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Estimating air pollution levels by numerical simulation depending on wind flow speed and dust source area

Pavel V. Amosov[1]*, Alexander A. Baklanov[2], Dmitriy V. Makarov[1], Vladimir A. Masloboev [1]
[1] Institute of North Industrial Ecology Problems, KSC RAS, Russia
[2] World Meteorological Organization, Switzerland
e-mail: p.amosov@ksc.ru

Abstract

Research aim *is to estimate atmospheric pollution levels in the town of Apatity, by numerical simulation, depending on the discrete arrangement of dust sources at the tailing dump closest to the town and the speed of wind flow.*

Methodology. *For computer 3D modeling, the COMSOL software was used. To calculate the aerodynamic properties the approach of incompressible fluid and standard (k–ε)-model of turbulence were used. The spread of dust pollution has been modeled by numerically solving the convective-diffusion equation of impurity transfer taking into account the deposition rate. Numerical experiments were performed for wind flow speeds between 5 and 23 m/s and a discrete representation of the dust source area between 2 and 10 ha.*

Results. *The spatial distributions of the model's aerodynamic properties and the interval (and total) distributions of dust pollution were obtained. The Starye Apatity area is most exposed to atmospheric pollution. Atmospheric pollution levels were analyzed and generalized to functional dependencies, depending on the values of the model's variable parameters. It is shown that the calculated dependencies between the maximum dust concentration and the dust source area can be described by linear functions, which allows predicting the critical dust source area, at which the level of air pollution reaches the threshold limit value. It is demonstrated that the dependence of the maximum dust concentration on wind flow speed at fixed dust source area values can be approximated by a power-law function.*

Summary. *A generalized analytical formula has been derived that allows predicting maximum dust concentrations in the town of Apatity depending on the discrete locations of dust sources at the tailing dump and the speed of wind flow.*

Key words: *tailing dump; wind speed; dust source area; discreteness; air pollution; numerical simulation.*

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Introduction. Simulation of dust behavior is a relatively new direction in scientific research but rather relevant and much in demand worldwide. Currently, within the UN, particularly as part of WMO program called "Sand and Dust Storm Warning Advisory and Assessment System" (SDS-WAS) [1, 2], the indicated direction is being actively developed to predict dust storms.

The object of this research is the tailing dump ANOF-2 (the town of Apatity, Murmansk region) with causes certain troubles to the citizens in the summer with strong winds from the northwest. In earlier research, based on the experience analysis and the application of formalized description of the dusting processes [3–12], the researchers of FRC KSC RAS answered some essential questions [13, 14]. In particular, the impact has been shown which is made by the height of the tailing storage dust source surface on the level of surface air dust pollution down the wind flow under wind speed variation [13]; the effect has been demonstrated which is exerted by the location of the tailing dump dust sources with similar surface area under the wind of gale force on the town's air pollution [14].

The present research is based on the numerical simulation being a follow-up study of the authors' investigation on air pollution assessment with the account of discretely located dust source areas of the tailing dump. Both wind flow speed variation and dust source area variation are taken into account.

Problem formulation. By the example of the tailing dump nearest to the town of Apatity, the research aims to assess the level of air pollution in the town depending on the incoming wind flow speed and the dust source area under discrete arrangement of dust source areas (fig. 1).

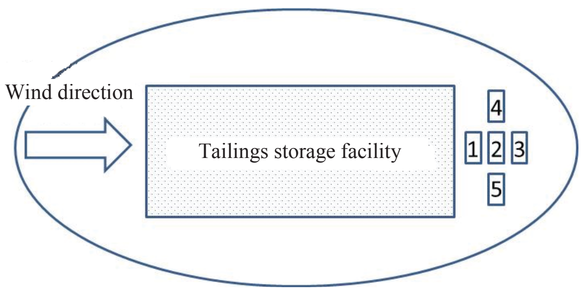

Fig. 1. Location diagram of the dust source areas 1–5 on the tailing dump site
Рис. 1. Схематичное расположение на территории хвостохранилища участков 1–5 пылящей поверхности

Computer model developed by the authors and presented in works [13, 14] is used as a base model. Input file required to create the geometry of the simulated area in COMSOL [15] is prepared with Google Earth maps of the ANOF-2 tailing dump of the town of Apatity (15 000 × 7000 m), 500–700 m grid. The surface of lake Imandra is a benchmark elevation (126 m, model's foundation). Beyond the dust source itself and Apatity town, the foothills of the Khibiny and some uplands are taken into account in the simulation model. The model of the tailings storage dust source surface represents an ellipse with the clipped water surface in the shape of a rectangular. The town boundary along the wind flow is 12 000–15 000 m, and 3000–6000 m in the transverse direction. The model's geometry corresponds to the design height of the tailing dump (200 m).

