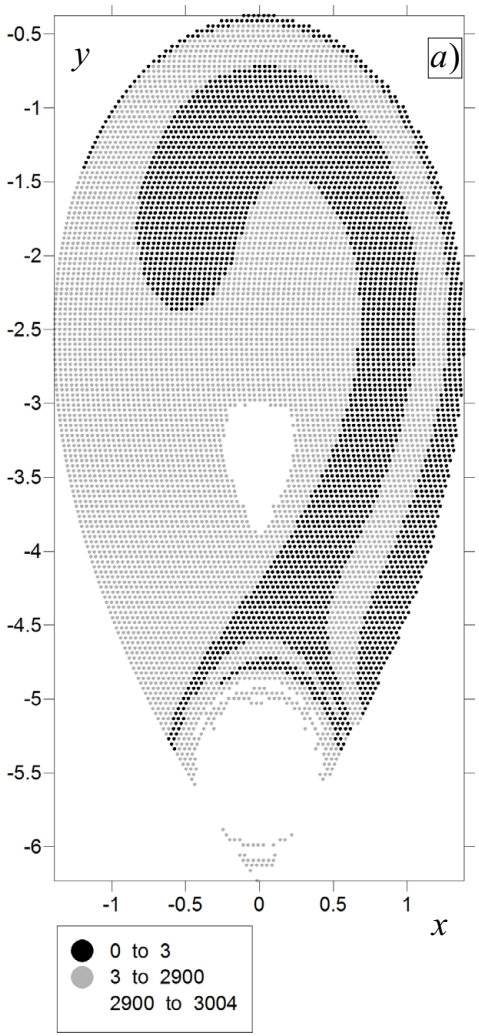
Particle radial velocity

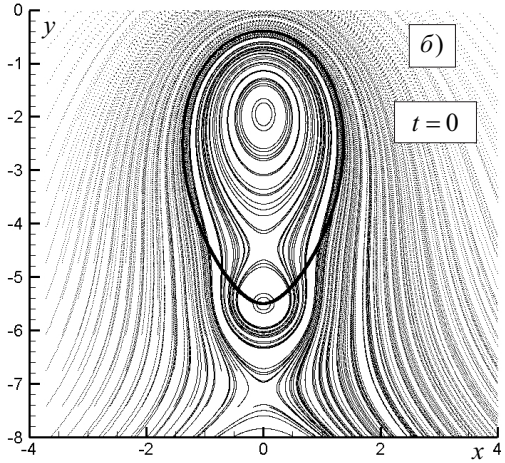


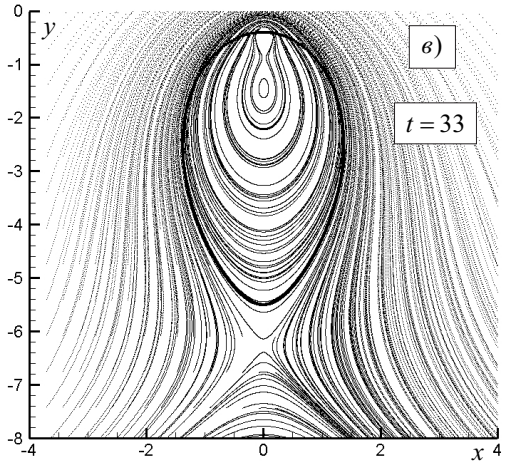
- Particle radial velocity, $\chi = \pi$
- $\kappa = \chi$ - line 1
  $\kappa = 0.5$ - line 2
  $\kappa = 0.1$ - line 3
  $\kappa = 0.001$ - line 4

