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Simulation of particle transport in urban environments with high spatial resolution

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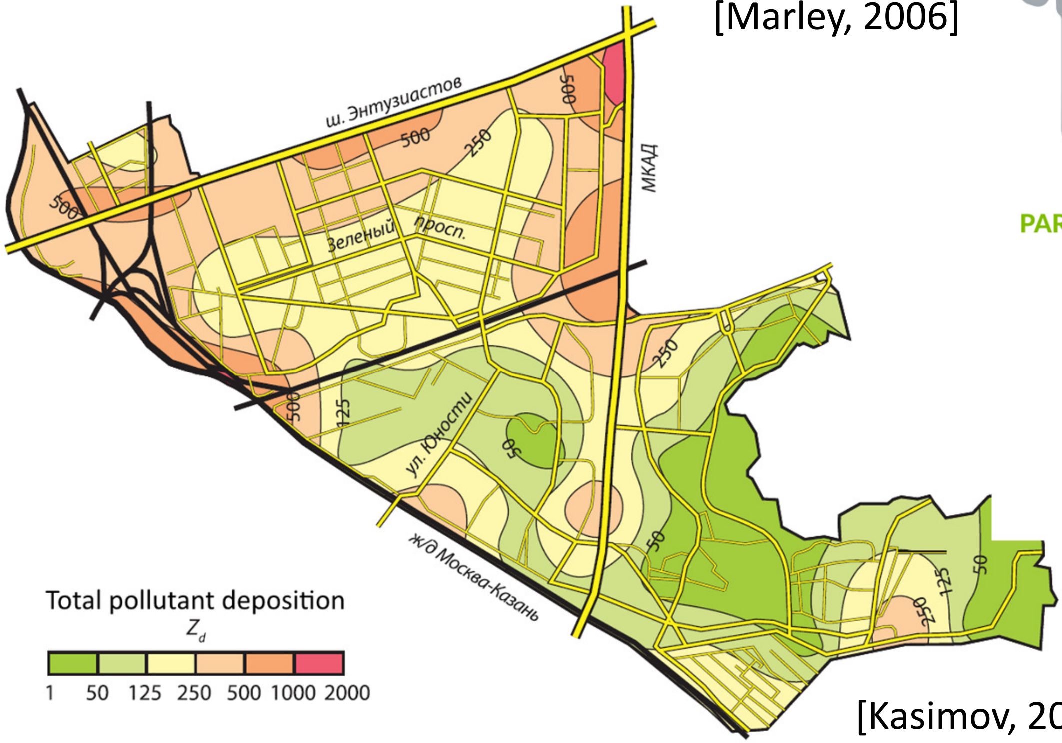
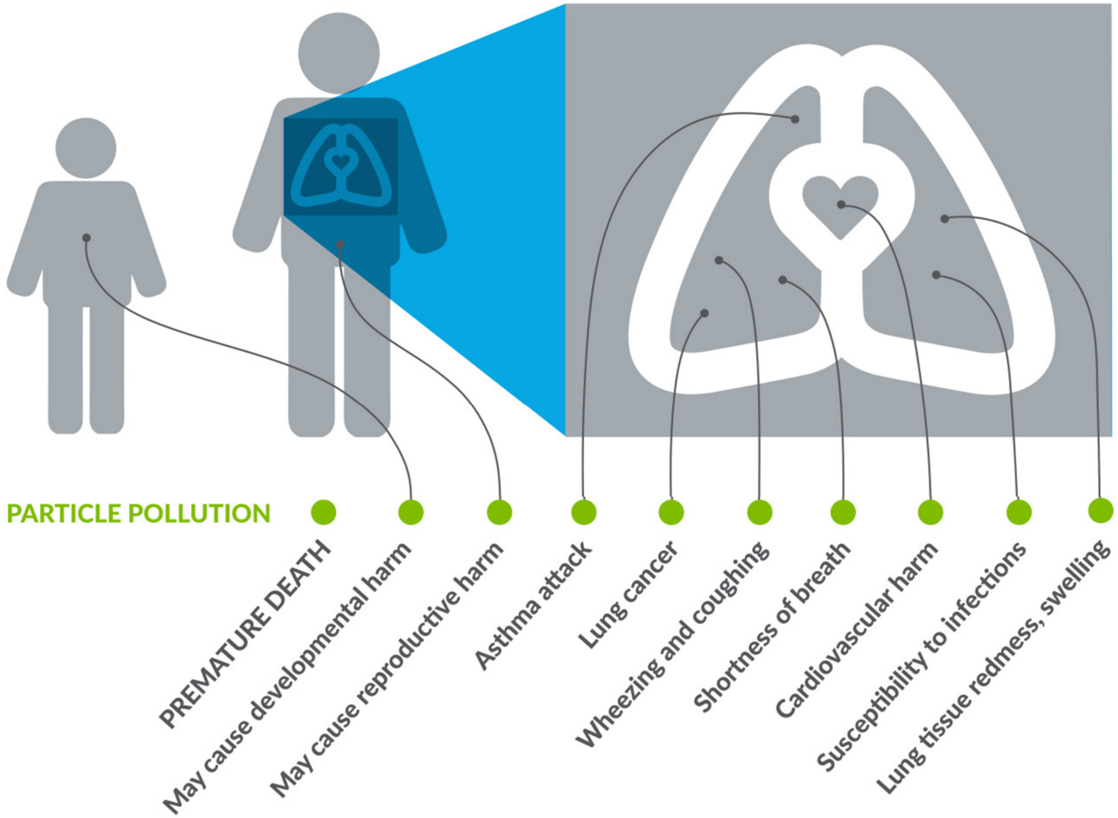
Motivation: atmospheric aerosol