Recall that in numerical simulation the choice has to be made between the desired accuracy of calculation and the capabilities of the computer hardware. Despite good computational performance of the available ASUSK95VJ computer, even with the grid coarser than standard, the required RAM for calculation reaches almost 6 GB. Further increase in the model's resolution lengthened computational time, which was impractical due to the uncertainties as to a series of parameters of the model.

Variation parameters accepted in the calculation are the following:

– wind flow speed – 5, 11, 17 and 23 m/s at the height of +10 m from the model's foundation;

Table 1. Predicted values of the dynamic velocity, interval and total values of the vertical mass flux

Таблица 1. Расчетные для каждого участка пыления значения динамической скорости, поинтервальные и суммарные величины вертикального потока массы

U_{10}, m/s	U_*, m/s	Vertical mass flux, kg/(m^2 · s)							
		I	II	III	IV	V	VI	VII	∑
					Area 1				
5.0	.5148E+00	.4480E-07	.1690E-06	.2892E-06	.3950E-06	.4256E-06	.3849E-06	.3278E-06	.2036E-05
11.0	.1134E+01	.1055E-05	.3979E-05	.6807E-05	.9300E-05	.1002E-04	.9061E-05	.7718E-05	.4794E-04
17.0	.1751E+01	.5995E-05	.2262E-04	.3870E-04	.5287E-04	.5696E-04	.5151E-04	.4388E-04	.2725E-03
23.0	.2370E+01	.2013E-04	.7593E-04	.1299E-03	.1775E-03	.1912E-03	.1729E-03	.1473E-03	.9148E-03
					Area 2				
5.0	.5093E+00	.4293E-07	.1620E-06	.2771E-06	.3786E-06	.4079E-06	.3688E-06	.3142E-06	.1952E-05
11.0	.1122E+01	.1011E-05	.3815E-05	.6526E-05	.8916E-05	.9606E-05	.8687E-05	.7400E-05	.4596E-04
17.0	.1734E+01	.5770E-05	.2177E-04	.3724E-04	.5088E-04	.5481E-04	.4957E-04	.4222E-04	.2623E-03
23.0	.2347E+01	.1937E-04	.7308E-04	.1250E-03	.1708E-03	.1840E-03	.1664E-03	.1418E-03	.8805E-03
					Area 3				
5.0	.4994E+00	.3967E-07	.1497E-06	.2561E-06	.3498E-06	.3769E-06	.3408E-06	.2903E-06	.1803E-05
11.0	.1100E+01	.9344E-06	.3525E-05	.6031E-05	.8240E-05	.8877E-05	.8028E-05	.6838E-05	.4247E-04
17.0	.1701E+01	.5344E-05	.2016E-04	.3449E-04	.4712E-04	.5077E-04	.4591E-04	.3911E-04	.2429E-03
23.0	.2303E+01	.1794E-04	.6769E-04	.1158E-03	.1582E-03	.1705E-03	.1541E-03	.1313E-03	.8156E-03
					Area 4				
5.0	.5157E+00	.4514E-07	.1703E-06	.2914E-06	.3981E-06	.4288E-06	.3878E-06	.3304E-06	.2052E-05
11.0	.1136E+01	.1063E-05	.4009E-05	.6859E-05	.9370E-05	.1009E-04	.9129E-05	.7776E-05	.4830E-04
17.0	.1753E+01	.6020E-05	.2271E-04	.3886E-04	.5309E-04	.5719E-04	.5172E-04	.4406E-04	.2736E-03
23.0	.2372E+01	.2021E-04	.7624E-04	.1304E-03	.1782E-03	.1920E-03	.1736E-03	.1479E-03	.9186E-03
					Area 5				
5.0	.4838E+00	.3496E-07	.1319E-06	.2256E-06	.3083E-06	.3321E-06	.3003E-06	.2558E-06	.1589E-05
11.0	.1066E+01	.8236E-06	.3107E-05	.5316E-05	.7263E-05	.7825E-05	.7076E-05	.6028E-05	.3744E-04
17.0	.1650E+01	.4726E-05	.1783E-04	.3050E-04	.4168E-04	.4490E-04	.4060E-04	.3459E-04	.2148E-03
23.0	.2233E+01	.1587E-04	.5988E-04	.1024E-03	.1400E-03	.1508E-03	.1364E-03	.1162E-03	.7215E-03

– dust source area – 2 ha (area 1), 4 ha (areas 1–2), 6 ha (areas 1–3), 8 ha (areas 1–4) and 10 ha (areas 1–5) (fig. 1).