Stationary dynamics

Small κ



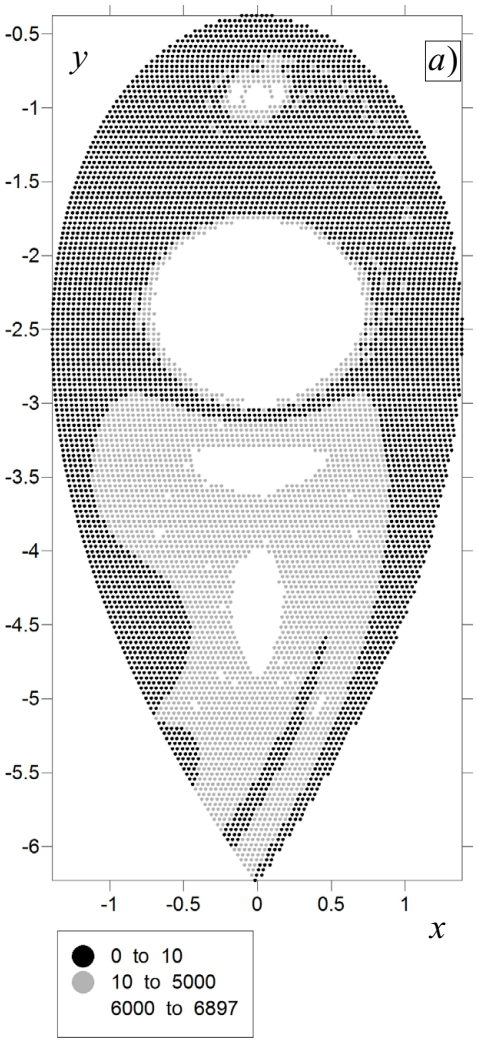


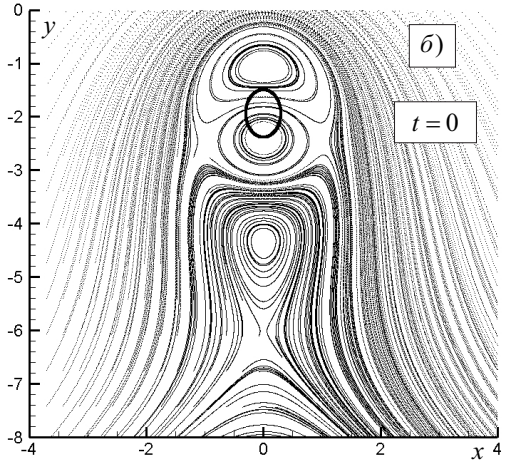


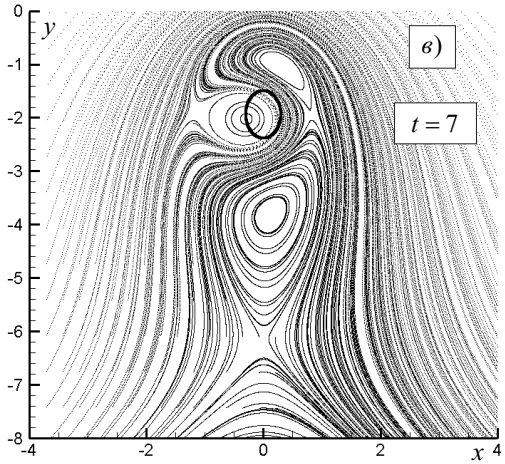
- (a) escape time, $\chi = \pi,\ \kappa = 0.135$
- (b) instantaneous flow topological structure at $t_1 = 0$
- (c) instantaneous flow topological structure at $t_2 = 33$

