Lagrangian Model of a Surface Advected River Plume in Marginal and Enclosed Seas

Alexander Osadchiev (*osadchiev@ocean.ru*) **and Peter Zavialov**

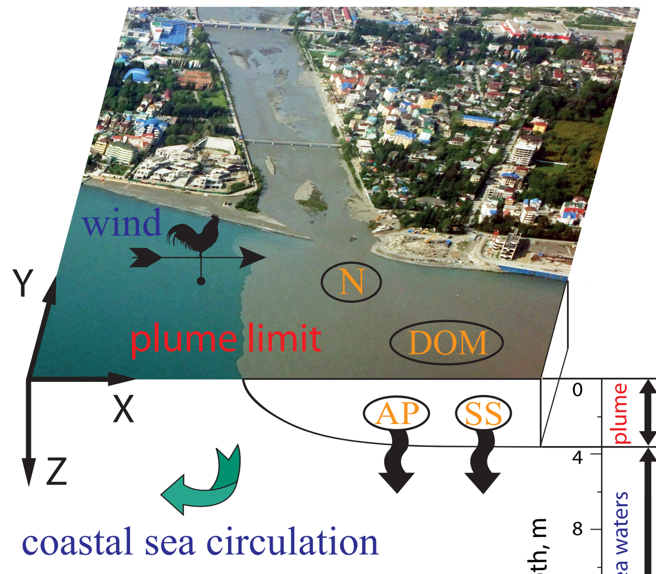
Shirshov Institute of Oceanology, Moscow, Russia

This poster participates in OSP

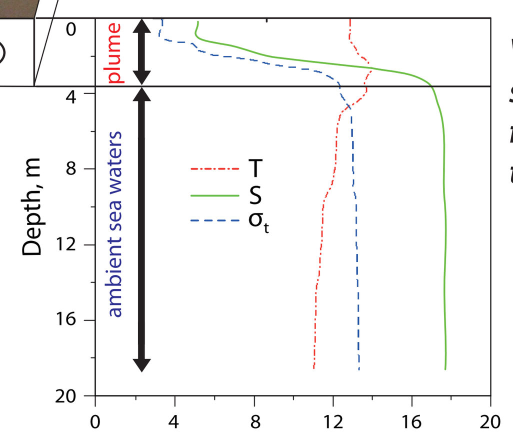
Outstanding Student Poster Contest

(1) Motivation: Why study river plumes?

River inflows bring significant amount of fresh water, buoyancy, heat, and momentum vorticity into the ocean. This is especially so for enclosed basins, inland seas, and saline lakes. Continental runoff is also the major source of suspended sediment (SS), dissolved organic matter (DOM), nutrients (N) and products of anthropogenic pollution (AP) in the ocean. Numerous observations showed that there is a great diversity of morphological forms and types of dynamical behavior of river plumes. They have their own highly variable motion which is influenced greatly by wind, coastal sea circulation, and shelf bathymetry. Studying the river plume dynamics is the key to understanding the mechanisms of continental runoff spreading in the ocean and its interaction with the sea waters.



Aerial view of Mzymta River plume and schematic of its interaction with ambient environment.



Vertical profiles of temperature, salinity, and density σ_t, obtained from CTD measurements within the Mzymta River plume.

(2) STRiPE model: Description

We developed a Lagrangian model of a surface-advected river plume, and tentatively identified it as STRiPE (Surface-Trapped River Plume Evolution). The model combines deterministic and stochastic approaches and is computationally unpretentious. River plume is represented as a set of particles. Every particle corresponds to a vertical water column from the surface to the boundary between the freshened surface and downlaying ambient sea water. The following equations are applied to each particle:

transport equations (terms labelled: Coriolis force, wind stress, vertical friction, lateral friction, pressure gradient force):

$$a_x^{i+1} = \underbrace{-fu^i}_{\text{Coriolis force}} + \underbrace{\frac{\tau_x^i}{\rho^i h^i}}_{\text{wind stress}} - \underbrace{\frac{\mu_v^i}{h^i}\frac{u^i - u_{sea}^i}{h^i}}_{\text{vertical friction}} + \underbrace{\frac{\mu_h}{h^i}\left(\frac{u_{x+\Delta x,y}^i + u_{x-\Delta x,y}^i - 2u^i}{\Delta x} + \frac{u_{x,y+\Delta y}^i + u_{x,y-\Delta y}^i - 2u^i}{\Delta y}\right)}_{\text{lateral friction}} - \underbrace{g\varkappa\frac{h_{x+\Delta x,y}^i - h_{x-\Delta x,y}^i}{\Delta x}}_{\text{pressure gradient force}}$$