Research methodology. Research methodology is similar to the previously used one [13, 14, 16].

For the indicated values of wind speed, stationary aerodynamic parameters of the model are calculated (velocity fields, coefficient of turbulent viscosity). A model of air dynamics of flow over the heterogeneous surface within the limits of approximation of incompressible flow complemented by a standard (k–ε)-model of turbulence. Calculation is made before the steady-state mode.

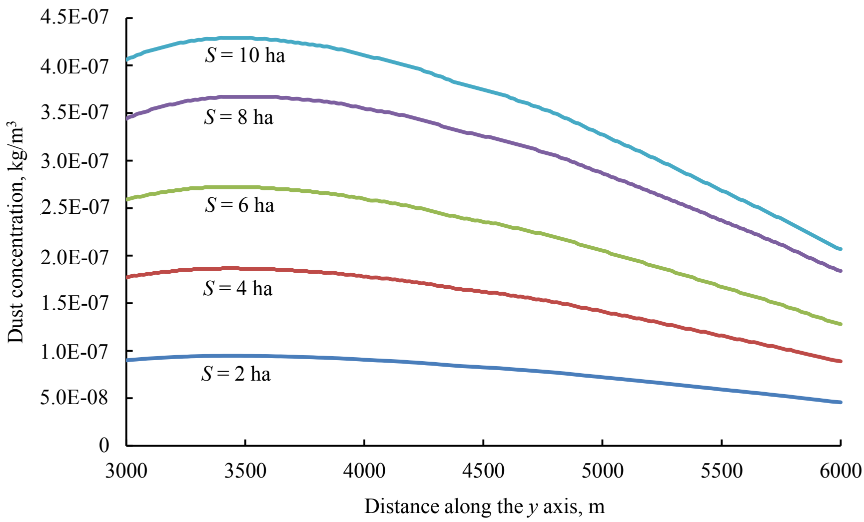

Fig. 2. Spatial distribution of the total dust concentration in the transverse direction to the wind flow at different dust source surface area values (wind speed 17 m/s)
Рис. 2. Пространственное распределение суммарной концентрации пыли в поперечном к направлению ветрового потока измерении при вариации площади пылящей поверхности (скорость ветрового потока 17 м/с)

The values of the longitudinal component of wind speed at the height of +10 m U_{10} over each dust source area and the value of the coefficient of turbulent viscosity and turbulent diffusion for the simulated area.

For each dust source area the values of dynamic velocity U_* are calculated, and the values of the vertical flux of mass are calculated for each interval (7 with its weight) of dust particle size [16] with the use of D. L. Westphal et al. approach [8, 16]. As an illustration of estimates, table 1 presents the predicted values, interval and total values of the vertical mass flux for each dust source area.

Static interval fields of dust distribution are calculated in the simulated area under the indicated variations of model parameters. To determine spatial distribution of pollution, the diffusion-convective transport equation is used.

Granulometric composition of final tailings from the surface of the established beach of the tailing dump ANOF-2 is represented in accordance with the data from the dissertation by A. V. Strizhenok [17]. Data processing made it possible to obtain quantitative indicators for the “weight” of each simulated interval of dust particles size. In table 2, for dust with the size interval up to 70 μm in diameter with 10 μm pitch, the values of interval “weight” and deposition rates for different-sized dust are presented calculated with Stokes approximation used in diffusion-convective transport.

Due to the analysis grid variation caused by discrete dusting areas set (fig. 1), damping parameters in approximation of convective terms have been selected to ensure the stability of calculation in a wide range of velocities set at the inflow boundary of the model. In particular, calculation stability at the whole wind flow speed range at the height of 10 m U_{10} from the foundation of the model (5–23 m/s) was ensured by: problem-solving software (Direct UMFPACK) and the coefficients of damping (Crosswind diffusion) for the equation of conservation of momentum and Turbulence isotropic for (k–ε)-model equations at level 0.7.