Particle size	Impact area
5 – 30 µm	Nose, Throat, Mouth
1 – 5 µm	Trachea, upper bronchi
< 1 µm	Lungs, circulatory system

[Marley, 2006]



[Kasimov, 2016]



[https://www.lung.org]

Objective

Objective: development of lagrangian tool for calculating aerosol dispersion in urban geometry with high spatial resolution

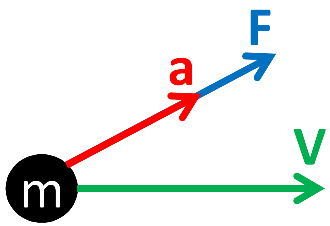
Tasks:

- Development of physical model of particle advection
- Implementation of the scheme in the program code
- Testing the model for idealized cases and real urban built-up areas

Particle Advection Physics

Newton's second law

$$m\mathbf{a} = m\frac{d\mathbf{V}}{dt} = \mathbf{F}$$



Medium resistance force

$$F_D = \frac{3\mu C_D Re}{4\rho_p d_p^2}$$

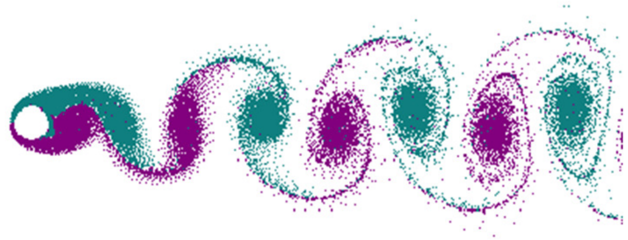
Motion equation

$$\frac{d\mathbf{u_p}}{dt} = \frac{\mathbf{g}(\rho_p - \rho)}{\rho_p} + F_D(\mathbf{u} - \mathbf{u_p})$$

The equation is solved by 4-order explicit Runge-Kutta method

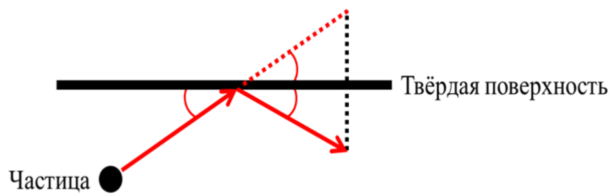
Trajectory calculation is possible for a variety of particles.