Stationary dynamics

Moderate κ



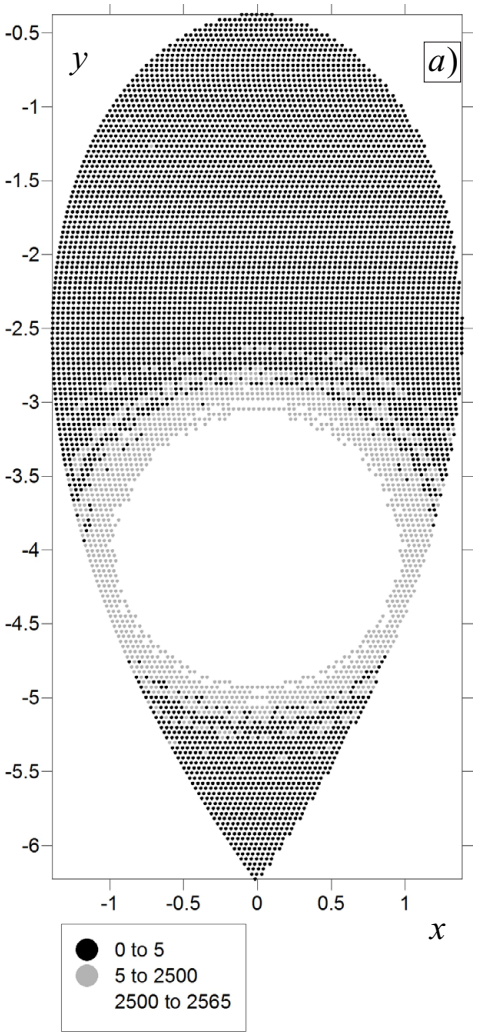


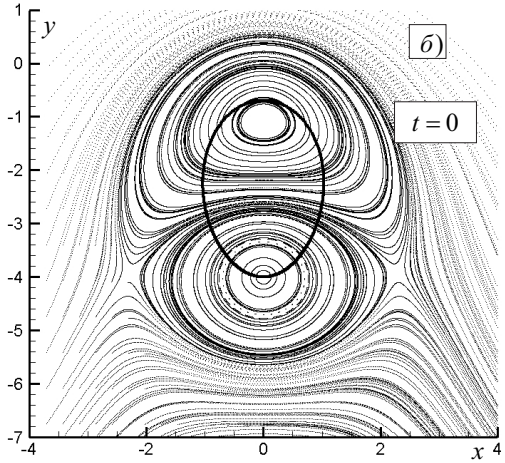


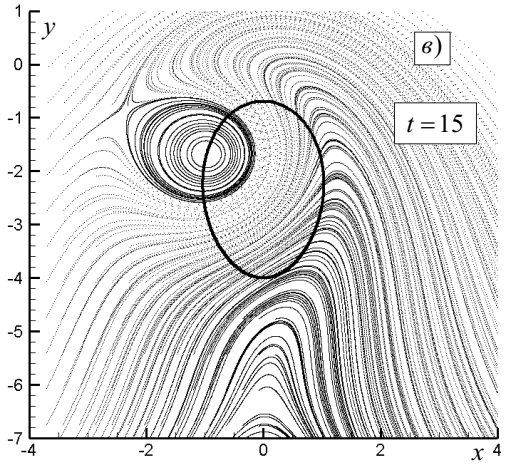
- (a) escape time, $\chi = \pi,\ \kappa = -0.435$
- (b) instantaneous flow topological structure at $t_1 = 0$
- (c) instantaneous flow topological structure at $t_2 = 7$