Output analysis of numerical experiments. Before analyzing the spatial distribution of dust concentration it is instructive to compare the values of dynamic velocity for the dust source areas (table 1). It is apparent that the dynamic velocity is maximum for area 4 and minimum for area 5. In a row of areas 1–2–3 the value of dynamic velocity reduces gradually. The values of vertical mass fluxes are in the same ratio. A possible reason for various values of the indicated calculated parameters for the spaced dust source areas may be the inhomogeneity of the velocity field for this region connected with the presence of an upland in the model northward of the tailing dump; the upland is the Khibiny foothill.

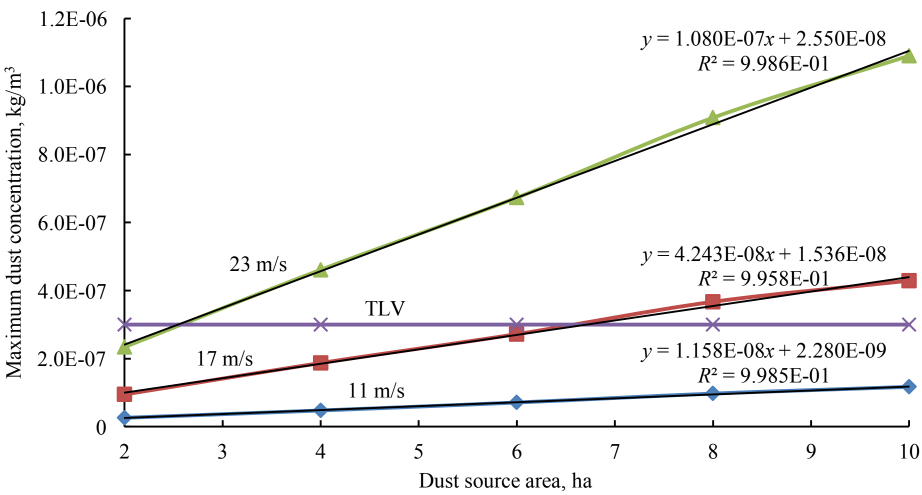

Fig. 3. Dependency of the maximum dust concentration on the dust source area at different wind flow speeds

Рис. 3. Зависимость максимальной концентрации пыли от площади пыления при вариации скорости ветрового потока

Some results of numerical experiments on predicting the spatial distribution of dust concentration are presented at fig. 2–4.

For example, at fig. 2 for 17 m/s wind the curves of spatial dust distribution in the dimension transverse to the wind flow direction are shown. Taking into account that for the inorganic dust containing silica in the interval of 20–70%, as maximum one-time concentration [18] the value of 0.3 mg/m^3 or $3 \cdot 10^{-7}$ kg/m^3 is established, the following conclusions can be made: it is the area of the Starye Apatity that is subject to maximum pollution; with dust source area more than 6 ha the threshold limit value (TLV) excess is predicted. The indicated excess with the dust source area more than 8 ha threatens not only the Starye Apatity but a half of the town.

Fig. 3 presents the ratios of maximum dust concentration and dust source area under wind flow speed variation from 11 m/s to 23 m/s. It is apparent that calculated dependences with high certainty factor are described by the linear functions; it makes it possible to predict the critical dust source area, at which the level of air pollution reaches the TLV. In particular, with 23 m/s wind it is necessary to reduce the dust source area down to about 2.5 ha, with 17 m/s wind – down to 6.8 ha, and with 11 m/s wind – 25 ha can be "allowed".

Fig. 4 presents the dependency of the maximum dust concentration on the dust source surface area for the wind flow speed of 5 m/s. Individual presentation of the indicated wind speed results is connected only with the visualization of results due to small values of pollution concentration. It is apparent that in this case the linear dependence works as well, which makes it possible to reach the critical dust source area of about 260 ha.