Turbulent eddies



[http://www.mcef.ep.usp.br]

Interaction with surfaces



C_D – drag coefficient
Re – Reynolds number

ρ_p – particle density
d_p – particle diameter
$\boldsymbol{u_p}$ – particle velocity

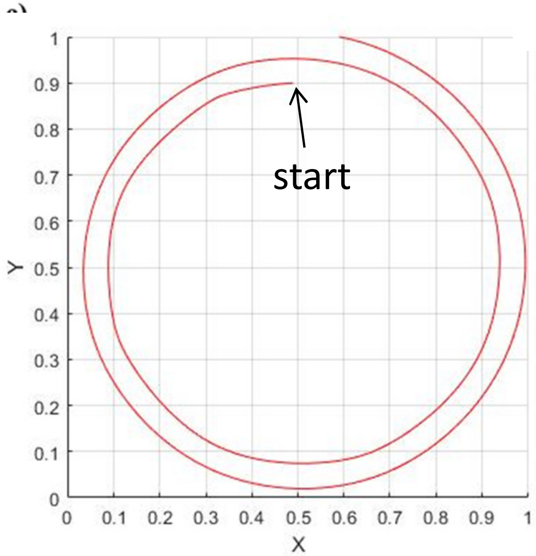
ρ – medium (air) density
$\boldsymbol{u}$ – flow velocity

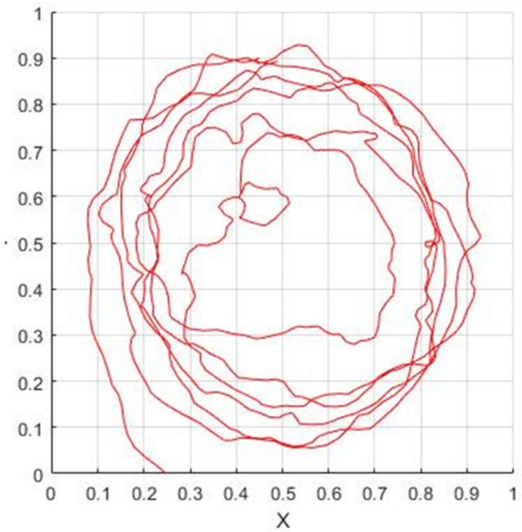
Testing for idealized flow

Circular flow $\mathbf{u} = \mathbf{\Omega} \times \mathbf{r}$

Laminar flow

Turbulent flow





$\mathbf{\Omega} = (0,0,1)$
$\mathbf{r}$ – position vector

Turbulence Parameterization

Flow velocity $\mathbf{u} = \bar{\mathbf{u}} + \mathbf{u}'$
$\mathbf{u}'$ – pulsation component
(normally distributed random variable)

Discrete random walk model

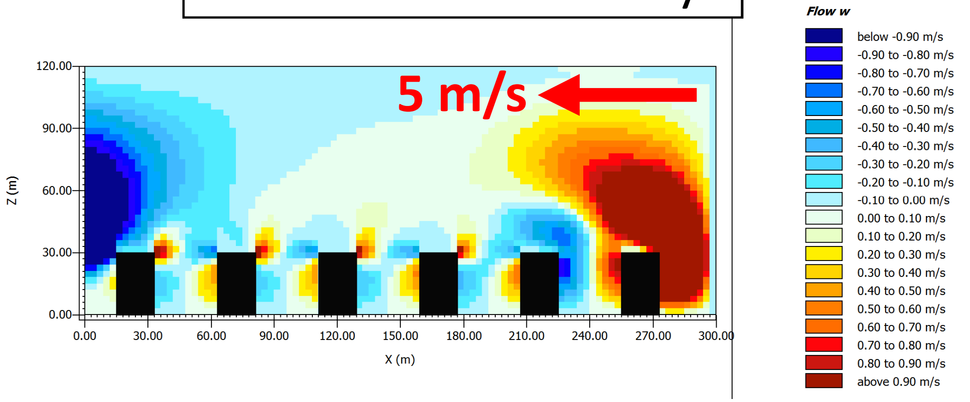
$\mathbf{u}'$ is generated for every large turbulent eddy