$$a_y^{i+1} = fv^i + \frac{\tau_y^i}{\rho^i h^i} - \frac{\mu_v^i}{h^i}\frac{v^i - v_{sea}^i}{h^i} + \frac{\mu_h}{h^i}\left(\frac{v_{x+\Delta x,y}^i + v_{x-\Delta x,y}^i - 2v^i}{\Delta x} + \frac{v_{x,y+\Delta y}^i + v_{x,y-\Delta y}^i - 2v^i}{\Delta y}\right) - g\varkappa\frac{h_{x,y+\Delta y}^i - h_{x,y-\Delta y}^i}{\Delta y}$$

$$x^{i+1} = x^i + u^i\Delta t + \frac{a_x^{i+1}\Delta t^2}{2} + \sqrt{2D_h^i\Delta t}\,\eta_x$$

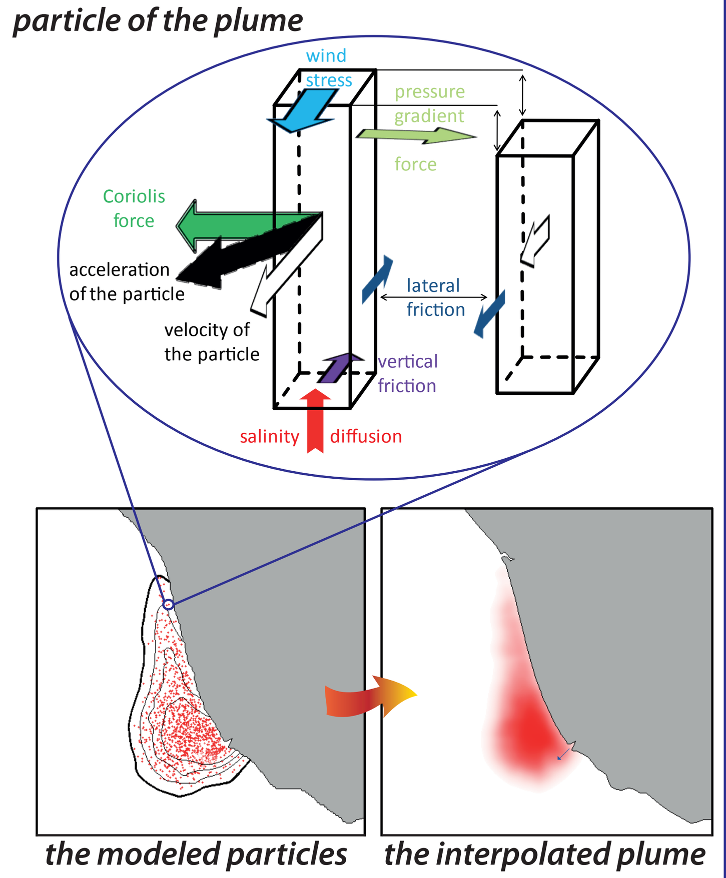
$$y^{i+1} = y^i + v^i\Delta t + \frac{a_y^{i+1}\Delta t^2}{2} + \sqrt{2D_h^i\Delta t}\,\eta_y$$

$$\eta_{x,y} \sim N(0,1),\quad D_h^i = \zeta_h\sqrt{\left(\frac{u_{x+\Delta x,y}^i - u_{x-\Delta x,y}^i}{\Delta x}\right)^2 + \frac{1}{2}\left(\frac{v_{x+\Delta x,y}^i - v_{x-\Delta x,y}^i}{\Delta x} + \frac{u_{x,y+\Delta y}^i - u_{x,y-\Delta y}^i}{\Delta y}\right)^2 + \left(\frac{v_{x,y+\Delta y}^i - v_{x,y-\Delta y}^i}{\Delta y}\right)^2}$$

dissipation equations: $\rho^{i+1} = \rho^i + D_v^i\frac{(\rho_{sea} - \rho^i)}{h^i}\Delta t,\quad h^{i+1} = h^i - D_v^i\Delta t,\quad D_v^i = \zeta_v\left(1 - \min\left(1, Ri^i\right)^2\right)^3$

Acceleration of a particle at every time step is computed from the momentum budget determined by the forces mentioned above, and the trajectory is simulated thereby.