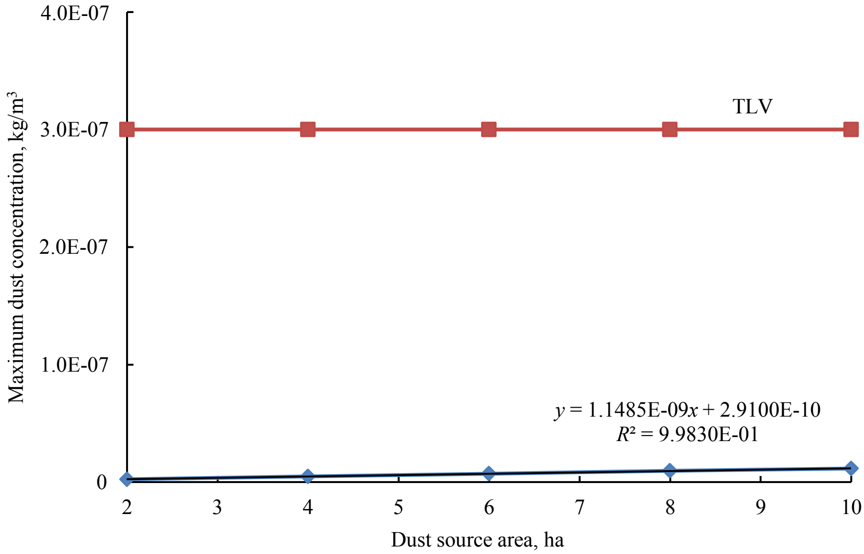

Fig. 4. Dependency of the maximum dust concentration on the dust source area at a wind flow speed of 5 m/s
Рис. 4. Зависимость максимальной концентрации пыли от площади пыления при скорости ветрового потока 5 м/с

The analysis of the summarized expression of the obtained estimates in the form of maximum dust concentration dependence under both simulation parameters variation (dust source area and wind flow speed) has shown that:

– there is the linear dependence between the required function and the dust source area;

– dependence on the wind flow speed is closer to the power-law function.

The analysis of dependences between maximum dust concentration and wind flow speed under fixed values of the dust source area testifies that with the certainty factor close to 1 the function under consideration is described by the power-law function $C_m = AV^B$, where V is wind speed, m/s. The values of coefficients A and B under various values of dust source area are presented in table 3.

Further analysis of coefficients A and B has shown that for the former coefficient the linear dependence $A = 10^{-12}(9.510S + 1.932)$ is valid, where S is the dust source area, ha; for the latter coefficient mean $B = 2.975$ may be used (maximum deviation of coefficient B from its mean value does not exceed 0.15%). The generalized function of two variables which makes it possible to roughly predict the level of maximum dust concentration in the atmosphere becomes $C_m = 10^{-12}(9.510S + 1.932)V^{2,975}$. The given expression correctness has been checked within the range to values indicated in "Problem formulation". Moreover, it appears that it could be extrapolated to large dust source areas as well. As far the wind flow speed is concerned, it can be said that its range is sufficient.

So, the information presented in this article can be considered as the statement of the methodological approach to Apatity's air pollution level estimate under the conditions ANOF-2 tailings storage dusting. The approach allows for the significance of two parameters (dust source area and wind speed) which have the main impact on the air pollution level down the wind flow.

Table 2. Interval weight and deposition rate as a function of dust particle size
Таблица 2. Значения «веса» интервала и скорости оседания в зависимости от диаметра частиц пыли

Mean diameter (interval range), μm	Interval "weight"	Deposition rate, m/s
5 (0–10)	0.022	0.00195
15 (10–20)	0.083	0.0175
25 (20–30)	0.142	0.0487
35 (30–40)	0.194	0.0955
45 (40–50)	0.209	0.1580
55 (50–60)	0.189	0.2360
65 (60–70)	0.161	0.3290

Summary. Based on the developed computer models (3D), the process of Apatity's air pollution has been studied under the conditions of ANOF-2 tailings storage dusting (maximum planned height). Apart from wind flow speed variation from 5 to 23 m/s, the investigation took into account the dust source area variation from 2 to 10 ha in the area of the tailings storage closest to the town of Apatity. At dust source area variation, the approach of discrete arrangement of dust sources has been applied.

Table 3. Values of the coefficient *A* and *B* in the approximation functions of the maximum dust concentration depending on wind flow speed at a given dust source area
Таблица 3. Значения коэффициентов *A* и *B* в функциях аппроксимации максимальной концентрации пыли от скорости ветрового потока при фиксированной площади пыления

Dust source area, ha	Coefficient *A*	Coefficient *B*
2	$2.086 \cdot 10^{-11}$	2.973
4	$3.985 \cdot 10^{-11}$	2.978
6	$5.853 \cdot 10^{-11}$	2.978
8	$7.967 \cdot 10^{-11}$	2.976
10	$9.605 \cdot 10^{-11}$	2.971

To carry out the prediction estimate of the vertical mass flux, the dependence of D. L. Westphal et al. was used; it is based on the functional dependence of dynamic velocity at a particular dust source area to the fourth power. Dynamic velocity is calculated through the average velocity of the wind flow at the height of +10 m over the particular dust source area.