$$\tau = \min(t_e, t_R)$$

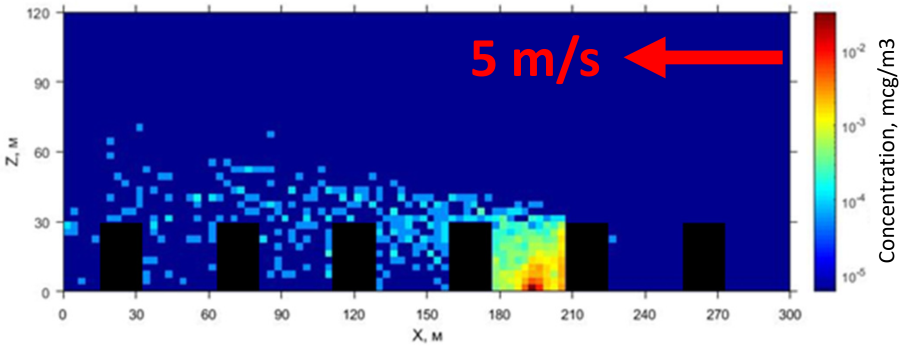
t_e – eddy lifetime
t_R – eddy crossing time

Urban canyon case

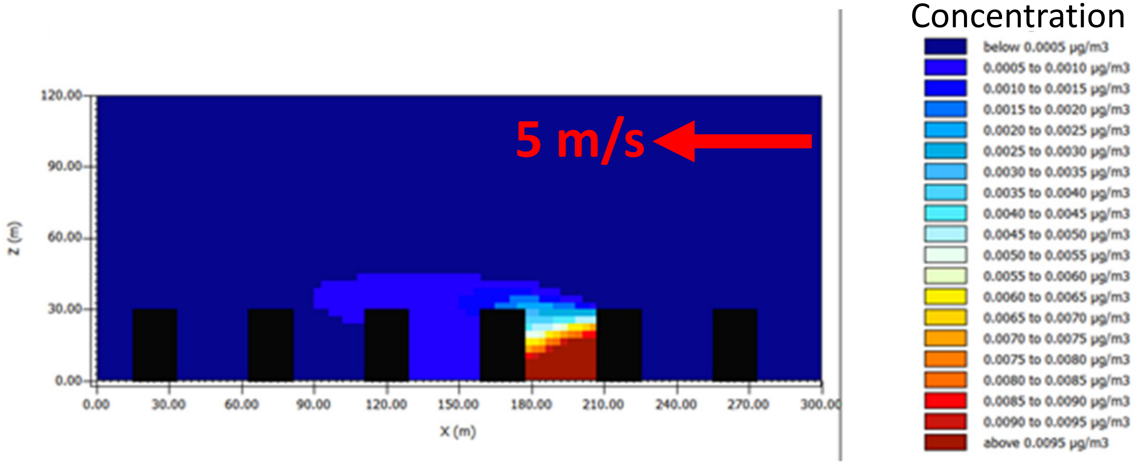
Flow vertical velocity



Developed model (lagrangian)



ENVI_MET model (eulerian)