Stationary dynamics

Large κ



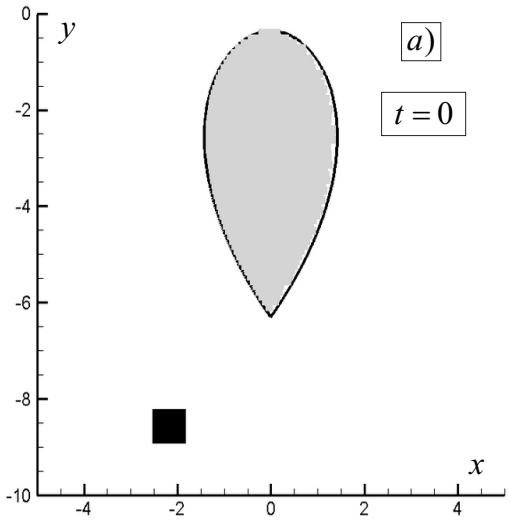


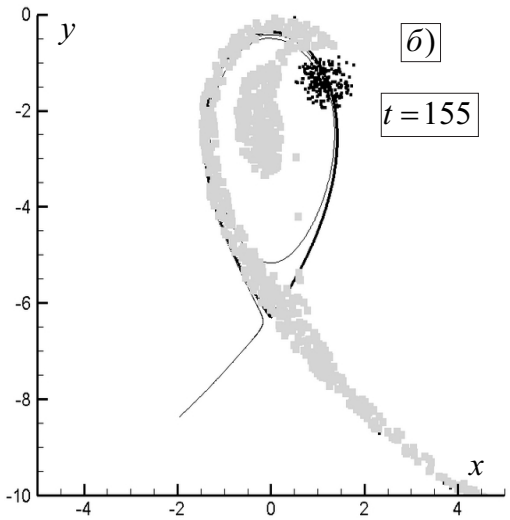


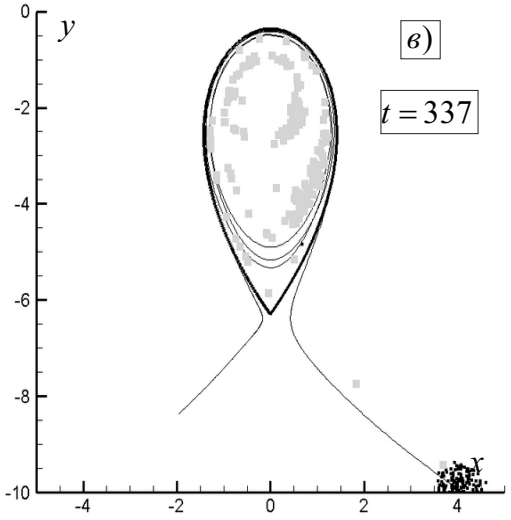
- (a) escape time, $\chi = \pi,\ \kappa = -2.5$
- (b) instantaneous flow topological structure at $t_1 = 0$
- (c) instantaneous flow topological structure at $t_2 = 4$

Nonstationary dynamics

Short-time interaction



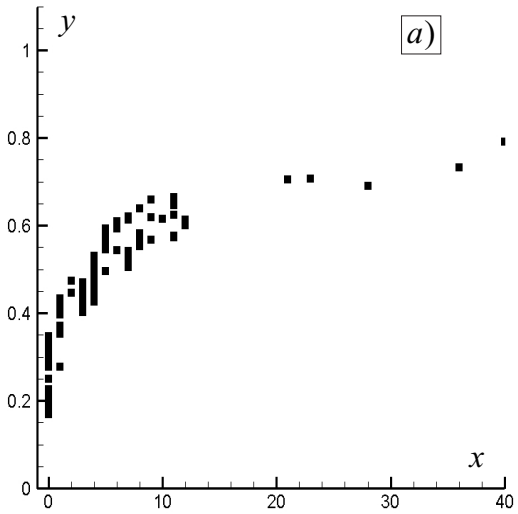


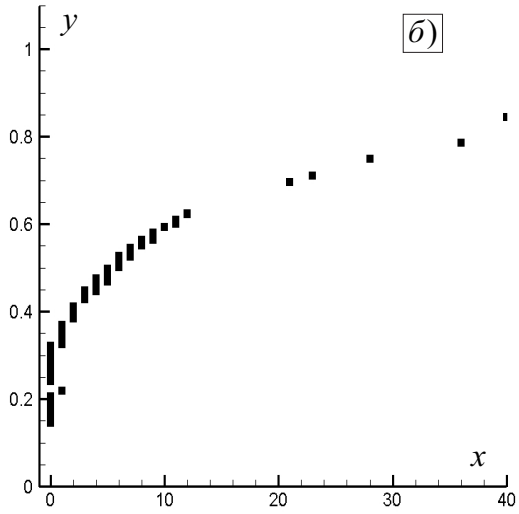


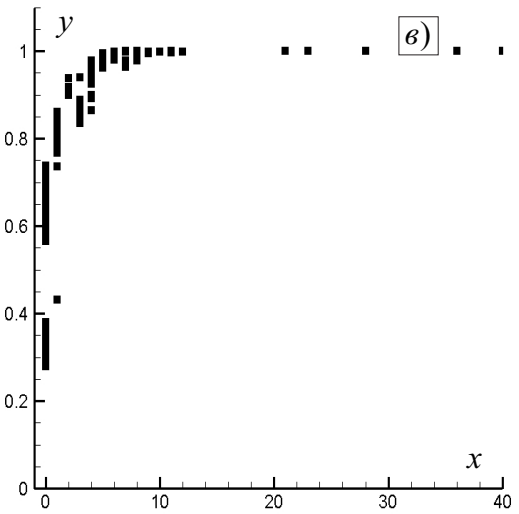
- Initial particle distribution
- One monopole revolution
- After monopole releasing

Nonstationary dynamics

Short-time interaction







- $\kappa = 0.01$
- $\kappa = -0.01$
- $\kappa = 0.1$