The analysis of the predicted values of dust concentration levels (dust particle size up to 70 μm) in the simulation parameters range under consideration is evidence of the following:

– the Starye Apatity area is most exposed to air pollution;

– the calculated dependences of maximum concentration of dust with high certainty factor are described by the linear functions; it makes it possible to predict the critical dust source area at which the air pollution level reaches the TLV. With 23 m/s wind flow speed it is necessary to reduce the dust source area down to about 2.5 ha, with 17 m/s wind to 6.8 ha, and with 11 m/s 25 ha may be allowed;

– the dependence between the maximum concentration of dust and wind flow speed under fixed values of dust source area is approximated by a power-law function.

Generalized analytical expression which makes it possible to predict maximum dust concentration has been obtained, being a function of two parameters (dust source area and wind speed) which significantly determine the level of air pollution with dust.

REFERENCES

1. WMO SDS-WAS, 2015: Nickovic S., Cuevas E., Baldasano J., Terradellas E., Nakazawa T., Baklanov A. Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS): Science and Implementation Plan 2015–2020. World Meteorological Organization, WMO WWRP 2015-5, Geneva, Switzerland, 2015. 37 p.

2. Shepherd G., Terradellas E., Baklanov A., et al. Global Assessment of Sand and Dust Storms. UNEP, WMO, UNCCD, United Nations Environment Programme, Nairobi, 2016. 139 p.

3. Marticorena B., Bergametti G. Modeling the Atmospheric Dust Cycle. Design of a Soil-Derived Dust Emission Scheme. *Journal of Geophysical Research-Atmospheres*. 1995; 100(D8): 16415–16430.

4. Shao Y., Raupach M. R. Effect of Saltation Bombardment on the Entrainment of Dust by Wind. *Journal of Geophysical Research-Atmospheres*. 1993; 98(D7): 12719–12726.

5. Shannon S. R. *Modelling the atmospheric mineral dust cycle using a dynamic global vegetation model. 2009*. Available from: https://www.paleo.bristol.ac.uk/~ggsrs/website/thesis/thesis.pdf [Accessed 24th March 2020].

6. Ginoux P., Chin M., Tegen I., Prospero J. M., Holben B., Dubovil O., Lin S. J. Sources and distributions of dust aerosols simulated with the GOCART model. *J. Geophys*. Res. 2001; 20: 20255–20273.

7. Ginoux P., Prospero J. M., Torres O., Chin M. Long-term simulation of global dust distribution with the GOCART model: correlation with North Atlantic Oscillation. *Journal of Environmental Modelling & Software*. 2004; 19: 113–128.

8. Westphal D. L., Toon O. B., Carlson T. N. A Case Study of Mobilization and Transport of Saharan Dust. *Journal of the Atmospheric Sciences*. 1988; 45: 2145–2175.

9. Gillette D. A., Passi R. Modeling Dust Emission Caused by Wind Erosion. *Journal of Geophysical Research-Atmospheres*. 1988; 93(D11): 14233–14242.

10. Zender C. S., Bian H. S., Newman D. Mineral Dust Entrainment and Deposition (DEAD) model: Description and 1990s dust climatology. *Journal of Geophysical Research-Atmospheres*. 2003; 108 (D14). doi:10.1029/2002JD002775.

11. Semenov O. E. *Introduction to experimental meteorology and climatology of sandstorms*. Almaty; 2011. (In Russ.)

12. Johnson K. C. A comparison of the NAVY Aerosol Analysis and Prediction System to in situ aerosol measurements in the continental U.S.: transport vs. Local production of soil dust aerosol. 2006. Available from: http://chem.atmos.colostate.edu/Thesis/Johnson_thesis_final.pdf [Accessed 26th January 2019].

13. Amosov P., Baklanov A., Rigina O. *Numerical modeling of dusting at tailing dumps*. LAP LAMBERT Academic Publishing; 2014. (In Russ.)

14. Amosov P. V., Baklanov A. A. The effect of the dust source geometry on air pollution estimates. *Gornyi informatsionno-analiticheskii biulleten (nauchno-tekhnicheskii zhurnal) = Mining Informational and Analytical Bulletin (scientific and technical journal)*. 2017; S23: 502–509. (In Russ.)