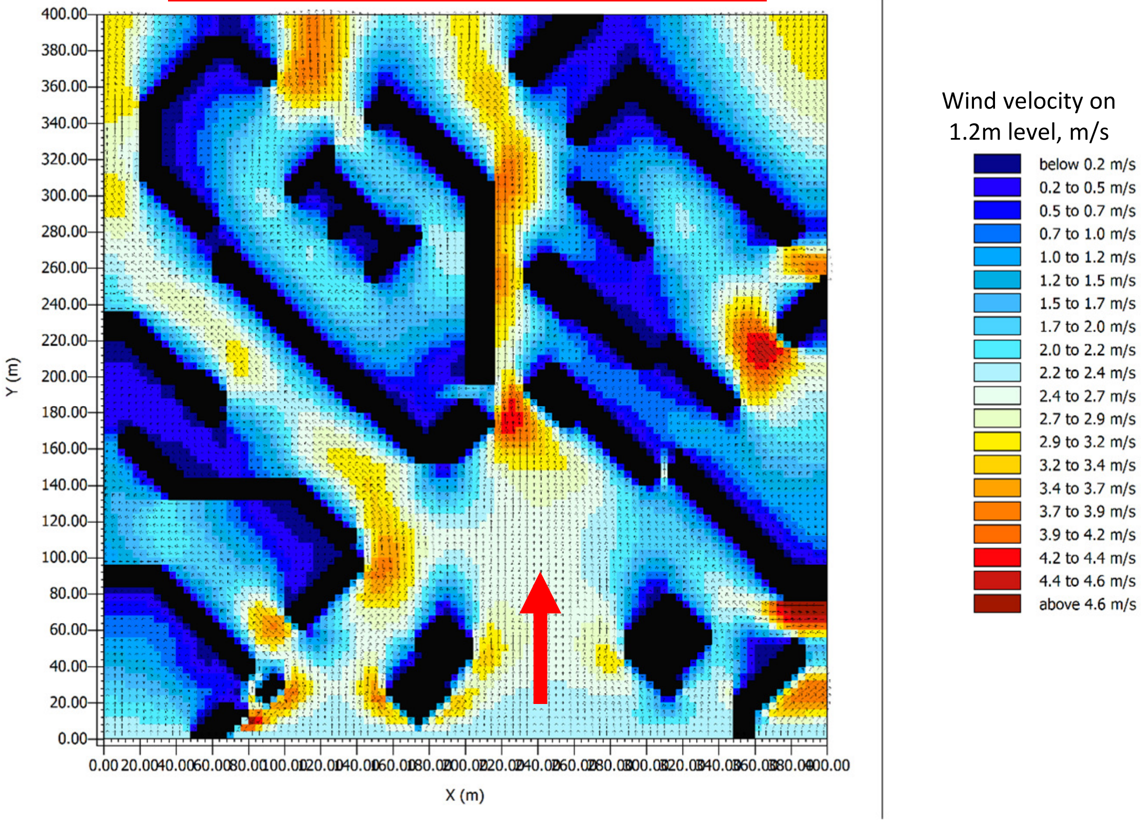


Close to real conditions Nadym city case

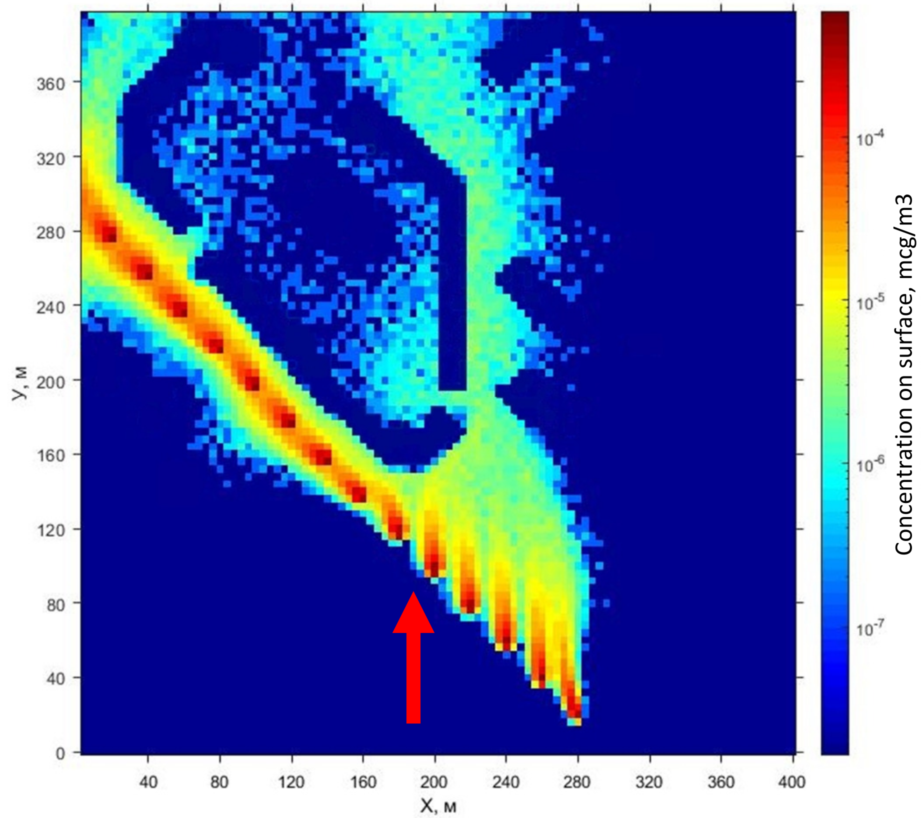
Nadym, 400x400 m

Flow velocity on 10m – **5 m/s**

1.2m level wind velocity



PM2.5 concentration on surface



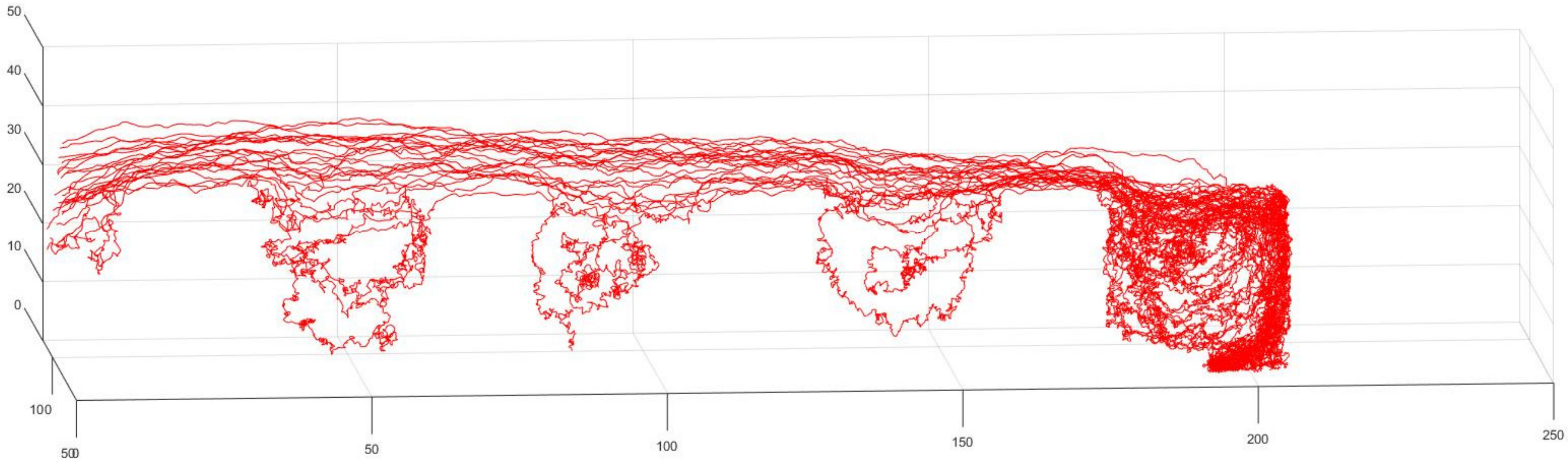
Conclusions

- **The 3D microscale Lagrangian model of particle advection was developed and implemented in the program code**

- The model has ability to calculate the particle dispersion in advanced geometry of urban areas and to accept various types of input data. In perspective this tool could be more accurate, than eulerian method

- Simple analytical and close to real conditions tests were successfully carried out

Thank you for attention!