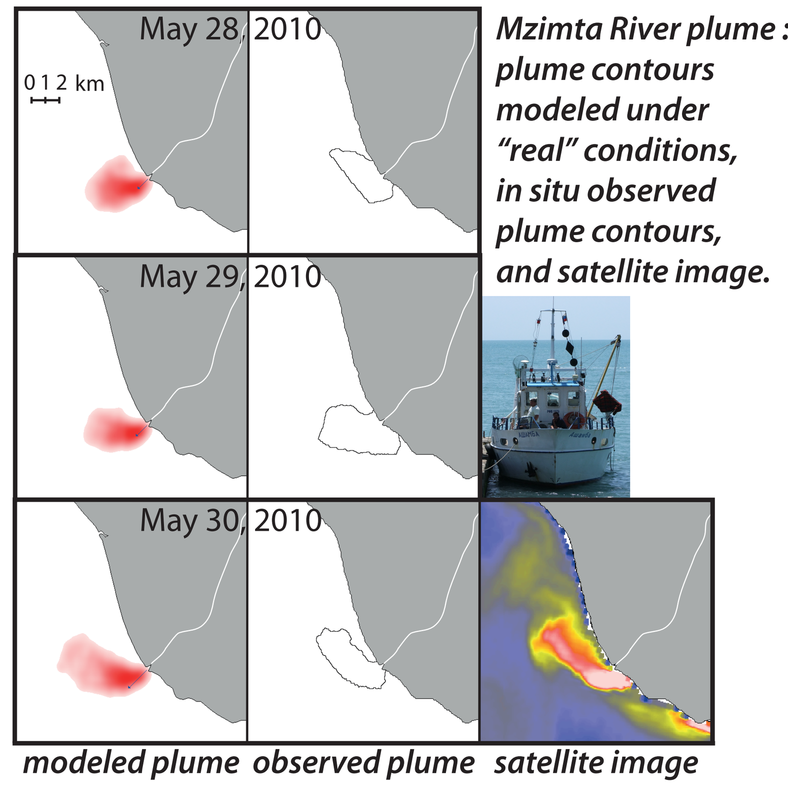
Schematic of the forces applied to an individual particle of the plume



the modeled particles *the interpolated plume*

(3) STRiPE model: Validation

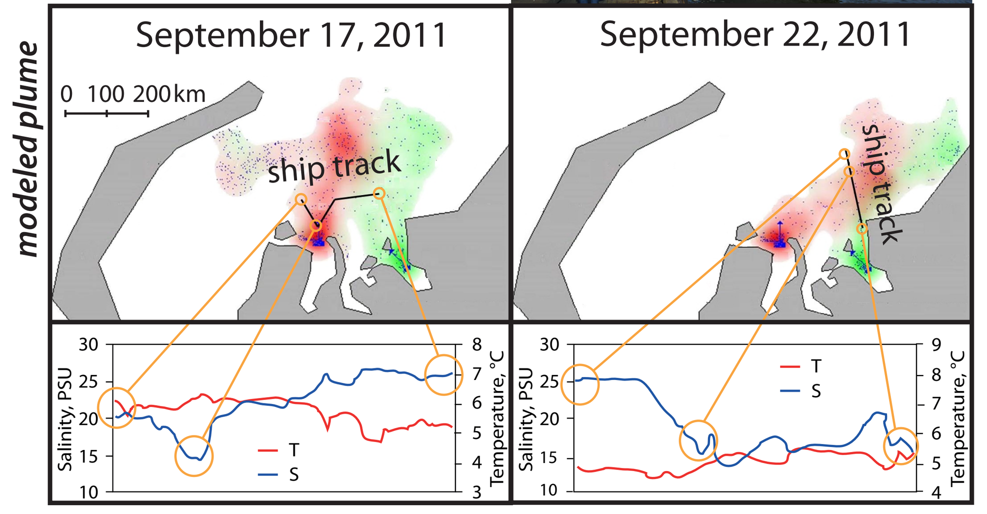
We applied the STRiPE model to simulate river plumes at different geographic settings and spatial scales. The simulations were performed with realistic shore lines, winds and discharge configurations for the Mzymta River plume at the eastern part of the Russian Black Sea coast, with the plume area smaller than 50 km², as well as the extensive Ob-Yenisey plume in the Kara Sea, whose area is of order 10000 km². The STRiPE model during selected trial periods was able to simulate the behavior of the both plumes close to that observed through in situ measurements and satellite imagery.



