Hydrodynamic modeling of the transport of heavy aerosols of various genesis in the atmospheric boundary layer

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Abstract: This paper presents the development of the Lagrangian particle transport model in the direction of modeling heavy particles. A description of the turbulence model and parameterizations is given. Comparison of model calculations with analytical solutions and field measurements data was carried out, which showed a high degree of correspondence and revealed the features of parameterizations.

1. Lagrangian model: description

Physics

Newton's second law

Medium resistance force

Buoyancy force

Equations of motion

$$\frac{\mathrm{d}\boldsymbol{u_p}}{\mathrm{d}t} = \frac{\boldsymbol{g}(\rho_p - \rho)}{\rho_p} + F_D(\boldsymbol{u} - \boldsymbol{u_p})$$

$$\frac{\mathrm{d}\boldsymbol{x_p}}{\mathrm{d}t} = \boldsymbol{u_p}$$

$\boldsymbol{u_p}$ – particle velocity, ρ_p – particle density, $\boldsymbol{u}$ – air velocity, ρ – air density

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Interactions with surfaces

Particle decay

Turbulence and stochastics

Turbulence parameterizations

$\boldsymbol{u} = \overline{\boldsymbol{u}} + \boldsymbol{u'}$

$\overline{\boldsymbol{u}}$ – mean velocity

$\boldsymbol{u'}$ – fluctuation

Random displacement model

0th order stochastic model

$$\boldsymbol{u'} = \frac{\partial K_s}{\partial x_i} + \frac{\xi\sqrt{2K_s}}{\Delta t}$$

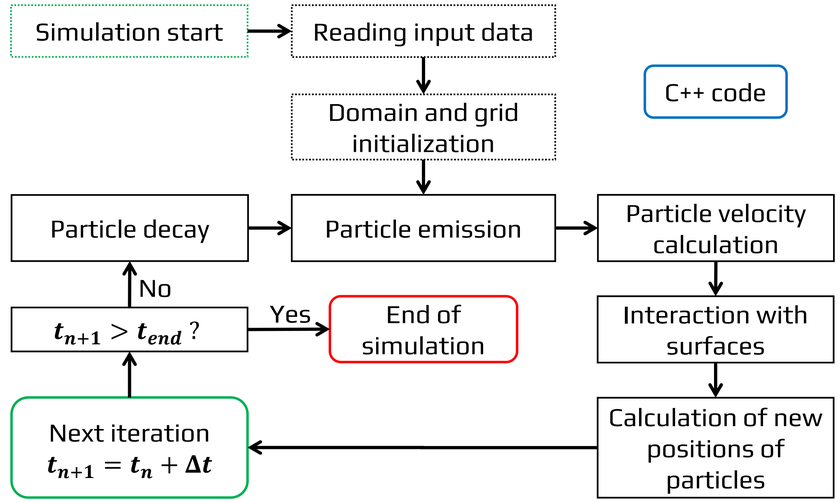
Langevin model

1st order stochastic model

$$\mathrm{d}\boldsymbol{u'} = a(\boldsymbol{x_p}, \boldsymbol{u'}, t)\mathrm{d}t + b\xi$$

K_s – turbulent diffusion coefficient, ξ – Gaussian random value

Work algorithm

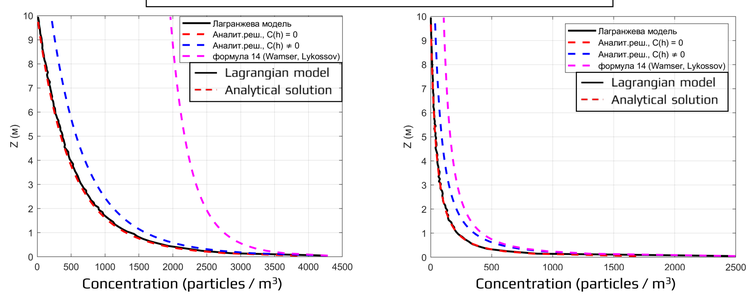


2. Results: modeling and measurements

Comparison with analytical solutions

Neutrally stratified boundary layer, d_p = 100 μm, RDM parametrization

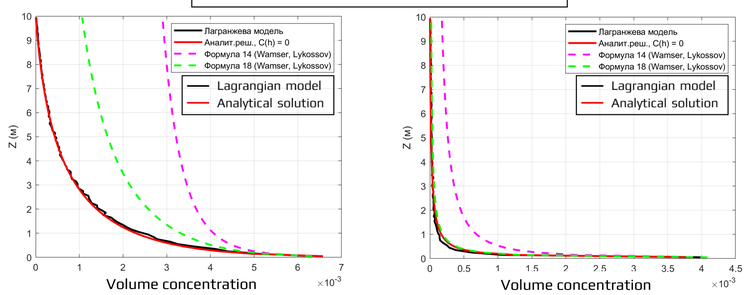
Particles do not affect stratification



$\rho_p = 100\ \mathrm{kg/m^3}$

$\rho_p = 400\ \mathrm{kg/m^3}$

Particles affect stratification

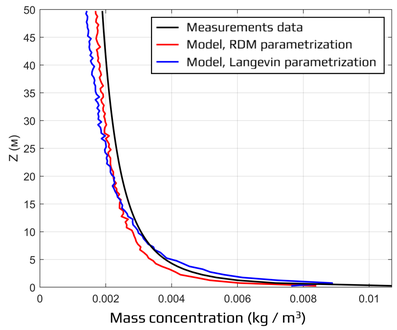


Verification on field measurements data

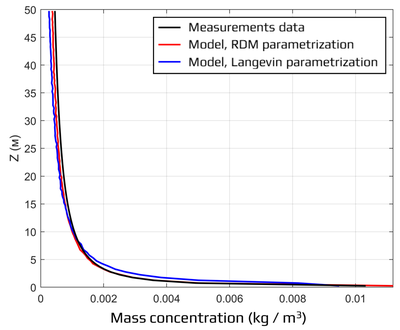
Data: measurements of vertical profiles of particle concentrations during dust and sand storms in Central Asia *(Semenov, 2020)*

$\rho_p = 2650\ \mathrm{kg/m^3}$, $u_* = 0.8\ \mathrm{m/s}$

Dust storm
d_p = 35 μm



Sand storm
d_p = 50 μm



References:

1. Semenov O.E. *Vvedenie v eksperimental'nuyu meteorologiyu i klimatologiyu peschanyh bur'*. Ed. O.G. Chkhetiani, I.A. Repina. Moscow, Fizmatkniga, 2020. 448 p.
2. Wamser C., Lykossov V.N. On the friction velocity during blowing snow // Contributions to Atmospheric Physics. — 1995. — Vol. 68, no. 1. — P. 85–94.

3. Conclusions

- The Lagrangian model implements stochastic parameterizations of 0th and 1st orders, which allow choosing, depending on the input data and the task
- The possibility of taking into account the influence of heavy particles on the stratification of the atmosphere has been implemented
- The model is verified on analytical solutions that take into account the mass and size of particles
- The model was successfully verified on field measurements of heavy dust and sand particles vertical concentration profiles

Acknowledgements

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