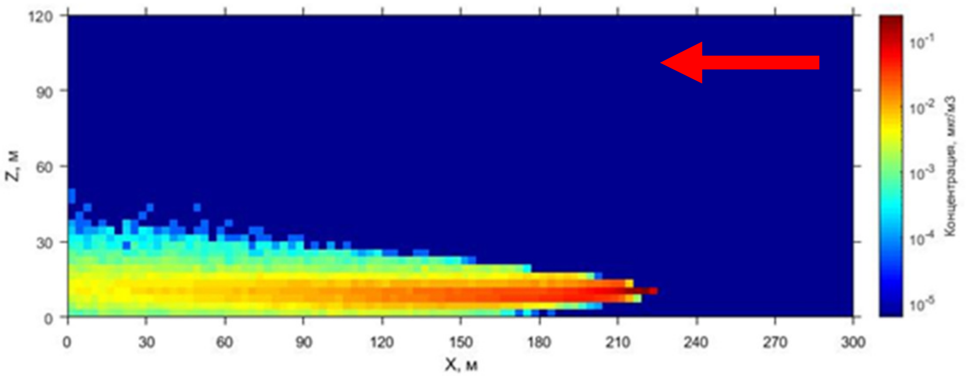


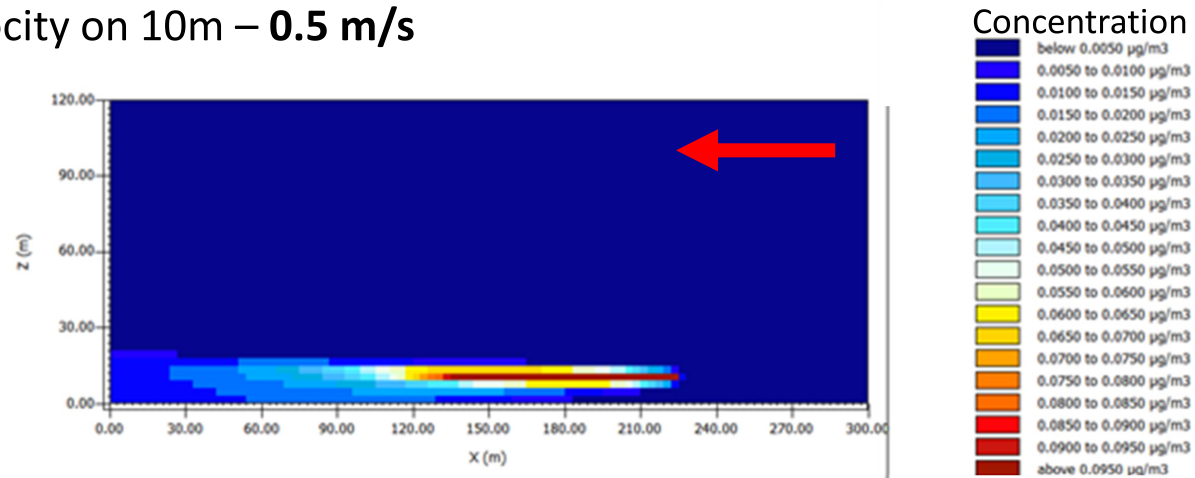
Flat surface: concentration

Developed model (lagrangian)

ENVI_MET model (eulerian)

Flow velocity on 10m – **0.5 m/s**





Flow velocity on 10m – **5 m/s**