Mzymta River plume: plume contours modeled under "real" conditions, in situ observed plume contours, and satellite image.

modeled plume *observed plume contour* *satellite image of the plume*

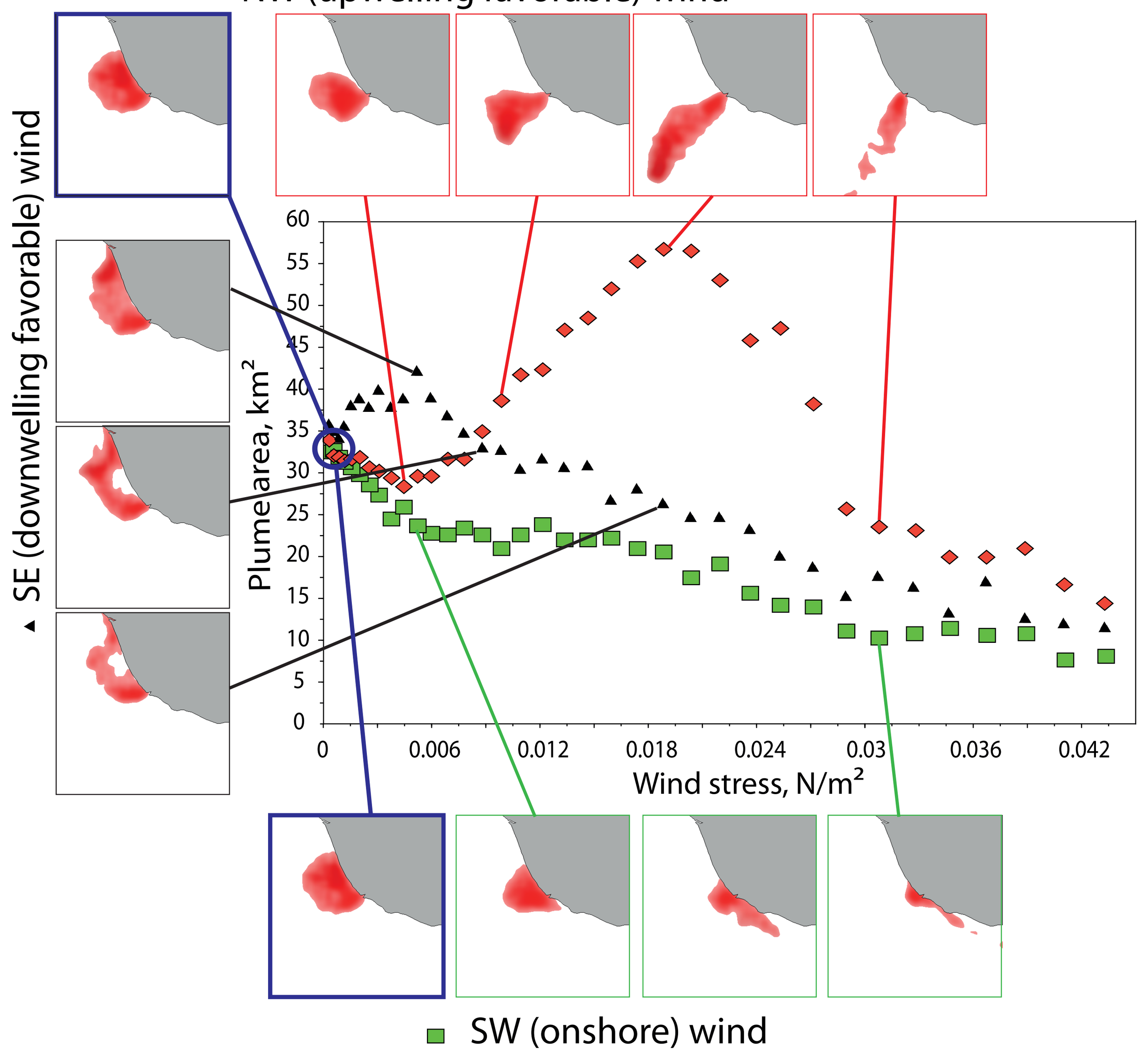
Ob-Yenisey plume: plume contours modeled under "real" conditions and in situ CTD surface measurements



CTD surface measurements

(4) STRiPE model: Diagnostic experiments

Further, using the STRiPE model, we also studied the general aspects of the plume dynamics.