15. COMSOL. Available from: https://www.comsol.ru [Accessed 12th January 2014].

16. Amosov P. V., Baklanov A. A., Masloboev V. A. Justification of the methodological approach to estimation the dust intensity at tailing dump. *Vestnik Kolskogo nauchnogo tsentra RAN = Herald of the Kola Science Center of RAS*. 2018; 1: 5–14. (In Russ.)

17. Strizhenok A. V. *Environmental safety management of alluvial anthropogenic materials at Apatit OJSC in the process of their formation: PhD in Engineering diss*. St. Petersburg; 2015. (In Russ.)

18. GN 2.16.1338-03. Maximum permissible concentrations (MPC) of pollutants in the atmospheric air in populated areas. Available from: http://ohranatruda.ru/ot_biblio/normativ/data_normativ/42/42030/ [Accessed 12th November 2016]. (In Russ.)

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Information about authors:

Pavel V. Amosov – PhD (Engineering), leading researcher, Institute of North Industrial Ecology Problems, KSC RAS. E-mail: p.amosov@ksc.ru

Alexander A. Baklanov – DSc (Physics and Mathematics), Professor, science officer, Science and Innovation Department of World Meteorological Organization. E-mail: aabaklanov@yahoo.com
Dmitriy V. Makarov – DSc (Engineering), Director, Institute of North Industrial Ecology Problems, KSC RAS. E-mail: mdv_2008@mail.ru
Vladimir A. Masloboev – DSc (Engineering), Chief science officer, Institute of North Industrial Ecology Problems, KSC RAS. E-mail: d.masloboev@ksc.ru

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Результаты оценки загрязнения атмосферы в зависимости от скорости ветрового потока и площади пыления методом численного моделирования

Амосов П. В.[1], Бакланов А. А.[2], Макаров Д. В.[1], Маслобоев В. А.[1]
[1] Институт проблем промышленной экологии Севера КНЦ РАН, Апатиты, Россия.
[2] Всемирная метеорологическая организация, Женева, Швейцария.

Реферат
Цель работы. *Оценка методом численного моделирования уровней загрязнения атмосферы г. Апатиты в зависимости от дискретного расположения участков пыления района хвостохранилища, ближайшего к городу, и скорости ветрового потока.*
Методика. *Компьютерное моделирование в трехмерной геометрии выполнено с помощью программы COMSOL. Для вычисления аэродинамических характеристик применялось приближение несжимаемой жидкости с привлечением стандартной модели турбулентности. Процесс распространения пылевых загрязнений промоделирован посредством численного решения конвективно-диффузионного уравнения переноса примеси с учетом скорости оседания. Численные эксперименты выполнены при вариации скорости ветрового потока от 5 до 23 м/с и дискретном представлении площади пыления от 2 до 10 га.*
Результаты и их анализ. *Получены пространственные распределения аэродинамических характеристик модели и поинтервальные (и суммарные) распределения пылевых загрязнений. Наибольшему загрязнению подвержена атмосфера района Старых Апатитов. Проанализированы и обобщены до функциональных зависимостей уровни загрязнения атмосферы в зависимости от значений варьируемых параметров модели. Расчетные зависимости максимальной концентрации пыли от площади пыления описываются линейными функциями, что позволяет сделать прогноз критической площади пыления, при которой уровень загрязнения атмосферы достигает ПДК. Зависимость максимальной концентрации пыли от скорости ветрового потока при фиксированных значениях площади пыления может быть аппроксимирована степенной функцией.*
Выводы и область применения. *Обобщенная функциональная зависимость позволяет прогнозировать максимальные концентрации пыли в г. Апатиты в зависимости от площади пыления дискретных участков хвостохранилища и скорости ветрового потока.*

Ключевые слова: *хвостохранилище; скорость ветра; площадь пыления; дискретность; загрязнение атмосферы; численное моделирование.*

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БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. WMO SDS-WAS, 2015: Nickovic S., Cuevas E., Baldasano J., Terradellas E., Nakazawa T., Baklanov A. Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS): Science and Implementation Plan 2015–2020. World Meteorological Organization, WMO WWRP 2015-5, Geneva, Switzerland, 2015. 37 p.
2. Shepherd G., Terradellas E., Baklanov A., et al. Global Assessment of Sand and Dust Storms. UNEP, WMO, UNCCD, United Nations Environment Programme, Nairobi, 2016. 139 p.
3. Marticorena B., Bergametti G. Modeling the Atmospheric Dust Cycle.1. Design of a Soil-Derived Dust Emission Scheme // Journal of Geophysical Research-Atmospheres. 1995. Vol. 100. No. D8. P. 16415–16430.
4. Shao Y., Raupach M. R. Effect of Saltation Bombardment on the Entrainment of Dust by Wind // Journal of Geophysical Research-Atmospheres. 1993. Vol. 98. No. D7. P. 12719–12726.
5. Shannon S. R. Modelling the atmospheric mineral dust cycle using a dynamic global vegetation model. 2009. URL: https://www.paleo.bristol.ac.uk/~ggsrs/website/thesis/thesis.pdf (дата обращения 24.03.2020).
6. Ginoux P., Chin M., Tegen I., Prospero J. M., Holben B., Dubovil O., Lin S. J. Sources and distributions of dust aerosols simulated with the GOCART model // J. Geophys. Res. 2001. Vol. 20. P. 20255–20273.
7. Ginoux P., Prospero J. M., Torres O., Chin M. Long-term simulation of global dust distribution with the GOCART model: correlation with North Atlantic Oscillation // Journal of Environmental Modelling & Software. 2004. No. 19. P. 113–128.

8. Westphal D. L., Toon O. B., Carlson T. N. A Case Study of Mobilization and Transport of Saharan Dust // Journal of the Atmospheric Sciences. 1988. No. 45. P. 2145–2175.

9. Gillette D. A., Passi R. Modeling Dust Emission Caused by Wind Erosion // Journal of Geophysical Research-Atmospheres. 1988. Vol. 93. No. D11. P. 14233–14242.

10. Zender C. S., Bian H.S., Newman D. Mineral Dust Entrainment and Deposition (DEAD) model: Description and 1990s dust climatology // Journal of Geophysical Research-Atmospheres. 2003. Vol. 108. No. D14. DOI: 10.1029/2002JD002775.

11. Семенов О. Е. Введение в экспериментальную метеорологию и климатологию песчаных бурь. Алматы: КазНИИЭК, 2011. 580 с.

12. Johnson K. C. A comparison of the NAVY Aerosol Analysis and Prediction System to in situ aerosol measurements in the continental U.S.: transport vs. Local production of soil dust aerosol. 2006. URL: http://chem.atmos.colostate.edu/Thesis/Johnson_thesis_final.pdf (дата обращения 26.01.2019).

13. Амосов П., Бакланов А., Ригина О. Численное моделирование процессов пыления хвостохранилищ. LAP LAMBERT Academic Publishing, 2014. 109 с.

14. Амосов П. В., Бакланов А. А. Влияние геометрических параметров источника пыления на оценку загрязнения атмосферы // ГИАБ. 2017. № S23. С. 502–509.

15. COMSOL. URL:https://www.comsol.ru/ (дата обращения 12.01.2014).

16. Амосов П. В., Бакланов А. А., Маслобоев В. А. Обоснование методического подхода к оценке интенсивности пыления на хвостохранилище // Вестник Кольского научного центра РАН. 2018. № 1. С. 5–14.

17. Стриженок А. В. Управление экологической безопасностью намывных техногенных массивов ОАО «Апатит» в процессе их формирования: дис. … канд. техн. наук. С.-Петербург, 2015. 184 с.

18. ГН 2.16.1338-03. Предельно допустимые концентрации (ПДК) загрязняющих веществ в атмосферном воздухе населенных мест. URL: http://ohranatruda.ru/ot_biblio/normativ/data_normativ/42/42030/ (дата обращения: 12.11.2016).

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Сведения об авторах:

Амосов Павел Васильевич – кандидат технических наук, ведущий научный сотрудник Института проблем промышленной экологии Севера КНЦ РАН. E-mail: p.amosov@ksc.ru

Бакланов Александр Анатольевич – доктор физико-математических наук, профессор, научный сотрудник отдела науки и инноваций Всемирной метеорологической организации. E-mail: aabaklanov@yahoo.com

Макаров Дмитрий Викторович – доктор технических наук, директор Института проблем промышленной экологии Севера КНЦ РАН. E-mail: mdv_2008@mail.ru

Маслобоев Владимир Алексеевич – доктор технических наук, научный руководитель Института проблем промышленной экологии Севера КНЦ РАН. E-mail: v.masloboev@ksc.ru

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