Modeled plume area as a function of wind stress magnitude for three "archetypal" wind forcings regimes

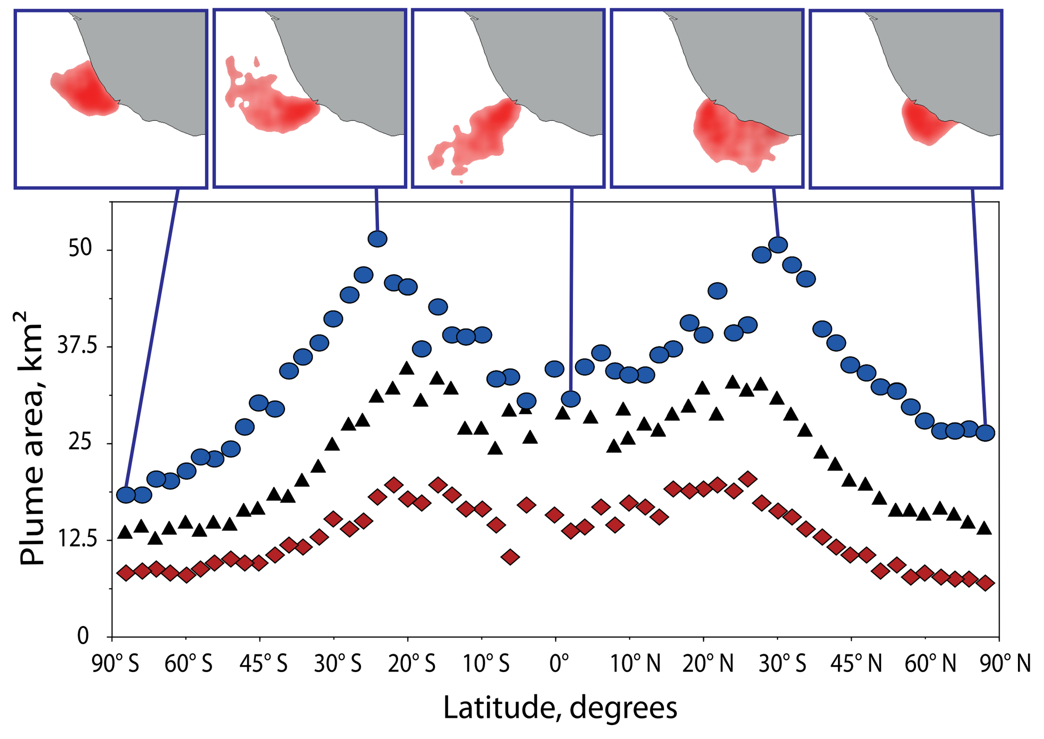
plume area vs wind stress

The dependence of the spatial extent of a plume of small size river on the wind was investigated. We identified 3 distinctive regimes of the plume evolution depending on the wind direction with respect to the shoreline and the river mouth geometry. For the offshore and "downwelling-favoring" alongshore winds, the plume area initially grows with the increase of wind stress τ, and then starts to decrease when τ exceeds certain critical value. For the onshore wind, the area decreases steadily (though not linearly) as τ increases. The most complex behavior is observed for the "upwelling-favoring" alongshore wind: the plume area initially decreases until the wind stress exceeds a certain critical value, then starts to increase with τ and attains a maximum, and then eventually drops to zero as τ continues to increase.

plume area vs Coriolis force

The dependence of the plume area on the Coriollis parameter, i.e. latitude, was investigated. The corresponding plot exhibited a distinctive "M-shaped" pattern, indicating that under otherwise equal conditions, the most spatially extensive plumes should form in the tropical regions. Qualitatively, this is because in the low latitudes, the Coriolis force is too small to prevent the plume from rapid horizontal dissipation while spreading into the sea, and in the high latitudes, it is too large to let the plume stretch away from the coast. The exact latitude of the maximum plume area depends on the river inflow velocity. This dependence, however, is largely offset by a much stronger dependence on the wind stress.

Modeled area of the unforced plume as a function of latitude as determined by Coriolis parameter under various river discharge rates



(5) Conclusions

- A Lagrangian particle tracking model of a surface-advected river plume (STRiPE) is developed.
- The STRiPE model is capable for realistically simulating the synoptic variability of small and medium river plumes (Mzymta River plume), and seasonal variability of large river plumes (Ob-Yenisey plume) under real forcing conditions.
- The STRiPE model appears to be a useful and convenient tool for investigating the general aspects of the plume dynamics. Using the model, 3 regimes of the plume evolution depending on wind direction were identified. Also it was found that the most spatially extensive plumes should form in the tropical regions.
- The model can be used for practical applications in the context of marine pollution, as well as sediment transport and nutrient cycling in the coastal zone, especially in enclosed basins, inland seas, and saline lakes.